

Article

Determination of the Expected Value of Losses Caused by the Cargo Transportation Insurance Risks by Water Transport

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Abstract: The purpose of this study was mathematical model development for assessing the cost of losses from risks in the maritime transportation of goods that are dynamic in nature, and developing a methodical approach to the dynamic costs assessment for each of the risks separately and integral costs for all risks and ensuring the fulfillment of the requirement to anticipate the insurance cost changes over the rate of change of the transportation integral risk (or its stage). The risks factor analysis in water transport, their classification and determination of the type and nature of their impact on sea transportation of goods were carried out. The groups of risk factors that lead to emergency situations for water transport in Ukraine were studied by comparing the data of 2019 and 2021 and determining their share in the total number of accidents before the start of the active phase of hostilities in Ukraine; the rates of their change were analyzed. This made it possible to develop a systematic assessment algorithm for the dependence of the expected and actual value of losses on risks and to create a mathematical approach to risks forecasting as a factor influencing the cost of expenses. As a result of the study, a methodical approach to forecasting the cost of losses from risks was formed for each of their types. However, the main attention was paid to the identification and assessment of dynamic risks, the impact of which has an absorbing nature relative to all others in their totality. Such risks in the waters of the Black and Azov seas today mainly include risks associated with the conduct of military operations, including such operations that go against international legal norms.

Keywords: cost of losses; risk assessment; water transport; mathematical model



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1. Introduction

1.1. Study Topicality

Conducting the presented study was due to a significant increase in the level of danger to shipping in the waters of the Black and Azov seas as a result of large-scale hostilities. However, even before the beginning of large-scale hostilities, significant fluctuations in the risks level for the transportation of goods by sea were observed. It is important that in some cases, and before the start of military operations, in the period 2014–2021, the value of the risk reached a critical limit. The critical value of risks can be increased to such a level that it is necessary to choose other transportation routes, even at a much higher cost of transporting goods by them. This requires a change in approaches to risk assessment.

The importance of this task is also due to the fact that the problem of transport risks is closely related to the insurance of sea transportation of goods, since a significant increase in the risks level can lead to significant changes in the freight cost of merchant ships.

The above conditions create the need for a relevant assessment of transport risks, since dynamic changes in their magnitude and the formation of dangerous trends in risk changes can significantly modify the insurance cost for sea transportation of goods. The existing methods for taking into account the impact of risks on cargo insurance do not foresee the possibility of significant fluctuations in the impact of the integral risk of sea transportation, which under modern conditions of transportation in the Black Sea–Azov basin leads to a significant level of irrelevance of forecasts based on the use of traditional approaches. The general approach proposed by the authors is that under the conditions of the dynamic nature of the influence of factors on the magnitude of risks during the transportation of goods by sea, the rate of change in the cost of freight would correspond to or even exceed the rate of change in the integral risk of transportation (or its stage).

Today, an approach is used to determine the size of the freight cost according to the largest probable value of the risk over a significant period. This approach is not competitive in conditions of dynamic changes in the amount of risks and their trends, in particular because competitors, knowing the relevant forecasts regarding the risk assessment in dynamics, will be able to offer the client more favorable conditions. This determines the urgency of creating a reliable methodical approach to determining the expected value of losses under dynamic changes in risks.

This made it necessary to develop a mathematical model of changes in the cost of marine cargo insurance in accordance with the rate of change in risk and forecasting the time when the risk will reach critical values. Therefore, the study was focused on the study of the features of determining the expected value of losses from risks with a dynamic nature of change and the probability of the value of risks approaching the critical limit. This is also important for the formation of a methodology for the insurance of cargo transportation by water transport in water areas close to the war zone.

1.2. Justification of the Need to Develop New Methodological Approaches

Marine cargo insurance is based on considerable experience and established legal practice. Scientific works in this field emphasize the connection between insurance amounts and the level of risk. Hellwege et al. [1] and Iodice et al. [2] relied on this connection in their writings. The authors [1,2] studied in detail the issues of maritime transportation risk management. This is extremely important for the safety of ships and cargoes and the reduction of insurance payments, which leads to a reduction in the cost of transportation. At the same time, the authors' assumption that the set of risks is unchanged can, in some cases, lead to irrelevant assessments of both risks and insurance amounts. In the scientific work of Clemente et al. [3], when forming a mathematical model, the need to take into account the dynamic nature of hedging coefficients was indicated. However, Clemente et al. [3] did not indicate the need to evaluate the coefficients taking into account the effects of risks. Balobanov et al. [4], when analyzing the peculiarities of marine transportation insurance in Ukrainian conditions, considered various types of risks, but not their dynamic nature. Balobanov et al. [4] indicated the need for organizational and legal provision of proper assessment of risk levels. Mitkov et al. [5] used an interesting approach to analyzing the relationship between insurance and transportation risks. Features of cargo insurance are considered as a method of risk management in sea transportation of goods and cargo. That is, the reverse influence in this dyad is indicated. This is used in our research as an opportunity to form an insurance trigger to avoid dangerous routes. In the article by Koh et al. [6], it is indicated that there is a glaring problem for maritime transportation in Ukraine. It is indicated that from February 2022, the cost of insurance of Black Sea shipping went out of control, that is, the level of military risks ceased to be covered by insurance premiums. The absorptive nature of military risks for sea transportation was previously indicated in the article by Nitsenko et al. [7]. In this case, the absorptive nature of risks means the achievement of a particular type of risk at such a level that the total impact of other risks cannot be taken into account for the insurance assessment. This allows us to

formulate the thesis that the appropriate level of insurance in sea transportation of goods would be based on a relevant risk assessment.

From this point of view, analytical reviews of scientific works on the issue of risk assessment in sea transportation of goods are interesting. In particular, Lim et al. [8] provided a detailed analytical review of scientific works on the impact of various risks on maritime transportation and their consequences, and they conduct a thorough discussion of risk assessment models. Taking into account the risks of military threats, the study of significant dynamic changes in risks in the given detailed analytical material is absent. In the analytical review of Ouedraogo et al. [9], methods of increasing the efficiency of supply chains in container transportation by sea using risk management are analyzed. This approach makes it possible to change the route of transportation due to an increase in the level of risk. This made it possible to take into account the possibility of changing transportation routes in our work. Unfortunately, the possibility of changing routes is not considered for a sufficiently long time interval, that is, it does not take into account the dynamic nature of the risk change. Esmer [10] applied an interesting quantitative risk assessment method (Fuzzy Analytic Hierarchy Process), which can be used in the presence of unclear impact parameters. The scientific work of Esmer [10] predicted future risks for sea transportation. The author limited his analysis to only nine main variables that will affect maritime transport in the future. The possibility of the dynamic nature of this influence was not considered. Kretschmann [11] offered an indicative approach to risk management of maritime transport. This approach is really able to reduce threats to sea transportation and eliminate their negative consequences. However, this approach does not take into account the possibility of the absorptive nature of risks, purposeful systematic activity to increase them and the probability of significant changes in risks in a short time. The work of Nguyen [12] is devoted to the definition and planning of the impact of risks on sea transportation. Nguyen [12] used the Bayesian model for this. This provides significant advantages in the analysis of uncertain risk impact parameters. However, the author relied on a predetermined set of risks and his model did not take into account the presence of the time parameter. Likun et al. [13] also used the Bayesian model, but they proposed a network approach to risk analysis. This is useful in the absence of the absorptive nature of these risks. Wan et al. [14] carried out a risk classification, which includes manifestations of malicious influence on cargo transportation, for example, terrorism. However, the time parameter was not included in the proposed model, and the authors did not take into account the possibility of changes in the level of threats over time. Zhang [15] classified the risks of sea transportation of goods and indicated the emergence of new risks associated with state terrorism and proposed a complex of state measures to reduce the consequences of these risks. Unfortunately, the author did not consider the possibility of using collective measures of groups of states or international organizations to reduce the levels of such risks. The impact of these risks is considered to be point-based rather than permanent with significant changes over time. Chang et al. [16] suggested implementing a risk mitigation strategy for container shipping by sea. Chang et al. [16] raised the question of whether the situation in the world shipping market affects the risk reduction strategies of shipping companies. Unfortunately, the model they used does not take into account the possibility of absorption risks, which is especially important for Taiwan's transportation routes today. Wan et al. [17] analyzed the risk factors for the threat assessment of the transportation chain. They developed a new risk factor classification framework that combines various classification methods into a logical hierarchy suitable for modeling risk factors affecting container shipping by sea. However, their axiomatics regarding the priority of IT risks, operational risks and human resource management risks are, in our opinion, doubtful. He et al. [18] proposed a model for making a decision on vessel detention. The authors pointed out the imbalance of the problem of vessel delays, which causes a definite uncertainty of the delay risk. The authors did not consider options for malicious actions that cause the delay. The machine learning algorithm proposed by the authors is not designed for the dynamic nature of the risk of delay and is considered

to be a point risk that does not lead to an increase in the risk of transportation along this route. The possibility of a dynamic change in the risk of adverse weather conditions is considered in scientific works for sea transportation of goods. In particular, this possibility is discussed in detail in the articles of Baksh et al. [19] and Adland et al. [20]. However, this risk is considered to be a point risk and is not permanent. Prediction of its changes is based on forecasts of meteorological services. Neutralization of its influence consists of avoiding going on the route in adverse weather conditions. In the detailed works of Koterko et al. [21] and Bazaluk et al. [22] on the assessment of the risks of the transportation of goods by sea under the conditions of the presence of military threats, there are many advantages, in particular, regarding the methods of simultaneous processing of deterministic, stochastic and fuzzy parameters. However, those proposed by the authors [21,22] do not take into account the possibility of dynamic changes in risks.

The analysis of literature sources indicated that, in addition to the above-mentioned unsolved problems, the problems related to the relevant zoning of the effects of dynamic risks, which affect the effective determination of the change in the cost of costs when the distance from the source of the threat changes, remained outside the attention of researchers. In addition, in the scientific literature, there are no universal methods for predicting the impact on the cost of individual risks and integral risk suitable for use in real time.

2. Materials and Methods

2.1. Methodology

The theoretical and methodological basis of the study became the fundamental scientific provisions of risk theory, in particular, regarding risk assessment as “an important parameter in the quantification of complex vulnerability as a central predictive variable in the risk equation”, and, in general, its methodology “determines various practices, methods and adaptation strategies” [23].

To solve the set goal, the research relied on approaches developed by other scientists. The first in the presented scientific work was the implementation of the general approach, “Insurance as a risk management strategy”, which was formulated in works [1,2] and detailed in scientific works [3–5].

The authors applied a comparative analysis to determine groups of factors that lead to the occurrence of risks in the transportation of goods by sea. For this, the data and approaches given in the works [11,12,16,17] were analyzed and used: aggregation method [11], Fuzzy Rules Bayesian Network (FRBN) model [12], fuzzy AHP analysis [16], risk matrix method [17]. In order to identify the rates of change in the technical and technological risk factors of water transport, the named factors were classified and subjected to critical analysis. The direct consequences of technical and technological risk factors that determine the level, pace and types of losses were determined. Technical and technological risk factors have been stratified before, in particular in works [11,12,16,17]. However, the main task of the analysis carried out by the authors of the presented article was to find out the types of losses and rates of changes in risks, which had not been carried out before. Determining the rate of change of the integral risk of transportation was necessary in order to determine the need to take into account its impact on losses due to the dynamic nature of this impact.

The need to take into account dynamic changes in the risks of cargo transportation in the Black Sea Basin and losses as a consequence of the specified risks was based on the determined nature and level of these risks specified, in particular, in scientific works [6,7].

The methodological basis of the formation of the mathematical model was the matrix and vector analysis, and the methods of risk modeling of cargo transportation by sea are described in scientific works [7,21].

The mathematical formalization for the development of the apparatus for mathematical forecasting of dynamic risks and losses as a result of their actions was based, first of all, on the mathematical apparatus, which is detailed in scientific works [7,10,21,22]. We used method of recursive review of the status vector of risks transportation route [7], quantitative risk assessment method [10], method of finding the best path that corresponds

to the integral destination function of transportation [21], the method of minimizing the entropy function [22]. First of all, it is necessary to point out the importance of using the approaches proposed in the mentioned scientific articles for the reconciliation of different data measurement scales: real numbers and stochastic and fuzzy variables. Failure to use approaches for harmonizing data of different measurement scales causes, in certain cases, significant irrelevance of forecasts.

Using the method of content analysis, the purpose of the research was formed: the mathematical model development for assessing the cost of losses from the risks of transporting goods by sea, first of all, risks that are dynamic in nature, and the implementation of a methodical approach to the dynamic assessment of losses for each of the risks separately and integral losses for all risks and ensuring compliance with the requirement to anticipate the change in the insurance cost over the rate of change in the integral risk of transportation (or its stage).

The importance of solving the problem of estimating the expected value of losses in shipping has increased significantly in connection with the war waged by the Russian Federation, the mining of sea lanes, the bombing of Ukrainian seaports and the sinking of civilian vessels by the Russian fleet, in particular, of other countries in the Black Sea. However, the risk of military operations and related losses, despite the fact that in wartime it significantly outweighs the entire complex of threats to shipping, is only one of the possible risks. Therefore, it was necessary to analyze the entire complex of possible risks, because all losses had to be taken into account. The expected amount of these losses is a significant factor of direct influence on the value of insurance premiums and on the cost of transportation, and is a factor of indirect influence on the volume of cargo transportation through the ports of Ukraine and on the prospects for renewing the marine infrastructure.

2.2. Algorithm for the Systematic Assessment of the Dependence of the Expected and Real Cost of Losses on Risks

The insurance premium for water transportation can be considered as the additive value of two components: cargo insurance and means of transportation insurance. That is, it can be formalized mathematically as follows:

$$S = S_{cargo} + S_{vessel} \tag{1}$$

where S_{cargo} —the amount of the insurance premium for the cargo; S_{vessel} —the amount of the insurance premium for the ship.

As a rule, in the conditions of an increased level of risk, the amount of the insurance premium for the cargo is 100% of its value; that is, its value is strictly regulated and the nature of the rate of change of the risk does not affect the amount of the insurance premium. The amount of the insurance premium for the ship is largely an indirect function of risks. This is confirmed, in particular, by the fact that the cost of providing insurance coverage for merchant ships according to Lloyd’s Agency increases due to the amount of risk. It is true that the owners of merchant ships pay annual insurance against war risks, as well as an additional premium for entering high-risk areas. These individual premiums are calculated according to the value of the vessel or hull for the week. The indirectness of the impact of risks on the amount of the insurance premium is determined by the fact that the direct functional dependence of the specified premium is available for the expected value of losses caused by the risks.

That is:

$$S_{vessel} \sim S_{vessel}(\vec{x}_1, \vec{x}_2, \vec{x}_3, \dots, \vec{x}_n) \tag{2}$$

where $\vec{x}_1, \vec{x}_2, \vec{x}_3, \dots, \vec{x}_n$ —a set of risk vectors for water transportation; $1, 2, 3, \dots, n$ —risk indices.

Then:

$$S_{vessel} = S_{vessel}(\vec{\theta}_1, \vec{\theta}_2, \vec{\theta}_3, \dots, \vec{\theta}_n) \tag{3}$$

where $\vec{\theta}_1, \vec{\theta}_2, \vec{\theta}_3, \dots, \vec{\theta}_n$ —a set of vectors of loss functions from each of the transportation risks.

The approaches to estimating the expected cost of losses from shipping risks, given in the regulatory framework, can be stratified as follows:

1. Estimates of losses directly in the monetary equivalent. Some methods suggest identifying losses from risks as a function of the probability of the occurrence of an undesirable event multiplied by the result of its impact, which is measured in monetary terms.
2. Estimated loss assessment consists in reducing the assessment to take into account the physical dimension (for example, the number of cases of injury or death, the number of wild animals that died as a result of an accident, etc.). In particular, MAMC [24] offers a quantitative model for the implementation of this option IWRAP MKII [24].
3. Qualitative assessment of losses from risks using vague or linguistic assessment methods. The result in this case is often given in the form of a loss matrix. In this case, MAMC suggests using a model PAWSA [24,25].
4. Index assessment. By combining the frequency and consequences of risks, an index for shipping zones is formed, which represents a relative category of losses. According to MCDA, this technique is called “Analysis of conclusions by many criteria” and is used to evaluate alternative options for actions, routes, etc.
5. Mathematical modeling according to many criteria. An approach that is able to reduce different scales of measurement of losses—quantitative, monetary, qualitative, and proposals for the selection and equipment of waterways to a single scale.
6. Expert opinion. In the absence of reliable data, practitioners sometimes recommend forming a loss estimate based on expert experience or opinion.

Obviously, according to the detailed methodology for estimating the expected cost of losses, all the mentioned approaches can be reduced to a monetary scale of measurement.

The system dependence of the expected and real cost of losses on risks is shown in Figure 1.

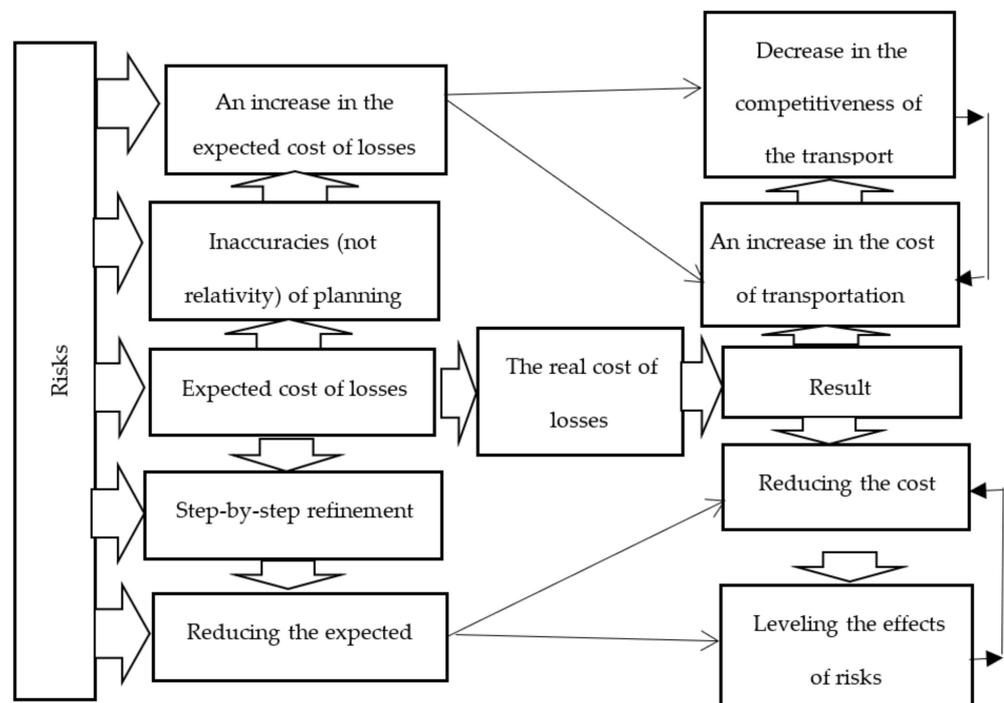


Figure 1. Algorithm for the systematic assessment of the dependence of the expected and real cost of losses on risks. Source: developed by the authors.

3. Results and Discussion

As the analysis of literature sources [12,21,22] shows, a significant degree of uncertainty often complicates the assessment of losses. This especially applies to the assessment of the consequences of risks, which must take into account the analysis of the impact of accidents on biogenesis, human health and the activities of economic entities in a certain area, close to the place of initiation of risks. This also applies to the above-discussed variant of informal indirect impact of the consequences of accidents on certain subjects/objects. The task can also be complicated by the fact that the impact of risks, not only on property or property relations, but also on the needs and interests of the subjects and on the formation of short-term and long-term problems for the involved parties, must be taken into account. In such cases, in order to move to the monetary dimension of the assessment, it is worth using the assessment of costs for the restoration of the biocenosis, the state of health of people and their treatment, and compensation for losses to business entities, etc.

The analysis (see Table 1) indicates a multi-layered structure of connections between the risk factors and the consequences of threats. As can be seen, each of the risks can have a whole set of consequences, so the use of a direct risk–consequence correlation is not possible. However, a rational approach is to analyze the effects of risk groups on a certain negative result. Therefore, a study was conducted of the effects of individual risk groups on the number of accidents in the pre-war period, for which there is statistical information for fairly significant time intervals.

Table 1. Classification of technical and technological risk factors of maritime shipping and their direct consequences.

№/№	Risk Factors				Effects		
	Parameters of Ships and Their Movement	Characteristics of Ships	Shipping Conditions	Waterway Configuration	Short-Term	Long-Term	
1	Quality of vessels	Big drop	Day/night	Depth	Injuring people	Impact on health and safety	
2	Competence of the crew	Small sediment	Excitement of the sea	Channel width	Oil spills	Violation of lifestyle	
3	Types of vessels	Commercial fishing vessels	Wind mode	Obstacles to proper visibility	Emissions of harmful substances	Impact on fisheries	
4	Species	Traffic density	Pleasure boats	Currents (river, tides, ocean)	The complexity of the waterway	Property damage	Impact on endangered species
5		The nature of the cargo	High-speed ships	Limitation of visibility	Bottom type	Refusal to use the waterway	Coastline destruction
6				Ice conditions	Stability (silting)		Destruction of reefs
7				Background lighting		Economical	
8				Debris			

A more detailed analysis indicated that this has a significant impact on this situation:

1. Ignoring the recommendations of international and national transport organizations by the command staff and crews of vessels.
2. Inadequate discipline of the crews in the performance of watch duty and unpreparedness for actions in the approach of emergency situations and during them.
3. Lack of training of crews for actions during accidents.
4. Inadequate technical preparation of the vessel before sailing, including technical preparation for sailing in limited conditions of the port water area and during sailing on river inland waterways.
5. Aging of vessels and their equipment.

6. A decrease in the qualification level of personnel due to changes in the personnel composition by age and significant trends towards the outflow of specialists to foreign transport companies.

Let us consider the factors of risk formation before the active phase of hostilities. Groups of factors that lead to emergencies for the period of 2019–2021 are shown in Figure 2. The conducted analysis, which is based on statistical information [21,22,24], made it possible to establish that different factors had different trends in the studied time interval. This proves that dynamic changes are characteristic even for risks in relatively stable periods of time. Thus, the share of navigational causes of accidents during this period tended to decrease (almost 1.5 times), the share of technical causes of accidents tended to increase (almost 1.5 times), and the share of organizational causes of accidents also increased (almost by a third). The trend of a significant reduction in the psychophysiological causes of accidents, the so-called “human factor”, was at 75%.

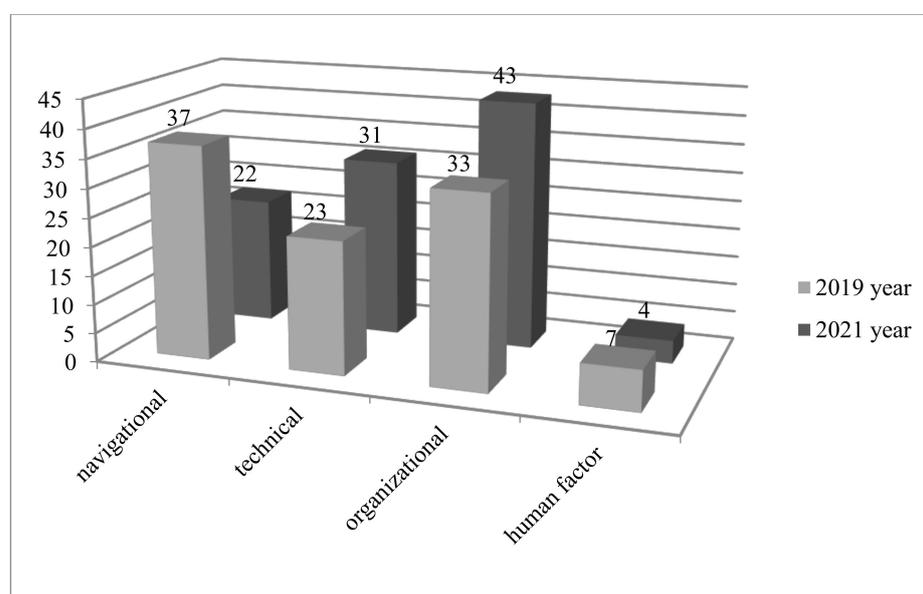


Figure 2. Groups of factors that lead to emergencies on water transport by comparing the data of 2019 and 2021, according to their share in the total number of accidents, percentage.

The analysis of the location of accidents made it possible to establish that in 2021, the majority of accidents ~57% occurred in seawater areas and waterways, and only ~43%—in inland waterways. The analysis of accidents by types of vessels indicated that in 2021, the majority of accidents (~49%) occurred on river vessels and vessels of the “river-sea” type, ~42% occurred on sea vessels and only ~9%—on small vessels.

It was established that the probability of accidents of dry cargo sea vessels of the domestic fleet was 3 per 10,000 voyages, with incidents 16 per 10,000 voyages (according to 2020 data). The probability of accidents of dry cargo river vessels of the domestic fleet was 7 per 10,000 voyages, with incidents—8 per 10,000 voyages (according to 2020 data). The probability of tanker accidents was 4 per 10,000 trips, and the probability of oil spills was 0.5 to 2.5 per 10,000 trips [26].

Regarding the cost of the consequences of tanker accidents: on 13 November 2002, the old tanker Prestige (year 1976, displacement 42.8 thousand tons) crashed near the coast of Spain on the route St. Petersburg–Gibraltar–Singapore with a cargo of 77,000 tons of Russian high-sulfur fuel oil, of which 50,000 tons fell into the waters of the Atlantic. Economic damage exceeded EUR 4.4 billion [27]. We estimate the average loss of marine transport for an extremely significant accident at USD 1.6 million, the average loss of an accident at USD 710,000, a significant incident at USD 290,000, and an incident at USD 100,000.

All the mentioned trends are taken into account by insurance companies, that is, insurance premiums increase depending on the existing trends of risk growth by routes or types of vessels, which leads to an increase in the cost of transport services, which, in turn, increases the value of products of Ukrainian enterprises on the world market and decreases competitiveness of the specified enterprises. First of all, this applies to products whose cost per ton is lower. These are, for example, raw materials, grains, etc. Under these circumstances, the share of transport costs in the cost of production increases, and changes in these costs have a more significant impact.

Using the given data, a mathematical risk forecasting apparatus was developed, which consists of the following. First, the target loss function is formed:

$$\vec{\theta} = \begin{pmatrix} \vec{\varphi}_{11}(\vec{x}_{11}) \cdots \cdots \vec{\varphi}_{i1}(\vec{x}_{i1}) \\ \vec{\varphi}_{12}(\vec{x}_{12}) \cdots \cdots \vec{\varphi}_{i2}(\vec{x}_{i2}) \\ \vec{\varphi}_{1j}(\vec{x}_{1j}) \cdots \cdots \vec{\varphi}_{ij}(\vec{x}_{ij}) \end{pmatrix} \tag{4}$$

where $\vec{\theta}$ —the vector of the objective loss function, $\vec{\varphi}_{ij}$ —the risk function vector, \vec{x}_{ij} —risk vector, i, j —indices of the corresponding cell of the risk matrix.

Further, loss prediction follows the following algorithm. Since the object/subject suffers losses from the cumulative impact of risks, to determine the impact, we find the coordinate positioning of the object/subject relative to the response surface in coordinates $\vec{\theta} - \vec{\varphi}_{ij} - \tau$, where τ —time axis.

Since the attractor functional on the response surface of the cost function is unknown, we use a step-by-step approach to forecast formation. To do this, we build a type matrix:

$$\frac{\partial \theta}{\partial \tau} = \begin{pmatrix} \frac{\partial \varphi_{11}}{\partial \tau} \cdots \cdots \frac{\partial \varphi_{i1}}{\partial \tau} \\ \frac{\partial \varphi_{12}}{\partial \tau} \cdots \cdots \frac{\partial \varphi_{i2}}{\partial \tau} \\ \frac{\partial \varphi_{1j}}{\partial \tau} \cdots \cdots \frac{\partial \varphi_{ij}}{\partial \tau} \end{pmatrix} \tag{5}$$

As is known, the first derivative is equivalent to the tangent function of the tangent to the response surface at the point of coordinate positioning of the object/subject for each section plane $\vec{\varphi}_{ij} - \tau$ multidimensional response surface of the objective function.

This makes it possible to estimate the cost trend from each of the risks separately ($\frac{\partial \varphi_{ij}}{\partial \tau}$) and the trend of integral costs for all risks ($\frac{\partial \theta}{\partial \tau}$) and to ensure the implementation of the requirement regarding the advance rate of change of the cost of insurance of the means of transportation over the rate of change of the integral risk of transportation (or its stage):

$$\frac{\partial S}{\partial \tau} \geq \begin{cases} \frac{\partial \theta}{\partial \tau} \\ \frac{\partial \varphi_{ij}}{\partial \tau} \end{cases} \tag{6}$$

It also becomes possible to highlight risk zones separated by isolines of risk influence on geographic maps, which allows mariners to visually determine the least risky routes.

A practical example of the selection of zones of risk influence can be the influence of the risk of military operations on the activity of seaports.

This impact is not uniform for Mariupol port and other ports of Ukraine: Odesa, Pivdennyi, Izmail, etc. The conducted analysis established that the Ukrainian ports of the Sea of Azov (Mariupol, Berdyansk) and ports close to the Kerch Strait (Kherson, Oktyabrsky) are located in the zone of increased risk for sea transportation of goods.

The change in risk for these ports has a significant dynamic nature. This can be proven by an example of one of the risks—the risk of a delay of 10 h or more by the military ships of the aggressor country of merchant ships. The analysis was carried out for vessels that were headed to or from the port of Mariupol in 2018 (see Figure 3). Figure 3 presents the averaged values of this risk in percentages for each month. Unfortunately, the graphic

representation of dynamic changes in risk over the 2018 period does not allow for detailing these changes over shorter periods of time. In some periods of time, significant changes occurred within weeks and even days. For example, on 1–3 September 2018, the value of the indicated risk increased from 24% to 32%; during the time period from 8 September to 24 September, the value was ~21%; after 24 September, it increased to 60%.

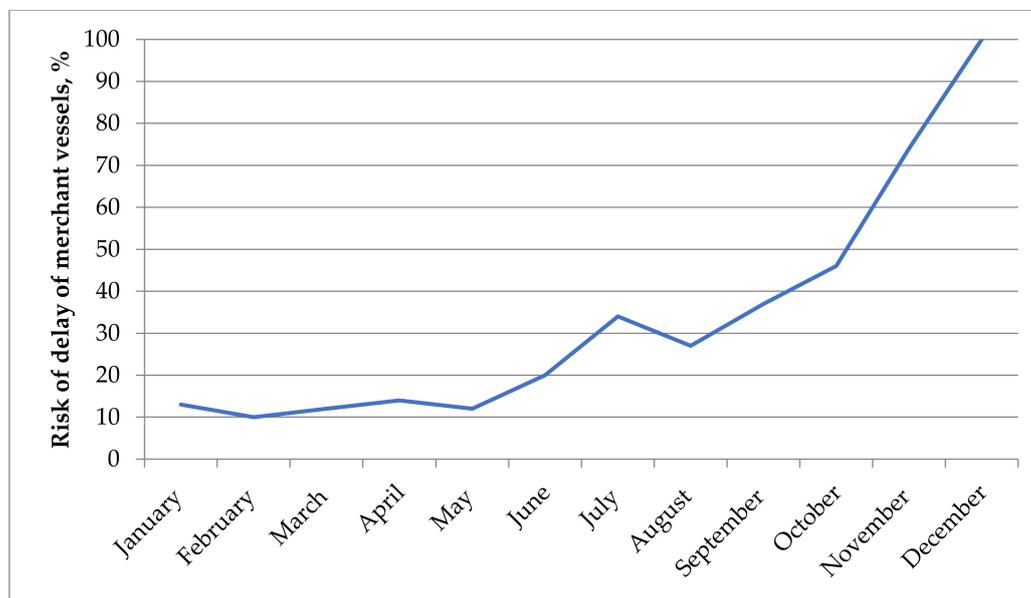


Figure 3. The risk of delay by warships of the aggressor of merchant ships that in 2018 were headed to the port of Mariupol (or departed from it) for a period of 10 h or more, percentages.

The value of the first derivative of this risk in time ($\frac{\partial \theta}{\partial \tau}$) corresponds to the tangent of the angle of inclination of each individual graph segment.

Since inequality (6) must be satisfied for the break-even operation of insurance companies, the nature of the change in risk and its magnitude led to a dynamic change in the first derivative over time objective loss function ($\frac{\partial \theta}{\partial \tau}$) and, according to the inequality (6), cost of insurance ($\frac{\partial S}{\partial \tau}$) for this direction of transportation. This, in particular, served as a trigger for the reorientation of cargo flows to other ports located in safer zones. This is proven by a significant change in the value of the first derivatives of transit transportation volumes, even to the opposite sign (see Figure 4).

In this case, the trend of the first derivative of the cost function is inversely proportional to the first derivative of transportation volumes.

The given analysis proves the need to take into account the dynamic nature of changes in risks and their impact not only on the magnitude of dynamic changes in the cost of insurance, but also on changes in cargo transportation routes to seaports of Ukraine.

For the Black Sea–Azov region, the main threats, the dynamic changes of which must be taken into account, are the risks caused by military actions. The specified risks have an absorbing nature. That is, their influence is greater than the level of integral influence of other factors. This makes it possible to use an approach in which the influence of other factors is taken into account as background. However, with the decrease in the level of military threats to the transportation of goods by sea, the influence of other factors becomes more significant for the formation of relevant forecasts of the transportation of goods by sea. Therefore, it would be taken into account for strategic level forecasts.

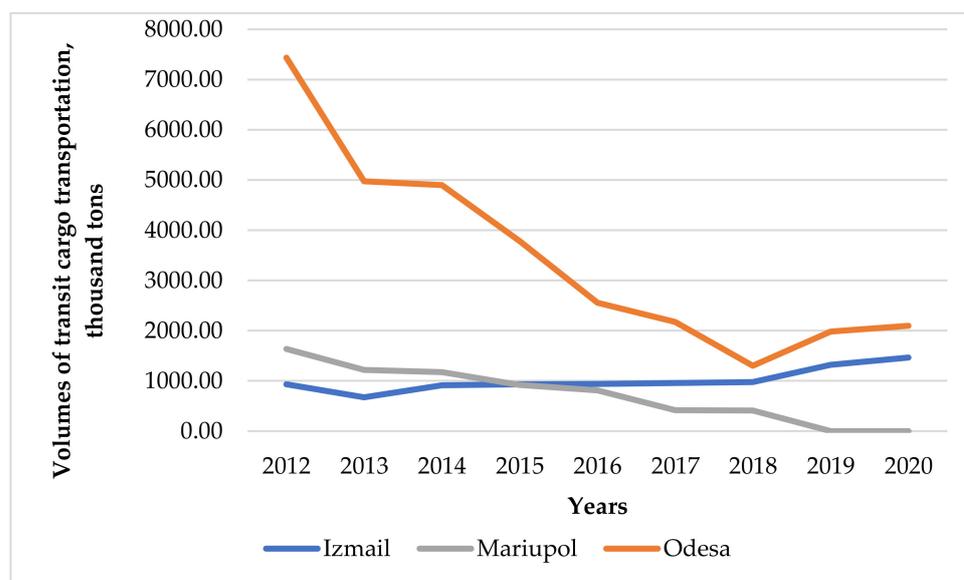


Figure 4. Changes over time in the volume of transit transportation of goods through the ports of Izmail, Mariupol and Odesa, thousands of tons.

4. Conclusions and Recommendation

In the scientific study, the results of which are presented in this article, a mathematical model was developed for estimating the cost of losses from the risks of sea transportation of goods. The first is risks that are dynamic in nature. In order to increase the reliability of the forecasts level, the indicated mathematical model is supplemented with an algorithm for the systematic evaluation of the dependence of the expected and real cost of losses on risks. A methodical approach to the dynamic assessment of costs for each of the risks of sea transportation separately and integral costs for all risks is also proposed. A necessary condition for the implementation of the presented methodical approach is to ensure the fulfillment of the requirement to anticipate the change in the insurance cost over the rate of change in the integral risk of transportation (or its stage). This forms approaches for the introduction of a decision support system for planning and forecasting the rate of change and the size of the cost of marine transportation insurance over the rate of change of the integral risk of transporting goods by sea.

The groups of factors that lead to the formation of risks in sea transportation are defined and the types of losses due to them are established.

The classification of technical and technological risk factors of maritime shipping and their direct consequences has been carried out, because it is the indicated consequences that determine the level and types of damages. The classification of technical and technological risk factors was preceded by a detailed analysis, which made it possible to divide accidents into separate groups. For risk factors, in particular, technical and technological factors, an assessment of the significance of the rates of their change was carried out to determine the rates of change of the integral risk as a whole.

It was determined that the main threats, the dynamic changes of which must be taken into account, are the risks caused by military actions. It has been confirmed that the risks caused by military actions have an absorbing nature. That is, their influence is greater than the level of integral influence of other factors. This makes it possible to use an approach in which the influence of other factors is taken into account as background. However, with the decrease in the level of military threats to the transportation of goods by sea, the influence of other factors becomes more significant for the formation of relevant forecasts of the transportation of goods by sea.

It was established that, in some cases, even before the start of large-scale military operations, the risk value for the transportation of goods by sea reached a critical limit in the waters of the Black and Azov seas. We defined the critical value of risks as their

increase to an unacceptable level. Then, based on the combination of the impact of risks and economic and political factors, it becomes necessary to choose other transport routes and other types of transport, even at a higher cost of transporting goods by the specified routes.

This required a change in approaches to risk assessment. Therefore, an approach has been developed that, with real-time forecasts, allows one to predict in advance the critical level of risks of cargo transportation by sea.

The developed mathematical approach also allows taking into account the requirements for the rate of change of the freight cost in advance of the rate of change of the integral risk of transportation. This approach ensures rational planning and forecasting of insurance premiums.

This increases not only the scientific significance of the conducted research, but also the effectiveness of its practical use. In particular, insurance and logistics companies, to solve planning and forecasting tasks, can also use the proposed estimate of the expected value of losses due to the risks of sea transportation of goods.

Further research would be aimed at developing a universal forecasting algorithm at both the tactical and strategic levels. Their inconsistency now reduces the accuracy of forecasts in the interval of matching tactical and strategic forecasts. The assessment of losses at a significant level of military threat requires clarification. This is because the impact of risks at such an intensity of hostilities has not been investigated before.

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