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Improved fuzzy AHP based game-theoretic model for shipyard selection

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ABSTRACT

Shipowners face the challenge of selecting shipyards to build a new ship, as shipyards are highly similar in terms of capacity and capability but highly heterogeneous with a variety of incentives to shipowners. Building a new ship takes at months and is very expensive, and selecting a prospective shipyard demands the shipowners to have a wealth of experience and knowledge. We develop an improved fuzzy AHP (IFAHP) based game-theoretic model to analyze two competitive shipyards. This model allows us to conduct pairwise comparisons on risks of selecting competitive shipyards. A case study in which two shipyards offering prospective services to the shipowners is conducted with several rounds of expert consultations. This study contributes to the literature by providing both the players and beneficiaries of a game with considerable insights on shipbuilding. We discuss some practical implications for both the shipowners and shipyards.

1. Introduction

Risk assessment is crucial for decision making to observe the vulnerability of the systems. Risk can be expressed as the multiplication of the probability of an event and its probable consequences. Risk assessment comprises the preventive measures along with the data of risk analysis. Since the consequences of undesired events are costly and even deadly, risk assessment is highly studied in the shipping industry-related literature. For example, risk assessment of Arctic navigation and Istanbul Strait are studied by Sahin and Kum (2015) and Şahin and Chan (2018). A systematic literature review for the individual collision risk assessment in ship navigation is presented by Ozturk and Cicek (2019). Risk analysis for the ship mooring operation is studied by Kuzu et al. (2019). Ship collision risk assessment is conducted by Zhang and Meng (2019). Risk assessment studies related to the shipping industry are not only limited to safe navigation or ship traffic but also ship investment and shipyards such as Yin et al. (2019), Li (2006), and Iwańkowicz and Rosochacki (2014).

Shipyards are one of the essential elements of the maritime industry. Many activities such as ship construction, ship maintenance, and the supply of spare parts are carried out in shipyards. Therefore, shipyard selection is vital for shipowners. Competing shipyards in the same region offer similar alternatives in many dimensions, such as capacity, workload, and economy. When the shipowners invest in a ship, they almost know which shipyard to be chosen. However, when a detailed analysis is done, the shipyard selection takes on a different level. This study includes a detailed analysis covering not only current conditions but also future situations such as economic, equipment, or service support. The shipbuilding industry is different from other construction or manufacturing sectors and has unique parameters. The shipbuilding industry has been described as a high-risk sector in many respects (Basuki et al., 2014). In this study, it is the first time the risk concept is introduced for the shipyards that can endure. The shipyards close to each other in terms of size, capacity, and capabilities develop some strategies as a marketing tool for their customers. In the free market, shipyards compete with these strategies. The pre-determined marketing strategies have a cost to the shipyards. The novelty of this study is a model for examining the potential costs of risks to the shipyards.

As the most crucial problem faced by shipowners is the ship's investment decisions, robust models are needed to handle this process as a whole (Engelen et al., 2006). For this study, the model is designed based on the following research questions: “Can a model be established in favor of the customer based on the strategies of the actors in the competitive environment?”, “Can this model be observed step by step to analyze the causes more deeply?” and "Can the results of this model be translated into practice?". The motivation of this study is to create a model that can choose an ideal shipyard, among others, with the same features in terms of capacity, size, and capabilities in a competitive environment in favor of the shipowner. We propose an improved fuzzy analytical hierarchy process (IFAHP) based game-theoretic model. The

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analytical hierarchy process (AHP) method and fuzzy sets are used because of their superiority, such as suitability to the human thought system and ability to handle the criteria more conveniently and quickly. The advantages and disadvantages of AHP are mentioned in Ishizaka and Labib (2011). The values obtained from AHP are adapted to the game theory, and the relevant data are processed. We employ game theory in order to determine the game values of the strategies of the competing shipyards and to provide maximum benefit to the shipowners. This model gives practitioners the most comprehensive answers to research questions and achieves the stated goals.

First of all, this model is used for the first time in the literature and is essential both for its contribution to the economy and for the convenience of shipowners in the competitive shipyard selection process. The most important contribution of this study to the literature is to create awareness for the decision making processes of maritime authorities, especially shipowners. It is emphasized that conventional methods need to be improved. The strengths of this model are the combination of well-established methods, ease of use, the potential for further improvement, practical applicability, and traceability. Contrary to the traditional approaches, this study deals with the background of shipyards rather than the only visible front side of the shipyards. In this study, the game-theoretic model is aimed to increase the quality by providing extra benefits from the marketing strategies of shipyards rather than the cost of the construction. In other words, a decision support system is aimed at quality management by making a risk assessment. Finally, this study provides a holistic and comprehensive insight for invisible and non-considerable situations to attract the shipowners for a shipping proposal with the same cost (same contract).

The study is presented as follows. In Section 2, the risk assessment of ship investment and applications of multi-criteria decision making (MCDM) methods in risk assessment are discussed. The explanations of methodology and proposed IFAHP based game-theoretic model along with the corresponding algorithm are provided in Section 3. The application is presented in Section 4. Section 5 presents discussions, while Section 6 finally concludes the paper.

2. Literature review

The literature is examined in two parts. The first part reviews the risk assessment and ship investments, while the second part reviews the risk assessment methods.

2.1. Risk assessment of ship investment

The locomotive of the global economy is the shipping industry, which consists of several sub-units such as shipbuilding, shipping transportation, ship scraping, etc. (Alexandridis et al., 2018; Du et al., 2017). All participants in the shipping sector are in multi-directional relationships. All parameters constituting the shipping industry in terms of economy and politics interact with each other, whether actors in these sectors are conscious or not (Sahin and Yip, 2017). Ship investment involves a dynamic and complex environment where it has numerous trade-offs, difficulties, and risks (McLean, 2013; Niese et al., 2015). Existing and probable risks have always been considered in maritime history (Garbatov et al., 2018). The banks might cause these risks and also involve the positions of countries in the maritime sector, capacities, and capabilities of shipyards (Kavussanos and Tsouknidis, 2016; Shu et al., 2018). Moreover, efforts to develop a sustainable economic model in this field proves the significance of risks in the shipbuilding market (Xu and Yip, 2012; Luo and Kou, 2018; Ross and Schinas, 2019). A risk can be defined as the function of multiplication of occurrence probability of an undesired event and its consequences (Wu et al., 2019). According to the practice and the observations from the field, shipowners make their investments mostly through conventional approaches. In one approach, they consider the return on investment (ROI) or loss probability after ship construction at the predetermined shipyards (Cullinane, 1995). Another approach considers technical characteristics such as ship tonnage, volumetric capacity, or ship type (Park et al., 2014; Lai et al., 2019). In both approaches, there is no study dealing with a shipyard comparison.

A number of risks faced by the maritime industry are explained in Gui-jun and Zhang (2015). For instance, political changes, global relationships, operational problems, financial uncertainties are some of the example risks for the shipyards (Gui-jun and Zhang, 2015). Ship investment criteria are studied in Branch (1988) and Rousos and Lee (2012). Generally, financial risks are emphasized in the literature. For instance, the studies of Pires et al. (2012) and Patterson (2016) focus on investment timing, financial strategies, and options. All the related elements are constituting a shipyard face and exposure several risks related to such as occupational, material, labor, payment, promotion, shipment timing, etc. (Barlas, 2012; Celik et al., 2009; Liu et al., 2019a). All risks have a financial impact and compensation. One of the innovative benefits of this study is the provision of a better product after measuring the risks that shipyards can endure. Risk assessment is defined as a process involving the identification, detailed analysis, and evaluation of all probable situations (Hegde and Rokseth, 2020). Risk assessment takes a critical role in the systems, including complex operational, technical, and organizational processes (Paltrinieri et al., 2019). In the literature, risk assessment is frequently studied, and its applications in the maritime industry can be observed in many different areas. These areas vary from navigation, ship mooring systems, ship collision, autonomous ships, human factors, etc. (Zhang et al., 2019; Fan et al., 2020; Zheng et al., 2020). Studies on ship investment decision making are few in the literature compared to other studies concerning the shipping industry (Fan and Luo, 2013). Ship investment is a very complex process in the presence of uncertainties and in a competitive environment, where shipowners find it difficult to decide without a suitable system (Luo and Fan, 2010).

Ship investment is a process that requires extensive capital and long-term returns that should be taken into account. Therefore, shipowners, shipyards, and banks agree that ship investment is a risky process (Zhu and Chen, 2014). Risk assessment in the ship investment process can be explained in several different perspectives depending on shipowners, banks, shipyards. For example, the technical risks of shipyards might be low-quality materials, ship maintenance, and poor quality labor or late delivery. The financial risks of shipyards might be difficulties in banking payment options (Patterson, 2016). Similarly, operational or marketing risks of shipyards might not create opportunities responding to the shipowner's demands (i.e., avoidance for more facilities on demand, avoidance for revising the contract in case of a need). Ship investment from the perspective of the shipowner is a laborious, time-consuming process based on the managerial, operational, strategical, and financial perspectives (Celik and Akyuz, 2018; Gkochari, 2015). Shipowners have various roles in the shipbuilding supply chain (Li et al., 2018). Shipowners must know the shipyard's functions and marketing strategies (Bulut et al., 2012; Zheng and Chen, 2018). Countries continuously compete with each other in ship construction (Jiang et al., 2013; Vishnevskiy et al., 2017; Chou, 2018). A comparison of countries is highly studied in the literature and can be found on several databases (Lee et al., 2014; Hossain et al., 2017). For example, one of the sectors that carry the Turkish economy as a developing country is the shipbuilding industry. Like other countries, Turkey encounters similar situations. Shipyards in Turkey are in a competition based on cost, service, prestige, and relative positions (Yercan, 1998).

In the literature, shipyards are studied either in a holistic perspective or as a single part of a system in detail. In other words, some studies work on the shipyard performance of the countries, and some focus on a shipyard incident in detail. To the best of our knowledge, there is no study comparing two or more shipyards based on risk assessment. They mostly focus on a comparison of two shipyards based on a single parameter. Furthermore, this study provides a tool that helps shipowners for decision making by calculating the risk values of which shipyards can tolerate. In the traditional approach, shipowners pay attention to specific criteria during the decision-making process of the ship's investment. These parameters can be classified into two categories: finance and engineering aspects. In the shipping market, the ROI is commonly preferred, which refers to the profitability and efficiency of the investment. ROI is a performance measure that deals with the current position and expected return (Farris et al., 2010). Its equation is expressed as ROI=(Gain - Cost) / Cost of investment. Loss probability in the shipping sector is firstly introduced in Duru et al. (2010). Loss probability refers to a percentage of results that give a deficit account. Loss probability represents defect rates in the simulation and is different from the classical meaning in the banking system (Duru et al., 2012). If the potential buyer's requirements are fulfilled after negotiations, then the shipping price is decided. Shipping price includes inspection of classification records, the expenses of dry-dock and delivery, and additional payments such as bunkers and stores. The remaining four criteria concern engineering aspects: fuel consumption, loaded draft, ship's economic speed, and the availability of cargo transfer equipment. Fuel consumption is a significant subjective parameter in terms of technical and operational concerns. The fuel consumption of a merchant ship is processed as an operational cost. The vessels are responsible for ensuring to meet the draft restrictions of the ports. The draft is a term that refers to the distance between the water surface and the underwater level of the ship. It depends on the cargo and ballast, whether it is loaded or cargo-free. In practice, there are several versions of drafts such as air-draft, saltwater arrival draft, freshwater arrival draft, brackish water arrival draft, bar draft, etc. The difference of these terms are based on the physical restrictions (i.e., bridges, rivers, etc.) A ship's economic speed represents operation time, and the availability of cargo transfer equipment expresses whether the ship can transfer cargoes by equipped cargo handling appliances.

In order to increase the shipyards' performance, several approaches (i.e., lean approach) are proposed (Sharma and Gandhi, 2017). These are mainly focused on shipyards; however, in the literature, there is no study dealing with shipowners' profits based on the endurance and maximum limit of shipyards' risks.

2.2. Applications of MCDM methods in risk assessment

Risk assessment methods have been studied extensively in almost every field in the literature, and have several diverse applications. The methods used in risk assessments are applied for complicated problems in many areas (Rausand, 2013; Aven, 2016). For example, there are applications in almost every field, such as ecological (Ramos-Miras et al., 2020), marine, chemical (Sciarrillo et al., 2020; Senol et al., 2015), health, etc. (Gyamfi et al., 2020; Ünver et al., 2019). Some of the MCDM method based risk assessments are AHP, the technique for order of preference by similarity to an ideal solution, failure modes and effects analysis, fault tree analysis, preference ranking organization method for enrichment of evaluations, etc. (Sahin et al., 2020). The studies are carried out by using deterministic approaches or fuzzy sets (Sahin and Soylu, 2020a). In the literature, it is observed that the number of risk assessment studies conducted using the AHP method is relatively high (Kheybari et al., 2020).

The AHP technique has been applied in almost every area in the maritime industry, such as shipbuilding, shipyard selection, ship accidents, the health and safety of seafarers, port operations, and technology decisions (Bellsolà Olba et al., 2020; Sahin and Soylu, 2020b; Sahin et al., 2015). In the study of Crispim et al. (2020), methods and areas for risk assessment are given in detail. Shipyards are classified by using the AHP method in Caner Akin et al. (2020). Barriers and enablers for shipyards are discussed by using the AHP method in Praharsi et al. (2020). Ports and terminals are analyzed based on safety by using the AHP method (Hervás-Peralta et al., 2020). There exist many studies related to risk assessment by using the same IFAHP method as we used

Table 1
Definitions and descriptions of the variables.

No	Variables	Definitions and descriptions
1	a_{ij}	The comparison element
2	R_{ij}	Fuzzy consistent judgment matrix
3	R_i	Summation of R_{ij} for j=1, 2, …, n
4	R_j	Summation of R_{ij} for i=1,2, …, m
5	F	Fuzzy judgment matrix
6	w_i	Element weights of ordering vector W
7	i	ith strategy (i=1, 2, …, m)
8	j	jth event (j=1, 2, …, n)
9	k	kth iteration

in this paper (Li et al., 2005; Şahin and Yazır, 2019). For example, Wu et al. (2009) use it for information systems security, Wu et al. (2020) prefer it for sustainability and system dynamics, Wang et al. (2012) deal with reliability design, and Tian et al. (2013) implement the IFAHP method for safety evaluations. As it is seen, IFAHP is designed for risk assessment and fits well for safety, reliability, and the subjects related to risk. IFAHP method is also implemented in maritime-related problems such as risk analysis of marine risers (Yu and Liu, 2014) and ship navigation in the Arctic region (Sahin and Kum, 2015).

Similarly, game theory is highly applied for risk assessment studies (Sohrabi and Azgomi, 2020). For instance, Cui et al. (2020) combine the Bayesian network and game theory to solve the damages of the pipelines. Water supply systems are analyzed by using the fuzzy game-theoretical model (Liu et al., 2020). System engineering and game theory are combined with a pipeline accident model (Xing et al., 2020). Hybrid game-theoretic MCDM is highly implemented in the literature, such as Lau et al. (2020), Goyal and Kaushal (2017), Nikkhah et al. (2019) and Han et al. (2019). However, there is no study on the game-theoretical IFAHP method. In the proposed method, the data are calculated via IFAHP after the data are collected, and then the game theory is executed.

The contributions of this paper are threefold. First, this paper investigates the ship's investment decisions from a shipyard perspective in a fuzzy manner and sheds light on the ship's investment literature. Second, this paper extends the game-theoretic model to an improved fuzzy analytical hierarchy process (IFAHP) that could examine pairwise relationships of rival shipyards. Third, different from many previous studies on individual's independent decision-making, this study uses MCDM in the presence of rival decision-makers and various relationships between decision-makers under different market conditions.

3. Methodology

MCDM techniques are applied in almost all disciplines. Pairwise comparison systems are preferred because of their ease of use and avoiding holistic generalizations by breaking the problem into small pieces. The methods used in this study are compatible with multi-expert group decisions, consistency of decision matrices, and linguistic expressions.

3.1. Improved fuzzy analytical hierarchy process method

IFAHP transfers the reciprocal judgment matrix into the fuzzy consistent judgment matrix. Normalized aggregation, square root, and eigenvector methods are also involved in the process (Yu and Liu, 2014; Kang and Xue, 2008). The variables and their descriptions are given in Table 1.

For the IFAHP method, $(0.1 \sim 0.9)$ scales are used. The scales and their meanings are given in Table 2.

The steps of IFAHP are shown below (Wang et al., 2012; Sahin and Kum, 2015):

Step 1: Comparative judgment matrix is set up as $F = (a_{ij})_{n\times n}$. The elements of matrix $F(a_{ij}, a_{ji})$ have the following properties: $0 < a_{ij} < 1, a_{ij} + a_{ji} = 1, a_{ii} = 0.5$.

Table 2
Number scale: (0.1 ∼ 0.9) and it's meaning.

a_{ij}	The significance of a_{ij}	a_{ji}
0.5	a_i is as important as a_j	0.5
0.6	a_i is slight precedence over a_j	0.4
0.7	a_i is obvious precedence over a_j	0.3
0.8	a_i is forceful precedence over a_j	0.2
0.9	a_i is extreme precedence over a_j	0.1

Step 2: Fuzzy complementary judgment matrix is established. It is listed as a fuzzy consistent matrix: $F = (r_{ij})_{nxn}$. r_i is the sum of rows as $r_i = \sum_{j=1}^{n} r_{ij}$, r_j is the columns of judgment matrix F as $r_j = \sum_{i=1}^{n} r_{ij}$ and $i, j = 1, 2, \dots, n$

Step 3: Transformation formula $r_i = \frac{r_i - r_j}{2n} + 0.5$ is used to solve the row sum $r_i = \sum_{i=1}^{10} t_i$. The fuzzy consistent judgment matrix $R = (r_{ij})_{nxn}$ is converted from fuzzy judgment matrix $F = (f_{ij})_{nxn}$.

Step 4: Rank aggregation method (Eq. (1)) or Square root (Eq. (2)) method is used to get the ordering vector.

$$W^{(0)} = (w_1, w_2, \dots, w_n)^T = \left[\frac{\sum_{j=1}^{n} e_{1j}}{\sum_{i=1}^{n}\sum_{j=1}^{n} e_{ij}}, \frac{\sum_{j=1}^{n} e_{2j}}{\sum_{i=1}^{n}\sum_{j=1}^{n} e_{ij}}, \dots, \frac{\sum_{j=1}^{n} e_{nj}}{\sum_{i=1}^{n}\sum_{j=1}^{n} e_{ij}} \right]^T \tag{1}$$

$$W^{(0)} = (w_1, w_2, \dots, w_n)^T = \left[\frac{\sqrt[n]{\prod_{j=1}^{n} e_{1j}}}{\sum_{i=1}^{n}\sqrt[n]{\prod_{j=1}^{n} e_{ij}}}, \frac{\sqrt[n]{\prod_{j=1}^{n} e_{2j}}}{\sum_{i=1}^{n}\sqrt[n]{\prod_{j=1}^{n} e_{ij}}}, \dots, \frac{\sqrt[n]{\prod_{j=1}^{n} e_{nj}}}{\sum_{i=1}^{n}\sqrt[n]{\prod_{j=1}^{n} e_{ij}}} \right]^T \tag{2}$$

Step 5: Transformation formula of $e_{ij} = \frac{r_{ij}}{r_{ji}}$ is used to obtain reciprocal matrix $E = (e_{ij})_{nxn}$ that is transformed from the fuzzy complementary judgment matrix $R = (r_{ij})_{nxn}$. $W^{(0)}$ solves high accuracy of the ranking vector.

For the iterative initial value V_0, iteration formula $V_{k+1} = EV_k$ is used to find the eigenvector V_{k+1} and infinite norm $\|V_{k+1}\|_\infty$ of V_{k+1}. While $\|V_{k+1}\|_\infty - \|V_k\|_\infty$ less than ε, $V_{k+1} = \lambda_{max}$ which is the largest eigenvalue. Then V_{k+1} is normalized and become the form of Eq. (3)

$$V_{k+1} = \left(\frac{V_{k+1,1}}{\sum_{i=1}^{n} V_{k+1,i}}, \frac{V_{k+1,2}}{\sum_{i=1}^{n} V_{k+1,i}}, \dots, \frac{V_{k+1,n}}{\sum_{i=1}^{n} V_{k+1,i}} \right)^T \tag{3}$$

Step 6:

$$V_k = \frac{V_{k+1}}{\|V_{k+1}\|_\infty} = \left(\frac{V_{k+1,1}}{\|V_{k+1}\|_\infty}, \frac{V_{k+1,2}}{\|V_{k+1}\|_\infty}, \dots, \frac{V_{k+1,n}}{\|V_{k+1}\|_\infty} \right)^T \tag{4}$$

is taken, and the ordering vector is $W^{(k)} = V_{i+1}$, and the calculation is completed. V_k becomes the new iterative initial value, which can be recalculated from the beginning.

3.2. Game theory

Game theory is a multidisciplinary approach with an analysis characteristic of the human thought system (Vasudeva et al., 2017). There is a balance in n-person finite games called Nash equilibrium (Myerson, 1999). In zero-sum games for two players, the equilibrium point is a great solution to reach a general conclusion in the context of the players' responses to each other's strategies. Players who have different strategies and know each other's strategies make their best actions in the competitive environment, and as a result, players can fix their decisions in maximum satisfaction. When the game reaches the equilibrium point, no one wants to deviate from their strategies, even if the players are self-conflicting. In other words, strategic stability is achieved even if strategy decisions do not dominate competitors (Aliahmadi et al., 2011).

Strategies \ Events	$K_1, K_2, \dots, K_n$
S_1	$X_{11}, X_{12}, \dots, X_{1n}$
S_2	$X_{21}, X_{22}, \dots, X_{2n}$
…	…
S_m	$X_{m1}, X_{m2}, \dots, X_{mn}$

Fig. 1. Decision matrix.

In static game models, each player determines the appropriate strategy according to all the opponent's actions. Reciprocal strategies form the solution at the equilibrium point of the game. Game theory is applied to the following assumptions. Each player must choose a strategy. A strategy should be the best alternative to an opponent's predicted strategy choice. In the case of game equilibrium, players' thoughts about their opponents' strategy choices must be rational because these strategies meet their expectations. Since each player acts based on the opponent's strategy, the players' basic expectations and actions must be consistent (Colman, 2016; Han et al., 2019; Liu et al., 2019b).

Elements in a decision problem consist of decision-makers, controllable and non-controllable variables (events), and the result (Ren et al., 2019; Tey et al., 2019). The decision-maker is responsible for the decision-making process and its outcome. Controllable variables represent a large number of strategies that are making a system in the decision-making process. The chosen strategy should serve as much as possible as the intended purpose. Uncontrolled variables are factors outside the system and where parties cannot intervene and determine what to do, such as socio-economic and social-cultural factors and advanced technological development. The result is a strategy chosen by the decision-makers (Aktan and Bahçe, 2007).

The method succeeds when all the following steps are taken into account in the decision-making process (Geckil and Anderson, 2016; Portillo and Humphrey, 2018). First, the decision criteria are determined. Second, possible decisions and outcomes of the decision-making process are identified. Third, the probability distribution type that is applied in the decision-making process is determined, and the possible probability values of the decision matrix inputs are assigned. Fourth, a function that measures the benefit is defined. Fifth, an experiment is done for decision options. Sixth, according to the experiment results, input possibilities might be reviewed, revised, or corrected. Seventh, the risks of process inputs are calculated for each possible decision. Eighth, the real probabilities used for inputs and the expected risks of each possible decision are calculated. Finally, the smallest expected risky decision is determined as the best solution (Rençber, 2012). Profit is maximized, and loss is minimized, as it is challenging to consider all possible scenarios in the game theory and make the best decision. In the decision process, the decision matrix is used to find the best strategy. The decision matrix is given in Fig. 1.

In a decision matrix, S represents strategies (controllable variables), K symbolizes Events (uncontrollable variables). X_{ij} is the decision maker's choice based on ith strategy and jth event. X_{ij} might also be the cost of ith strategy in case of occurring the jth event where $i = 1, 2, \dots, m$ is the number of strategies and $j = 1, 2, \dots, n$ is the number of events.

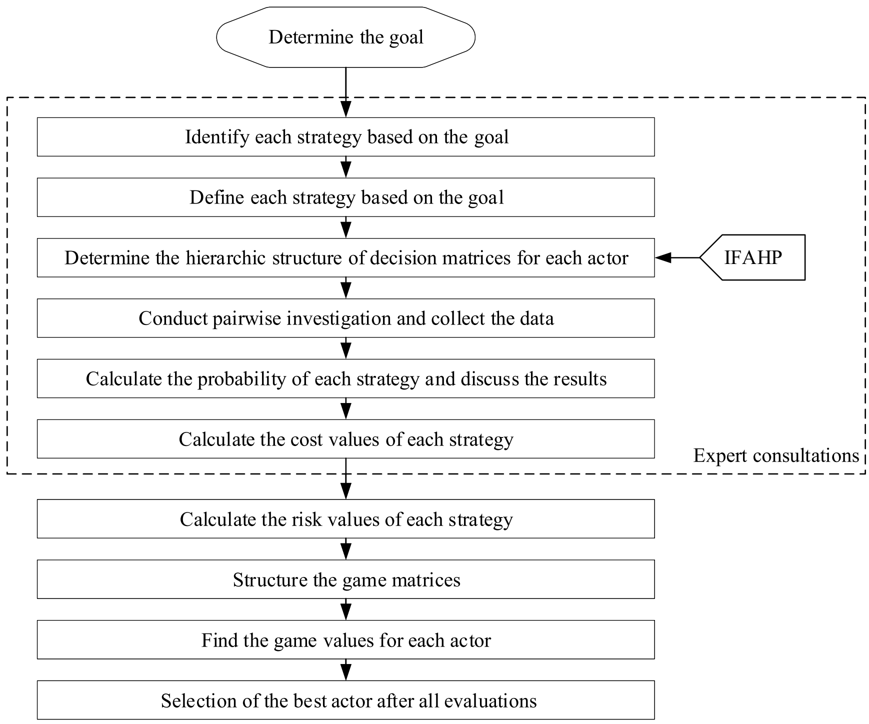


Fig. 2. Improved Fuzzy AHP based Game-theoretic Model.

The game value and the selection probabilities of the strategies in a competitive environment are found as follows:

$$[X_1, X_2, X_n] = \frac{\mathrm{I} \cdot \mathrm{adjA}}{\mathrm{I} \cdot \mathrm{adjA}'} \tag{5}$$

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_m \end{bmatrix} = \frac{\mathrm{adjA} \cdot \mathrm{I}'}{\mathrm{I} \cdot \mathrm{adjA} \cdot \mathrm{I}'} \tag{6}$$

$$\mathrm{g} = \frac{|\mathrm{A}|}{\mathrm{I} \cdot \mathrm{adjA} \cdot \mathrm{I}'} \tag{7}$$

where meanings of symbols A is the coefficient matrix, adjA is the additional matrix of a matrix, |A| is the determinant of a matrix, I is a row vector whose elements are one (1) and equal to the size of matrix A, I' is the transposition of row vector I', and g is the value of the game.

3.3. Proposed model

Fig. 2 indicates the proposed improved fuzzy AHP based game-theoretic model for risk assessment on strategies offered by two competitive shipyards. In the literature of multi-criteria decision making, there are three common types of research approaches and they include: quantitative research, qualitative research, mixed methods. We have adopted a mixed method to consider both quantitative and qualitative data by using improved fuzzy AHP. The variables, the strategies of shipyards, are collected from structured interviews of 27 field experts. The strategies surveyed are defined and discussed in Appendix. Then, two competitive shipyards are evaluated in a game-theoretic model quantitatively. The model is applied to a real case of shipyard selection.

4. Application

4.1. Case study

In the application of this study, a comprehensive list is organized, and numerous experienced experts are invited for face-to-face and online meetings. The main concern to determine the expert is their both academic and industrial experience. Twenty-seven (27) experts accepted our invitations and a critical discussion is conducted on determining the strategies of shipyards in the first round. As reported in Table 3, the 27 experts are all shipyard related.

They are divided into shipyard owner, shipowner, shipbuilding and planning manager, quality manager, finance manager, work development and projects manager, and academicians. Our approach synthesizes various field experts' opinions and reduces potential preference bias. They finally agreed on eight strategies, as given in Figs. 3 and 4. The descriptions of the strategies are provided in Table 4.

These strategies are significant in terms of customer expectations. Then experts are asked about the risk levels of the competitive strategies of the competing shipyards for ship investment. The data collection and application are conducted between March 2019 and May 2019. The profiles of the experts are given in Table 3. The areas of study and experience of the experts are ship design, shipbuilding, and ship navigation. Also, surveys are applied to the shipyard owners. The help of two separate forms completes expert consultations, and they are applied via face-to-face and online interviews. They completed the questionnaires by making several rounds in three sessions. The participation and replies to the questionnaires by the experts are 100%. Designing the problem, determining strategies, and defining these strategies have been carried out by interviewing with the experts at the national level. Shipowners and shipyard behaviors are taken into account, considering country realities and international markets. After expert interviews, the results of the survey are combined, and the results are analyzed. The steps of IFAHP are performed one by one. Pairwise decision comparisons and their complementary matrices are transformed as the fuzzy consistent matrix. The reciprocal matrices are obtained as a result of the transformation of complementary decision matrices. Relative priorities are found after the weight vector is computed. The hierarchical structures of the risk assessment of the ship investment model are provided in Figs. 3 and 4. Aggregated pairwise judgment matrix of the A player's strategies in terms of the B player's strategies is given in Table 5.

In this study, matrices are created for both actors. The positions of each strategy, according to each case, are subject to all expert considerations. Similarly, the aggregated pairwise comparison matrices

Table 3
Profiles of the experts.

No	Education	Job title	Shipyard experience (in years)	Academic experience (in years)
1	Ph.D.	Academician	10	36
2	Ph.D.	Academician	5	20
3	Ph.D.	Academician	4	20
4	Ph.D.	Academician	3	12
5	M.Sc.	Academician	7	7
6	M.Sc.	Academician	8	5
7	M.Sc.	Academician	5	2
8	B.Sc.	Shipowner	15	NA
9	B.Sc.	Shipowner	13	NA
10	B.Sc.	Shipowner	12	NA
11	High school	Shipowner	7	NA
12	High school	Shipyard Owner	39	NA
13	B.Sc.	Shipyard Owner	20	NA
14	B.Sc.	Shipyard Owner	12	NA
15	B.Sc.	Quality Manager	15	NA
16	B.Sc.	Quality Manager	10	NA
17	B.Sc.	Quality Manager	9	NA
18	B.Sc.	Quality Manager	9	NA
19	B.Sc.	Shipbuilding and Planning Manager	15	NA
20	B.Sc.	Shipbuilding and Planning Manager	13	NA
21	B.Sc.	Shipbuilding and Planning Manager	13	NA
22	B.Sc.	Shipbuilding and Planning Manager	12	NA
23	B.Sc.	Shipbuilding and Planning Manager	10	NA
24	B.Sc.	Finance Manager	14	NA
25	B.Sc.	Finance Manager	3	NA
26	B.Sc.	Finance Manager	3	NA
27	B.Sc.	Work Development and Projects Manager	5	NA

Table 4
Descriptions of shipyards' strategies.

	Strategies	Descriptions
1	Material-based risk	Technical characteristics of ships. Materials to be used in shipbuilding.
2	Late delivery risk	The process or period from the ship construction decision to the delivery date of the ship.
3	Risk of not being tolerated in favor of the shipowner	Flexibility and tolerance. The contractual terms of the shipyard in favor of the shipowner.
4	Risk of not providing promotions	Whether the shipyard offers promotions in favor of the shipowner.
5	Risk of poor quality labor	Technical infrastructure. Quality of technical personnel.
6	Risk of payment difficulty	Easy of payment. The financial power of the shipowner.
7	Ship (Facility) maintenance risk	Maintenance and repair facilities.
8	Risk of failure to provide extra facilities on demand	Provide extra facilities upon shipowner's requests.

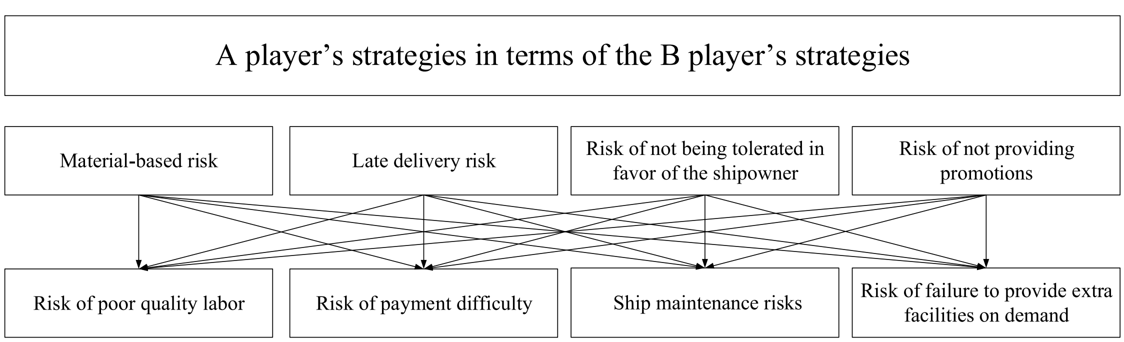


Fig. 3. Hierarchical structure of A-player's strategies in terms of B-player's strategies.

of the B-player's strategies in terms of the A-player's strategies are given in Table 6.

Table 7 provides $R = (r_{ij})_{nxn}$ as mentioned in step 3.

Ordering vector can be found by two different methods as rank aggregation and square root methods. In this study, we prefer to use the rank aggregation method (Eq. (1)). Eq. (4) shows the ordering vector. Weights of combinations are calculated by using the formulas given in the methodology section.

In the game theory, shipyards develop many strategies to attract the shipowner. Even if the shipyards are ultimately profitable, the strategies have some risks. As seen in Tables 8 and 9, the probability of occurrence of these strategies is given in the table as 0–1 range. Risk = Event probability × Results (Dumbravă and Iacob, 2013). Shipyard strategies also have costs. In the following scale in Table 10, the cost scale of the shipyards is generalized after the consensus of expert consultations.

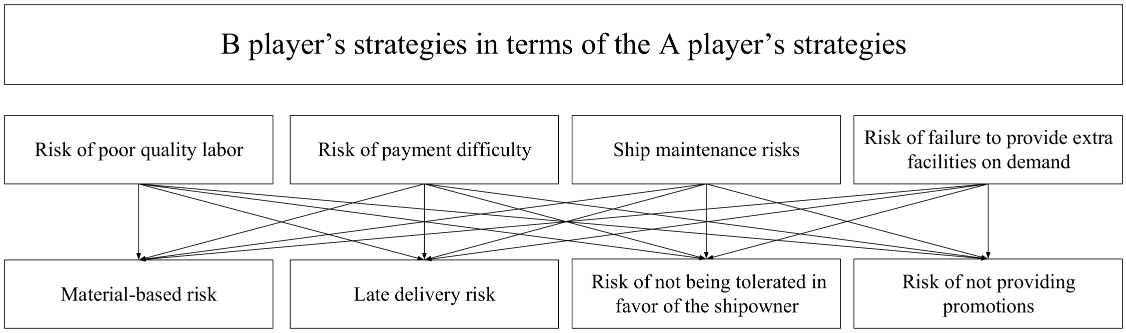


Fig. 4. Hierarchical structure of B-player's strategies in terms of A-player's strategies.

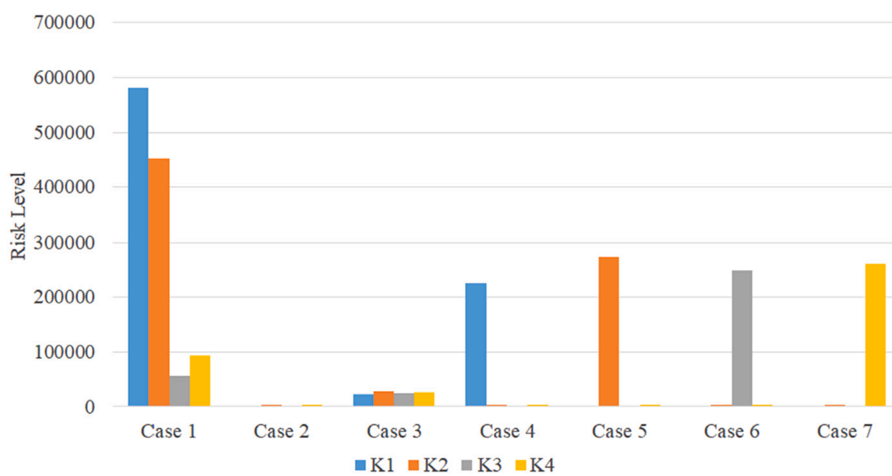


Fig. 5. Changes of risk levels for A player's strategies in terms of the B player's strategies in sensitivity analysis.

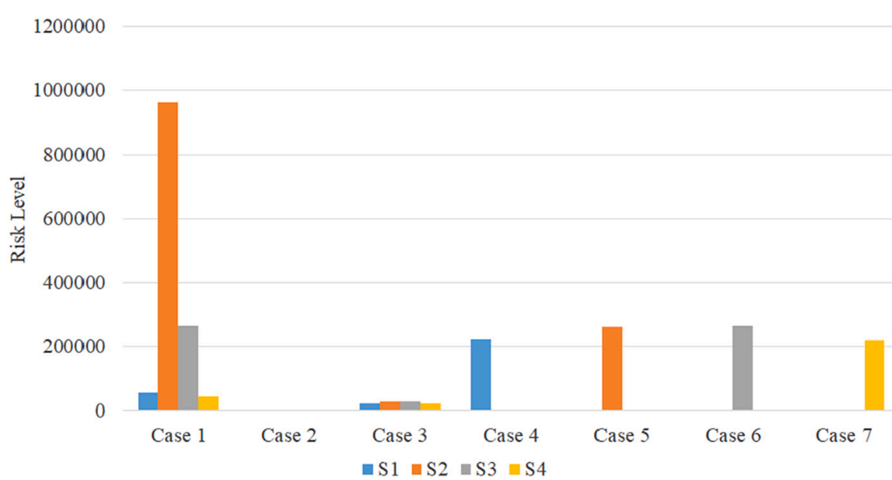


Fig. 6. Changes of risk levels for B player's strategies in terms of the A player's strategies in sensitivity analysis.

Complex, unpredictable, time, and space-dependent factors take roles in the shipbuilding process. When building a ship, thousands of variables are involved in the process such as ship's service sector, tonnage, the financial situation of the shipowner, shipyard's location, the size of the shipyard, the experience of the shipyard, the economic structure of the country where the shipyard is located, international transportation conditions, and the freight market. After the analysis of an extensive exchange of ideas with sector representatives, it has been concluded that the ship's investment is a dynamic process requiring specialized expertise and experience. The experts agreed that it is difficult to determine the exact cost of a ship before the process starts due to fragile factors such as exchange rate, natural disasters, political decisions, international financial crises, etc. For this scenario, the approximate costs for each strategy taken from the experts are given in Table 11 in the United States Dollars (USD). After the expert consultations cost of each strategy are calculated. Fuzzy expressions are primarily preferred because it is close to the human thought system. Then, the mean of approximate values in the intervals represented by the fuzzy expressions are obtained as the data given in Table 10.

Table 5
The aggregated pairwise comparison matrices of the A player's strategies in terms of the B-player's strategies.

K_1	S_1	S_2	S_3	S_4
S_1	0.50	0.43	0.49	0.39
S_2	0.57	0.50	0.56	0.49
S_3	0.51	0.44	0.50	0.51
S_4	0.61	0.51	0.49	0.50
K_2	S_1	S_2	S_3	S_4
S_1	0.50	0.38	0.52	0.52
S_2	0.62	0.50	0.57	0.50
S_3	0.48	0.43	0.50	0.48
S_4	0.48	0.50	0.52	0.50
K_3	S_1	S_2	S_3	S_4
S_1	0.50	0.43	0.38	0.38
S_2	0.57	0.50	0.60	0.47
S_3	0.62	0.40	0.50	0.48
S_4	0.62	0.53	0.52	0.50
K_4	S_1	S_2	S_3	S_4
S_1	0.50	0.31	0.39	0.40
S_2	0.69	0.50	0.56	0.51
S_3	0.61	0.44	0.50	0.49
S_4	0.60	0.49	0.51	0.50

Table 6
The aggregated pairwise comparison matrices of the B player's strategies in terms of the A-player's strategies.

S_1	K_1	K_2	K_3	K_4
K_1	0.50	0.38	0.41	0.47
K_2	0.62	0.50	0.51	0.57
K_3	0.59	0.49	0.50	0.58
K_4	0.53	0.43	0.42	0.50
S_2	K_1	K_2	K_3	K_4
K_1	0.50	0.43	0.44	0.52
K_2	0.57	0.50	0.47	0.56
K_3	0.56	0.53	0.50	0.63
K_4	0.48	0.44	0.37	0.50
S_3	K_1	K_2	K_3	K_4
K_1	0.50	0.47	0.49	0.59
K_2	0.53	0.50	0.52	0.66
K_3	0.51	0.48	0.50	0.62
K_4	0.41	0.34	0.38	0.50
S_4	K_1	K_2	K_3	K_4
K_1	0.50	0.50	0.41	0.57
K_2	0.50	0.50	0.43	0.57
K_3	0.59	0.57	0.50	0.62
K_4	0.43	0.43	0.38	0.50

Table 7
Fuzzy consistent judgment matrix.

S_1	K_1	K_2	K_3	K_4
K_1	0.5000	0.4444	0.4500	0.4833
K_2	0.5556	0.5000	0.5056	0.5389
K_3	0.5500	0.4944	0.5000	0.5333
K_4	0.5167	0.4611	0.4667	0.5000
S_2	K_1	K_2	K_3	K_4
K_1	0.5000	0.4764	0.4597	0.5139
K_2	0.5236	0.5000	0.4833	0.5375
K_3	0.5403	0.5167	0.5000	0.5542
K_4	0.4861	0.4625	0.4458	0.5000
S_3	K_1	K_2	K_3	K_4
K_1	0.5000	0.4792	0.4917	0.5514
K_2	0.5208	0.5000	0.5125	0.5722
K_3	0.5083	0.4875	0.5000	0.5597
K_4	0.4486	0.4278	0.4403	0.5000
S_4	K_1	K_2	K_3	K_4
K_1	0.5000	0.4972	0.4625	0.5292
K_2	0.5028	0.5000	0.4653	0.5319
K_3	0.5375	0.5347	0.5000	0.5667
K_4	0.4708	0.4681	0.4333	0.5000

Table 8
Final weights of A player's strategies in terms of the B-player's strategies.

$W_1(2)$	0.2270	0.2638	0.2454	0.2638
$W_2(2)$	0.2400	0.2743	0.2361	0.2496
$W_3(2)$	0.2129	0.2661	0.2489	0.2721
$W_4(2)$	0.2029	0.2822	0.2538	0.2610

Table 9
Final weights of B-player's strategies in terms of the A player's strategies.

$W_1(2)$	0.2202	0.2752	0.2691	0.2355
$W_2(2)$	0.2369	0.2605	0.2785	0.2241
$W_3(2)$	0.2542	0.2763	0.2628	0.2067
$W_4(2)$	0.2461	0.2489	0.2861	0.2189

Table 10
Consequence Scale.

Min	Max	Degree of preference
100	999	Very low
1000	9999	Low
10000	99999	Moderate
100000	999999	High
1000000	9999999	Very high

The weights of strategies constitute the decision matrix of game theory. Table 12 shows the weights of A-player's strategies in terms of the B-player's strategies. The risk levels of the shipyard are indicated in Table 12. It means that shipyard A is competing with shipyard B based on the strategies of risk of low quality labor, risk of payment difficulty, ship maintenance risks, and risk of failure to provide extra facilities on demand. According to the game theory, the Nash Equilibrium for strategies of A (the row) is g = USD 30.986. In the case of realizing their strategies, the maximum amount of risk that A can tolerate is found to be USD 30.986. Similarly, as it is shown in Table 13, shipyard B can overcome USD 21.700 based on the game theory of which its steps are given in the methodology section.

In such a case, the shipyard A, which offers more opportunities for the shipowner to the hypothetical ship, should be a priority for the shipowner.

4.2. Sensitivity analysis

Sensitivity analysis is a holistic approach to measure the performance of a criterion when the other factors are involved in comprehensively. In this study, we employed a sensitivity analysis based on the study of Celik and Akyuz (2018). Sensitivity analysis is conducted to evaluate the impacts of shipyard strategies under a fuzzy environment for the validation of outcomes. Seven cases are generated for each player, as given in Tables 14 and 15. Current, all low, all medium weights are used to analyze the sensitivity of the critical shipyard strategies. Cases 4 to 7 are generated to see the high values for the specific strategies of the competitors and the low values for other strategies. The changes in risk levels and rankings are given in Figs. 5 to 8. As can be seen, K_2 shows the highest importance in seven cases. Then, K_1 follows it. Similarly, S_3 indicates the highest importance in seven cases, then S_2 follows it.

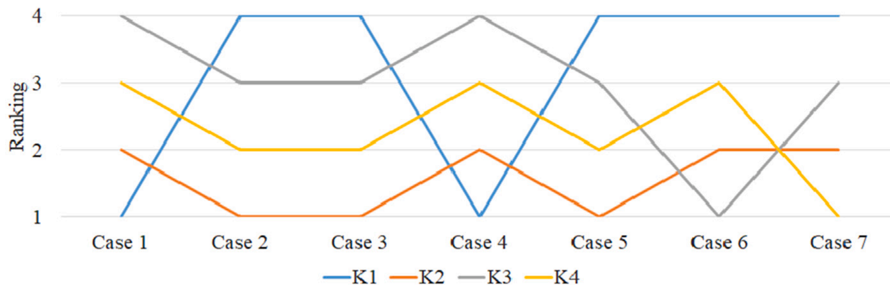


Fig. 7. Changes of rankings for A player's strategies in terms of the B player's strategies in sensitivity analysis.

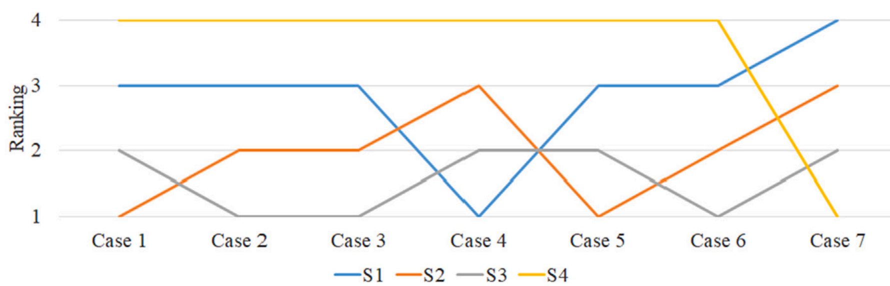


Fig. 8. Changes of rankings for B player's strategies in terms of the A player's strategies in sensitivity analysis.

Table 11
The approximate costs for each strategy taken from the experts.

Cost	S_1	S_2	S_3	S_4	K_1	K_2	K_3	K_4
	2560000	1650000	227000	360000	246800	3698000	1000000	200000

Table 12
The risk levels of different and independent strategies for A player's strategies in terms of the B player's strategies.

Strategies	Material-based risks	Late delivery risk	Risk of not being tolerated in favor of the shipowner	Risk of not providing promotions
Risk of poor quality labor	581126.04	0	0	0
Risk of payment difficulty	0	452640.70	0	0
Ship maintenance risks	0	0	56499.42	0
Risk of failure to provide extra facilities on demand	0	0	0	93960.14

Table 13
The risk levels of different and independent strategies for B player's strategies in terms of the A player's strategies.

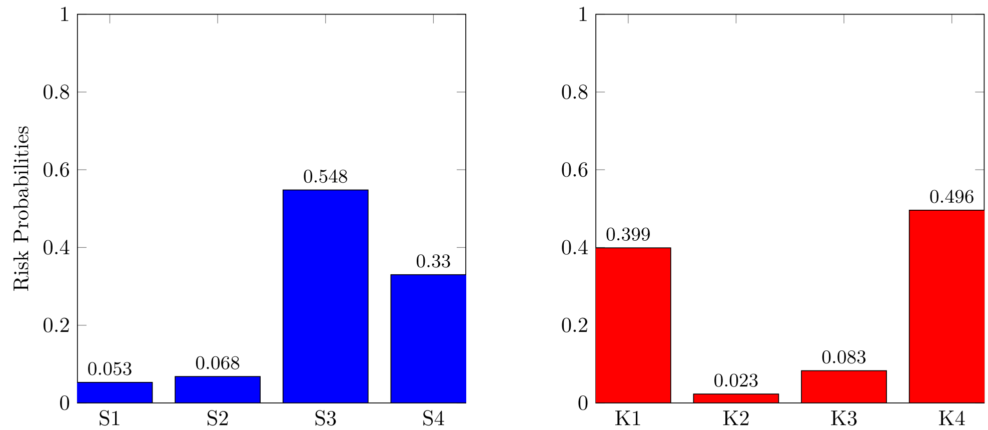
Strategies	Risk of poor quality labor	Risk of payment difficulty	Ship maintenance risks	Risk of failure to provide extra facilities on demand
Material-Based Risks	54347.56	0	0	0
Late delivery Risk	0	963201.13	0	0
Risk of not being tolerated in favor of the shipowner	0	0	262802.70	0
Risk of not providing promotions	0	0	0	43783.04

Table 14
The case combinations for A player's strategies in terms of the B player's strategies with different weights.

		K_1	K_2	K_3	K_4
Case 1	Current	K_{w1}	K_{w2}	K_{w3}	K_{w4}
Case 2	All low	K_{w5}	K_{w6}	K_{w7}	K_{w8}
Case 3	All medium	K_{w9}	K_{w10}	K_{w11}	K_{w12}
Case 4	S1 High, The Rest Low	K_{w13}	K_{w6}	K_{w7}	K_{w8}
Case 5	S2 High, The Rest Low	K_{w5}	K_{w14}	K_{w7}	K_{w8}
Case 6	S3 High, The Rest Low	K_{w5}	K_{w6}	K_{w15}	K_{w8}
Case 7	S4 High, The Rest Low	K_{w5}	K_{w6}	K_{w7}	K_{w16}

Table 15
The case combinations for B player's strategies in terms of the A player's strategies with different weights.

		S_1	S_2	S_3	S_4
Case 1	Current	S_{w1}	S_{w2}	S_{w3}	S_{w4}
Case 2	All low	S_{w5}	S_{w6}	S_{w7}	S_{w8}
Case 3	All medium	S_{w9}	S_{w10}	S_{w11}	S_{w12}
Case 4	K1 High, The Rest Low	S_{w13}	S_{w6}	S_{w7}	S_{w8}
Case 5	K2 High, The Rest Low	S_{w5}	S_{w14}	S_{w7}	S_{w8}
Case 6	K3 High, The Rest Low	S_{w5}	S_{w6}	S_{w15}	S_{w8}
Case 7	K4 High, The Rest Low	S_{w5}	S_{w6}	S_{w7}	S_{w16}



(a) Risk probabilities of shipyard A
(b) Risk probabilities of shipyard B

Fig. 9. Risk probabilities of shipyard A.

4.3. Validation

Several studies in the literature deal with the reliability and validation, which are two crucial parameters for the MCDM and game-theoretical approach (Deng and Jiang, 2019; Madani and Lund, 2011; Wee et al., 2020). AHP and game theory are valid methods and approaches. Since improved fuzzy AHP based game-theoretic model is an entirely new approach, to the best of our knowledge, there is no existing model that fits completely to compare those. Therefore, for the hybrid approaches, there exist analytical requirements for the candidate method, of which it provides a decision support system for the ship's investment in favor of the shipowner. These requirements are the use of linguistic variables, fuzzy expressions, ease of use with pairwise comparisons, ability to work in a competitive environment, availability of desired parameters such as financial technical or operational concerns, traceability of each step, and sensitivity analysis. To solve the problem, a decision-making process is conducted. In this process, the final model is developed step by step. The model providing all these analytical requirements are obtained. Field experts test the obtained data. Findings prove that the method is valid.

5. Discussion

5.1. Performance evaluation of the developed model

As this paper intends to develop a MCDA model for shipyard selection, the results are shown in Fig. 9. The probability of each strategy in the game matrix is given in the graphical form (Fig. 9). Accordingly, the most advantageous of these risky situations for shipyard A is poor quality labor (S1 = 0.053). Contrary to the assumption, coefficients for variation of the parameters affecting labor in labor costs are relatively low. Control is more comfortable for the shipyard, but the warranty period (S3 = 0.548) involves risks that occur outside the control of the shipyard. Other strategies for shipyard A are the risk of failure to provide extra facilities on demand (S4=0.330) and the risk of payment difficulty (S2=0.068). The riskiest strategy of shipyard B is expected by the shipowner to offer shipowners extra opportunities other than shipbuilding in a highly competitive environment (K4=0.496). Other strategies for shipyard B are material-based risks (K1=0.399), risk of not being tolerated in favor of the shipowner (K3=0.083), and late delivery risk (K2=0.023). The results show that a feature of this model is in favor of the shipowners.

Fuzzy logic is integrated into the system, making it closer to the human thought system. The financial risks are kept to a minimum due to the setting of the game. It reflects real-time business cases that financial risk is minimized in a competitive environment.

Table 16
Multiple shipyards and multi-strategy game.

		Shipyard 1											
		K_1			K_2			K_3			K_4		
		Shipyard 2			Shipyard 2			Shipyard 2			Shipyard 2		
		L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
	M_1												
	M_2												
Shipyard 3	M_3												
	M_4												
	M_5												

Table 17
Evaluation of criteria to choose a shipyard for the construction of new shipbuilding.

	C_1	C_2	C_3	C_4	C_5
C_1	0.00	0.29	0.29	0.14	0.29
C_2	0.25	0.00	0.25	0.25	0.25
C_3	0.00	0.00	0.00	0.00	1.00
C_4	0.20	0.20	0.40	0.00	0.20
C_5	0.00	0.50	0.50	0.00	0.00

Managerial implications for ship investment versus shipyard strategies can be found in Appendix. Separate interviews have been conducted, and experts have provided future directions of shipbuilding industry. If more experts are involved in the expert consultation process, it will take longer time to have expert interviews, collect data, and questionnaire process.

This method is ready to be extended to multiple market players with different number of strategies. The proposed IFAHP based game-theoretic model can also be developed by alternative MCDA methods (deterministic, heuristic, computational intelligence). Table 16 demonstrates three shipyards with different number of strategies. Shipyard 1 consists of four strategies (K = 1,2,3,4), Shipyard 2 has three strategies (L = 1,2,3), and Shipyard 3 has five strategies (M = 1,2,3,4,5). There exist sixty decisions to be made in this setting. However, as it can be seen here, as the number of shipyards and/or strategies increases, the complexity increases but compromise the clarity of results. Optimization and other techniques can be chosen to conduct the analysis with great clarity, while the complexity increases.

5.2. Academic and managerial implications

The research findings have the following academic implications. First, the criteria influencing shipyard selection, especially those related to risk and finance, are identified in the form of competitive games. It triggers new research directions on MCDM and game theory in the

Table 18
Expert evaluations for marketing strategies of shipyards.

	Extremely important	Forcefully important	Obviously important	Slightly important	Important
High quality labor	0.67	0.33	0.00	0.00	0.00
Ease of payment	0.67	0.33	0.00	0.00	0.00
Maintenance facilities	0.33	0.33	0.00	0.33	0.00
Provide extra facilities upon request	0.00	0.33	0.33	0.33	0.00
High quality materials	0.67	0.33	0.00	0.00	0.00
Delivery on time	0.67	0.33	0.00	0.00	0.00
Flexibility and tolerance	0.33	0.33	0.33	0.00	0.00
Promotions	0.00	0.00	0.67	0.00	0.33

Table 19
Expert evaluations for expectations of shipowners from the shipyards as a marketing strategy.

	Extremely important	Forcefully important	Obviously important	Slightly important	Important
High quality labor	0.67	0.33	0.00	0.00	0.00
Ease of payment	0.67	0.33	0.00	0.00	0.00
Maintenance facilities	0.67	0.00	0.00	0.33	0.00
Provide extra facilities upon request	0.00	0.33	0.33	0.33	0.00
High quality materials	0.33	0.67	0.00	0.00	0.00
Delivery on time	1.00	0.00	0.00	0.00	0.00
Flexibility and tolerance	0.00	0.67	0.33	0.00	0.00
Promotions	0.33	0.00	0.33	0.00	0.33

future to address the general setting of competitive markets. Secondly, the method is pioneered to make the overall decision result rationalized by considering two decision-makers of different criteria. This method is also applicable to solve other MCDM problems with varying criteria in a dynamic market. Thirdly, the relative weights of criteria are determined by an IFAHP, and fuzzy expressions establish the structure of AHP. The model is demonstrated with a real application and found useful in processing risk and qualitative information simultaneously. Fourthly, the proposed model, with the aid of the game theory, enables shipowners to evaluate and select the most preferred ship in a dynamic environment. Moreover, the results of ship evaluation can also enable professional staff to recognize current strengths and the defects of competitive strategies, then get more rational decision-making through strategy repositioning. It will significantly improve the overall selection of game settings and MCDM.

Besides academic implications, this study also provides some guidance for shipowners and shipyards on how to deal with conflicting strategies in a shipbuilding service. The study may support shipyards in dealing with shipowner's expectations of providing extra facilities on demand. In interviews with field experts, it has observed that shipyard executives were struggling to understand why some strategies were effective in attracting shipowners, while others were not. This study provides an overall systematic framework that allows the shipyard executives to evaluate a mix of strategies in developing a better service to shipowners. On the other hand, this study's findings may support shipyard executives to increase the labor costs or the labor salaries, because it is not the highest concern of the shipowners. As this study demonstrates, shipyards have to manage multiple strategies simultaneously, the mix of strategies may be even more pronounced than individual strategy. In this study, we encourage shipyards executives to foster strategies more integrative for serving shipowners in this competitive shipbuilding industry. Therefore, managerial implications based on the relative importance of the different criteria and different strategies can help guide competing shipyards as decision-makers and assist in ship investment based on shipyard strategies.

6. Conclusions

In this study, an improved fuzzy AHP (IFAHP) based game-theoretic model is presented to assist shipyard selection. The main goal of this paper is to investigate whether the combination of IFAHP and game theoretic model is a good approach for solving a MCDM problem of selecting one shipyard in a competitive market. The model is proposed from the perspective of human thinking style, particularly with pairwise comparison. A 10-step process is developed by using IFAHP and game-theoretic model. The study provides a risk assessment tool to help the shipowners for guiding the shipyard selection and proves the applicability of the method, along with its consistency.

From the case study and sensitivity analysis, it is found that time in delivery is the most important factor of shipyard selection and quality labor is the second most important one. From the expert consultations, shipowners tend to focus more on shipbuilding process than on future ship maintenance. Shipyards are advised to endure higher costs of shipbuilding.

Three future research directions could be explored to increase our understanding of ship investment and the roles of shipyards and other decision-makers. First, only shipowners have been consulted. Other related field experts' knowledge (e.g. marine insurers, ship charterers, etc.) and ship operators' opinions can be collected in future research. Second, only two shipyards have been considered and assumed to be competitors. A future research study could be conducted with multiple market players to extend the present research to competition and cooperation among market players. This could be the multiple strategies in a ship selection game. Third, the way to finance shipbuilding is not considered. Ship leasing is a popular source of ship financing (Yu et al., 2019) but many banks consider ship leasing for ship investors. The consideration of ship leasing may or may not lead to different strategies of ship investment, which would be evaluated by further study.

CRediT authorship contribution statement

Bekir Sahin: Conceptualization, Methodology, Validation, Writing - review & editing. **Devran Yazir:** Visualization, Investigation, Software, Writing - original draft. **Ahmet Soylu:** Supervision, Writing - review & editing. **Tsz Leung Yip:** Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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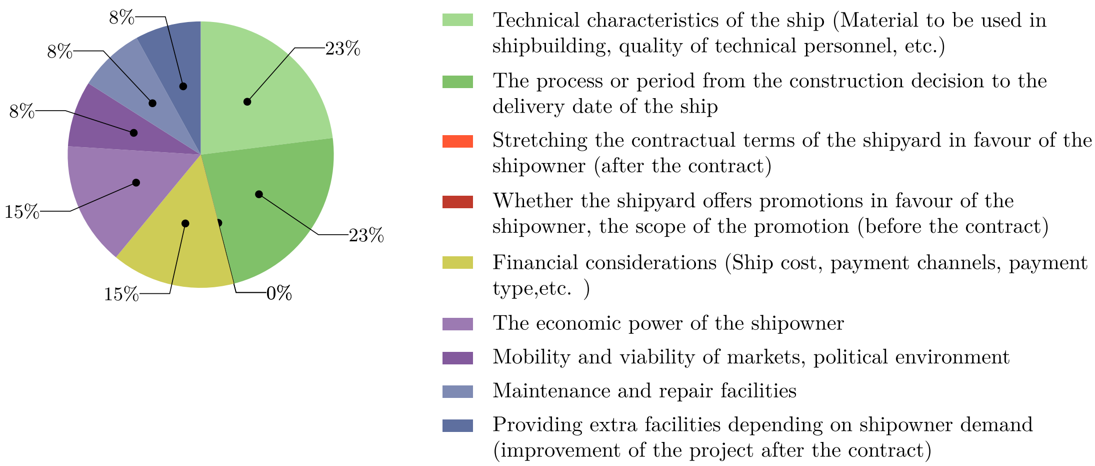
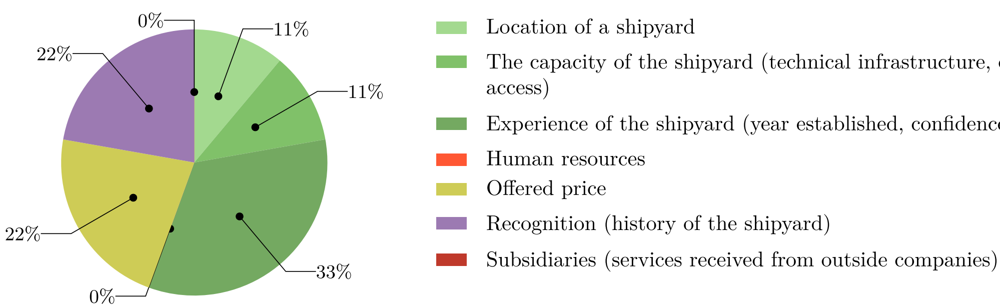
Appendix. Expert consultations

1- What should a shipowner pay attention to during a shipbuilding decision process?



2- What should the shipowner pay attention to when deciding to a shipyard for a shipbuilding?



3- What should the shipowner pay attention to when choosing from multiple shipyards for the construction of new shipbuilding? In this question, the experts are asked to evaluate the criteria given below in a pairwise comparison manner.

- C1 — Technical infrastructure (Material to be used in shipbuilding, quality of technical personnel, etc.)
- C2 — Process or period for a delivery date of the ship
- C3 — Whether the shipyard offers promotions in favor of the shipowner, scope of promotion
- C4 — Financial considerations (Ship cost, payment channels, payment type,etc.)
- C5 — Capacity for providing extra facilities depending on shipowner demand

Expressions in the row are provided as a priority over the expressions in a column as given in Table 17

4- What should shipyards offer shipowners as a marketing strategy?

Experts evaluate the importance of marketing strategies of shipyards, as given in Table 18. Here, importance levels are expressed high to low as extremely important, forcefully important, obviously important, slightly essential and vital. The data are given as a percentage of the average of expert evaluations.

5- What should shipowners expect from the shipyards as a marketing strategy?

Similarly, experts evaluate the importance level of shipowners' expectations from the shipyards as given in Table 19.

6 - How do you assess the shipbuilding industry in developing countries?

In the interviews we have conducted with experienced professionals at local, we asked the state of the shipbuilding industry in developing countries. Overall we have reached the following generalizations. The shipbuilding industry in developing countries such as Turkey is still in the development stage, and there exist many difficulties in terms of planning and efficient production. There are several advantages for the shipowner, such as customer-oriented construction management and provision of service for specific shipbuilding. There are also opportunities in the production of offshore platforms. Turkish shipyards are technologically behind from a global perspective. Research and development investments are given little importance in recent years, but the increase still left behind from the current advances. Some experts have maintained hope for the future of the shipbuilding industry in Turkey and commented that it would be better.

7 - How can two shipyards compete with each other?

Experts point out the following important points for a shipyard in a competitive environment. Main competition parameters can be itemized as timely delivery, reasonable price, adequate quality, customer orientation, quality of material, cheap and high-quality labor, and flexibility for shipowner's wishes according to the situations that may arise later. Shipyards can set a robust organizational structure and realize a life-long learning approach in their company.

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