Emergency risk assessment for maritime and multimodal freight and passenger transport in the Far East

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Abstract. This article will emphasise the importance of ensuring the efficiency and safety of multimodal transport, which requires a comprehensive approach to risk assessment, taking into account the characteristics of transport, the geography of transport, administrative and legal constraints. It will explore modern methods of emergency risk analysis and outline the main risk factors for their occurrence.

1 Introduction

The occurrence of emergencies (emergencies) on water in the process of cargo or passenger transportation is inevitable due to the negative impact of various kinds of factors. For this reason, the task of pre-empting or mitigating their negative impact remains a priority today.

Although the International Maritime Organisation (IMO) has developed a set of documents and recommendations in terms of safety and the level of professional training of maritime specialists has increased, the accident rate in the maritime fleet still remains high and is not significantly reduced.

The peculiarity of multimodal transport is that cargoes move in time and space using different modes of transport. Accordingly, to ensure the efficiency and safety of such transportation, a comprehensive approach should be taken in the technical and technological field in accordance with the requirements of national and international acts, and in the field of risk assessment, taking into account the specifics of transport, administrative and legal restrictions, and the geography of transportation.

Analysis of risk factors and methods of their consideration in the practice of cargo transportation shows that, to date, in domestic and foreign practice, there is no definitively formed scientific basis for ensuring the safety of transportation and security of cargo, people and the environment according to risk criteria. Moreover, as the analysis of data on transport accidents shows, the consequences of accidents and incidents can be very severe, and losses many times exceed the costs of their prevention.

The information base for this study is legislative and regulatory acts of the Russian Federation (RF); official statistics data; theoretical and methodological developments of foreign and domestic economists devoted to the problem in question; monographs, materials.*

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In 2022, cargo turnover throughout the Russian Federation was 3 trillion t·km (99.7% of the 2021 level) and 6.9 billion tonnes (99.6% of the 2021 level). Commercial cargo turnover was 2.9 trillion t·km (99.8% of the 2021 level) and the volume of commercial cargo transportation was 2.9 billion tonnes (100% of the 2021 level). Cargo transshipment volume in sea ports of the Russian Federation stood at 841.7 million tonnes (100.7% of the 2021 level). As for passenger traffic, 0.58 billion passenger-kilometres were carried in 2022 (139.3% of the 2021 level), passenger traffic was 9.14 million persons (105.8% of the 2021 level). Maritime transport accounted for 3.42 million people (75.7% of the 2021 level) and passenger traffic was 0.031 billion passenger kilometres (87.8%).

2 Methodology for risk assessment of seagoing vessels

The following assumptions have been made in developing this methodological part of the risk assessment for seagoing vessels:

1. The occurrence and development of an emergency will follow the scenario shown in the figure.

2. The occurrence of emergencies and accidents is represented as a sequence of incompatible events and joint events.

The group of incompatible events includes: dangerous failures of technical means of the j-th kind (j = 1, 2, ..., J) on the route chain l (l = 1, 2, ..., L). Thus only one event can be the cause of collision or grounding.

3. Group of events are joint events, one of which with a certain probability may occur after the occurrence of event Alj.

In other words, this event may be the cause of a collision, grounding, shipwreck with i-th type of consequences (B1 - wreck; B2 - collision; B3 - grounding).

Using fundamental concepts of probability theory, the probability of occurrence of failure/conditions of the j-th type with i-th damage \( P(Al_ji) \), can be calculated, as a statistical average, from the ratio of the number of ships/vehicles that have suffered accidents due to failure of the j-th type with i-th damage in navigation areas/roads l to the total number of ships/vehicles passing through these areas:

\[
P(Al_ji) = \frac{\sum N_{jil}}{\sum \sum N_l}
\]

Weighted estimates of failures of the j-th type with i-th damage in navigation areas l are calculated by the formula:

\[
\omega(Al_ji) = \frac{\sum N_{jil}}{\sum \sum \sum N_{jil}}
\]

Since the causes of accidents become clear only after investigation of the circumstances of the vehicle accident, the probabilities of occurrence of events \( P(A_{jl}) \) are regarded as 'subjective' and a priori probabilities. Thus, the events \( A_{jl} \) should be regarded as a group of 'hypotheses' that give rise to the events \( B_i \).

As a consequence, if an \( A_{jl} \) event has occurred, the probability of the 'hypotheses' that give rise to \( B_i \) events can be estimated by applying Bayes' theorem, based on the probability multiplication formula:

\[
P(B_i | A_{jl}) = \frac{P(B_i)P(A_{jl} | B_i)}{P(A_{jl})}
\]
\[ P(A_j^i | B_i) = \frac{P(A_j^i) P(B_i | A_j^i)}{\sum_{j=1}^{I} \sum_{l=1}^{L} P(A_j^i) P(B_i | A_j^i)} \]

\[ \gamma(B_i | A_j^i) = \frac{\sum_j \sum_i \sum_i N_{jil}}{T_i} \]

\[ \gamma(B_i | A_j^i) = \frac{\sum_j \sum_i \sum_i N_{jil}}{T_l \times \sum_l S_{il}} \]

where \( \sum_{SIT} \) is the number of ships passing through areas \( l \) in time \( T \).

\[ R(B_i | A_j^i) = 1 - \exp \left( -\gamma(B_i | A_j^i) T_i \right) \]

\[ R(B_i) = \sum_{j=1}^{I} P(A_j^i) \times R(B_i | A_j^i) \]

\[ R(B) = \sum_{i=1}^{3} \sum_{j=1}^{I} P(A_j^i) \times R(B_i | A_j^i) \]

The risk price of accidents \( R_{il} \) can be calculated as the product of the accident probability \( P(B_i | A_j^i) \) by the estimated damage \( \int W_{il} dl \) (damage function in the case of one vehicle/vessel):

\[ R_{il} = P(B_i | A_j^i) \int W_{il} dl \]

Thus, the presented methodology for calculating the probability of emergency and accident risk forms the fundamental basis for the formation of integral risk assessments.

In multimodal transportation two main components of the route are considered - sea and land (land); three types of transport are involved. Based on accident rate analysis, it was found that the root causes of accidents are mainly failures of technical means (main engine, propeller group, vessel de-energisation), severe weather conditions, operator errors, etc. It turns out that when forming risk assessments, accident causality is taken into account, risk calculations by cause and consequence, which allows calculating probability of accident risks on the multimodal transportation route based on statistical data and expert assessments [1].
Risk assessment of transportation on a given route (transportation by sea, transportation by rail, transportation by road) can be represented as the sum of risks of the following formula:

\[ R_w = R_1 + R_2 + R_3 \]  

(14)

where \( R_1 \) is the risk of damage related to shipwreck; \( R_2 \) - risk of damage due to technical failures; \( R_3 \) - risk of damage due to accidents on railway/road transport in interaction with other means of transport.

The resulting probability of occurrence is calculated using the probability addition formula. Analysis of accidents and incidents in maritime, railway and road transport shows that natural risks dominate over man-made ones, i.e. most accidents occurred due to dangerous interaction of technical facilities and operators with the interacting environment (e.g. hurricanes, tsunamis, avalanches, etc.).

3 Causes of emergencies, their consequences in navigation and damage assessment

Some of the reasons why an emergency may occur in a watercraft carrying cargo or passengers include loss of stability, grounding, collision with another vessel, loss of buoyancy, etc. By classification they can be divided into:

1. **Shipwreck** - wreckage or total structural destruction of the vessel.
2. **Accident** - ship damage or stranding for at least 48 hours (passenger ship - 24 hours).
3. **Emergency** - the same accident but of shorter duration.

Any emergency situation (Fig. 1) on water is characterized by isolation of people, including those injured, relative scarcity of rescue means and medical aid forces, as well as a possibility of panic among people in distress. Table 1 shows the causes of accidents at sea with merchant vessels and their number for the years 2021-2022.

In addition, injuries can occur in the form of mechanical injuries, hypothermia, thermal burns, drowning and acute chemical poisoning. The consequences of disasters are usually assessed by the number of deaths and the number of people injured, although casualties also include people who have suffered severe mental trauma and people most adversely affected by extreme environmental conditions in a disaster (low or high temperature, hurricane, storm, exposure to ice). Of the recent major disasters we would like to mention the sinking of the autonomous trawler “Dalny Vostok”. It sank in the Sea of Okhotsk 300 kilometres from Magadan in 2015. There were 132 people on board the fishing vessel, of whom 78 were citizens of the Russian Federation and 54 were citizens of Ukraine, Latvia, the Republics of Vanuatu and the Union of Myanmar. A total of 69 people died. According to investigators, the Dalny Vostok trawler wreck was caused by the vessel tilting to the port side when lifting the trawl with its 130-ton catch. However, the sinking of the vessel was possible for a number of reasons, the most significant of which was the unsuitable condition of the trawler.

<table>
<thead>
<tr>
<th>Types of ship accidents</th>
<th>Quantity (accident/serious accident)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2021</td>
</tr>
<tr>
<td>Navigational, total</td>
<td></td>
</tr>
<tr>
<td>Collision</td>
<td></td>
</tr>
<tr>
<td>Grounding</td>
<td></td>
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<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Statistical data on water accidents across Russia
Of these ships lost

2. Technical, total

- loss of movement
- damage to ship structures and mechanisms
- hull damage
- explosions, fires
- loss of stability, buoyancy
- displacement of cargo or change in its properties
- loss of towed object

Of these ships lost

3. Death or missing person, cases

4. Getting grievous bodily harm, cases

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Fig. 1. Ratio of accidents by month
Know that a ship in distress may be on the surface of the water, grounded, beached ashore or sink. In such a situation, victims may remain on board, in rescue boats, in the water or underwater. The main distress signal on board a vessel is the international distress call - **SOS** signal, indicating the coordinates of the place of emergency. Sometimes a ship is unable to sound the distress alert. If it fails to make contact within the prescribed time, it is considered to be missing. After that, search vessels are dispatched to the area of the last communication session and survey the entire territory, where the vessel could have reached in the time elapsed since the last communication session [2].

Of the variety of risks (Figure 2) inherent in multimodal transport, it is simpler to divide them into three main groups:

1) risks of loss/loss of vehicle and cargo;
2) risks of accidents and incidents that do not result in loss of vehicle and cargo;
3) risks of failure of technical means ensuring the transportation and preservation of cargo.

Based on the analysis of a large number of marine vessel accidents, it can be concluded that, in general terms, the accident scenario develops according to the scheme shown in Figure 3.
Circumstances here refer to conditions which may directly or indirectly contribute to an emergency or directly cause an accident. In some circumstances (e.g. lack of necessary weather information, approaching hurricane or tsunami), severe weather conditions are the cause of an emergency, which could result in the vessel being thrown against rocks, structurally destroyed or flooded. Thus, the circumstances give rise to risks of failures, errors, insurmountable forces of nature, which cause accidents (collision, grounding, loss of ship and cargo). The consequences of emergencies in water transport include:

1. Explosions of hazardous cargo resulting in death of passengers, port/wharf workers and ships.
2. Fires on cargo, passenger, oil or fishing vessels causing similar consequences.
3. Huge material damage to the maritime fleet.
4. Spillage of oil products, formation of large oil slicks in the sea and coastal waters, destruction of beaches, which cause great ecological damage to the environment.

Vessels in distress on the water are difficult to render assistance, as the search for the stricken is difficult (Table 2).

<table>
<thead>
<tr>
<th>Water temperature, degrees C</th>
<th>Time of unconsciousness, h</th>
<th>Time of death, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>10</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>20</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>25</td>
<td>12</td>
<td>relatively safely</td>
</tr>
<tr>
<td>30</td>
<td>70</td>
<td>72</td>
</tr>
<tr>
<td>35</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>3</td>
<td></td>
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</table>
4 Conclusion

Many Russian and foreign scientists are dealing with the issue of maritime and multimodal transportation safety. It can be concluded from this article that most major accidents and disasters on ships are not caused by the forces of nature (hurricanes, storms, fog, ice), but by human error. Water transport is a very specific area of operational service. It is a special risk category because it is characterised by potential operational hazards and high vulnerability, and it is often the source of man-made and environmental disasters.

The graphs and tables in this paper show that accidents involving damage and loss of ships often result in numerous fatalities, significant material damage and significant adverse environmental consequences. Violations of legal and technical norms, illegal interference into activity of this type of transport, so called "human factor", represent particular danger.

To ensure utmost safety while transporting people, carriers must monitor the quantity of life-saving equipment and total number of people on board, they must inspect vessels in due time, and end-of-life vessels must be scrapped. The relationship as well as the liability of carriers and passengers for breach of obligations arising from contracts of carriage should be regulated by the relevant laws and regulations of the Russian Federation or by international treaties.

In the course of this study, the main causes of fatalities on water transport have been identified and the risks of emergencies on water transport have been assessed. Clearly, there is an objective need to improve the safety and efficiency of maritime and multimodal freight transport.

References

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