Determination of refuge places for oil tankers in emergencies in the Chinese Bohai Sea

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\begin{abstract}
This study considered three major emergency scenarios for oil tankers: explosion and fire on board, oil leaking from the ship into the sea, and sinking of the ship. A total of 25 main harbors and 51 main anchorages along the Bohai Sea were considered as potential places of refuge (PoR) to which oil tankers could be towed in an emergency. Three categories of indicators including 18 criteria were constructed given a total of 76 potential PoR. For visualization and further evaluation, a GIS-based score mapping system was built using normalization and rectilinear grids covering the whole domain for each of the criteria. All criteria were weighted equally and were then overlapped to present an overview of the ranking of all PoR in the Bohai Sea under each scenario. The least ranked five PoR for each scenario included in the final findings should be avoided by decision makers when they face a decision on where to tow an oil tanker for sheltering in emergency conditions. This paper provides a quantitative assessment method for determining PoR to which oil tankers should be towed in emergency conditions and suggests appropriate PoR with high rankings for oil tankers in the Chinese Bohai Sea.
\end{abstract}

1. Introduction

According to the Guidelines on Places of Refuge for Ships in Need of Assistance issued by the International Maritime Organization (IMO), a place of refuge (PoR) refers to a location where a ship in need of assistance can be taken to enable it to stabilize its condition, thus reducing the hazards to navigation, human life, and the environment. As the only instrument and standard on PoR [1], the IMO guidelines were initiated following a series of notorious oil spill accidents such as Erika in 1999, Castor in 2000 and Prestige in 2002 [2]. In the case of Prestige, one of its tanks burst in northwestern Spain while it was carrying 77,000 t of heavy oil in November 2002. The captain called for help but the Spanish, French, and Portuguese governments all refused to allow the ship to dock in their ports for fear of pollution of their coasts. As a result, the ship split in half and sank, releasing 20 million US gallons of oil into the ocean. The accident caused huge economic and ecological losses to the surrounding areas [3–5]. The estimation of short-term losses in all affected economic sectors amounts to almost €770 million [6], and the Spanish society placed a value of the environmental losses around €574 million [5]. Hence, a pre-designated PoR is needed to mitigate damage in future emergencies [7].

Such catastrophes sounded the alarm to coastal states. Since 2003, more and more countries have started to take measures to respond to the IMO guidelines. The EU has taken action to provide practical guidance for the competent authorities involved in managing a request for a PoR for ships by issuing EU Operational Guidelines on PoR. At the 3rd meeting of the EU Cooperation Group on PoR in 2015, a decision was made to test the guidelines using a practical case scenario. Under the terms of the community vessel traffic monitoring and information system (VTMIS) directive (Directive 2002/59/EC), EU member states...
have been required to designate "one or more competent authorities which have the required expertise and the power, at the time of the operation, to take independent decisions on their own initiative concerning the accommodation of ships in need of assistance." Some countries have taken further action in addition to the official directive to designate PoR. There have been two principal approaches to this problem [8]: First, some countries have clearly outlined PoR in advance. For example, Denmark designated a total of 22 sites along its coastline as potential PoR [9], and Latvia designated 7 coastal PoR including harbors and anchorages [10]. Second, other countries did not identify PoR but instead produced standard criteria and procedures that could guide endangered oil tankers to an appropriate place for sheltering. For instance, the United Kingdom maintains a list of approximately 800 potential sites as PoR, even including environmentally-sensitive areas [11]. The decision will be made under assessment of the contingent situation once accidents occur. The US has not designated potential PoR for oil tankers either, but guidelines for PoR decision-making have been issued by the National Response Team (NRT) including identification of important factors such as weather, sea state, tide and for consideration, and a decision-making process has been presented [12,13]. China has a high demand for imported crude oil, which mainly relies on marine transportation by oil tankers. In 2015 alone, 3,355 billion tons crude oil were imported. Accidents related to oil tankers have threatened the Chinese coasts in the past 30 years. According to the statistics [14], from 1990 to 2010, approximately 22,035 t were lost in Chinese waters, and 71 spills had a volume exceeding 50 t. However, China has neither designated potential PoR nor presented a decision-making process for oil tankers, which could result in chaos and inappropriate decision-making in the case of an emergency.

To our knowledge, quantitative selection methods for PoR for oil tankers are rarely available. Most previous publications have focused on legal aspects [15–17] or transboundary issues [18,19]. To our knowledge, no studies have covered quantitative assessments for PoR of oil tankers; thus, the technical method requires further discussion. To fill the research gap and to provide data of practical importance for Chinese coastal management, our study focused on how to determine PoR for oil tankers in emergencies in China with a focus on demonstrating a concrete methodology in the specific case of the Chinese Bohai Sea.

The Chinese Bohai Sea is one of the busiest sea areas in China, and shipping accidents remain frequent there [20]. Moreover, coastal regions of the Bohai Sea are economically developed, and the Bohai Sea is a semi-enclosed shallow sea with average and maximum water depths of 18 and 70 m, respectively. Due to its specific ecological and economic importance, it is highly vulnerable to oil spills of any size. Finally, given that the Bohai Sea is China’s inland sea, it would not cause any disputes with neighboring countries when PoR were designated. Hence, the Bohai Sea was selected as an ideal area for our study.

2. Data and methods

In this study, three major scenarios were explored in which an oil tanker would need to be towed to a PoR for further assistance. These scenarios include explosion and fire on board without leakage of oil, oil leaking into the sea, and the risk of sinking. For each scenario, corresponding criteria to be examined were selected. In general, three major categories of indicators were considered by combining empirical evidence and the IMO guidelines: the emergency response capacities-based indicator, the environmental indicator, and the social indicator. Moreover, each type of indicator contained a variety of criteria: rescue capability, towing capacity, firefighting capability, protective suits for rescue team, capacity for containing oil, capacity for trans-shipping oil, capacity for cleanup of spilled oil, nature reserve areas, distance from the coast, wind speed, wave height, maximum ocean current velocity, slope degree, bathymetry, seabed material, population, tourist attractions, and mar/aquaculture (Tables 1–3). As the criteria considered in each scenario were not identical, the three scenarios and their corresponding criteria were explored as shown in Fig. 1.

2.1. Scenario 1: explosion and fire on board

When explosions and/or fires occur on oil tankers, the most urgent response must be to rescue of the crews. Hence, the rescue capability was first considered and then the towing capacity and firefighting capability were considered. In order to obtain the emergency capabilities on the sea surface, inverse distance weighting (IDW) interpolation was used for the evaluation. The IDW method is a type of deterministic method for multivariate interpolation with a scattered set of points. It assumes that each input point has a local influence that diminishes with distance, and it weights the points closer to the processing cell greater than those farther away.

Moreover, the designated PoR under this scenario should be far away from densely populated areas because of the adverse social impacts [21] and because oil pollution can harm human health both in physically [22] and mentally [23]. Thus, the influence of population density in every county around the Bohai Sea was taken into consideration. A threshold of 20 nautical miles from the coastlines was assumed. Outside this distance, it was thought that the oil would not pose a threat to human health.

2.2. Scenario 2: oil leakage into the sea

Once the spilled oil was observed on the sea surface, the oil combat

<table>
<thead>
<tr>
<th>Table 1</th>
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<tr>
<td>Details of all involved criteria and their normalization rules for the emergency response capacities-based indicator.</td>
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<table>
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<tr>
<th>Label</th>
<th>Criteria</th>
<th>Data obtained</th>
<th>Description</th>
<th>Normalized score (0–100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Rescue capability</td>
<td>Obtained from local MSA</td>
<td>Continuous data representing the quantity of rescue ships</td>
<td>The more rescue ships, the higher the score</td>
</tr>
<tr>
<td>X&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Towing capacity</td>
<td>Obtained from local MSA</td>
<td>Continuous data representing the quantity of tugs</td>
<td>The more tugs, the higher the score</td>
</tr>
<tr>
<td>X&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Firefighting capability</td>
<td>Obtained from local MSA</td>
<td>Continuous data representing the quantity of fireboats</td>
<td>The more fireboats, the higher the score</td>
</tr>
<tr>
<td>X&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Protective suits for rescue team</td>
<td>Obtained from local MSA</td>
<td>Continuous data representing the quantity of chemical splash proof suits</td>
<td>The more chemical splash suits required, the higher the score</td>
</tr>
<tr>
<td>X&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Capacity for containing oil</td>
<td>Obtained from local MSA</td>
<td>Continuous data representing the quantity of contaminated oil booms</td>
<td>The more oil booms, the higher the score</td>
</tr>
<tr>
<td>X&lt;sub&gt;6&lt;/sub&gt;</td>
<td>Capacity for trans-shipping oil</td>
<td>Obtained from local MSA</td>
<td>Continuous data representing the quantity of unloading pumps</td>
<td>The more unloading pumps, the higher the score</td>
</tr>
<tr>
<td>X&lt;sub&gt;7&lt;/sub&gt;</td>
<td>Capacity for cleanup of spilled oil</td>
<td>Obtained from local MSA</td>
<td>Continuous data representing the quantity of oil skimmers</td>
<td>The more oil skimmers, the higher the score</td>
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Note: MSA, Maritime Safety Administration.
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