Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

Published by Research Publishing, Singapore.
doi: 10.3850/978-981-18-8071-1_P580-cd

Agent-based modelling and analysis of search and rescue (SAR) operations in the Barents Sea

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Despite the significant increase in maritime activities in recent years in the Barents Sea, maritime search and rescue (SAR) modelling and simulation in the Arctic waters, including in the Barents Sea is a relatively less researched area. The present study proposes an agent-based modelling framework, which models and simulates different SAR scenarios and evaluates the performance of the SAR system under various operating conditions, while considering the dynamicity and uncertainties of the weather and sea conditions.

Keywords: *Agent based modelling, Arctic offshore, Search and rescue operations, Barents Sea*

1. Introduction and problem statement

Remoteness of the Arctic offshore environment, combined with harsh meteorological and oceanographic conditions can hinder search and rescue (SAR) operations. Additionally, there is a scarcity of port infrastructure along the Arctic coastline that may negatively affect the SAR operations (Naseri, Barabady 2016). While different studies have been conducted on maritime SAR modelling and simulation (Ai et al. 2019; Norrington et al. 2008; Siljander et al. 2015), the research focused on the Arctic waters and the Barents Sea is still limited.

Agent-Based Modelling (ABM) (Van Dam, Nikolic, and Lukszo 2012), has been applied extensively to model complex systems, whose behaviour evolves from the interactions of system agents with one another and with the environment. The aim of this paper is to develop an agent-based modelling framework to analyse the SAR operations in the Arctic waters. It considers the dynamicity and uncertainties related to met-ocean parameters and constrains related to the SAR infrastructure. Different rescue scenarios are simulated and the performance of the SAR system under different conditions are evaluated.

2. Model description

Let a geographical region in the Barents Sea be divided into cells ω_{jk}, $j = 1, \dots, v$, $k = 1, \dots, w$. Each cell is characterised by some weather and sea parameters including temperature, wind speed, significant wave height, and wind chill index, denoted by, $wind^{\omega_{jk}}$, $wave^{\omega_{jk}}$, $temp^{\omega_{jk}}$, and $wci^{\omega_{jk}}$ respectively. The ABM consists of different agents, including rescue vessels, rescue helicopters, and evacuees, who need to be rescued. For a generic SAR operation, we can consider below activities:

i. vessels and helicopters depart from the base and arrive at the location of the distressed ship (i.e., a_1 and a_2),
ii. once the rescue crew are at the location, the evacuees are embarked on the vessel or the helicopter (i.e., a_3 and a_4),
iii. the vessel or the helicopter should travel back to the rescue base (i.e., a_5 and a_6), and
iv. the evacuees are disembarked from vessels and helicopters (i.e., a_7 and a_8).

These activities are performed in the Barents Sea, modelled by defining an overall severity level, $Z^{a_i} \in [\zeta_n]$, $i = 1, \dots, 8$, $n = 1, \dots N$ with N being the total number of the severity levels, as a function of the severity levels of met-ocean parameters.

The agents perform the activities until all of the evacuees are rescued and transported to either of the recue bases. The time required to complete each activity, τ_{a_i}, is dependent on the type of the activity and the severity of the operating conditions $\tau_{a_i} = g_i(a_i, L^{a_i}), i = 1, \dots 8$, with

$g_i(\cdot)$ being the expert-based mapping function to estimate τ_{a_i} for activity a_i performed under operating conditions with severity L^{a_i}. The value of L^{a_i} is conditional on the location of the agent, ω_{jk}, and calendar time, t, which is introduced to consider the dynamicity of the weather and sea conditions.

In this modelling framework, the refuelling time of helicopters and vessels are included as a random variable. Also, note that, τ_{a_i}, $i = 1{,}2{,}5{,}6$ (i.e., sailing and flying activities), depends on the speed of vessels and helicopters, which are dependent on the severity level of the operating conditions. Finally, the total time to rescue all the evacuees can be considered as the SAR system performance measure.

3. Results and Discussion

The ABM is developed for a hypothetical SAR operation. The study area and SAR bases for vessels and helicopters are shown in Fig. 1a. The distressed ship has 500 people onboard. In total, there are 10 vessels and 4 helicopters contributing to the SAR operation (see Fig. 1)

Fig. 1 The study area and the location of SAR bases

To estimate the total rescue time in different months of the year, 50 simulations were run for each respective month. The model parameters are obtained in consultation with SAR field operators and experts, and are elicited in the form of probability distributions to account for the uncertainties associated with expert data. Metocean parameters are NORA10 modelled data, collected from the repository of Meteorological Institute of Norway (3-hourly data from 1980 – 2012). As illustrated by the box plot of the total rescue time in each month in Fig. 2, there is a clear seasonality in total rescue time, where the longest and shortest rescue times occurring during Nov – Feb and Jun – Aug, respectively.

4. Conclusion

The proposed ABM framework can model the SAR operations in the Barents Sea considering its severe operating conditions, while considering their dynamicity. The results of the simulations of the paper shows a clear seasonality in total time of rescue operation, with longest rescue operations taking place in wintertime (Nov–Feb). The flexibility and scalability of the agent-base models allow us to run a variety of SAR scenarios. The proposed framework can be used to inform decision-makers and improve the effectiveness of SAR operations in the Arctic waters.

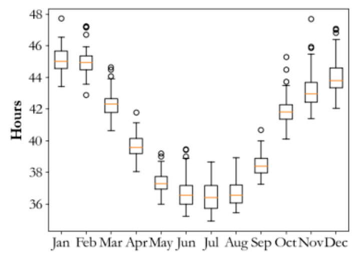

Fig. 2. The time of rescue for each month in hours

Acknowledgement

We would like to acknowledge the Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education (Diku) for their support under Project UTF-2020-SouthKorea/10014.).

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