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THREATS TO SHIPPING IN THE BLACK SEA AND THEIR GLOBAL IMPACT

Summary. The article examines the threats to cargo transportation in the Black Sea and the directions of their impact on the maritime transport industry both regionally and globally. The assessment of the military component of these threats is important for all aspects of the transport fleet, primarily because the significance of military threats is greater than that of other risks to maritime transport. In particular, it is indicated that the consequences of threats to the merchant fleet due to hostilities in the Black Sea are not only sunken and damaged vessels, people lost,

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but also dynamic changes in freight rates and even an increase in the average service life of merchant vessels of the warring parties. This increases the risks of accidents and has already led to significant threats to marine biocenosis, which contradicts the principles of green shipping. The above principles, as proven by research, are also contradicted by the trend of reducing the development of alternative fuel infrastructure, which leads to a reduction in the possibilities of its further use by merchant fleet vessels. The importance of introducing fragmented logistics schemes, primarily expanding the use of the ro-ro network, for reducing the impact of threats is noted. The study confirms that the threat of sea pollution with a significant uncertain component is also represented by the systematic illegal transshipment of oil products in the open sea to avoid sanctions. At the same time, the study indicates that the significant uncertainty of wartime threats complicates the relevant assessment and forecasting of the parameters of all aspects of maritime transportation. It is also noted that the impact of the uncertainty of military risks limits the use of recursive vector autoregression for forecasting the freight rate. Therefore, a mathematical model is proposed to separate uncertainty from the impact of other factors that are considered as "colored" noise. It is also proposed to use an interval approach with an uneven distribution of the resulting function over the area of existence with its subsequent refinement by parameter estimation methods with other metrics. The mathematical model allows taking into account the different orientations of the impact vectors of uncertain factors, which increases the relevance of the forecast. The increasing relevance of maritime transport forecasts will contribute to risk prevention measures and resource provision to mitigate their consequences. Taking into account the uncertain component of risks is important not only in wartime, since this component is also present in maritime transport risks in peacetime. This will ensure the appropriate level of sustainability of cargo transportation by sea, reasonably shape the directions for the introduction of digital, green technologies, methods for optimizing logistics routes, etc.

Keywords: maritime transport, shipping sustainability, uncertainty of threats, maritime logistics, global crises, digitalization, green shipping, alternative fuels

1. INTRODUCTION

Maritime transport needs sustainable development to effectively ensure the functioning of the global market. To do this, it must resolve the dichotomy of increasing environmental sustainability and economic efficiency. However, the implementation of decarbonization, digitalization, logistics optimization, and other technological innovations as areas of "green shipping" is becoming a tangible obstacle not only to economic factors, but also to local and global crises, the cause of which, in particular, is military action (Kotenko et al., 2022).

The growth of risks of maritime transportation, even in individual water areas, has a negative impact not only on the operational efficiency of transport companies but also on the global maritime transport industry as a whole due to changes in logistics chains, significant port congestion, problems with crew formation, etc. The operational efficiency of the merchant fleet is reduced by long-term delays of vessels, a significant level of insurance rates, a high probability of compensation for injured crew members, etc.

In areas of increased risk, due to the threat of destruction, it is not even economically feasible to use more expensive vessels using modern technologies; in transportation logistics, shorter

routes should not be used, but safe routes should be chosen. The risks of pollution of the sea and air environment in such conditions increase. Therefore, the task of taking risks into account is acute for all aspects of maritime transportation. But taking risks into account in war conditions is a difficult task because they not only have a different mathematical nature: deterministic-stochastic, and fuzzy-and differ in the presence of a significant component that has signs of uncertainty.

It is the problem of the uncertain impact of war that causes the difficulties of formalizing risks and therefore negatively affects the assessment of the entire set of factors of maritime transportation, which prevents the implementation of measures to neutralize threats. Therefore, its solution is the path to sustainable shipping.

2. LITERATURE REVIEW

Management of economic processes, primarily in the field of maritime transport, which is characterized by a relatively significant level of risk, is aimed at ensuring sustainability in all aspects: economic (Fialkovska, 2025), environmental, both in terms of water pollution (Ravikumar, 2025) and coastal pollution (Shovkun-Zablotska et al., 2024), logistical, both from the point of view of coordinating the supply chain (Lopes et al., 2025), and from the point of view of reducing logistical risks (Mazur et al., 2022), technological (Oral et al., 2023), etc.

In particular, social sustainability, which should be aimed at the formation of corporate social responsibility, the protection of not only ship crews, but also workers of land-based maritime infrastructure, and more broadly - the population of coastal regions, also does not bypass the need to assess the risks to human life and health as a consequence of the activities of the maritime transport industry (Oloruntobi et al., 2023).

Various tools are used for this. Tools for digitalization of both the production and business activities of transport companies (Kapidani et al., 2020), as well as the digitalization of the entire maritime transport complex (Golubkova et al., 2021), including ports (Jović et al., 2022), are used. Integrated approaches that strengthen various components of sustainability, in particular, green shipping, both in a global aspect (Chen et al., 2024) and in view of the automation of technological processes of vessels (Mba, 2024) are implemented. But in times of crisis, especially a crisis of a military nature, the definition of sustainable maritime practices and operational efficiency of shipping companies need to be revised, which is often ignored by scientists (Mba, 2024).

At the same time, researchers, when analyzing the risks of sustainability of maritime transport, do not even take into account uncertain threats (Nitsenko et al., 2024; Lam, 2025). But these threats significantly limit even the use of modern digital means of supporting maritime transport. This applies, for example, to the Fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method, which is based on fuzzy variables and is used to optimize the cost of bunkering (Chrysafis, et al., 2022), since the Fuzzy TOPSIS method is not suitable for use in the case of uncertain risks. Also not relevant in wartime is the fuzzy DEMATEL () approach aimed at assessing the risks of accidents with damage to ship structures, since military threats can be not only fuzzy. Researchers using the DEMATEL (Decision Making Trial and Evaluation Laboratory) approach often do not even include military risks in the list of possible causes of ship damage (Kuzu, 2021).

The use of some models that are considered to take into account uncertain risks, such as Weibull models and long-normal models, is not always justified in cases of military risks (Ching et al., 2022). In particular, because these models rely on data series, statistical methods,

Markov-Monte Carlo chains. But a significant part of military threats is not described by statistical methods. Even in thorough reviews of methods for predicting maritime transport risks, there is no mention of the specifics of assessing military threats (Huang et al., 2023; Nitsenko et al., 2025). And these threats have a wide range of impacts. Thus, toxins as a result of the bombing of ships and port infrastructure spread not only in the Black and Azov Seas, but also in the Baltic Sea (Greenpeace in Central and Eastern Europe, 2024), because part of the catchment basins of Ukrainian rivers connects with the water area close to the ports of the Baltic Sea and through ballast water can reach all ports in the world (Rata et al. 2018), which limits the possibilities of green shipping even in water areas remote from the combat zone.

At the same time, even recognizing the significant impact of the war in the Black Sea basin on the global maritime transportation market, in particular LNG (Liquefied Natural Gas) transportation, scientists focus on the problems of maritime logistics, the extension of transport routes, bypassing the problem of assessing the impact of military threats (Ke et al. 2024). From the point of view of maritime logistics, this is, to a certain extent, substantiated, since even in wartime conditions it did not stop the introduction of online logistics platforms in the ports of warring countries by companies such as China Merchant Port Group, Compagnie Maritime d'Affrètement Compagnie Générale Maritime Group and blockchain platforms (Yarovyi, 2024). Some researchers even point out that military risks make transportation in the zone of military conflict attractive, due to the increase in freight rates, bypassing the assessment of the threat of destruction of the vessel (Fasii, 2023). This indicates the different direction of the vectors of influence of military threat factors, which complicates the integral assessment of their impact.

Determining and formalizing the impact of military risks is a difficult task. This is evidenced, for example, by the fact that these risks are often combined with other types of risks, in particular geopolitical ones (Rogozińska, 2023), or, as it was done in the study of logistics processes by Ponomarenko et al. (2023) – with “the influence of external factors that lead to instability”. Failure to take into account the unpredictable effects of war reduces the relevance of using proven methods for assessing the risks of maritime transportation such as: Fuzzy AHP (Analytic Hierarchy Process) and TOPSIS (Gulen et al. 2025), Fuzzy cognitive mapping (Soner, 2025), MIMAH (Methodology for the Identification of Major Accident Hazards) and Fuzzy Bayesian networks methodologies (Ay Cenk, 2025), Bayesian network model (Park Sang-A, 2025), etc. In general, this indicates the feasibility of expanding and radically revising the approach called the integrated hybrid method (Yorulmaz et al. 2025).

A review of the literature indicates a significant impact of war on all aspects of maritime transportation, including not only economic and military-strategic (Bazaluk, 2017), but also environmental, logistical, and other aspects of activities related to the transportation of goods by sea. At the same time, the influencing factors are parameters with different metrics, including uncertain ones.

The predominant impact of threats caused by war increases the need to take into account uncertain factors, which will make it possible to predict dangers with an appropriate level of relevance. This will increase the ability of both shipowners and seaport administrations to prevent threats and mitigate their consequences. Taking into account uncertain factors is also important for the merchant fleet to acquire the necessary level of sustainability in the post-war period, to properly shape development directions in the introduction of digital, green technologies, methods for optimizing logistics routes, etc.

3. MATERIALS AND METHODS

The study uses mathematical methods to analyze both statistical data and uncertain factors characteristic of large-scale war conditions. The proposed mathematical approach is based on the thesis that the weight of military risks outweighs the total weight of other threats to cargo transportation in water areas where hostilities are taking place. The first step of mathematical modeling is to separate uncertainty from the influence of other factors that are considered as "colored" information noise. A feature of "colored" noise, as it is known, is the possibility of its description by deterministic, stochastic, or fuzzy methods (Kotenko et al. 2023).

It is proposed to consider the uncertain influence of a factor or group of factors as a numerical value belonging to the interval of possible values. Uncertainty is considered as the approximation of the selected mathematical models with a set of resulting values $\underline{A}_1$ and $\underline{A}_3$ to the model with a set of resulting values $\underline{A}_2$, which are accepted as relevant. The model with a set of resulting values $\underline{A}_2$ is selected to confirm the forecast for the past period of time and is refined with the acquisition of information about each subsequent period of time. For this, the probability of coincidence of the resulting values $\underline{A}_1$, $\underline{A}_3$ with $\underline{A}_2$ is calculated as:

$$\varphi_{12}\left(\forall\overline{A}_1 \stackrel{\text{def}}{=} \overline{A}_2\right) = \int \gamma_1\left(\overline{A}\right)\gamma_2\left(\overline{A}\right)dA;\ \theta_1 \cap\ \theta_2, \overline{A}_1 \in \overline{A},\ \overline{A}_2 \in \overline{A} \tag{1}$$

$$\varphi_{32}\left(\forall\overline{A}_3 \stackrel{\text{def}}{=} \overline{A}_2\right) = \int \gamma_3\left(\overline{A}\right)\gamma_2\left(\overline{A}\right)dA;\ \theta_3 \cap\ \theta_2, \overline{A}_3 \in \overline{A},\ \overline{A}_3 \in \overline{A} \tag{2}$$

where $\gamma_1, \gamma_2, \gamma_{32}$ are uncertainty functions, $\theta_1, \theta_2, \theta_3$ are value ranges $\underline{A}_1$, $\underline{A}_2$ and $\underline{A}_3$.

The uncertainty functions are found using the operator transformation method, and, accordingly, the application of integral operators:

$$\gamma_A\left(\overline{A}\right) = \int_{-\infty}^{+\infty} \ldots \int_{-\infty}^{+\infty} \gamma_X(\overline{x})\,\psi(\overline{x}, \overline{A},\ F_1,\ F_2,\ F_3)d\overline{x} \tag{3}$$

where $\underline{x}$ is an array of input data that varies in the interval $[x_1, x_2]$, $x_1 \in A,\ x_2 \in A$; $F_1,\ F_2,\ F_3$ are generalized mathematical operations on the array of input data (nonlinear single or binary, integro-differential). This procedure makes it possible to separate the influence of uncertain risks from the influence of deterministic, stochastic, and fuzzy factors.

Further, from a number of mathematical models, two are selected, with maximum values φ_{12} and φ_{23}. Moreover $\underline{\theta}_3 \succ \underline{\theta}_1$. That is, the value ranges $\underline{\theta}_3$ and $\underline{\theta}_1$ in the multidimensional value space are limited by the surfaces of the maximum, defined by the data range $\underline{\theta}_3$, and the minimum, defined by the data range $\underline{\theta}_1$, values of the region of existence of the uncertain component of the factor $\overline{A}$. Then, since the type of uncertainty (stochastic or fuzzy) may be unknown a priori, the operator transformation method is applied, and the relevant set of resulting values $\overline{A}_2$ is identified with the risk component R_u, which is determined by uncertainty and is calculated as:

$$R_u = \iint g(\varphi_{12}, \varphi_{32}) \frac{\gamma(\overline{A}_1 | \overline{A}_3)\,\gamma_1}{\int \gamma(\overline{A}_1 | \overline{A}_3)\,\gamma_1 d\overline{A}_1} d\overline{A}_1\, d\overline{A}_3 \tag{4}$$

where g is the probability of intersection of the maxima of the functions φ_{12} and φ_{32},

and the interval values of this risk are calculated accordingly, as:

$$R_{u12} = \iint \overline{\varphi}_{12} \frac{\gamma(\overline{A}_1 | \overline{A}_2)\,\gamma_1}{\int \gamma(\overline{A}_1 | \overline{A}_2)\,\gamma_1 d\overline{A}_1} d\overline{A}_1\, d\overline{A}_2 \quad (5)$$

$$R_{u32} = \iint \overline{\varphi}_{32} \frac{\gamma(\overline{A}_3 | \overline{A}_2)\,\gamma_3}{\int \gamma(\overline{A}_3 | \overline{A}_2)\,\gamma_3 d\overline{A}_3} d\overline{A}_3\, d\overline{A}_2 \quad (6)$$

where $\underline{\varphi}_{12}$, $\underline{\varphi}_{23}$ are the average values of the corresponding probabilities.

Accordingly, deterministic, stochastic, and fuzzy risk components are determined using established methods, and their weight coefficients in the integral risk are determined using the method proposed in the article by Kotenko et al. (2023). Since, as noted above, the weight of military risks outweighs the total weight of other threats to cargo transportation, these threats allow us to adjust the model with a set of resulting values $\overline{A}_2$ in the intervals of the maximum ($\underline{A}_3$) and minimum ($\overline{A}_1$) values of $\overline{A}$.

Also, the vector approach allows us to take into account the different directions of the vectors of influence of uncertain factors, which will allow us to more accurately indicate the surfaces of the maximum, determined by the data area $\underline{\theta}_3$, and the minimum, determined by the data area $\underline{\theta}_1$, values of the area of existence of the uncertain factor $\overline{A}$.

Graphically, this result in a three-dimensional projection using the example of calculating the cargo turnover of seaports of Ukraine, is interpreted as shown in Fig. 1.

Comparison with forecasts of other researchers (Zaborskyi et al., 2025), who use static methods, in particular the ARIMA method (Autoregressive Integrated Moving Average, which does not take into account uncertain factors), indicates a significant discrepancy with the presented data (Fig. 1).

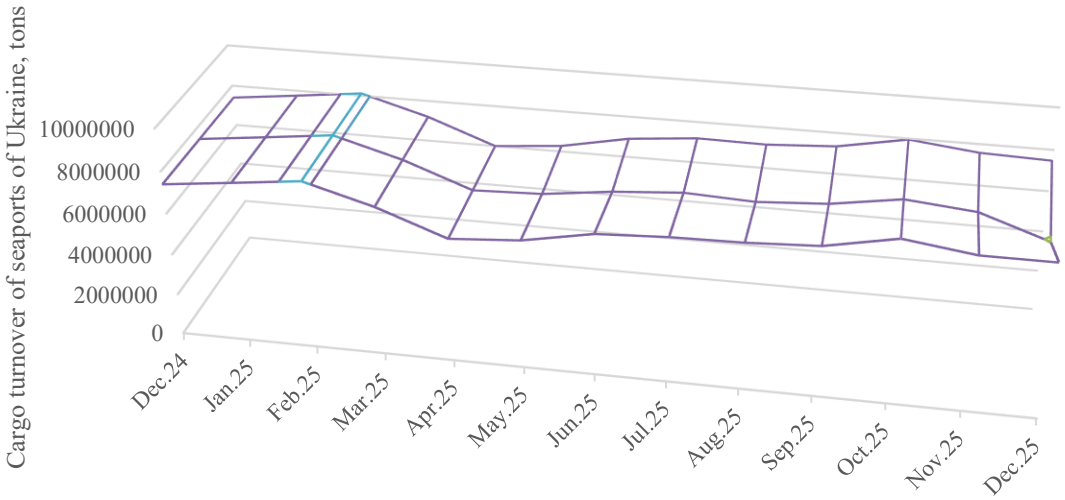

Fig. 1. The result of the forecast of cargo turnover of seaports of Ukraine in conditions of uncertain military risks in the Black Sea area
Source: developed by the author

In the calculation, the data array $\overline{x} \in \overline{A}_2$ was used as the information from the State Enterprise Sea Ports Administration of Ukraine (2023) and the State Enterprise Sea Ports Administration of Ukraine (2024).

Graphically, the models with the resulting values $\overline{A}_1$, $\overline{A}_2$ and $\overline{A}_3$ are combined in Figure 2, where the solid line shows the data of past periods, the dotted lines represent the data of $\overline{A}_1$ and $\overline{A}_3$, and the dashed line shows the probable forecast.

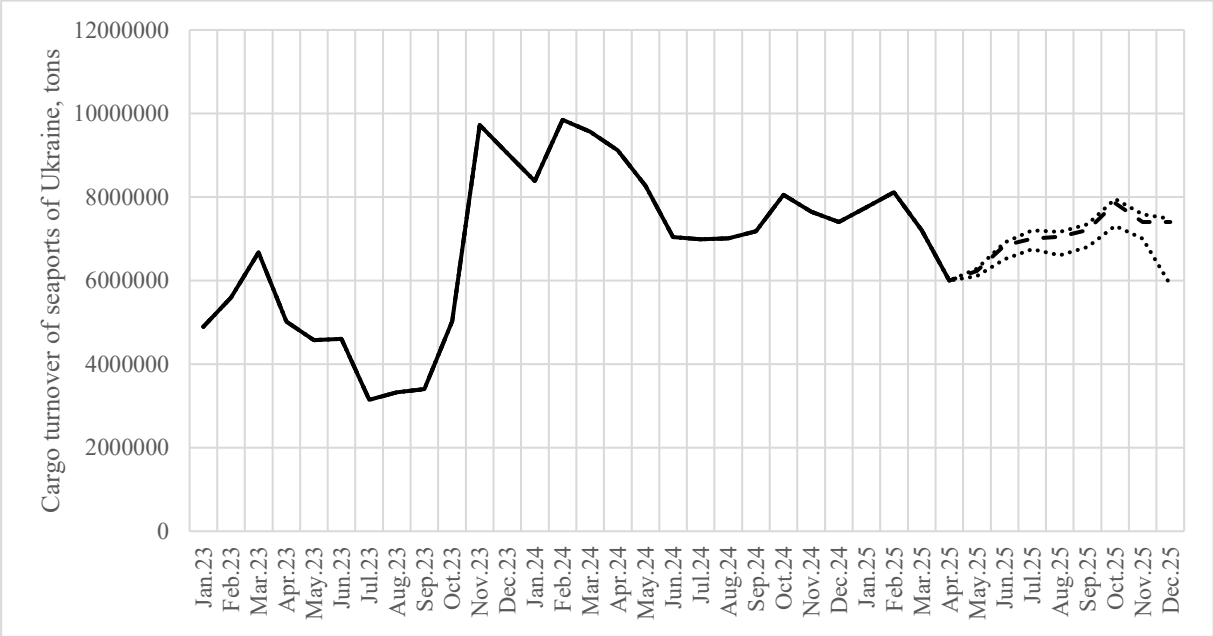

Fig. 2. Cargo turnover of sea ports of Ukraine in 2023-2025
Source: developed by the author using data from
the State Enterprise SeaPorts Administration of Ukraine (2023, 2024)

The application of a statistical model and a forecasting model under uncertainty to estimate the service life of tankers in the global transportation market (Fig. 3) indicates an increase in this indicator due, in particular, to the rapid increase in the fleet of outdated Russian tankers for transshipment of petroleum products, which is also the reason for the lack of change in this trend in subsequent periods of time.

Fig. 3 and Fig. 4 show the equations of polynomials that approximate the forecast results using the developed methodology.

A significant factor in this influence was the fact that in 2022-2023 the world fleet lost 63 ships, and 68 fleet units were destroyed during hostilities in the Black Sea during this period, including merchant ships, including tankers, under the flags of the Marshall Islands, Moldova, Panama, Dominica, Tanzania, and Ukraine. Also in 2024, 300 port infrastructure facilities, 177 vehicles, and 22 merchant ships under the flags of countries not participating in the conflict were damaged as a result of missile strikes.

This is one of the restraining factors in the renewal of the tanker fleet. In previous periods of time, shipping companies tried to get rid of tankers with an operating life of more than 15 years. But the tankers that Russia purchases or leases during this period of time to circumvent sanctions have already been in operation, sometimes for more than 26 years, which affects the global performance of the tanker fleet.

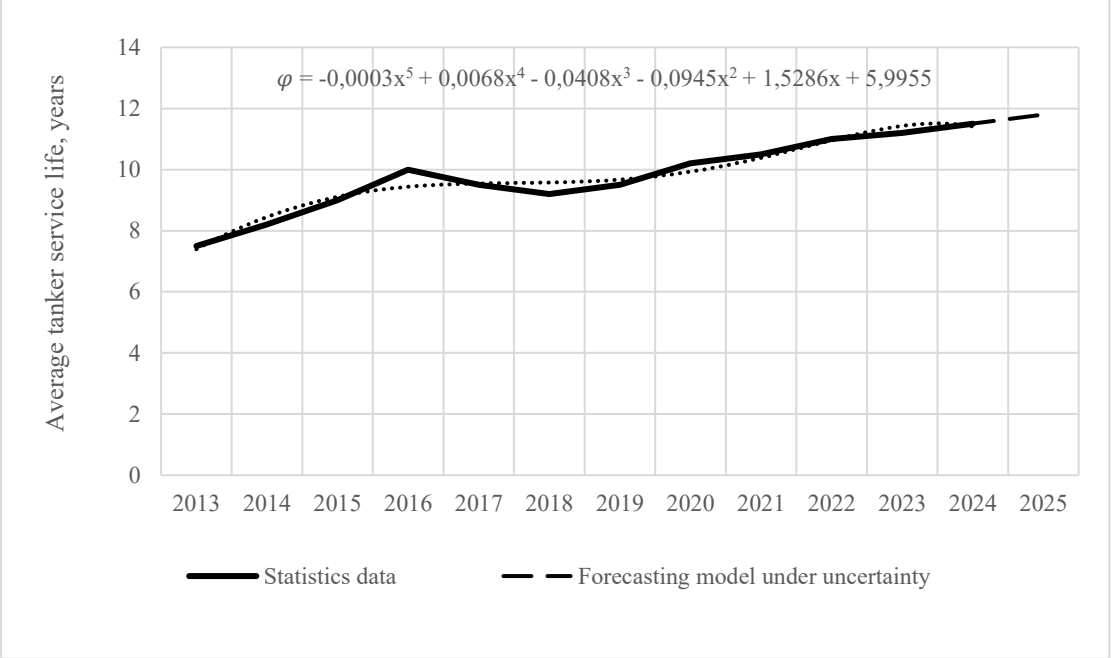

Fig. 3. Average tanker service life in the global maritime transportation market, years
Source: developed by the author based on data UNCTAD (2024)

A sign of the global crisis in maritime transport due to hostilities in the Black Sea basin is also the overloading of EU ports located in other seas due to the global change in maritime logistics. The global change in maritime logistics has affected not only the transportation of oil products but also other types of cargo. Even container transportation has been affected, although the participants in the conflict do not have a significant share in this type of cargo. But these countries supply metals to the global market, so their shortage leads to changes in container production volumes, which also creates uncertainty in the global market.

The application of a statistical model and a forecasting model under uncertainty to forecast the average service life of Ukrainian merchant vessels (Fig. 4) shows identical results - with a significant risk of losing vessels due to hostilities, owners will replace retired vessels only with less expensive vessels with a significant service life. This also indicates that the pace of deployment of new automated tankers, which are capable of ensuring compliance with environmental standards set by influential transport organizations, in particular the International Maritime Organization (IMO), will be reduced, but their cost and, accordingly, payback, due to increased transportation risks, is higher.

The use of tankers with a service life that significantly exceeds the service life of a tanker in the global transportation market, and even the use of tankers unsuitable for certain conditions, increases the risk of incidents at sea. An example is the accident on 15.12.2024 of the river tankers "Volgoneft-212" and "Volgoneft-239" under the flag of the Russian Federation while passing through the Kerch Strait for transshipment of oil from ship to ship in the Black Sea.

It is characteristic from the point of view of assessing the service life of tankers in the global transportation market (Fig. 3) that the service life of the tankers "Volgoneft-212" and "Volgoneft-239" is more than 50 years.

Oil cannot be pumped out of the tanks of sunken ships and they permanently generate a flow of pollution that forms a long-term threat to the biocenosis of the Black Sea. The threat of sea pollution due to illegal transshipment in the open sea to circumvent the sanctions imposed on

the Russian Federation is becoming a permanent risk of war. Thus, on 03.06.2024, the fact of oil transshipment from the Aframax tanker IMO 9247443 near Greece was discovered. This indicated the use of this tanker on a permanent basis as a hub for sanctioned oil products, which allows hiding their origin (SPRAVDI, 2025). This is also a clear indication of the direct challenges of the war to green and sustainable shipping and the leveling of the international community's policy measures in the use of alternative fuels, decarbonization and, in general, green transportation of cargo, primarily in water areas close to the combat zone, but also the creation of threats to the water areas of other seas.

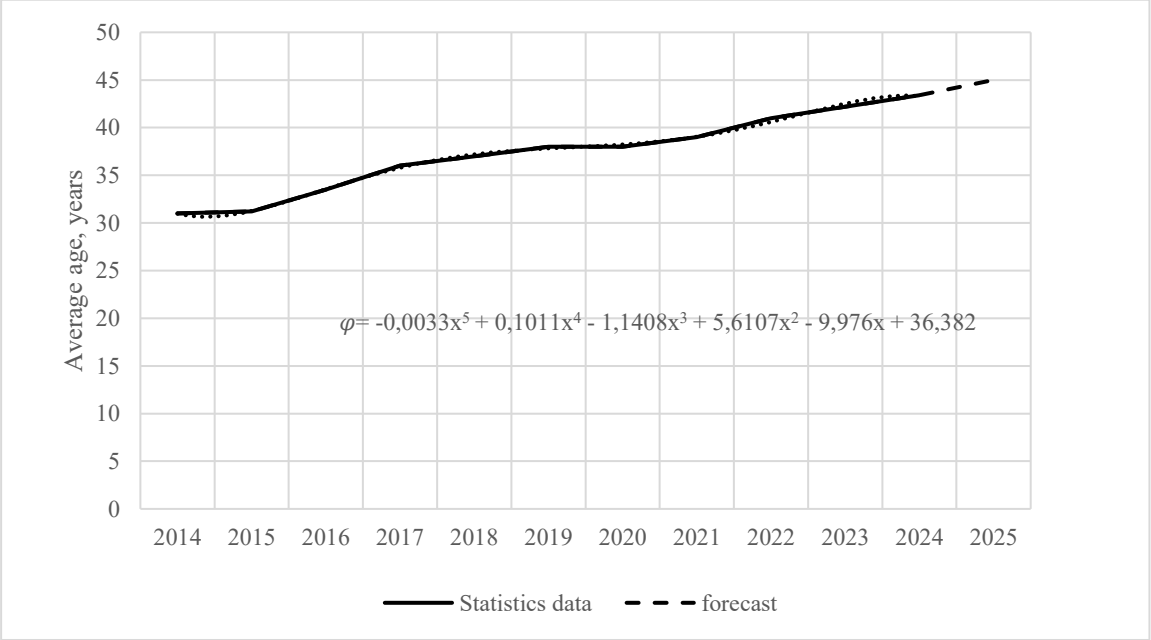

Fig. 4. Average life of Ukrainian merchant ships
Source: developed by the author based on data UNCTADStat (2024)

4. RESULTS

As mentioned, a set of variables of different formats is used to assess risks: stochastic, deterministic, and fuzzy values. Military actions have led to the need to take into account variables of another format - uncertain. The impact of uncertain factors, primarily military threats, on maritime transportation has its own characteristics: its importance may be greater than the combined importance of other risk factors; the rate of its change is significant – in a short time it can change from small to unacceptable values.

In addition, military risks with a component of uncertainty determine the nature, pace, and values of parameters of all aspects of maritime transportation: logistics, fuel consumption, environmental pollution, etc. The impact of this type of risk determines not only the local characteristics of sea transportation - in the water area close to the combat zone, but also the characteristics of the global maritime transportation market. Moreover, these risks can serve as a trigger for a crisis in the maritime industry on a global scale. At the same time, the threats of war are not always of an uncertain nature. With a certain stabilization of military risk, it will have an unclear, stochastic, or even deterministic nature. Thus, the delay of ships from Ukrainian ports of the Sea of Azov in the Kerch Strait by the military forces of the Russian

Federation had an uncertain nature (see Fig. 5) and the factor of growth in the average service life of Ukrainian merchant ships (see Fig. 4) in war conditions acquires a statistical nature.

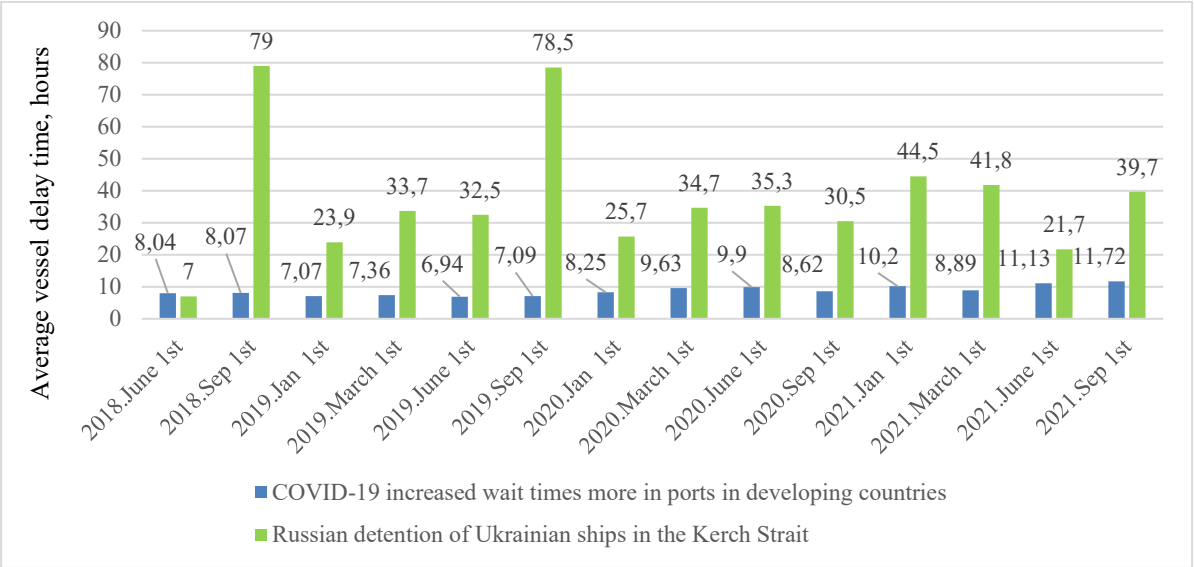

Fig. 5. Comparison of data on wait times in ports in developing countries due to COVID-19 and the Russian Federation's unjustified detention of Ukrainian vessels in the Kerch Strait
Source: developed by the author based on data from
Black Sea news (2021), UNCTAD (2023)

Calculations of the value of the correlation coefficient (-0.1419), which shows the level of statistical connection of the indicators of vessel delays in the Kerch Strait due to the pandemic and for military reasons, indicated that its value is not only insignificant (as is known, a significant level of correlation coefficient values starts from 0.5), but even negative. This confirms the uncertain, rather than stochastic, nature of the delays of Ukrainian vessels during the passage of representatives of the Russian authorities through the Kerch Strait during the non-pandemic period.

The problem of calculating and analyzing military risks is not only their uncertainty and dynamic nature. They can take various forms: vessel delays in ports for days, weeks, and even months; a sudden increase in the price of tanker rental even with a significant level of their depreciation due to restrictions on oil transportation; transportation costs due to a significant increase in insurance rates (see Fig. 6); threats to the biocenosis due to permanent pollution of the sea with oil products from sunken Russian ships, the purpose of which was exclusively river transportation, that is, they a priori should not have been used for sea transportation, etc. A sign of the impact of the war on maritime transport is also the fact that the Lloyd's Markets Association (LMA) added to the list of high-risk zones not only the Azov-Black Sea water areas adjacent to the countries participating in the war, but also the internal waters of Ukraine and water areas throughout the territory of the Russian Federation. This triggered an increase in P&I (Protection and Indemnity) rates for other insurance companies. Also, given the growing threat of damage to the ship or its loss, insurance rates for H&M (hull and machinery) have increased. But the interval nature of the introduction of additional insurance premiums for ships going to the ports of Greater Odessa in February 2023 (0.75% of the ship's value) and the Danube ports of Ukraine (0.3-0.5%) (see Fig. 6) indicates that although freight rates depend on military risks, they are determined by the fact of the occurrence of the risk and not by the result of its forecast.

Fig. 6 uses the standard unit of measurement of the freight rate – the price of transporting one ton of cargo ($/ton).

It should be noted that since military threats to the seaports of the countries participating in the war actually level the concept of the competitiveness of their ports, the factor of the influence of competition on freight rates was excluded from consideration.

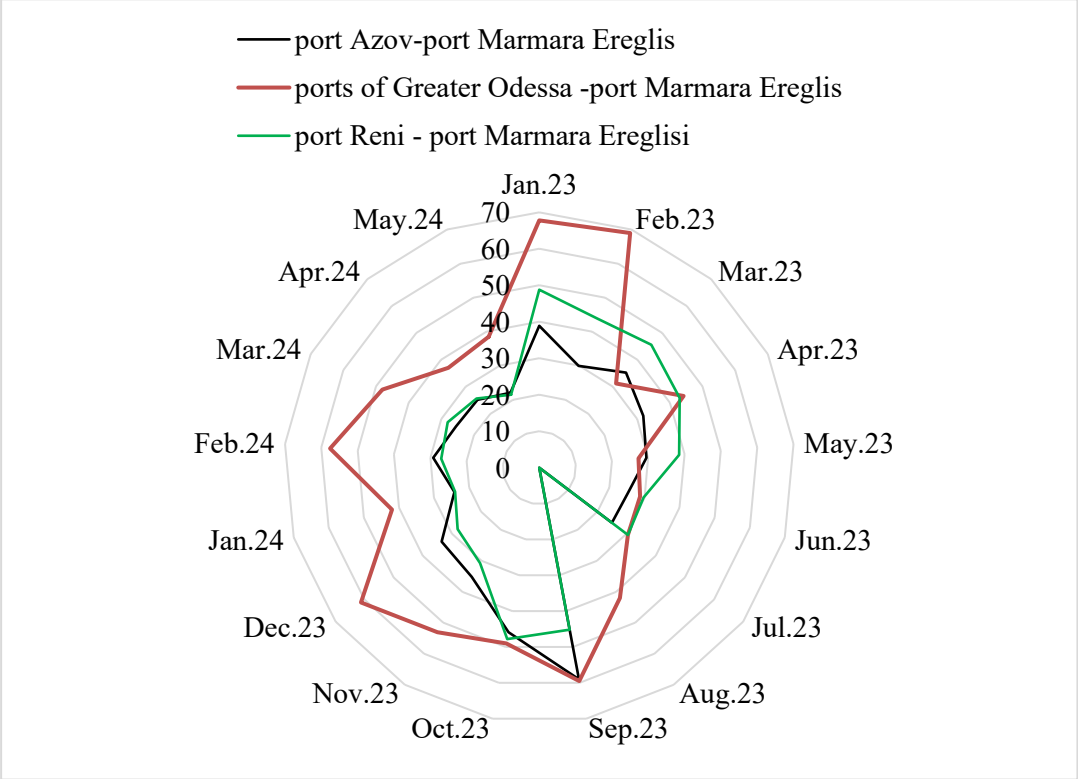

Fig. 6. Dynamics of freight rates, $/tons
Source: developed by the author based on data from the Information Agency Metal Expert LLC (2025)

This is confirmed in particular by the fact that in December 2023, freight rates for Ukrainian ports differed by more than half (see Fig. 6) although the seaport of Reni is located in the Odessa region. The impact of uncertainty also forces reconsidering the idea that freight rate changes are exclusively cyclical in nature, since this, in particular, is refuted by the data presented in Fig. 6.

This limits the traditional use of recursive vector autoregression for freight rate forecasting and increases the need to apply methods that take into account uncertain risk components.

At the same time, the uncertain component of war risks is implicitly present in the assessment of the level of liability of some tanker fleet insurance companies for their obligations. If before the large-scale hostilities, the insurers in the maritime transportation market were mainly Western companies, then, as an inspection by Estonian institutional structures showed, more than 25% of insurance policies for ships transporting oil from the Baltic ports of the Russian Federation were provided by Russian insurance companies (Bloomberg, 2024). Since 7% of the total volume of maritime transportation of petroleum products passes through the Danish straits, this problem has also arisen for the Danish authorities (Bloomberg, 2024). The same problem has arisen for the Turkish authorities, since

the Russian insurance companies Ingosstrakh and Sogaz provide the largest amount of insurance for tankers transporting oil from the Black Sea ports of the Russian Federation through the Bosphorus and the Dardanelles. This is reinforced by the fact that the volumes of crude oil shipments from the Russian Federation's Black Sea coast berths – Novorossiysk, including the Caspian Pipeline Consortium terminal (4 million tons per year), constitute about 2% of the global market for maritime transportation of petroleum products.

The risks of testing in practice, in the event of a significant oil spill, the reliability of insurance companies, whose share of the insurance market was obtained as a result of a significant deformation of the global insurance system, which has proven its effectiveness over a sufficiently long period of time, are characterized by a significant level of uncertainty.

Significant threats to shipping in certain water areas require the introduction of fragmented logistics schemes, primarily the expansion of the ro-ro network. Although this results in increased fuel consumption and, accordingly, increased emissions of carbon and nitrogen oxides into the atmosphere, this does not reduce the need to optimize routes and modes of economical use of fuel resources. Since changes in shipping risks are dynamic, reducing losses requires highly effective digital technologies, in particular, artificial intelligence (AI), cloud computing, digital twins, etc. The importance of AI technologies is increasing for the needs of managing ro-ro networks, in conditions of a forced increase in their density, to minimize overloading of ro-ro vessels and maximize the use of ro-ro network capacities. The consequence caused by the war is an increase in the gamma index in the Black Sea water area for the countries participating in the war, which is an integral indicator of the level of connectivity of national ro-ro networks. The growth of this indicator occurs due to the growth of the number of connections of national ro-ro networks. For example, for Ukraine, this indicator has increased almost to the level of leading countries - Bulgaria and Georgia. The gamma index is a relative indicator of the economic efficiency of ro-ro transportation and therefore indicates that the vector of geopolitical factors can both worsen and contribute to the indicators of the state of shipping in the Black Sea.

The use of ro-ro vessels in intermodal transportation also requires a significant level of coordination, since the economic efficiency of the ro-ro network depends on the arrival of appropriate volumes of cargo at ports, which leads to the possibility of imbalances in direct and return cargo flows. There is also a problem of inconsistency with related modes of transport. The problem of using ro-ro vessels in intermodal transportation under the influence of military risks can also be significant dynamic deviations of such parameters as the time of vessels en route and the time of service in ports. This also requires the use of digital resources.

The use of artificial intelligence for the implementation of autonomous navigation systems is also of particular importance, since it makes it possible to reduce crews and, thereby, protect them from risks. But the problem is that widely used software complexes for forming optimal logistics routes based on AI (Artificial Intelligence), such as Wärtsilä's Fleet Optimization Solution (Mba, 2024) are unsuitable for use in conditions of military threats.

At the same time, the problem of using alternative fuels changes emphasis under military risks, since the risk of environmental pollution by the greenhouse gas methane increases significantly due to the depressurization of Liquefied Natural Gas (LNG) tanks not only on ships but also in bunkering ports and due to the risk of destruction of the ship or port infrastructure by explosion with minor damage to hydrogen or LNG fuel systems. The use of biofuels, on the contrary, reduces the risk of sea pollution compared to traditional fuel oil. But this requires additional costs for the development of infrastructure and logistics for the supply of biofuels, which is problematic for the parties to the conflict. This requires a review of

traditional methods of taking risks into account, even at the stage of forming a set of parameters for assessing threats and determining the vector and weight of their impact.

Countries whose territories occupy a significant part of the Black Sea coast stopped equipping ports with bunkering capacities for alternative fuels as a result of the war. Therefore, even the most widely used alternative fuel by the world fleet - LNG, has a share of use in the Black Sea area of less than 0.57%, and methanol - less than 0.05% (European Maritime Safety Agency, 2025). This significantly narrows the opportunities for promoting green shipping of the countries in the northern Black Sea, which are world leaders in the export of agricultural products, i.e., would have significant prospects for the production of biofuels in peacetime, in particular, biomethane, Fischer-Tropsch synthetic diesel fuel, and renewable methanol. Moreover, according to forecasts, in 2030 the total cost of ownership of resources for the production of some types of biofuels, in particular hydrotreated vegetable oil and Fischer-Tropsch synthetic diesel, will be equivalent to the same figure for marine fossil fuels (European Maritime Safety Agency, 2025). At the same time, the introduction of alternative fuel bunkering capacities by countries not directly involved in hostilities in the Black Sea region, in particular the renewable methanol bunkering infrastructure in the port of Constanta (Romania), will contribute to green shipping in the northern part of the Black Sea. The threat of higher emissions from polluting ships has long been felt in Turkey, which controls the straits of the Black and Mediterranean Seas, which is why this country actively promotes the use of alternative fuels.

The integration of legal and administrative measures in the water areas of concentration of transport routes of vessels with the program "Digital Twin of the Ocean" looks promising, which allows the use of real-time information from onboard sensors of vessels, and satellite control systems. This will accelerate the processes of decarbonization of shipping in the Black Sea after the end of hostilities.

This indicates a significant need for maritime transport to assess military threats. At the same time, failure to take into account the level of uncertainty of these threats leads to improper relevance of the results, which causes complications for many aspects of maritime transportation. Therefore, in some cases, assessment methods, for example, in the insurance business, deliberately overestimate the level of threats. Since the metrics of risk factors are different: stochastic, deterministic, and fuzzy; are uncertain, then the proposed approach of “colored” noise makes it possible to separate the metric of uncertain factors from others and further apply known calculation methods (Kotenko et al., 2023).

5. CONCLUSIONS

The threats to cargo transportation in the Black Sea and the directions of their impact on the maritime transport industry were investigated. It was found, in contrast to the approaches proposed in the studies of Chrysafis et al. (2022), that failure to take into account the uncertain component of risks reduces the relevance of forecasts in all aspects of maritime transportation: technological, logistical, in the field of cargo and ship insurance, etc. This is especially true in the conditions of hostilities, which are characterized by a high level of uncertainty. Unfortunately, the effects of war are often not even taken into account by researchers in the list of causes of ship damage (Kuzu, 2021). The presented study also indicates that in addition to the direct impact of war on the formation of threats to shipping, there is also a significant indirect impact, which is often not taken into account by researchers (Huang et al. 2023). In particular, it is indicated that hostilities in the Black Sea basin lead to a steady trend of increasing the average service life of merchant ships, primarily ships of the warring parties.

This increases the risks of accidents and has already led to significant threats to marine biocenosis. It is indicated that in some cases the weight of uncertain factors may be greater than the deterministic, stochastic and fuzzy parameters, which are traditionally used to assess the level of threats to cargo transportation by sea. It is also noted that the influence of uncertainty of military risks limits the use of recursive vector autoregression for forecasting freight rates, contrary, in particular, to the statements of Jeon et al. (2021).

The study proposed an approach that differs from the methods of other researchers (Park Sang-A, 2025) in that it uses isolating and assessing uncertain components of threats to maritime transport. The results of calculations using statistical approaches and an algorithm with uncertain parameters indicated convergence in the absence of uncertainty and a substantiated divergence of results in the presence of an uncertain influence. Comparison with the results of forecasts using the ARIMA method (Zaborskyi et al., 2025) confirmed the greater relevance of the proposed method.

It is proposed to conduct risk assessment using an interval approach with an uneven distribution of the resulting function over the area of existence and requiring its subsequent refinement as new data is received. Therefore, the developed approach does not exclude the use of parameter estimation methods with other metrics, in particular the method used by Gulen et al. (2025). These methods are proposed to be used at the second stage of analysis to correct the forecast in the identified interval of values. Also, the vector approach used in the proposed mathematical model allows taking into account the different orientations of the vectors of influence of uncertain factors, which will increase the relevance of the assessment of the resulting function.

The increasing relevance of maritime transport forecasts will increase the ability of all stakeholders to prevent threats and mitigate their consequences. Taking into account the uncertain component of risks is important not only during war, but also necessary in the post-war period for the merchant fleet to acquire a greater level of sustainability, form development directions in the introduction of digital, green technologies, methods for optimizing logistics routes, etc.

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