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## A DECISION-SUPPORT TOOL FOR DEMOLITION SALE OF A VESSEL

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Review paper

### Summary

The fundamental goal of any business is to create value for its owners. In shipping, the value is not only created with freight income, but also with the trade of the vessel itself. A ship has a limited lifetime and can be traded in different markets. The lowest value it will ever receive is its scrap price. An owner may decide to sell a vessel to scrap due to various reasons together with her physical condition and age. In this paper, a fuzzy Analytic Hierarchy Process based decision model is used to provide practitioners with a decision support tool for demolition sale versus further trading of a vessel. The usage of the tool is further illustrated with five actual cases.

*Key words:* maritime management; demolition sale; ship management; shipping; decision support tools; fuzzy analytic hierarchy process; scoring guide; actual cases

### 1. Introduction

World seaborne trade accounts for more than 80% of the volume of the total world merchandise [1]. World seaborne trade reached to 10.7 billion tons and is transported by 1,746.4 million dead-weight tons (dwt) of world fleet [1]. Even though there are many factors that determine the market conditions at any given time, the supply and the demand have a big influence on the shipping markets [2].

Shipping is affected by almost every economic and geopolitical crisis in the world. As a result of the 2008 global financial crisis, the world layup capacity has reached its highest levels ever, and even newer vessels are being demolished [3].

It is a capital-intensive industry and a good knowledge of a ship's life cycle and its management is crucial in avoiding financial losses or making financial gains that can be substantial. Shipping is one of the few industries where the main capital asset, the ship itself, is traded [4]. Shipowners are therefore constantly required to make the decision of ordering, buying, selling or scrapping a vessel, which needs a close market follow up and forecasting. However, as Kou and Luo [3] stated, supported with a review of the existing literature, there is only a limited number of studies on modelling the strategic decisions behind ship investments.

A shipowner in the global shipping industry operates in four closely associated markets: the newbuilding market where new vessels are traded, the sale and purchase market for trading second-hand ships, the freight market for trading sea transport and the demolition market for trading scrap vessels [5], [6]. An alternative categorization for shipping markets is given by Wijnolst and Wergeland [7] where they distinguish between ‘real’ markets for ships, which are the newbuilding market, the demolition market and the spot freight market; and ‘auxiliary’ markets for time charters and second-hand vessels. Since the same shipowners are trading in all of the shipping markets they are interrelated and any change in one will affect the others [8]. Ship demolition is a strategic decision used to balance the fleet capacity in the shipping industry [9].

Considering all these, this study aims to provide the decision makers with a decision support tool for making demolition decisions. The tool is built on a hierarchical model having 4 main and 13 sub-criteria. Three international experts, Turkey Country Manager of RINA Group, Chief Shipping Analyst of BIMCO (Baltic and International Maritime Council), and Director of Braemar Acum Shipbroking Group Limited, filled in pairwise comparisons for those criteria. Buckley’s fuzzy AHP method is then used for prioritization yielding the model with weights. A scoring guide for the decision makers is added to the model to help them in evaluating the demolition candidates against aforementioned 13 sub-criteria. To illustrate the practical usage of the decision support tool, and testing the reliability of it, demolition scores are calculated for 5 actual scenarios. The results are compared with the compromised decisions of a board of shipowners giving a perfect match in the final decisions.

It should be noted that this decision support tool cannot be used in situations where rules and regulations restrict the vessels from further trading.

The rest of the study is organized as follows: Section 2 presents a literature review. In Section 3, methodology of this study is defined. In Section 4, the decision-support tool for demolition decision is introduced. It includes detailed information about the proposed model, weights of the criteria, a scoring guide for the decision makers, and explains how a demolition decision can be given for a ship. Section 5 illustrates the usage of the tool with five actual scenarios. At the end, a conclusion is given in Section 6.

## 2. Literature Review

Shipping is a cyclical industry and speed reduction, lay-up and scrapping are the main three methods of capacity adjustment [10]. The world fleet growth is established by the delivery of new ships and scrapping the old ones. Shipowners have to continuously make a capacity adjustment decision in this very volatile industry. Historically, high lay-up volumes had been observed during the 1930s world economic depression and shorter but deeper recessions of 1958 and early 1980s. However; in the long lasting depression the shipping industry is in since 2008 financial crises, there has been historically low lay-up rates but high scrapping rates.

There are many factors in deciding the scrapping decision. Hess et al. [11], in their report conducted for the US Navy, explain that the decision whether a ship lives or dies is economical. Yin and Fan [9] underline the effects of ship obsolescence, technological changes and environmental regulations on demolition decision. They also consider the significant effects of operating costs and the state of the shipping market on that decision [9]. Buxton [12] argues that scrap sale decision of an owner is due to the state of both second-hand and freight markets. When both of the markets are in recession and there is no operating income, the owner has to either lay-up or scrap his/her vessel. Mikelis [13] and Kagkarakis et al. [14] point out a positive correlation between the demolition prices and freight markets and claim that demolition price a vessel gets is not only determined by the shipping markets but mostly due to demand for the steel itself.

The price offers the shipowner will receive for an end-of-life (EOL) ship will be affected by many factors like the geographical position of the ship, her physical condition, items remaining on board such as bunkers, and deal terms such as 'on delivery', 'as-is, where-is' [15]. However; the main determinant of the price will be based on the type of the vessel and the quantity of the steel available on the vessel since the major portion of the weight of the ship (60% to 80%) is steel [16]. Therefore; the scrap price is sensitive to changes in the steel price [17].

The world fleet increased from 766 billion dwt to 1,428 billion dwt between the years 2002-2012 [1]. The increase in the fleet (supply) occurred as a result of the growth in the world trade [18]. The financial crises of 2008 caused rapid decline in the world trade which led to millions of tons of decrease in the world trade (demand) causing imbalance in the world fleet (supply and demand) which then led to a sharp decline in both asset prices and the freight rates.

Despite of the fact that an average shipping cycle is considered to be around eight years [6], it is not easy to forecast the bottom or peak of the market. Although there exist various types of vessels, due to the cargo they transport are employed in different types of trade, shipping cycles affect them all [19].

### 3. Research Methodology

In this study, a hierarchical model consisting of four main criteria and thirteen sub-criteria is presented. The model is expected to help practitioners as the main part of a ready-to-use decision support tool. Hence, to proceed with the tool, it is needed to define the priorities of those main and sub-criteria.

In the evaluation process of these components, available information is mostly subjective and imprecise. Hence, experts prefer to use natural language expressions rather than sharp numerical values in their evaluations. Modelling using fuzzy logic offers a preferred systematic approach in such situations [20], [21]. Moreover, advantages of using fuzzy numbers in dealing with the inexact information inherent in transportation problems have already been highlighted [22].

Fuzzy AHP is a widely used technique especially for calculating the relative weights of some criteria [15]. Aydin et al. [23], for example, use it to weigh the customer satisfaction criteria while they are studying the problems of rail transit customers in Istanbul. Çakıroğlu et al. [24] use it to select a suitable tugboat alternative given the type of a propulsion system. Li et al. [25] use it for developing a composite business efficiency index score and a composite service effectiveness index score for urbanized areas to compare transit efficiency and effectiveness. Demirel et al. [26] use a hybrid method composed of fuzzy AHP and ELECTRE to select the most effective roll stabilizing system to be used in a trawler type fishing boat. Although they do not use a fuzzy method, in the further research part of their conclusion, Özceylan et al. [27] mention some shortcomings of their research, and advise researchers to adopt fuzzy multi criteria decision making approaches like fuzzy AHP to cope with fuzziness.

Considering these, fuzzy AHP is decided to be the weighing approach for the criteria in this study. There are several fuzzy AHP methods offered in the literature out of which Buckley's [28] was preferred. It is an easy extension of classical AHP [29] to the fuzzy case. Moreover, it guarantees a unique solution to the reciprocal comparison matrix [30].

The steps of the methodology can be summarized as follows:

**Step 1.** To proceed with the method, firstly, a questionnaire is formed to gather the preferences of experts via pairwise comparisons done in linguistic expressions. These expressions and corresponding triangular fuzzy numbers ( $\tilde{a}_{ij} = (l, m, u)$ ) are shown in Table 1.

**Table 1** Linguistic Scale and Corresponding TFNs for Pairwise Comparisons

<i>Linguistic scale</i>	<i>Triangular fuzzy number</i> (Where criterion <i>i</i> is preferred to criterion <i>j</i> )	<i>Triangular fuzzy number</i> (Where criterion <i>j</i> is preferred to criterion <i>i</i> )
Equally important	(1, 1, 3)	(1/3, 1, 1)
Weakly important	(1, 3, 5)	(1/5, 1/3, 1)
Essentially important	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strongly important	(5, 7, 9)	(1/9, 1/7, 1/5)
Absolutely important	(7, 9, 9)	(1/9, 1/9, 1/7)

If two criteria are perfectly indistinguishable, only then they are considered “just equal”, and the corresponding TFN for this case is (1, 1, 1).

**Step 2.** The pairwise comparisons are then placed in decision matrices such as

$$\tilde{A} = \begin{vmatrix} (1,1,1) & \tilde{a}_{12} & \cdot & \cdot & \cdot & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \cdot & \cdot & \cdot & \tilde{a}_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdot & \cdot & \cdot & (1,1,1) \end{vmatrix} \quad (1)$$

where  $\tilde{a}_{ij}$  represents the triangular fuzzy number corresponding to the comparison of criteria *i* and *j* by the decision maker. The items below the diagonal line are calculated such as  $\tilde{a}_{ji} = \tilde{a}_{ij}^{-1}$  or, with a clearer notation,

$$\text{for } \forall \tilde{a}_{ij} = (l, m, u), \tilde{a}_{ji} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right). \quad (2)$$

**Step 3.** All the matrices are checked for consistency. To check the individual decision matrices for consistency, the values within them are defuzzified first [31], [32]. Given the triangular fuzzy number  $\tilde{d} = (l, m, u)$ , the crisp number ( $\mu_{\tilde{d}}$ ) representing this fuzzy number is calculated by using Eq. (3).

$$\mu_{\tilde{d}} = \frac{l+2m+u}{4} \quad (3)$$

Consistency ratio (CR) for the matrix at hand is then calculated using Eqs. (4), and (5);

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (4)$$

$$CR = \frac{CI}{RI} \quad (5)$$

where *CI* is the consistency index,  $\lambda_{max}$  refers to the largest eigenvector of the matrix, *n* represents the number of criteria, and *RI* is the corresponding random index for *n* criteria. *CR* values lower than 0.1 are accepted satisfactory indicating a consistent evaluation. If any of the matrices is found inconsistent, initial linguistic evaluations need to be revised until a consistent decision matrix is reached.

**Step 4.** Next step is the aggregation of the individual matrices as in Eq (6);

$$\tilde{a}_{ij}^{Aggregate} = \sqrt[m]{\tilde{a}_{ij}^{DM_1} \otimes \tilde{a}_{ij}^{DM_2} \otimes \dots \otimes \tilde{a}_{ij}^{DM_m}} \quad (6)$$

where  $\tilde{a}_{ij}^{Aggregate}$  denotes the aggregated fuzzy comparison value of criterion  $i$  to criterion  $j$  ( $\tilde{a}_{ij}$ ) in the aggregated matrix,  $m$  is the number of decision makers involved in the decision,  $\tilde{a}_{ij}^{DM_k}$  is the  $\tilde{a}_{ij}$  value for  $k^{th}$  decision maker ( $DM_k$ ) for  $k= 1, 2, \dots, m$ , and  $\otimes$  is the fuzzy multiplication sign.

**Step 5.** Then, the fuzzy weight matrix is calculated by Buckley's Method as adapted from [33] as follows:

$$\tilde{r}_i = \sqrt[n]{\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in}} \quad (7)$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1} \quad (8)$$

where  $\tilde{r}_i$  is the geometric mean of fuzzy comparison value of criterion  $i$  to each criterion,  $\tilde{w}_i$  is the weight of criterion  $i$ , and  $\oplus$  is the fuzzy addition sign.

**Step 6.** After the calculation of the fuzzy weights, defuzzification and normalization are applied simultaneously by using Eq(9);

$$w_r = \frac{w_{rl} + 2w_{rm} + w_{ru}}{\sum_{i=1}^n (w_{il} + 2w_{im} + w_{iu})} \quad (9)$$

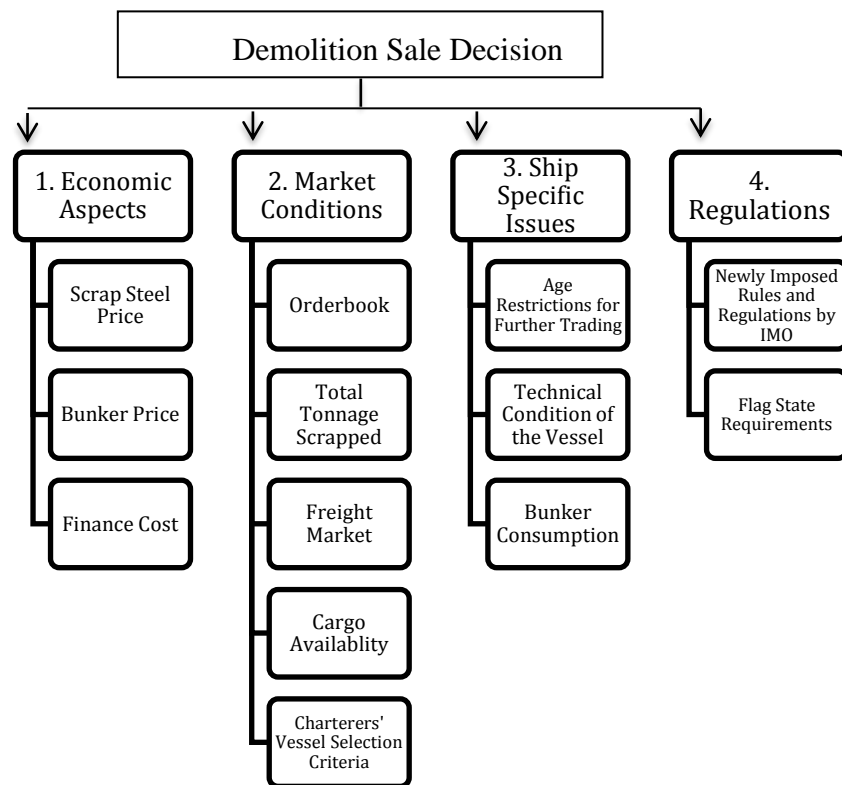
where the importance weight of  $r^{th}$  criterion,  $w_r$ , is a crisp number,  $n$  is the total number of the criteria, and  $w_{rl}$ ,  $w_{rm}$  and  $w_{ru}$  are the lower (smallest likely value), medium (the most probable value), and upper (the largest possible value) weight values of the triangular fuzzy number  $\tilde{w}_r$ , respectively.

#### 4. Decision-support Tool for Demolition Decision

The proposed decision support tool consists of a decision model having prioritized decision criteria, a scoring guide, and a calculation table for overall demolition scores for vessels under focus.

##### 4.1 Proposed Model

All ships have a trading life, and the product life cycle for a commercial ship is about 30 years [13]. However, there are many determinants for the decision of the timing of the scrap sale of a vessel other than age. General economic aspects, current conditions in shipping market, physical condition of the vessel (ship specific issues) and new rules and regulations make up the four main criteria that affect the demolition decision of a shipowner. Those main criteria can further be broken down into sub-criteria as illustrated in Figure 1.



**Figure 1.** Proposed Model for Demolition Sale Decision

For constituting a common understanding, the criteria and sub-criteria mentioned in the model can be explained as below:

### **Economic Aspects**

Like in every major investment decision, market conditions such as the condition of the freight markets, commodity prices and finance markets affect all the investment decisions of a shipowner.

#### *Scrap Steel Price:*

The scrap value of a vessel is a direct function of the demand for scrap steel which in turn defines the price of it, and scrapping costs [34], [35]. Since the main aim of a shipowner is to get the highest price possible for his asset, the ship, an owner with a vessel close to EOL needs to follow scrap steel price and trends closely for the best possible timing of the scrap sale.

#### *Bunker Price:*

The owners' decision to scrap a vessel mainly depends on the difference between expected future income of the vessel and the cost of maintaining her. Bunker costs account for the largest part of the voyage costs; therefore, high bunker costs can easily force the shipowners towards a scrap sale of a vessel making it infeasible to trade it further [36].

#### *Finance cost:*

Finance cost is an important determinant in a capital-intensive industry like shipping. Higher interest rates (libor) increase the cost of shipping loans and increased finance cost might weaken the owner's cash flow position leading the owner towards the scrapping decision [10].

### **Market conditions**

Freight market conditions also have an important impact on the decision of scrapping a vessel. A synthetic analysis of the world trade shows that world seaborne trade is strongly linked to the world economy [37]. Also, supply-demand balance within the industry has a direct impact on the demolition decisions. The shipping trade primarily depends on the cargo that needs to be

transported (i.e. demand) and ships available to transport the cargo (i.e. supply) [38]. Demand for shipping (freight rates) is dependent on the world fleet size (supply). Excess supply leads to lower freight market, which pushes the older vessels out of business leading the owner towards a scrapping decision.

*Orderbook:*

Orderbook provides the shipowners with information on the future supply of vessels which is used for the decision making process for further trading and sale and purchase decisions for the existing vessels in their fleet. High level of deliveries, ceteris paribus, is considered to be an indication of lower future freight rates which again leads the shipowners to make decision regarding older tonnage vessels that they possess [39]. An owner would be reluctant to pass necessary surveys for further trading of the vessel if there is an excess amount of new vessels coming to the market.

*Total tonnage scrapped:*

The second element in the supply side of the supply-demand balance is total tonnage scrapped. This variable should be scored considering the total dwt of vessels scrapped a year ago. A high tonnage here indicates a shrink in the supply, thus it decreases the probability of further demolition.

*Freight Market:*

One of the major factors that drive the market for scrapping ships is the freight market since higher the spot rates lower the probability of scrapping as the shipowners would like to make the most out of their assets. So, the freight market can be considered as a market where the shipowner trades his risk. A shipowner would trade his vessel in voyage charter (spot) if he were optimistic about the future, which would then allow him to earn higher freight rates; and fix his vessel in a long-term time charter to secure his future earnings if he were pessimistic about future market rates. In one hand, during a market boom, the shipowner would be willing to trade his vessel until the last day her survey allows and would even be willing to pass the necessary intermediate or special survey as long as he has positive cash flow. On the other, in a depressed, low freight market, vessels as young as 15 years can go to scrap depending not only on the scrap metal prices but also on future expectations of the freight markets [19].

*Cargo Availability:*

Cargo volume is one of the major determinants of the shipping market as it has huge and immediate effect on demand for vessels. When there is an increase in cargo volume, demand for vessels increase, which then affect the freight markets immediately in favour of the owners. A shipowner would be willing to continue trading his old vessel only if he has access to cargo that brings positive cash flow.

*Charterers' Vessel Selection Criteria*

Charterers have their own criteria for selecting a vessel to transport their cargoes. In the good freight market, they are ready to take the most competitively priced vessel whereas if the freight market is down and is in favour of the charterers they tend to have more criteria for selecting a vessel. If the charterers' selection criteria no longer allow employments for an older vessel, the shipowner might be forced to a scrap sale.

**Ship Specific Issues**

Although the UNCTAD review of maritime transport categorizes vessels under basic categories such as tankers, bulk carriers, general cargo ships, container ships, and other ships, every ship has her own characteristics besides their type, tonnage and age [40]. Those ship specific issues influencing the demolition sale decision can be explained as below.

*Age Restrictions for Further Trading:*

An older vessel would have less debt and when she is competing for a cargo she can create a positive cash flow with relatively lower freight rate than a new vessel which usually has a higher income requirement. Nevertheless, an older vessel can trade longer only if there are no surveys due and is creating positive cash flow for her owner. Even the insurance cost alone is significantly higher for an older vessel compared to a new one.

*Technical Condition of the Vessel:*

Age is not necessarily the only sign of the technical condition of the vessel. Regardless of her age, every vessel has a different technical condition. The shipyard the vessel was built, maintenance, the cargoes transported, and the accidents occurred all have an effect on the technical condition of the vessel. Also, some owners are known for operating older tonnage and since this is their expertise, they are more economical and better in taking care of older vessels.

*Bunker Consumption:*

Bunker consumption of a vessel depends not only on the sailing speed but also on the design and structure of the ship [41]. In a competitive and relatively low freight market, a vessel that consumes more bunker will require higher freight rate for brake-even.

**Regulations**

Regulations are one of the major forces that push shipowners sell their vessels to scrap instead of second-hand sale or further trading.

*Newly Imposed Rules and Regulations by IMO:*

IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Therefore, all the players of the shipping industry must follow any new rules and regulations set by IMO. Sometimes these new rules and regulations require a massive investment, which might require many years to compensate and cannot be justified for older tonnage. The shipowners would then have to sell their vessels to scrap instead of making these large investments for further trading.

*Flag State Requirements:*

Every vessel has a flag state and each flag state has its own rules and regulations. The flag state choice is influenced by several factors like hostile trade partners, strict regulations, competitive advantages, and national taxation [42]. If there is a new rule and regulation by the flag state of a vessel, which cannot justify the investment to comply with the regulation, the shipowner will again be forced to sell his vessel for scrap.

**4.2 Weights of the Criteria**

After building the model, a questionnaire was prepared for pairwise comparisons. The questionnaire was sent to three international experts, Turkey Country Manager of RINA Group, Chief Shipping Analyst of BIMCO (Baltic and International Maritime Council), and Director of Braemar Acn Shipbroking Group Limited. Via an interactive process, experts filled in the questionnaires. The weights of the main and sub-criteria are then calculated following the steps explained in the methodology. The calculation of the weights of main criteria, as an example, are given together with the results below to numerically illustrate the process. Readers could also refer to [43] and [44] for some other numerical examples on the same methodology.

**Step 1 and 2:** Individual pairwise comparison values from the experts are collected via surveys. The linguistic variables are then converted into triangular fuzzy numbers as given for main criteria in Table 2.



**Table 2.** Pairwise comparisons of the experts with regard to main criteria

## a) Evaluations of Expert #1

Criteria	Economic Aspects			Market Conditions			Ship Specific Issues			Regulations		
Economic Aspects	1.000	1.000	1.000	0.143	0.200	0.333	3.000	5.000	7.000	0.111	0.143	0.200
Market Conditions	3.000	5.000	7.000	1.000	1.000	1.000	5.000	7.000	9.000	0.200	0.333	1.000
Ship Specific Issues	0.143	0.200	0.333	0.111	0.143	0.200	1.000	1.000	1.000	0.111	0.111	0.143
Regulations	5.000	7.000	9.000	1.000	3.000	5.000	7.000	9.000	9.000	1.000	1.000	1.000

## b) Evaluations of Expert #2

Criteria	Economic Aspects			Market Conditions			Ship Specific Issues			Regulations		
Economic Aspects	1.000	1.000	1.000	0.111	0.143	0.200	0.333	1.000	1.000	0.143	0.200	0.333
Market Conditions	5.000	7.000	9.000	1.000	1.000	1.000	5.000	7.000	9.000	3.000	5.000	7.000
Ship Specific Issues	1.000	1.000	3.000	0.111	0.143	0.200	1.000	1.000	1.000	0.333	1.000	1.000
Regulations	3.000	5.000	7.000	0.143	0.200	0.333	1.000	1.000	3.000	1.000	1.000	1.000

## c) Evaluations of Expert #3

Criteria	Economic Aspects			Market Conditions			Ship Specific Issues			Regulations		
Economic Aspects	1.000	1.000	1.000	1.000	3.000	5.000	0.200	0.333	1.000	1.000	3.000	5.000
Market Conditions	0.200	0.333	1.000	1.000	1.000	1.000	0.200	0.333	1.000	1.000	3.000	5.000
Ship Specific Issues	1.000	3.000	5.000	1.000	3.000	5.000	1.000	1.000	1.000	1.000	3.000	5.000
Regulations	0.200	0.333	1.000	0.200	0.333	1.000	0.200	0.333	1.000	1.000	1.000	1.000

**Step 3.** All the matrices are defuzzified and checked for consistency.

The defuzzified evaluation of Expert 1 for the pairwise comparison of Economic Aspects and Ship Specifications, for example, is calculated as  $\frac{3+2 \times 5+7}{4} = 5$

The complete defuzzified matrix for Expert #1 for the main criteria, as an example, is given in Table 3.

**Table 3.** Defuzzified evaluation matrices of the experts with regard to main criteria

Criteria	Economic Aspects	Market Conditions	Ship Specific Issues	Regulations
Economic Aspects	1.000	0.219	5.000	0.149
Market Conditions	4.565	1.000	7.000	0.467
Ship Specific Issues	0.200	0.143	1.000	0.119
Regulations	6.702	2.143	8.400	1.000

The inconsistency levels of the evaluation matrices for the main criteria are then calculated as 0.096 for Expert #1, 0.098 for Expert #2, and 0.085 for Expert #3 proving that the evaluations are consistent since each value is lower than 0.1.

This step is applied to every single evaluation matrix of each expert. Once a result greater than 0.1 is found, the evaluations are revised by the experts until an acceptable consistency level is reached.

**Step 4.** To be able to end up with a group decision on the weights of the main and sub-criteria, the matrices are aggregated using geometric mean as in Eq. (6). The aggregated decision matrix for the main criteria is given in Table 4.

The fuzzy pairwise comparison of Economic Aspects and Ship Specific Issues within Table 4, for example, can be calculated as:

$$\tilde{a}_{13} = \left( \sqrt[3]{3.000 \times 0.333 \times 0.200}, \sqrt[3]{5.000 \times 1.000 \times 0.333}, \sqrt[3]{7.000 \times 1.000 \times 1.000} \right) \\ = (0.585, 1.186, 1.913)$$

**Table 4.** Aggregated evaluation (decision) matrix for main criteria

Criteria	Economic Aspects			Market Conditions			Ship Specific Issues			Regulations		
Economic Aspects	1.000	1.000	1.000	0.251	0.441	0.693	0.585	1.186	1.913	0.251	0.441	0.693
Market Conditions	1.442	2.268	3.979	1.000	1.000	1.000	1.710	2.537	4.327	0.843	1.710	3.271
Ship Specific Issues	0.523	0.843	1.710	0.231	0.394	0.585	1.000	1.000	1.000	0.333	0.693	0.894
Regulations	1.442	2.268	3.979	0.306	0.585	1.186	1.119	1.442	3.000	1.000	1.000	1.000

**Step 5.** The fuzzy weights are calculated for main and sub-criteria using Eqs. (7) and (8).

To numerically illustrate the calculation process, calculation of the weights of the main criteria is given as follows:

Considering  $\tilde{r}_i(r_{il}, r_{im}, r_{iu})$ ;

$$r_{1l} = \sqrt[4]{a_{11l} \times a_{12l} \times a_{13l} \times a_{14l}} = \sqrt[4]{1.000 \times 0.251 \times 0.585 \times 0.251} = 0.4384$$

$$r_{1m} = \sqrt[4]{a_{11m} \times a_{12m} \times a_{13m} \times a_{14m}} = \sqrt[4]{1.000 \times 0.441 \times 1.186 \times 0.441} = 0.6929$$

$$r_{1u} = \sqrt[4]{a_{11u} \times a_{12u} \times a_{13u} \times a_{14u}} = \sqrt[4]{1.000 \times 0.693 \times 1.913 \times 0.693} = 0.9793$$

$$\tilde{r}_1 = (0.4384, 0.6929, 0.9793).$$

After following the same process, all  $\tilde{r}_i$  values for the main criteria are calculated as follows:

$$\tilde{r}_1 = (0.4384, 0.6929, 0.9793),$$

$$\tilde{r}_2 = (1.2009, 1.7711, 2.7394),$$

$$\tilde{r}_3 = (0.4480, 0.6929, 0.9724),$$

$$\tilde{r}_4 = (0.8380, 1.1760, 1.9396).$$

Using these  $\tilde{r}_i$  values, fuzzy weights ( $\tilde{w}_i(w_{il}, w_{im}, w_{iu})$ ) of the main criteria can be calculated such that:

$$w_{1l} = \frac{r_{1l}}{\sum_{i=1}^4 r_{iu}} = \frac{0.4384}{0.9793 + 2.7394 + 0.9724 + 1.9396} = 0.0661,$$

$$w_{1m} = \frac{r_{1m}}{\sum_{i=1}^4 r_{im}} = \frac{0.6929}{0.6929 + 1.7711 + 0.6929 + 1.1760} = 0.1599,$$

$$w_{1u} = \frac{r_{1u}}{\sum_{i=1}^4 r_{ir}} = \frac{0.9793}{0.4384 + 1.2009 + 0.4480 + 0.8380} = 0.3348.$$

Thus,  $\tilde{w}_1 = (0.0661, 0.1599, 0.3348)$ .

Following the explained operations, fuzzy weights of the main criteria can be found as:

$$\tilde{w}_1 = (0.0661, 0.1599, 0.3348),$$

$$\tilde{w}_2 = (0.1811, 0.4088, 0.9364),$$

$$\tilde{w}_3 = (0.0676, 0.1599, 0.3324),$$

$$\tilde{w}_4 = (0.1264, 0.2714, 0.6630).$$

**Step 6.** After the calculation of the fuzzy weights, the crisp weights for the main criteria are calculated as given below via defuzzification and normalization as in Eq. (9):

$$w_1 = 0.153, \quad w_2 = 0.411, \quad w_3 = 0.153, \quad w_4 = 0.283.$$

To illustrate the calculation process,  $w_1$ , for example, can be calculated such that:

$$\begin{aligned} w_1 &= \frac{w_{1l} + 2w_{1m} + w_{1u}}{\sum_{i=1}^4 (w_{il} + 2w_{im} + w_{iu})} \\ &= \frac{0.0661 + 2 \times 0.1599 + 0.3348}{0.0661 + 2 \times 0.1599 + 0.3348 + \dots + 0.1264 + 2 \times 0.2714 + 0.6630} = 0.153 \end{aligned}$$

For the sub-criteria, calculated local weights are multiplied by the weight of the parent main criteria to yield the global weights. The weights of all the criteria within the model are presented in Table 5.

**Table 5.** Weights of the criteria

Main Criteria	Weights	Sub-criteria	Local Weights	Global Weights
Economic Aspects	0.153	Scrap Steel Price	0.363	0.056
		Bunker Price	0.277	0.042
		Finance Cost	0.360	0.055
Market Conditions	0.411	Orderbook	0.051	0.085
		Total tonnage scrapped	0.207	0.021
		Freight Market	0.314	0.129
		Cargo Availability	0.334	0.137
		Charterers' Vessel Selection Criteria	0.094	0.039
Ship Specific Issues	0.153	Age Restrictions for Further Trading	0.574	0.088
		Technical Condition of the Vessel	0.216	0.033
		Bunker Consumption	0.210	0.032
Regulations	0.283	Newly Imposed Rules and Regulations by IMO	0.553	0.156
		Flag State Requirements	0.447	0.127

#### 4.3 Demolition Decision for a Ship

Given the aforementioned model, the score levels for all the sub-criteria those would be used in the evaluation of any demolition sale decision (i.e. the scoring guide) are given in Table 6. In case of a demolition evaluation, decision makers should easily evaluate their own ship under focus using the score guide and assign a score ( $S_i$ ; for  $i=1, 2, 3, \dots, 13$ , indicating the criterion number) from 1 to 5 for each criterion.

Weighted score for each criterion ( $WS_i$ ), and total demolition score (TDS) can then be calculated by using Eqs. (10) and (11), consequently, as shown in Table 7.

$$WS_i = w_i \times S_i \quad (10)$$

$$\text{Total Demolition Score (TDS)} = \sum_{i=1}^{13} WS_i \quad (11)$$

where  $i$  represents the number of each sub-criterion.

It should be noted that a higher score in TDS would lead to demolition sale.

To validate the scoring scheme and threshold score, highly experienced decision makers are told some cases. They were asked to evaluate the situations at hand in a panel discussion, and come up with one single decision: Demolition or further trading. During the panel, they were not equipped with the tool. Same cases were evaluated simultaneously with the tool and the results were compared.

During this session, the threshold for demolition score is decided to be 2.5. It means that if the calculate demolition score is below 2.5, the final decision will be further trading the ship. Scores equal to or larger than 2.5 will lead to a demolition decision.

**Table 6.** The scoring guide

Main Criteria	Sub-Criteria	Conditions	Score
Economic Aspects	Scrap Steel Price (SSP)	$SSP < \$200$ per LWT	1
		$\$200 \leq SSP < \$300$ per LWT	2
		$\$300 \leq SSP < \$400$ per LWT	3
		$\$400 \leq SSP < \$500$ per LWT	4
		$SSP \geq \$500$ per LWT	5
	Bunker Price	IFO price $< \$400$ per m/ton	1
		$\$400 \leq$ IFO price $< 500$ per LWT per m/ton	2
		$\$500 \leq$ IFO price $< 600$ per LWT per m/ton	3
		$\$600 \leq$ IFO price $< 700$ per LWT per m/ton	4
		IFO price $\geq \$700$ per m/ton	5
	Finance Cost	Libor $< 2\%$	1
		$2\% \leq$ Libor $< 3\%$	2
		$3\% \leq$ Libor $< 4\%$	3
		$4\% \leq$ Libor $< 5\%$	4
		Libor $\geq 5\%$	5
Market Conditions	Orderbook	Increase in total dwt ordered $< 12\%$	1
		$12\% \leq$ Increase in total dwt ordered $< 14\%$	2
		$14\% \leq$ Increase in total dwt ordered $< 16\%$	3
		$16\% \leq$ Increase in total dwt ordered $< 18\%$	4
		Increase in total dwt ordered $\geq 18\%$	5
	Total tonnage scrapped	Total dwt vessels scrapped $> 40,000,000$	1
		$40,000,000 \geq$ Total dwt vessels scrapped $> 30,000,000$	2
		$30,000,000 \geq$ Total dwt vessels scrapped $> 20,000,000$	3
		$20,000,000 \geq$ Total dwt vessels scrapped $> 10,000,000$	4
		Total dwt vessels scrapped $\leq 10,000,000$	5
	Freight Market	Baltic Dry Index $> 2,000$	1
		$2,000 \geq$ Baltic Dry Index $> 1,500$	2
		$1,500 \geq$ Baltic Dry Index $> 1,000$	3
		$1,000 \geq$ Baltic Dry Index $> 500$	4
		Baltic Dry Index $\leq 500$	5
	Cargo Availability	Total cargo increase $> 3\%$	1
		$3\% \geq$ Total cargo increase $> 2\%$	2
		$2\% \geq$ Total cargo increase $> 1.5\%$	3
		$1.5\% \geq$ Total cargo increase $> 1\%$	4
		Total cargo increase is $\leq 1\%$	5
	Charterers' Vessel Selection Criteria	It is never a problem	1
		It creates very little trouble	2
		It creates problem occasionally	3
		It creates problem in some regions	4
		It creates problem in every fixture	5

**Table 6.** The scoring guide (continued)

Main Criteria	Sub-Criteria	Conditions	Score
Ship Specific	Age Restrictions for Further Trading	Vessels' age < 10	1
		$10 \leq \text{Vessels' age} < 15$	2
		$15 \leq \text{Vessels' age} < 20$	3
		$20 \leq \text{Vessels' age} < 25$	4
		Vessels' age $\geq 25$	5
	Technical Condition of the Vessel	Technical condition of the vessel is very good	1
		Technical condition of the vessel is good	2
		Technical condition of the vessel is mediocre	3
		Technical condition of the vessel is bad	4
		Technical condition of the vessel is very bad	5
	Bunker Consumption	Bunker consumption < 4 ton/day	1
		$4\% \leq \text{Bunker consumption} < 6\%$	2
		$6\% \leq \text{Bunker consumption} < 8\%$	3
		$8\% \leq \text{Bunker consumption} < 10\%$	4
		Bunker consumption $\geq 10$ ton/day	5
Regulations	Newly Imposed Rules and Regulations by IMO	Cost of implementation < \$250,000	1
		$\$250,000 \leq \text{Cost of implementation} < \$500,000$	2
		$\$500,000 \leq \text{Cost of implementation} < \$750,000$	3
		$\$750,000 \leq \text{Cost of implementation} < \$1,000,000$	4
		Cost of implementation $\geq \$1,000,000$	5
	Flag State Requirements	Cost of implementation < \$250,000	1
		$\$250,000 \leq \text{Cost of implementation} < \$500,000$	2
		$\$500,000 \leq \text{Cost of implementation} < \$750,000$	3
		$\$750,000 \leq \text{Cost of implementation} < \$1,000,000$	4
		Cost of implementation $\geq \$1,000,000$	5

**Table 7.** Demolition Score Calculation Table

Sub-Criteria	Weight ( $w_i$ )	Score ( $S_i$ )	Weighted Score ( $WS_i$ )
1. Scrap Steel Price	0.056	$S_1$	$WS_1 = 0.056 * S_1$
2. Bunker Price	0.042	$S_2$	$WS_2 = 0.042 * S_2$
3. Finance Cost	0.055	$S_3$	$WS_3 = 0.055 * S_3$
4. Orderbook	0.085	$S_4$	$WS_4 = 0.085 * S_4$
5. Total tonnage scrapped	0.021	$S_5$	$WS_5 = 0.021 * S_5$
6. Freight Market	0.129	$S_6$	$WS_6 = 0.129 * S_6$
7. Cargo Availability	0.137	$S_7$	$WS_7 = 0.137 * S_7$
8. Charterers' Vessel Selection Criteria	0.039	$S_8$	$WS_8 = 0.039 * S_8$
9. Age Restriction for Further Trading	0.088	$S_9$	$WS_9 = 0.088 * S_9$
10. Technical Condition of the Vessel	0.033	$S_{10}$	$WS_{10} = 0.033 * S_{10}$
11. Bunker Consumption	0.032	$S_{11}$	$WS_{11} = 0.032 * S_{11}$
12. Newly Imposed Rules and Regulations by IMO	0.156	$S_{12}$	$WS_{12} = 0.156 * S_{12}$
13. Flag State Requirements	0.127	$S_{13}$	$WS_{13} = 0.127 * S_{13}$

$$\text{Total Demolition Score} = \sum_{i=1}^{13} WS_i$$

## 5. Application of the decision-support tool

To illustrate the decision-support tool and verifying its validity, five actual cases (evaluations for five different vessels) are given as below.

### Vessel # 1

The first case scenario takes place in August 2009. The vessel analysed is a 1984 built, 17,850 dwt multi-purpose roll on roll off vessel (MPP). It was purchased and passed her special survey and was fixed for a long term time charter to a first class Far Eastern charterer right before the Lehman Brothers financial crises of 2008. After her first voyage, the market collapsed. First class Charterers immediately cancelled the contract and started arbitration proceedings in London. The shipowner was left with an old vessel, which had just passed her special survey in a good trading condition. Shipowner had three choices: further trading, second-hand sale or scrap sale. After five spot shipments the vessel was still earning far below her operating expenses. The scrap price was \$260 and the bunker price at Fujairah was \$ 372.80. The USD libor was 1%. 14,630,000 dwt of the total world fleet was scrapped in 2008. There was 55.5% increase in the total world fleet and Baltic Dry Index was 2,685. Total seaborne cargo had decreased 4% and every fixture was a problem since there was no cargo for her specific trade. She was 25 years old at the time of decision and was in a good condition. She used to consume 8 tons/day more than a new vessel and did not require any additional cost for neither IMO nor Flag State requirements.

Considering these, scores for Vessel #1 can be defined as in Table 8.

**Table 8.** Scores for Vessel #1

Evaluation sub-criteria	Actual value	Score
1. Scrap Steel Price	\$ 260.00	2
2. Bunker Price	\$ 372.80	1
3. Finance Cost	1%	1
4. Orderbook	55.5%	5
5. Total tonnage scrapped	14,630,000 dwt	4
6. Freight Market	2,685	1
7. Cargo Availability	- 4%	5
8. Charterers' Vessel Selection Criteria	It creates a problem in every fixture	5
9. Age Restriction for Further Trading	25	5
10. Technical Condition of the Vessel	Good	2
11. Bunker Consumption	8 tons/day	4
12. Newly Imposed Rules and Regulations by IMO	None	1
13. Flag State Requirements	None	1

### Vessel # 2

In 2006, the owner had a 25-year old Panamax (75,000dwt) vessel with special survey due. The scrap steel price was \$345 and the bunker was trading at \$310. The libor was 6%. 6,100,000 dwt of total world fleet was scrapped in 2005. There was 26.91% increase in the total world fleet and Baltic Dry Index was 2,718. There was 4.0% increase in the total seaborne cargo. The vessel was in a bad condition. There was never a problem fixing her. She used to consume no more than 2 tons/day extra than a new vessel and did not require any additional cost for neither IMO nor Flag State requirements.

Considering these, scores for Vessel #2 can be defined as in Table 9.

**Table 9.** Scores for Vessel #2

Evaluation sub-criteria	Actual value	Score
1. Scrap Steel Price	\$ 345.00	3
2. Bunker Price	\$ 310.00	1
3. Finance Cost	6%	5
4. Orderbook	26.91%	5
5. Total tonnage scrapped	6,100,000 dwt	5
6. Freight Market	2,718	1
7. Cargo Availability	4%	1
8. Charterers' Vessel Selection Criteria	There was never a problem fixing her	1
9. Age Restriction for Further Trading	25	5
10. Technical Condition of the Vessel	Bad	4
11. Bunker Consumption	2 tons/day	1
12. Newly Imposed Rules and Regulations by IMO	None	1
13. Flag State Requirements	None	1

**Vessel # 3**

In 2008 the owner had a 1983 built product tankers, (25,000 dwt). Special survey of the vessels was due. The scrap steel price was \$630 and the bunker was trading at \$509. The libor was 3%. 6,400,000 dwt of total world fleet was scrapped in 2007. There was 52.11% increase in the total world fleet and Baltic Dry Index was 8,053. There was 4.3% increase in the total seaborne cargo and it was impossible to fix her. She was 25 years old and was in a bad condition. She used to consume no more than 2 tons/day extra than a new vessel. There was no steel renewal requirement. The cost of newly imposed rules and regulations by IMO was expected to be around \$1.5 million. Flag state requirements were estimated as \$1.2 million.

Considering these, scores for Vessel #3 can be defined as in Table 10.

**Table 10.** Scores for Vessel #3

Evaluation sub-criteria	Actual value	Score
1. Scrap Steel Price	\$ 630.00	5
2. Bunker Price	\$ 509.00	3
3. Finance Cost	3%	3
4. Orderbook	52.11%	5
5. Total tonnage scrapped	6,400,000 dwt	5
6. Freight Market	8,053	1
7. Cargo Availability	4.3%	1
8. Charterers' Vessel Selection Criteria	It was impossible to fix her	5
9. Age Restriction for Further Trading	23	4
10. Technical Condition of the Vessel	Very bad	5
11. Bunker Consumption	2 tons/day	1
12. Newly Imposed Rules and Regulations by IMO	\$1.5 million	5
13. Flag State Requirements	\$1.2 million	5

**Vessel # 4**

In 2017, the owner had a 1999 built 46,000 dwt dry bulk vessel with intermediate survey due. The scrap steel price was \$325 and the bunker was trading at \$357. The libor was 1%.

44,400,000 dwt of total world fleet was scrapped in 2016. There was 6.5% increase in the total world fleet and Baltic Dry Index was 740. There was 2.4% increase in the total seaborne cargo. Charterers never had a problem fixing her. She was 18 years old and was in a good condition. The market was slightly improving. Orderbook was coming down in favour of the owner. She used to consume no more than 2 tons/day extra than a new vessel. IMO regulations would not be due until next special survey, which would be due in 2020 which meant no incurring costs for IMO or Flag State requirements.

Considering these, scores for Vessel #4 can be defined as in Table 11.

**Table 11.** Scores for Vessel #4

Evaluation sub-criteria	Actual value	Score
1. Scrap Steel Price	\$ 325.00	3
2. Bunker Price	\$ 357.00	1
3. Finance Cost	1%	1
4. Orderbook	6.5%	1
5. Total tonnage scrapped	44,400,000 dwt	1
6. Freight Market	740	4
7. Cargo Availability	2.4%	2
8. Charterers' Vessel Selection Criteria	It is never a problem	1
9. Age Restriction for Further Trading	18	3
10. Technical Condition of the Vessel	Good	2
11. Bunker Consumption	2 tons/day	1
12. Newly Imposed Rules and Regulations by IMO	None	1
13. Flag State Requirements	None	1

### **Vessel # 5**

In 2003 the owner had a 1981 built Panamax combination carrier (75,000 dwt) vessel, which had a major accident in the British Channel. The vessel was due to pass intermediate survey and the cost of repair was \$5,000,000 and would take 3 months to repair. The scrap steel price was \$178 and the bunker was trading at \$166. The labor was 1%. 29,470,000 dwt of total world fleet was scrapped in 2002. There was 14.32% increase in the total world fleet and Baltic Dry Index was 1694. There was 3.0% increase in the total seaborne cargo. Charterers never had a problem fixing her. She was 22 years old and was in a very bad condition. She used to consume no more than 2 tons/day extra than a new vessel. The value of the vessel due to the accident decreased to scrap value. However, there were no additional costs due to newly imposed rules and regulations.

Considering these, scores for Vessel #5 can be defined as in Table 12.

All those scores are then fed in Table 13 for further calculations as defined in Section 4.3.

### **Decisions about the vessels**

Vessel #1: Demolition score is 2.644. This score means that the owner needs to give a scrap decision. This decision is parallel with the actual decision given by the owner. In reality, there was no second-hand buyer and the owner was left with the only alternative, scrap sale.

Vessel #2: Demolition score is 2.207. This score means that the owner can further trade the ship. In reality, the owner had the following options: spend an important sum of money to pass special survey for further trading, second-hand sale or scrap sale. He decided to pass her special survey even though the survey required 800 tons of steel renewal because the freight market was at record high due to supply shortage in the dry bulk fleet. As a result of a good decision, he benefited for a couple more years from the good freight market.



**Table 12.** Scores for Vessel #5

Evaluation sub-criteria	Actual value	Score
1. Scrap Steel Price	\$ 178.00	1
2. Bunker Price	\$ 166.00	1
3. Finance Cost	1%	1
4. Orderbook	14.32%	3
5. Total tonnage scrapped	29,470,000 dwt	3
6. Freight Market	1,694	2
7. Cargo Availability	3%	2
8. Charterers' Vessel Selection Criteria	It is never a problem	1
9. Age Restriction for Further Trading	22	4
10. Technical Condition of the Vessel	Very bad	5
11. Bunker Consumption	2 tons/day	1
12. Newly Imposed Rules and Regulations by IMO	None	1
13. Flag State Requirements	None	1

Vessel #3: Demolition score is 3.526. This score means the owner should give a scrap decision right away. Since the score is way too high, the decision seems an easy one.

Vessel #4: Demolition score is 1.845. The owner should continue trading the vessel until the next special survey.

Vessel #5: Demolition score is 1.874. The score means that the owner should continue trading the ship. In reality, the owner decided to spend the money and repair the vessel because he saw the opportunity in the coming freight market due to the unbalance in supply and demand.

## 6. Conclusion

Shipowners' income arises from their vessels and they naturally aim to receive maximum possible income from their assets. However, shipping is a cyclical business, which is very difficult to forecast, and investments do not always perform as initially planned. There are many factors that need to be considered when making a shipping investment decision and in this paper a decision support tool has been developed to aid the shipowners in making a scrap sale decision.

To build the tool, first, a model having four main and thirteen sub-criteria was constituted. During the process, literature review and actual expertise of some shipowners were utilized. Then the criteria and sub-criteria were weighed via pairwise comparisons of three well known international experts. Also, the calculation process for the weights of the criteria was explained in detail illustrated with some numerical examples to let practitioners use their own preference evaluations, if they desire to do so. Then, a scoring guide was prepared in line with the criteria. The tool was completed with a Demolition Score Calculation Table (see Table 13).

A shipowner is only expected to know the actual values/facts for his vessel and the environment. Thus, he can score the case at hand against thirteen criteria using the scoring guide. Finally, with simple mathematical operations such as addition and multiplication in Table 13, he can come up with a single demolition score for his vessel. If the score is less than 2.5, the decision will be further trading the ship, else the vessel needs to be sold for scrap. To help the practitioners with scoring, 5 actual cases were given in detail, and results were briefly discussed.

For future research, the model can further be customized for specific types of vessels (e.g. roro, container, etc.).

**Table 13.** Scoring matrix for 5 ships

	Weight	Ship #1		Ship #2		Ship #3		Ship #4		Ship #5	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Scrap Steel Price	0.056	2	0.112	3	0.168	5	0.280	3	0.168	1	0.056
Bunker Price	0.042	1	0.042	1	0.042	3	0.126	1	0.042	1	0.042
Finance Cost	0.055	1	0.055	5	0.275	3	0.165	1	0.055	1	0.055
Orderbook	0.085	5	0.425	5	0.425	5	0.425	1	0.085	3	0.255
Total Tonnage Scrapped	0.021	4	0.084	5	0.105	5	0.105	1	0.021	3	0.063
Freight Market	0.129	1	0.129	1	0.129	1	0.129	4	0.516	2	0.258
Cargo Availability	0.137	5	0.685	1	0.137	1	0.137	2	0.274	2	0.274
Charterers' Vessel Selection Criteria	0.039	5	0.195	1	0.039	5	0.195	1	0.039	1	0.039
Age Restriction for Further Trading	0.088	5	0.440	5	0.440	4	0.352	3	0.264	4	0.352
Technical Condition of the Vessel	0.033	2	0.066	4	0.132	5	0.165	2	0.066	5	0.165
Bunker Consumption	0.032	4	0.128	1	0.032	1	0.032	1	0.032	1	0.032
Newly Imposed Rules and Regulations by IMO	0.156	1	0.156	1	0.156	5	0.780	1	0.156	1	0.156
Flag State Requirements	0.127	1	0.127	1	0.127	5	0.635	1	0.127	1	0.127
			<b>2.644</b>		<b>2.207</b>		<b>3.526</b>		<b>1.845</b>		<b>1.874</b>

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