TANKER SELECTION BASED ON AN ENTROPY-WEIGHTED FUZZY MATTER APPROACH

(DOI No: 10.3940/rina.ijme.2021.a4.607)

Haoqiang Li, College of Management, Shenzhen University, China; College of Transport and Communications, Shanghai Maritime University, China, **Jihong Chen***, College of Management, Shenzhen University, China; College of Transport and Communications, Shanghai Maritime University, China; Commercial College, Xi'an International University, China; Qianhai Shengang Institute of International Finance, China; Shenzhen Research Center for China Blue Oceans, China, **Zheng Wan***, College of Transport and Communications, Shanghai Maritime University, China, **Xiao Cao**, College of Transport and Communications, Shanghai Maritime University, China, **Yaqing Shu**, School of Navigation, Wuhan University of Technology, China and **Yun Bai**, Center for Advanced Infrastructure and Transportation, Rutgers University, USA

KEY DATES: Submitted: 25/08/2020; Final acceptance: 25/01/2021; Published: 25/03/2021

SUMMARY

As an important aspect of global economic development, the choice of ship type for offshore oil transportation is a key issue in shipping companies making investment decisions. These can have far-reaching impacts regarding economic benefits and operational developments by shipping companies. To facilitate relatively accurate scientific decisions to evaluate the economic nature of tankers on investment plans, the study assigns entropy weights to various indicators and models tanker type economic arguments based on the entropy-weighted fuzzy matter-element approach, and by calculating the Euclid approach degree of each tanker evaluates the choice of tanker ship type. The results from the study show that the entropy-weighted fuzzy matter-element method is very effective in dealing with tanker selection and decision-making under complex and multi-attribute scenarios. Several conclusions are drawn and further work suggested.

NOMENCLATURE

C	The characteristics related to the matter
e_j	The entropy of the *j*th evaluation indicator
g_j	Difference
IRR	Internal return rate
M	The matter to be evaluated
NPV	Net present value
PBP	Payback period
P_{ij}	Percentage of the *i*th evaluated object to the *j*th evaluation indicator
Qt	Annual shipping quantity of vessel
R	Matter-element. When Magnitude x is fuzzy, R is a fuzzy matter-element
R_n	N eigenvectors present an n-dimensional fuzzy matter-element
RFR	Required freight rate
VI	Vessel investment
w_j	The final weighting coefficient
x	The magnitude of Characteristic C related to Object M to be evaluated
x_{ij}	The observed data of the *i*th evaluated object for the *j*th evaluation indicator
Δ_{ji}	Sum of squared differences of corresponding items of R_{0n} and $\overline{R}_{mn}$
$\mu(x)$	The fuzzy magnitude of Characteristic C related to the matter, that is, the membership degree of the corresponding magnitude of Characteristic C related to Matter M to be evaluated

1. INTRODUCTION

With the global energy demand on the rise, petroleum has become one of the primary energy sources for industrial development in various countries, which has also boosted the boom of petroleum carriers. Tankers, as the most important marine carriers for petroleum, have witnessed fast improvements in design and construction. In recent years, vessel investment levels have been surging, attracting increasing attention to tanker type selection and investment for construction (Kou and Luo, 2018).

Maritime shipping, as a technologically advanced and capital-intensive industry, is prone to great risks for investment and operations, especially when the ship upsizing trend has diversified the sources of shipping and ship investment funds and gives rise to uncertainties in investment decisions. The shipping industry consumes a large number of funds with prolonged return periods of investment. Moreover, the huge capital flows in vessel investment concern the survival, profitability, and development of shipping enterprises and shipowners. These combined have made ship enterprises more prudent for making decisions on tanker purchase which is a major strategic investment.

Tanker companies are exposed to huge operational risks from the beginning of the investment. Tanker enterprises not only need to design reasonable conditions for use of the invested vessels and arrange appropriate transportation tasks but also conduct thorough investigations into the current shipping market and analyze and predict the prospects. The economic argument for vessel type selection is a process of studying the economic effects of investment moves in a socialist system. It is a comprehensive outcome of the practical issues of shipping industry development and the theoretical issues of productivity economics. Zhang et al. (2006) and Pan et al. (2019) proposed that, before making a new shipbuilding investment, it is necessary to base on existing conditions of use, established shipping tasks, and the previous transporting experience by the same types of vessels to establish a vessel type solution with multiple constraints. Then through technical and economic evaluations of candidate vessel types, a technically advanced and feasible, and operationally economical, and reasonable vessel type solution can be settled to bring out the best of their economic benefits and promote modernization of vessels, to better serve the development of petroleum transporters. This is the main purpose of the economic evaluation of tankers.

Economic evaluation for vessel selection is a complex systematic project. Duru et al. (2017) proposed that the project requires lengthy investigation and elaborate calculation and analysis. With the help of formulas, more than 100 economic and operating indicators that comply with the current operational and vessel purposes can be extracted. Among these indicators, we can select appropriate ones to establish a balanced indicator system and then use proper methods to evaluate, compare and filter vessel type solutions for a vessel type solution that best meets customer needs. Moon et al. (2015) believed that this is a difficult and complicated process as the formulas used, the initial data selected and the evaluation system established will all impact the final determination of vessel types. In practice, it is possible that multiple vessel type solutions for transportation can complete the intended tasks of shipping enterprises on the same route or under the same transporting conditions, with, however, different economic benefits. How to evaluate the many solutions that meet technical and transporting conditions and select the one with the best economic effectiveness is what economic evaluation aims to address. This article utilizes project management, fuzzy matter-element decision analysis, engineering economics, and other related basic theories to select appropriate tanker types and related economic indicators in a bid to assign entropy weights and establish a fuzzy matter-element model, which serves the purposes of exploring tanker type selection for shipping enterprises' tanker investment and offering theoretical bases for the economic evaluation of tanker types.

The rest part of this article is structured as follows. After reviewing relevant literature, Section 2 identifies the shortcomings in the current research and proposes the subject of research in this article. Section 3 sorts out the indicators related to the economic evaluation of tankers and select the indicators applicable to tanker type evaluation. Section 4 proposes an entropy-weighted fuzzy matter-element evaluation model structure and lists the specific steps for tanker type selection. In section 5, the fuzzy matter-element argument model based on entropy weight is applied to carry out economic analysis on six tankers, and finally, the best tanker is selected. In Section 6, the last section, the author summarizes the article and presents shortcomings in the study.

2. LITERATURE REVIEW

The crude oil transportation industry is one featuring extremely high risks in prices. The ever-changing freight rates and related costs have exposed shipping market players to huge operational risks (Muñoz et al., 2016). Vaezi and Verma (2018) believed that sudden increases or declines of supplies in the oil market can produce a domino effect on global economic development and the tanker industry bears the brunt. Saadi et al. (2018) said that crude oil prices, fuel oil prices, and tanker freight rates have fluctuated to varying degrees in recent years and that the diversity of options in different markets (that is, bulk carrier market, crude oil market, container market, natural gas, and chemical market) has added to the complexity of shipping investment. In addition, other evaluations are also necessary for key issues, such as return on investment, catastrophic risks, and the oil crisis, to ensure the viability of transport enterprises.

2.1 THE ECONOMIC VARIABLE OF SHIP SELECTION

The economic variables of tanker solution evaluation have always been the key factors for shipping enterprises to select vessels. Scholars from various countries have also launched in-depth research on the economic factors involved in tanker transportation. Zhang (2018) thought that shipping investment decisions cannot go without the evaluations on the latest information of technical and commercial variables of the shipping market, as uncertainties in the complex relationships between these market variables may pose significant commercial risks to investors, shipowners, ship operators, and tanker charterers. Beenstock and Felsenstein (2016) proposed a comprehensive econometric model, which was empirically applied to the global tanker market to dynamically identify tanker freight rates, idle costs, prices of new vessels and used vessels, and fleet scales. Alizadeh and Talley (2011) investigated the tanker market to identify the importance of specific contractual factors in determining tanker freight rates and oil prices. The estimation results showed that the delayed period of tankers can determine the freight rate and tax rate, and other determinants of freight rate include hull type and navigation route of the vessels. Poulakidas and Joutz (2009) analyzed the impact of soaring oil prices on tanker prices to identify the environment of the relationship between transport market prices and oil prices, and used the dynamic model that explains spot tanker prices to study the degree of impact of the spot (voyage) levels and volatility on oil prices and the shipping industry in bull and bear markets. The results showed that there is a relationship among spot crude oil price, future crude oil price, crude oil inventory, and tanker price. This has provided theoretical support to better understand the relationship between freight rates and crude oil prices and improve operational management and budget planning decisions. Zhang(2018) analyzed the impact of changes in oil prices on fuel prices and tanker freight rates, using copula multivariate models of various options to analyze oil price and tanker market variables and related effective methods and reveal the time-varying effects of related variables. Adland and Cullinanen(2005) proposed a simple argument solely based on logic and marine economy theories to refute the applicability of the expectation theory in the bulks freight market. The results showed that risk premiums must be time-variable and must be determined systematically by the freight market status and the time charter period. The study drew signs of risk premiums attributable to various risk factors, where possible, and the conclusion that the theoretical net risk premium is usually negative, but short-term chartering contracts may change in a strong freight market. These studies all demonstrated that the economic variables in the tanker market are strongly dependent and closely related to the global economy.

2.2 QUANTITATIVE THEORY OF SHIP SELECTION

Since shipping decision-makers for vessel investment are subject to the impacts of financial uncertainties or the difficulty in quantifying financial nomenclature, related literature took the complicated economic factors into account while converting them into optimization problems to work out solutions. Rousos and Lee (2012) explored the need and possibility of extending the traditional viewpoints to a multi-criteria environment to expand shipping investment decision-making, and proposed a multi-criteria decision-making model as an alternative to the traditional analytic hierarchy process (AHP) - Discounted Cashflow Model (DCM) to strike the best balance between net present value, internal return rate, project risk profile, decision-maker mentality, and other parameters. They set shipping investment evaluation as a multi-criteria optimization problem and solved it using the analytic hierarchy process. Shipping decision-makers can make the best trade-off between financial and non-financial aspects based on their personal preferences and values. Multi-criteria analysis is also very effective under certain hypotheses and constraints. Xie et al (2008) proposed a new method-evidence inference method when uncertainty exists in the multi-criteria decision analysis method. The method was used for selecting the optimal vessel type from a group of candidates to serve the designing of new reference vessels. The method can consider both the quantitative and qualitative attributes of complex properties in the process of vessel type selection. The research results showed that when qualitative and quantitative information with or without uncertainty must be considered, the evidence-based inference method can support the multi-criteria vessel selection process. The results produced by this method include a ranking of candidate vessel types as well as the pros and cons of performance distribution types at different evaluation levels, which information is essential to help decision-makers make informed choices and understand the impacts of risks associated with the selected vessel types. Nst et al. (2018) proposed a strategy to minimize shipping costs to ensure the feasibility of transporting crude palm oil by sea. This strategy is used to select chartered vessels as barges or as chemical carriers. The study concluded that choosing a "barge chartering contract" or a "chemical carrier chartering contract" is a random decision. Therefore, a two-stage stochastic planning model was used to identify the optimization model and then to provide strategic decision-making support for vessels that transport crude palm oil by minimizing shipping costs.

The previous literature conducts analysis and studies on oil price formation, the definitiveness, and volatility of various variables in the tanker industry and the market value, with certain progress made in comparative analysis and empirical research on the economics of tanker types. Against this context, this article makes an in-depth quantitative analysis of the economic attributes involved in tanker selection and provides a scientific theoretical basis for tanker enterprises' tanker selection for investment.

3. INDICATOR SYSTEM AND FACTORS

Evaluating the economic benefits of vessels requires specific indicators, and different types of vessels have different indicator systems. For vessel investors, different economic indicators of the same type of vessels can display different priorities. Therefore, a single economic indicator cannot accurately reflect the economic benefits of multiple candidate vessel types. To better describe and guide tanker investment and selection of shipping enterprises, it is necessary to select scientific economic indicators and establish a well-structured economic indicator system, given the characteristics of vessel type solutions of having multiple attributes and featuring coexistence of certainties and uncertainties, selected static indicators such as vessel's transporting capacity, unit shipping cost, and annual profit to evaluate vessel's shipping performance (Najibi et al., 2009). Bijwaard and Knapp (2009) believed that, for investors and operators of shipping enterprises, vessel investment is a long-term process with dynamic returns. Dynamic indicators can measure investment returns in an economic sense. In particular, when the time value of funds is considered, dynamic indicators can evaluate the economic status throughout a vessel's operating cycle in an all-round manner.

Based on the research of the above literature, this article takes into account the static and dynamic indicators of the economic evaluation of vessels and selects five economic indicators (see Table 1) that apply to the economic evaluation of tanker types, namely VI (vessel investment), NPV (net present value), IRR (internal rate of return), PBP (payback period), and RFR (required freight rate). In the economic sense, ship investment is a long-term dynamic income process. Static indicators can reflect the advantages and disadvantages of investment, but can not accurately measure the size of investment income. Dynamic indicators can consider the economic situation of the whole operation cycle of ships. From the intuitive calculation formula, these five dynamic indicators can cover most static indicators and express them more comprehensively.

3.1 VESSEL INVESTMENT

Invested cost of the vessel, that is, the investment of the vessel. The amount is the actual amount paid by shipping enterprises for vessel production and applies to both new and second-hand vessels. VI is extensively used and is the most fundamental and direct economic indicator concept. It is available in a straightforward manner.

3.2 NET PRESENT VALUE

The amount after deducting the amount of vessel investment from the discounted operating receipts and disbursements of the vessel each year under the benchmark yield. Gollier (2010) believed that the indicator applies to cases of known income and is an economic indicator to measure whether vessel investment could be recovered, especially suitable for the circumstances where the investor has limited capital but seeks the maximum benefits. The critical point appears when the net present value is zero. When the net present value is greater than zero, it means that the investor is profitable; when the net present value is smaller than zero, it means that the investment plan has a deficit; when the net present value is exactly zero, it means that the investment plan has just reached the benchmark yield with no profit or loss. Žižlavský (2014) thought that when the investor has sufficient funds and pursues the absolute value of the operated project, the NPV indicator can be used for evaluation. When the investor kind of runs short of funds but sees the same period of use and pursues the relative value, the NPV index can be used for evaluation.

3.3 INTERNAL RETURN RATE

Internal return is the rate of return when the total income is equal to the total cost. The sum of the discounted values of cash flows in each year of the invested project is the project's net present value, and the discount rate when the net present value equals zero is the internal return rate of the project. It can be understood as the investment recovery capability of the solution, reflecting the maximum loan interest rate that the solution can afford. The indicator applies to economic evaluation for loan investment and income estimation of the solution. Ng and Beruvides (2015) believed that the internal return rate is the desired return rate for an investment, and is the discount rate that makes the net present value of the invested project equal to zero. In general, the project is considered feasible when the internal return rate is greater than or equal to the benchmark yield.

Table 1：Selection of Indicators and Factors for Tanker Economy Evaluation

Factor	Type	Definition	Reference
Vessel investment	Upper limit indicator	Invested cost of the vessel, that is, the investment of the vessel.	Luo and Fan,2010; Fan and Luo, 2013; Celik et al. ,2018
Payback period	Lower limit indicator	The profit after deducting the total cost from the annual operating revenue of the vessel, excluding the years of interest payment of investment.	Mahlia et al. ,2011;Lin et al. ,2015; Zis et al. ,2016
Required freight rate	Lower limit indicator	The revenue required by the minimal unit shipping capacity to meet the preset benchmark yield.	Lun and Quaddus, 2009; Benth and Koekebakker, 2016;Chen et al. ,2017
Net present value	Upper limit indicator	The differences between discounted receipts and disbursements of each year based on the rate of return on investment.	Sobel et al. ,2009;Gollier,2010; Wiesemann et al.,2010
Internal return rate	Upper limit indicator	The rate of return on investment that zeros the net present value during the vessel period of use (or repayment of capital and interest).	Keča ,2010; Magni,2013; Simand Wright., 2017

3.4 PAYBACK PERIOD

The payback period is the minimum period for repaying the amount of investment with all the revenue gained during the vessel operation period. The payback period is calculated using the rate of return on investment and the annual yield to reflect the recovery rate of investor funds. When the expected rate of return on investment is equal to the internal return rate, the payback period is the period of use of the vessel. When the investment is a one-time investment, the return of each period is the same.

3.5 REQUIRED FREIGHT RATE

The required freight rate stands for the minimum income per ton of cargoes for a tanker investor to achieve the target return rate. Its value is equal to the ratio of the average annual cost (AAC) to the annual shipping quantity of vessels (Q_t). The AAC is the sum of the annualized present value of investment (compound interest included) and the operating cost of the year.

4. ECONOMIC EVALUATION MODEL OF TANKERS

4.1 MODEL STRUCTURE

The entropy-based fuzzy matter-element evaluation model is structured to involve the following parts. First, identify the underpinning data for each candidate vessel type. Then build the composite fuzzy matter-element of tankers to get the standard and difference-squared fuzzy matter-element. Apply the entropy weighing method to identify the weights of various indicators and finally calculate the Euclid approach degree and evaluate the selected result. See Figure 1 for the economic analysis framework of tanker type selection based on entropy-weighted fuzzy matter-element.

4.2 MODELING STEPS

The matter-element analysis method is an emerging discipline that integrates mathematics, systematics, and cognitology among others. When dealing with matters, especially the problems of different and incompatible types, people often combine the target matter, the characteristics of the matter, and the specific magnitudes of the matter under the target characteristics for consideration(Wang, et al., 2015). Such a way of thinking describes specific laws of changes of objective matters in a more accurate manner.

Entropy is an important concept in social science and physical science, which is a measure of uncertainty and information. The attribute value of the evaluation index is a carrier of information, and entropy can be used as a tool to evaluate the relative importance of the index attribute or scheme. In the process of decision-making, due to the uncertainty, incompleteness, and inaccuracy of decision information, fuzzy set theory is widely used in decision-making. In this paper, the idea and method of entropy are applied to fuzzy decision-making, which can make full use of the information contained in the attribute value of the evaluation index to express the preference information of decision-makers. When dealing with uncertain information, it is more expressive than fuzzy sets, and the evaluation results are more objective.

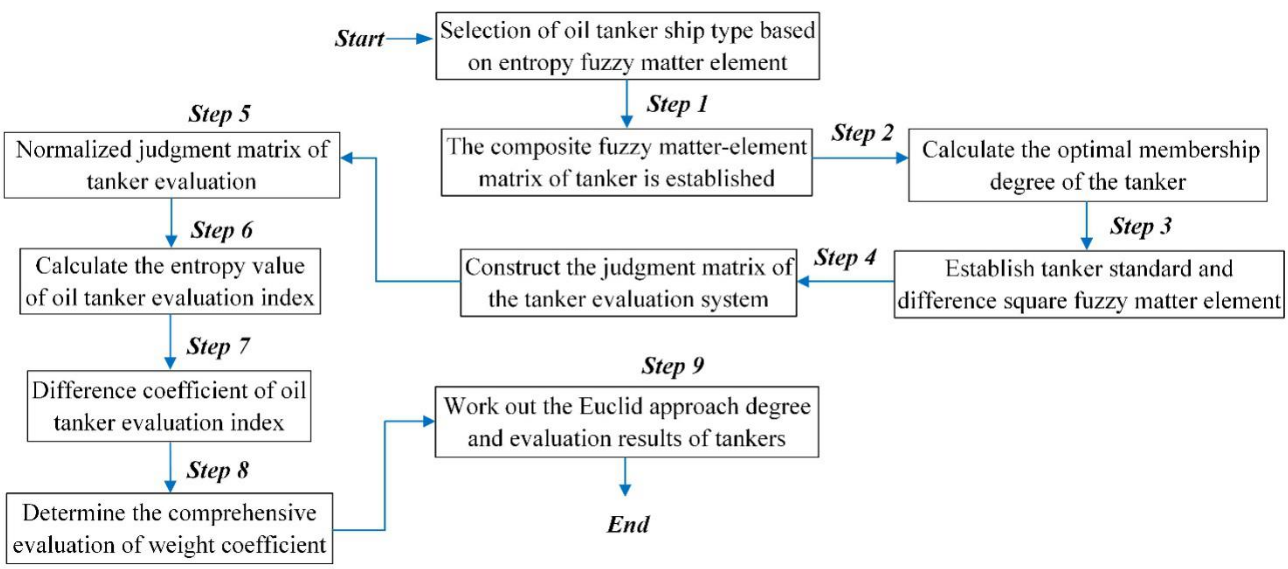

Figure 1: Framework of Tanker Type Selection Based on Entropy-weighted Fuzzy Matter-Element

To construct a tanker economic evaluation model based on entropy-weighed fuzzy matter-element, first, we need to introduce triangular fuzzy numbers into required economic evaluation indicators to quantify the indicators. The tanker type is a matter. The selected economic indicators for it are characteristics and the specific values of the characteristic indicators are the magnitudes. The three constitute the matter-element in a matter-element model. Then leveraging the entropy-weighed method, we determine the entropy weight of each evaluation indicator and apply the fuzzy matter-element analysis method to tanker type selection to form an entropy-weighed fuzzy matter-element decision-making model. The model is designed to act as a final solution for ship companies to build up an evaluation indicator system for tanker selection and identify the optimal vessel types. Calculation steps are as follows:

Step 1: Build a composite fuzzy matter-element matrix for tankers.

The approach uses three elements: things, characteristics, and values, so that all things constitute the basic elements composed of these three elements, that is, matter elements. If the magnitude among the three elements becomes fuzzy, the basic unit becomes a fuzzy matter-element, too. Fuzzy matter-element is expressed as follows:

$$R=\begin{bmatrix} & M \\ C & \mu(x) \end{bmatrix} \tag{1}$$

When Matter M has multiple related characteristics C_i $(i=1, 2, 3...n)$, and the magnitudes corresponding to the multiple characteristics are x_i $(i=1, 2, 3...n)$, we can call the R_n expressed by n eigenvectors an n-dimension fuzzy matter-element, expressed as follows:

$$R_n=\begin{bmatrix} & M \\ C_1 & \mu(x_1) \\ C_2 & \mu(x_2) \\ C_3 & \mu(x_3) \\ \vdots & \vdots \\ C_n & \mu(x_n) \end{bmatrix} \tag{2}$$

When there are m matters $M_j(j=1,2,3,...,m)$ to be evaluated and they share n characteristics C_i, we can get an n-dimension fuzzy matter-element with m matters to be evaluated R_{mn}, expressed as follows:

$$R_{mn}=\begin{bmatrix} & M_1 & M_2 & M_3 & \cdots & M_m \\ C_1 & \mu(x_{11}) & \mu(x_{21}) & \mu(x_{31}) & \cdots & \mu(x_{m1}) \\ C_2 & \mu(x_{12}) & \mu(x_{22}) & \mu(x_{32}) & \cdots & \mu(x_{m2}) \\ C_3 & \mu(x_{13}) & \mu(x_{23}) & \mu(x_{33}) & \cdots & \mu(x_{m3}) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_n & \mu(x_{1n}) & \mu(x_{2n}) & \mu(x_{3n}) & \cdots & \mu(x_{mn}) \end{bmatrix} \tag{3}$$

It is worth noting here that the magnitude has two subscripts, the first indicating the matter to be evaluated and the second indicating the characteristic index.

In specific practices, when the matter and the defined magnitudes of its characteristics are specific values, the aforementioned fuzzy magnitudes $\mu_{(x_{ji})}$ can be replaced by the specific magnitudes x_{ji}, so that we can get an n-dimension composite matter-element R_{mn} with m matters, expressed as follows:

$$R_{mn}=\begin{bmatrix} & M_1 & M_2 & M_3 & \cdots & M_m \\ C_1 & x_{11} & x_{21} & x_{31} & \cdots & x_{m1} \\ C_2 & x_{12} & x_{22} & x_{32} & \cdots & x_{m2} \\ C_3 & x_{13} & x_{23} & x_{33} & \cdots & x_{m3} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_n & x_{1n} & x_{2n} & x_{3n} & \cdots & x_{mn} \end{bmatrix} \tag{4}$$

Step 2: Calculate preference memberships of tankers.

When the magnitude is fuzzy, that is, the comprehensive evaluation of a fuzzy matter-element, the degree of membership can help with effective evaluation for a multiple-element fuzzy matter. The concept of membership degree is derived from that of the fuzzy evaluation function. The membership degree is defined as: if any element t within the Range U of the studied object always has a number $V(t)\in[0,1]$ corresponding to it, we call V as a fuzzy set of U and call $V_{(t)}$ as the degree of membership of t to V. Membership degree, means the degree of membership. Unlike weight, membership degree refers to the degree of the latter being attached to the former, or in other words, the former determines the latter. In the case of weight, it means that proportion of the latter in the former, or in other words, the degree of impact of the latter on the former, that is, the latter determines the former. Based on the fuzzy matter-element matrix R_{mn} established in the preceding part, the preference membership degree refers to the membership degree of the Characteristic Value x_{ji} corresponding to the Characteristic C_i of each matter to be evaluated to various evaluated fuzzy magnitudes of the standard solution. In general, the calculated preference membership degree is a positive value.

Formulas for calculating the preference membership degree vary among different characteristic magnitude types. When the magnitude is a lower limit indicator that prefers greater values, the formula is as follows:

$$u_{ji}=\frac{x_{ji}}{\max_j x_{ji}} \tag{5}$$

When the magnitude is an upper limit indicator that prefers smaller values, the formula is as follows:

$$u_{ji}=\frac{\min_j x_{ji}}{x_{ji}} \tag{6}$$

The preference membership degree fuzzy matter-element $\overline{R}_{mn}$ is hence constructed and expressed as follows:

$$\overline{R}_{mn}=\begin{bmatrix} & M_1 & M_2 & M_3 & \cdots & M_m \\ C_1 & u_{11} & u_{21} & u_{31} & \cdots & u_{m1} \\ C_2 & u_{12} & u_{22} & u_{32} & \cdots & u_{m2} \\ C_3 & u_{13} & u_{23} & u_{33} & \cdots & u_{m3} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_n & u_{1n} & u_{2n} & u_{3n} & \cdots & u_{mn} \end{bmatrix} \quad (7)$$

Step 3: Build the standard and difference-squared fuzzy matter-element of a tanker.

With the aforementioned preference membership degree fuzzy matter-element $\overline{R}_{mn}$, we can build the n-dimension standard fuzzy matter-element R_{0n}, expressed as follows:

$$R_{0n}=\begin{bmatrix} & M_0 \\ C_1 & u_{01} \\ C_2 & u_{02} \\ C_3 & u_{03} \\ \vdots & \vdots \\ C_n & u_{0n} \end{bmatrix} \quad (8)$$

In this article, the largest preference membership degree values are selected in the standard matter-element.

Then we build the difference-squared fuzzy matter-element $R_{\triangle}$ with the n-dimension standard fuzzy matter-element R_{0n} and the preference membership degree fuzzy matter-element $\overline{R}_{mn}$, expressed as follows:

$$R_{\triangle}=\begin{bmatrix} & M_1 & M_2 & M_3 & \cdots & M_m \\ C_1 & \triangle_{11} & \triangle_{21} & \triangle_{31} & \cdots & \triangle_{m1} \\ C_2 & \triangle_{12} & \triangle_{22} & \triangle_{32} & \cdots & \triangle_{m2} \\ C_3 & \triangle_{13} & \triangle_{23} & \triangle_{33} & \cdots & \triangle_{m3} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_n & \triangle & \triangle_{2n} & \triangle_{3n} & \cdots & \triangle_{mn} \end{bmatrix} \quad (9)$$

Where $\triangle_{ji}=(u_{ji}-u_{0i})^2$ $(j=1,2,3,\ldots,m;\ i=1,2,3,\ldots,n)$.

Step 4: Build the judgment matrix for the tanker evaluation system.

To build the evaluation system, first, we need to identify the target objects and indicators and then identify the evaluated objects $U_i = (1, 2, 3\ldots n)$ based on the target tasks. Meanwhile, we also need to select appropriate evaluation indicators V_j $(j = 1, 2, 3\ldots, m)$ based on the evaluated objects to build the matrix T with n evaluated objects and m evaluation indicators, as follows:

$$T=\begin{bmatrix} & U_1 & U_2 & \ldots & U_n \\ V_1 & x_{11} & x_{21} & \ldots & x_{n1} \\ V_2 & x_{12} & x_{22} & \ldots & x_{n2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ V_m & x_{1m} & x_{2m} & \ldots & x_{nm} \end{bmatrix} \quad (10)$$

The observed data used in this article are the economic indicators of the vessel, and the data indicator $x_{ij} > 0$.

Step 5: Work out a normalized tanker evaluation matrix.

After getting the data indicator x_{ij} from the above steps, different evaluation indicators V_j correspond to different data and the evaluation indicators may be larger in number in actual practice, leading to different dimensions in the observed data among different groups of indicators for the same object. To ensure objectivity and feasibility of the established evaluation system, we need to normalize the observed data x_{ij} under each indicator V_j, that is, de-dimensioning. There are many ways to do this, which we will detail in the next section. Normalize the indicators using the following formula:

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (11)$$

Step 6: Calculate entropy values of tanker evaluation indicators.

Based on the entropy formula, we can work out the entropy value for the jth evaluation indicator during the evaluation of the n evaluated objects and m evaluation indicators, as follows:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad (12)$$

Where $0 \le e_j \le 1$.

Step 7: Work out the difference coefficient of tanker evaluation indicators.

For a given evaluation indicator V_j, the smaller the value difference of the data indicator x_{ij} corresponding to each evaluated object U_i, the larger the entropy value e_j of the indicator, based on the formulas in Steps 2 and 3, which also means the smaller amount of information the indicator can provide, and hence the smaller significance and weight of the indicator. So we can know that the larger the value difference of the data indicator, the smaller the entropy value, the more information the indicator can provide, and the larger weight of the indicator. Based on the above, we can define the difference degree g_j and the formula is as follows:

$$g_j = 1 - e_j \quad (13)$$

Where the larger the value of g_j, the higher significance of the indicator in the evaluation system.

Step 8: Identify the weighting coefficient for the comprehensive evaluation.

With the entropy values from the above formula, we can work out the weighting coefficient w_j of each indicator using the formula as follows:

$$w_j = \frac{g_j}{\sum_{i=1}^{m} g_i} \quad (14)$$

Step 9: Work out the Euclid approach degree and evaluation results of tankers.

The approach degree is a fuzzy set concept and used to describe the degree of similarity between fuzzy sets, that is, the degree of similarity between each solution with the optimal solution. Its calculation can overcome the lack of homogenization during the weighted averaging argument. The greater the approach degree, the higher similarity between the two solutions. The smaller the approach degree, the lower similarity between the two solutions. The approach degree for each solution helps with our comparison and selection of target solutions in the evaluation system.

This article, drawing on the generalized fuzzy operator concept, adopts the $M(\cdot,+)$ model and calculates the Euclid approach degree in a "multiply before add" method. The reason why we didn't use other models is that the $M(\cdot,+)$ the model features the convenience of calculation and meets the practical needs of engineering computing. The formula is as follows:

$$R_{pH}=\begin{bmatrix} & M_1 & M_2 & M_3 & \cdots & M_m \\ pH_j & pH_1 & pH_2 & pH_3 & \cdots & pH_m \end{bmatrix} \quad (15)$$

Where $pH_j=1-\sqrt{\sum_{i=1}^{n} w_i \Delta_{ji}}$ indicates the approach degree of the i-th solution with the optimal solution.

5. EMPIRICAL ANALYSIS

5.1 DATA COLLECTION

The article collects and sorts out the vessel type parameters of six Aframax tankers of 80,000 to 120,000 DWT and uses TANK1 - TAMK6 to represent the six Aframax tankers (see Table 2). The five evaluated economic indicators are respectively vessel investment VI, net present value NPV, internal return rate IRR, payback period PBP and required freight rate RFR. Based on the tanker type parameters of the six tankers in Table 2, we can work out the corresponding economic indicator data in Table 3.

5.2 MODEL APPLICATION

From Table 3, we can construct the composite fuzzy matter-element for the comprehensive evaluation of tankers. The matters to be evaluated are six tankers of TANK1 to TANK6, expressed as M_1 - M_6, respectively. The characteristics are the five economic indicators shown in Table 3. We build up a five-dimension composite matter-element for the six solutions and express it as $R_{6,5}$, as follows:

$$R_{6,5}=\begin{bmatrix} & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 \\ VI & 20312.2 & 15619.6 & 8848.9 & 7038.9 & 8580.7 & 8848.9 \\ NPV & 13922.1 & 12698.9 & 6263.4 & 5324.8 & 5970.5 & 6184.6 \\ IRR & 0.127 & 0.095 & 0.086 & 0.112 & 0.091 & 0.085 \\ PBP & 9.2 & 8.8 & 9.9 & 7.9 & 8 & 10.1 \\ RFR & 90.49 & 83.79 & 79.1 & 87.1 & 81.78 & 78.43 \end{bmatrix}$$

5.2 MODEL APPLICATION

From Table 3, we can construct the composite fuzzy matter-element for the comprehensive evaluation of tankers. The matters to be evaluated are six tankers of TANK1 to TANK6, expressed as M_1 - M_6, respectively. The characteristics are the five economic indicators shown in Table 3. We build up a five-dimension composite matter-element for the six solutions and express it as $R_{6,5}$, as follows:

$$R_{6,5}=\begin{bmatrix} & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 \\ VI & 20312.2 & 15619.6 & 8848.9 & 7038.9 & 8580.7 & 8848.9 \\ NPV & 13922.1 & 12698.9 & 6263.4 & 5324.8 & 5970.5 & 6184.6 \\ IRR & 0.127 & 0.095 & 0.086 & 0.112 & 0.091 & 0.085 \\ PBP & 9.2 & 8.8 & 9.9 & 7.9 & 8 & 10.1 \\ RFR & 90.49 & 83.79 & 79.1 & 87.1 & 81.78 & 78.43 \end{bmatrix}$$

Table 2 ： Parameters of Reference Tanker Types

Parameter	TANK1	TANK2	TANK3	TANK4	TANK5	TANK6
Vessel length/m	248.97	243.8	250.17	243.97	240.5	248
Vessel width/m	43.8	42	44	42.03	42	43
Vessel age/years	7	10	15.4	14.2	15.2	16.2
Draft/m	15	15.64	14.92	14.92	14.88	14.32
Gross tons/t	61320	59258	62371	57248	57683	57022
Speed/knots	15.7	14.4	14.6	14.6	14.2	15.2
DWT/tons	115724	115126	112045	109841	106499	105109

Source: Clarksons

Table 3：Summary of Economic Indicators of Aframax Tanker Type

Indicator	TANK1	TANK2	TANK3	TANK4	TANK5	TANK6
VI	20312.2	15619.6	8848.9	7038.9	8580.7	8848.9
NPV	13922.1	12698.9	6263.4	5324.8	5970.5	6184.6
IRR	0.127	0.095	0.086	0.112	0.091	0.085
PBP	9.2	8.8	9.9	7.9	8	10.1
RFR	90.49	83.79	79.1	87.1	81.78	78.43

Calculate the preference membership degrees of the magnitudes for various vessel types under different economic indicators. Among the five economic indicators to be evaluated, we can observe that the vessel investment VI, payback period PBP and required freight rate RFR indicators belong to upper limit indicators, while the net present value NPV and internal return rate IRR belong to lower limit indicators. As per the calculation of the preference membership degrees and the types of various economic indicators, we can use Formulas (5), (6), and (7) to work out the preference membership degree composite matter-element $\overline{R}_{6,5}$ of tankers, based on the following:

$$\overline{R}_{6,5}=\begin{bmatrix} & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 \\ VI & 0.3465 & 0.4506 & 0.7955 & 1.0000 & 0.8203 & 0.7955 \\ NPV & 1.0000 & 0.9121 & 0.4499 & 0.3825 & 0.4289 & 0.4442 \\ IRR & 1.0000 & 0.7480 & 0.6772 & 0.8819 & 0.7165 & 0.6693 \\ PBP & 0.8587 & 0.8977 & 0.7980 & 1.0000 & 0.9875 & 0.7822 \\ RFR & 0.8667 & 0.9360 & 0.9915 & 0.9005 & 0.9590 & 1.0000 \end{bmatrix}$$

Build a standard and difference-squared fuzzy matter-element of tanker based on Formula (9). This article selects the magnitude of the biggest membership degree value of 1 in $\overline{R}_{6,5}$ as the magnitude in the standard matter-element and then calculates the sum of squared differences of the various items in the standard fuzzy matter-element with the various items in the preference membership degree composite matter-element to get $R_{\triangle}$ as follows:

$$R_{\triangle}=\begin{bmatrix} & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 \\ VI & 0.4270 & 0.3018 & 0.0418 & 0.0000 & 0.0323 & 0.0418 \\ NPV & 0.0000 & 0.0077 & 0.3026 & 0.3813 & 0.3262 & 0.3089 \\ IRR & 0.0000 & 0.0635 & 0.1042 & 0.0140 & 0.0804 & 0.1094 \\ PBP & 0.2000 & 0.0105 & 0.0408 & 0.0000 & 0.0002 & 0.0474 \\ RFR & 0.0178 & 0.0041 & 0.0001 & 0.0099 & 0.0017 & 0.0000 \end{bmatrix}$$

With the entropy weighing method, the weights of various evaluation indicators are calculated. Then with Formula (10), the composite matter-element evaluation matrix of tankers is established; with Formula (11), the normalized evaluation matrix of various economic indicators is established. With the help of Formula (12), the entropy value e_j can be calculated. The results are as follows:

$$e_j=(0.8720 \quad 0.6336 \quad 0.6771 \quad 0.7941 \quad 0.8551)$$

Meanwhile, with Formulas (13) and (14), the entropy weights w_j can be calculated. The results are as follows:

$$w_j=(0.1090 \quad 0.3121 \quad 0.2802 \quad 0.1754 \quad 0.1234)$$

With Formula (15), the approach degree is calculated. Finally, the Euclid approach degrees of tankers and results can be worked out:

$$R_{pH}=\begin{bmatrix} & M_1 & M_2 & M_3 & M_4 & M_5 & M_6 \\ pH_j & 0.7714 & 0.7646 & 0.6321 & 0.6477 & 0.6421 & 0.6259 \end{bmatrix}$$

Based on the economic evaluation results of the six tanker types backed by the above entropy-weighted fuzzy matter-element model, we can rank the six tanker types by economic value as follows:

TANK1>TANK2>TANK4>TANK5>TANK3>TANK6

Tanker Type 1 is the most economical, followed by Types 2, 4, 5, 3, and 6 in order.

6. CONCLUSIONS AND PROSPECTS

6.1 MAIN CONCLUSIONS

The economic evaluation of tanker types is a process of selecting the optimal design schemes involving multiple objects and parameters. To make the evaluation results accurate to secure a satisfactory solution, it is necessary to cover as many required parameters as possible. These parameters are often determinate or indeterminate, and quantitative or non-quantitative. It is difficult to obtain satisfactory results relying on qualitative or quantitative analysis alone. This article introduces the background in detail, expounds on the necessity of economic evaluation of tankers, and adopts suitable evaluation schemes targeting the characteristics of various indicators for tanker economic evaluation. By filtering economic indicators, the article shortlists the indicators for evaluating candidate vessel types and calculates the entropy values and weights of candidate vessel types. Based on this, it builds a comprehensive evaluation model of fuzzy matter-element. The optimal solution is determined after analysis of the model results. A summary can be found as follows:

(1) The research object of this paper is the ship type of oil tanker. Facing the current oil tankers with so many kinds and uses, how to make the research objectives targeted and have practical investment reference value for shipping enterprises in a certain range is an important premise. By

analyzing the existing oil tanker types and weighing the advantages and disadvantages, the author finally chose six Aphra oil tankers as the object of economic demonstration.

(2) In this paper, a fuzzy matter-element model is constructed and weighted by the entropy method to form a comprehensive evaluation model. Through a large number of data investigation, collection, screening, and analysis, five dynamic economic indicators, namely ship investment, net present value, internal rate of return, necessary freight rate, and investment payback period, are finally selected. Compared with other static indicators, it can better reflect the economic situation of a ship in its whole life period. By using this method, the evaluation results can be expressed more objectively and directly for the system with multiple evaluation objects and multiple indicators.

(3) The process of oil tanker economic demonstration in this paper provides a feasible method for oil tanker investment decision-making of shipping enterprises. Facing the current weakening of world economic growth and the pressure from all sides, shipping enterprises pay attention to how to obtain the best benefit in the process of investment decision-making. This method solves this problem objectively and flexibly and proves that the obtained ship type has both technological advancement and economic benefit, which is worth learning from in investment decision-making.

6.2 PROSPECTS

As mentioned in the preceding part, the economic evaluation of vessels is a complex and systematic project, which requires not only much collection and analysis of the raw data, but also a correct choice from so many options. Both quantitative and qualitative efforts are indispensable. The final evaluation result must be a comprehensive one to reflect many possibilities from multiple angles. However, the information communication between shipping enterprises, relevant departments, and the author is not two-way or is even blocked, in the actual evaluation. This produces difficulties for information collection. Meanwhile, vessels are subject to impacts from various aspects during actual operations and not all of these impacts are controllable, which also brings risks to the final result.

There are still many deficiencies in the study and further research is required.

(1) Whether the evaluation result is close to the actuality depends on the accuracy of the selected raw data. The preliminary investigation, screening, and analysis of the data should be based on massive data networks and information resources. After the evaluation results are ready, how to fine-tune the results in the face of uncontrollable risks in practice is also a future focus of this article.

(2) The evaluated objects selected in this article are confined to a certain scope to make the results comparable and reasonable, but this also makes it infeasible to evaluate the tankers of different tonnages and backgrounds. How to apply the evaluation to tankers of different types and tonnages is also one of the follow-up tasks of the article.

(3) In the specific establishment process, the standard for establishing the preferential membership degree fuzzy matter-element from composite matter-element and the de-dimensionalization method is not unique. This article uses more convenient and more universal formulas. Comparing the application results from other formulas is also worthy of research.

7. ACKNOWLEDGEMENTS

The authors gratefully acknowledge supports from the National Natural Science Foundation of China (Grant No.51879156, 71704103 and 51409157), the Program for Professor of Special Appointment (Eastern Scholar) at Shanghai Institutions of Higher Learning, and the High-level talent project funding plan of the transportation industry supported by the Ministry of Transport of the People's Republic of China (Grant No. 2019-012). However, the authors are solely responsible for all the views and analyses in this paper.

8. REFERENCES

1. ADLAND, R. and CULLINANE, K. (2005) *A time-varying risk premium in the term structure of bulk shipping freight rates*, Journal of Transport Economics and Policy (JTEP), Vol. 39, No. 2, pp. 191-208.
2. ALIZADEH, A.H. and TALLEY, W.K. (2011)*Vessel and voyage determinants of tanker freight rates and contract times*, Transport Policy, Vol. 18, No. 5, pp. 665-675.
3. BEENSTOCK, M. and FELSENSTEIN, D. (2016) *Double Spatial Dependence in Gravity Models: Migration from the European Neighborhood to the European Union*, Spatial Econometric Interaction Modelling, Springer, pp. 225-251.
4. BENTH, F. E. and KOEKEBAKKER, S. (2016) *Stochastic modeling of Supramax spot and forward freight rates*, Maritime Economics & Logistics, Vol. 18, No. 4, pp. 391-413.
5. BIJWAARD, G.E. and KNAPP, S.(2009) *Analysis of ship life cycles—The impact of economic cycles and ship inspections*, Marine Policy, Vol. 33, No. 2, pp. 350-369.
6. CELIK GIRGIN, S., KARLIS, T. and NGUYEN, H.-O. (2018) *A critical review of the literature on firm-level theories on ship investment*, International Journal of Financial Studies, Vol. 6, No. 1, p. 11.

7. CHEN, F., MIAO, Y., TIAN, K., DING, X. and LI, T. (2017) *Multifractal cross-correlations between crude oil and tanker freight rate*, Physica A: Statistical Mechanics and its Applications, Vol. 474, pp. 344-354.
8. DURU, O., CLOTT, C. and MILESKI, J. P. (2017) *US tanker transport: Current structure and economic analysis*, Research in transportation business & management, Vol. 25, pp. 39-50.
9. FAN, L. and LUO, M. (2013) *Analyzing ship investment behaviour in liner shipping*, Maritime Policy & Management, Vol. 40, No. 6, pp. 511-533.
10. GOLLIER, C. (2010) *Expected net present value, expected net future value, and the Ramsey rule*, Journal of Environmental Economics and Management, Vol. 59, No. 2, pp. 142-148.
11. KEČA, L. (2010) *Assessment of cost-efficiency for wood production in poplar plantations in Ravan Srem, based on internal rate of return*, Glasnik Šumarskog fakulteta, No. 102, pp. 25-40.
12. KOU, Y. and LUO, M. (2018) *Market driven ship investment decision using the real option approach*, Transportation Research Part A: policy and practice, Vol. 118, pp. 714-729.
13. LIN, W., CHANG, K.-C. and CHUNG, K.-M. (2015) *Payback period for residential solar water heaters in Taiwan*, Renewable and Sustainable Energy Reviews, Vol. 41, pp. 901-906.
14. LUN, Y. V. and QUADDUS, M. A. (2009) *An empirical model of the bulk shipping market*, International Journal of Shipping and Transport Logistics, Vol. 1, No. 1, p. 37.
15. LUO, M. and FAN, L. (2010) *Determinants of Container Ship Investment Decision and Ship Choice*, *International Forum on Shipping,* Ports and Airports *(IFSPA)*, Vol. 2011, p. 449.
16. MAGNI, C. A. (2013) *The internal rate of return approach and the AIRR paradigm: a refutation and a corroboration*, The Engineering Economist, Vol. 58, No. 2, pp. 73-111.
17. MAHLIA, T. M. I., RAZAK, H. A. and NURSAHIDA, M. (2011) *Life cycle cost analysis and payback period of lighting retrofit at the University of Malaya*, Renewable and Sustainable Energy Reviews, Vol. 15, No. 2, pp. 1125-1132.
18. MOON, D.-S., KIM, D.-J. and LEE, E.-K. (2015) *A study on competitiveness of sea transport by comparing international transport routes between Korea and EU*, The Asian journal of Shipping and logistics, Vol. 31, No. 1, pp. 1-20.
19. MUÑOZ, J. A., ANCHEYTA, J. and CASTAÑ EDA, L. C. (2016) *Required viscosity values to ensure proper transportation of crude oil by pipeline*, Energy & Fuels, Vol. 30, No. 11, pp. 8850-8854.
20. NAJIBI, H., REZAEI, R., JAVANMARDI, J., NASRIFAR, K. and MOSHFEGHIAN, M. (2009) *Economic evaluation of natural gas transportation from Iran's South-Pars gas field to market*, Applied Thermal Engineering, Vol. 29, No. 10.
21. NG, E.H.and BERUVIDES, M. G. (2015) *Multiple internal rate of return revisited: frequency of occurrences*, The Engineering Economist, Vol. 60, No. 1, pp. 75-87.
22. NST, S. S., NABABAN, E. and MAWENGKANG, H. (2018) *An Optimization Model For Strategy Decision Support to Select Kind of CPO's Ship*, *IOP Conference Series:* Materials Science and Engineering, Vol. 300, IOP Publishing, p. 012007.
23. POULAKIDAS,A.andJOUTZ,F.(2009) *Exploring the link between oil prices and tanker rates*, Maritime Policy & Management, Vol. 36, No. 3, pp. 215-233.
24. ROUSOS, E.P. and LEE,B. S. (2012) *Multicriteria analysis in shipping investment evaluation*, Maritime Policy & Management, Vol. 39, No. 4, pp. 423-442.
25. SAADI, F. H., LEWIS, N. S. and MCFARLAND, E. W. (2018) *Relative costs of transporting electrical and chemical energy*, Energy & Environmental Science, Vol. 11, No. 3, pp. 469-475.
26. SIM,T.and WRIGHT, R. H. (2017) *Stock valuation using the dividend discount model: An internal rate of return Approach*, Growing Presence of Real Options in Global Financial Markets, Emerald Publishing Limited, pp. 19-32.
27. SOBEL, M. J., SZMEREKOVSKY, J. G. and TILSON, V. (2009) *Scheduling projects with stochastic activity duration to maximize expected net present value*, European Journal of Operational Research, Vol. 198, No. 3, pp. 697-705.
28. VAEZI, A. and VERMA, M. (2018) *Railroad transportation of crude oil in Canada: Developing long-term forecasts, and evaluating the impact of proposed pipeline projects*, Journal of Transport Geography, Vol. 69, pp. 98-111.
29. WANG, C., WU, A., LU, H., BAO, T. and LIU, X. (2015) *Predicting rockburst tendency based on fuzzy matter–element model*, International Journal of Rock Mechanics and Mining Sciences, Vol. 75, pp. 224-232.
30. WEI-JUN, P., JIE, R. and RUN-DONG, W. (2019) *Air Traffic Management Process Quality Assessment Model Based on Improved Fuzzy Matter Element Analysis*, Journal of Physics: Conference Series, Vol. 1187, IOP Publishing, p. 052069.
31. WEI-YING, Z.,YAN, L.,ZHUO-SHANG, J. and LIN-YI, D. (2006) *Multi-objectives fuzzy optimization model for ship form demonstration based on information entropy*, Journal of Marine Science and Application, Vol. 5, No.1, pp. 12-16.

32. WIESEMANN, W.,KUHN, D.and RUSTEM, B. (2010) *Maximizing the net present value of a project under uncertainty*, European Journal of Operational Research, Vol. 202, No. 2, pp. 356-367.
33. XIE, X., XU, D.L.,YANG, J.-B., WANG, J., REN, J. and YU, S. (2008) *Ship selection using a multiple-criteria synthesis approach*, Journal of Marine Science and Technology, Vol. 13, No. 1, pp. 50-62.
34. ZHANG, Y. (2018) *Investigating dependencies among oil price and tanker market variables by copula-based multivariate models*, Energy, Vol. 161,pp.435-446.
35. ZIS, T., ANGELOUDIS, P., BELL, M. G. and PSARAFTIS, H. N. (2016) *Payback period for emissions abatement alternatives: Role of regulation and fuel prices*, Transportation Research Record, Vol. 2549, No. 1, pp. 37-44.
36. ŽIŽLAVSKÝ , O . (2014) *Net present value approach: method for economic assessment of innovation projects*, Procedia-Social and Behavioral Sciences, Vol. 156, pp. 506-512.

