Enhancing the sustainability of the Finnish-Swedish Winter Navigation System by intelligent icebreaking assistance

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The present extended abstract is based on the published study[1]

Introduction

Shipping in cold regions is complicated by ice, causing less energy- and cost-efficient transportation compared to open water. Climate change makes decarbonizing shipping in ice relevant for two reasons. First, breaking the ice requires much energy and generates significant emissions because ships are still mainly powered by fossil fuels. Second, the prospect of melting ice attracts more ships to cold regions, making shipping in ice more intensive. Ice-related challenges can be managed by providing efficient icebreaking assistance to improve the performance of the merchant ship traffic in ice. Some researchers proposed decision-support tools to optimize the cost- and time-related indicators of ice-infested maritime navigation in the Gulf of Bothnia[2,3,4] and the Arctic[5]. It is noted that the existing research on centralized icebreaking assistance modelling and optimization mainly studies the economic and social components of sustainability, leaving the environmental component out of consideration. The present study presents a new simulation-based framework to minimize greenhouse gas emissions of the Finnish-Swedish Winter Navigation System (FSWNS), consisting of merchant vessels and icebreakers operating in the Gulf of Bothnia.

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Greenhouse gas emissions are minimized by improving the performance of centralized icebreaker assistance.

Materials and methods

The proposed approach estimates the total CO2 emission and cost-efficiency of the assisted fleet and icebreakers, helping to select the most desirable icebreaking assistance principles according to the user's preferences and contributing to developing sustainable icebreaking policies. We developed a decision-support tool using the multimethod framework Anylogic, allowing for the use of agent-based and discrete-event simulation elements in one model. The method has exceptional adaptability, computational speed, and user-friendliness. It entails the individual modelling of various entities, such as transportation vessels, icebreakers, ports, routes, and ice conditions, each following specific rules, formulas, and algorithms. These modelling processes draw upon established practices and experiences of the FSWNS navigation. Because of the high modularity of a tool, the changes in logic and calculations of the system can be easily implemented by adjusting the code of individual types of agents. The estimated performance of the FSWNS is the result of the interaction of multiple agents.

The total CO_2 emissions of the FSWNS are calculated using Eq. (1).

$$CO_2\ emission = \sum_{n=1}^{n_{max}} \sum_{t=1}^{t_{max}} \Delta t' C_f \left(\frac{P_d SFC_1}{\eta_{tr}} + \frac{P_{hl} SFC_2}{\eta_{hl}} \right), \ (1)$$

where n is the number of merchant and icebreaking vessels in the FSWNS, and t is the number of the simulation period. The duration of the simulation period $\Delta t'$ is the predefined elementary timestep for the integration. C_f is the conversion factor between fuel consumption and CO_2 emission. P_d is the propulsion power used, predefined in the model for a specific type of ship. P_{hl} is the hotel load of a ship. SFC_1 and SFC_2 are the specific fuel consumptions for the main engine and the electric generator. η_{tr} and η_{hl} are the power transmission efficiency for propulsion and the hotel load.

The total cost of the FSWNS operation is calculated using Eq. (2).

$$Cost = \sum_{n=1}^{n_{max}} \sum_{t=1}^{t_{max}} \Delta t' \left(R_n + C_{fuel} \left(\frac{P_d SFC_1}{\eta_{tr}} + \frac{P_{hl} SFC_2}{\eta_{hl}} \right) \right), (2)$$

where R_n is the time charter rate of a merchant vessel or an icebreaker, C_{fuel} is the fuel price.

Results

The analyzed demonstration cases have shown significant prospects for applying the developed tool for more efficient icebreaker assistance in decarbonizing and minimizing the cost of operation. The obtained solutions may provide seven per cent less CO2 emissions and fourteen per cent less costs than the configuration based on the existing navigation practice. The developed tool can quickly estimate many alternative icebreaking policies, giving the decision-maker the freedom to select the most promising solutions considering individual preferences.

Implications for sustainable maritime operation

According to the current study's findings, we have formulated policy recommendations to reduce carbon emissions in the Finnish-Swedish icebreaking assistance operations. These recommendations outline their impact on various key performance indicators (KPIs). Nevertheless, before we can practically implement the reccomendations, it is crucial to undertake further development of the tool. This is necessary because certain essential aspects of the Finnish-Swedish Winter Navigation System have not yet been considered.