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Decarbonization as a new challenge for ship routing systems

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Extended Abstract

1 INTRODUCTION

New standards and objectives declared by international regulatory organizations of waterborne transportation (IMO, PIANC etc.) impose strong requirements for significant reduction of greenhouse gas emissions from commercial cargo vessels (Kondratenko et al., 2025a). These ambitious goals (for example, the target of net-zero emissions by 2050) can be achieved in two principal ways. The first involves the development and implementation of various technical solutions – both entirely new designs of "green" and unmanned vessels, as well as retrofitting existing vessels. The latter means transforming them to the use of alternative fuels or equipping them with additional emission-absorbing devices or alternative propulsion systems (Kondratenko et al., 2025b). Such solutions are potentially highly effective, but require significant capital investments and a relatively long timeframe. The second approach concerns significantly improving the operational efficiency of existing vessels. It means the development and widespread implementation of decision-support and information systems, both onboard and onshore (i.e., used in the offices of shipping and logistics companies). This approach requires significantly lower financial investment, while the positive results (fuel economy or reduced emissions) are often comparable to those of more demanding technical solutions.

Weather routing software — advisory tools that enable path finding and route planning based on forecasted environmental dynamics, vessel characteristics, and specified optimality criteria and constraints – explicitly relates to the latter way. Such software is already widely used in shipping practice. Traditionally, it focus on maximizing commercial targets (searching the fastest or shortest route, optimizing profits while taking into account strict delivery constraints, etc.). Sustainable and environmentally responsible shipping, however, poses new challenges for users and developers of this class of software. This report considers the related challenges and presents our vision for promising new methods and approaches to the weather routing service. The issue is demonstrated with the current state and prospective development of the author's software product - a web service for routing transoceanic voyages of transport vessels developed by the "Argestes" company.

2 MATERIAL AND METHODS

Our solution is an open-access internet service (see <https://routing.argests.net/>), allowing any user to calculate and analyze the optimal route (both trajectory and mode of movement) for a given ship from a given departure to a given destination point within a given time period. We tried to support a minimal entry threshold in our product – to set the vessel, one needs to set nothing more than an IMO number. The service integrates the following principal modules and functional components:

- Original and fast hybrid cell-wave numerical algorithm of path finding in dynamic and heterogeneous media.). We extend the traditional isocost-oriented approach, and the main idea is the new effective method for eliminating unpromising points at each step of the iterative algorithm of wave propagation (Topaj, Tarovik, 2025)
- Built-in database of ship parameters (tankers, container ships, bulk carriers etc). Over 107,000 simplified ship digital models, sourced from trusted classification societies
- Versatile ship performance model taking into account the full spectrum of environmental influences on resistance, fuel consumption, and seaworthiness parameters. The main advantage of the newly proposed model is its simplicity, which makes it a useful tool in the case when high-fidelity simulators are unavailable or impossible to implement due to the lack of input data.
- Relevant free-access weather forecasts from trustworthy providers (Copernicus, NOAA, ECMWF). Wind, wave, ice, and bathymetry data are seamlessly integrated into our routing engine during the calculation process. Ice and mixed-conditions navigation is also supported.

- Geoprocessor module permits avoiding spatiotemporal zones of prohibited or risky navigation. It also allows accounting for canal tolls, strait queue delays, appointed passage time slots, and other operational constraints.

Using our service, one can plan a future voyage for a fixed schedule or a free departure/arrival window. The optimization system intelligently balances parameters to produce results that are both operationally robust and economically sound. The latter is provided by setting one of the pre-defined customized optimization criteria (cost, fuel, time, risk, distance, etc.). As a result, the user obtains a family of recommended routes and can compare them or have a visual playback of alternatives to make the most informed strategic decision.

3 CHALLENGES AND PROSPECTS

In our view, the new functionality for the future automated systems of optimal routing, driven by the decarbonization requirements of maritime shipping, has to cover at least the following issues:

1. Direct calculation of total emissions for main greenhouse gases (carbon dioxide, methane, nitrous oxide) and the CII index per voyage for each alternative route variant. Such functionality is already implemented in the current version of the service.
2. Calculation of sulfur emissions on route segments depending on the explicitly specified fuel type for each voyage and the local operating regime of the ship engine.
3. Implementation of a versatile system for the choice of criteria and constraints in the mathematical optimization problem being solved. Now, the criterion could be minimal emissions, while the constraint could be, for example, the obligation to deliver cargo within a specified time window. The numerical optimization algorithm used in the current version of our system is defined by a single scalar score and an arbitrary number of terminal and integral constraints of any type. So, it seems to be sufficiently flexible for any of the mentioned modifications.
4. Input and taking into account when calculating the optimal route, the emission control areas (ECA) and vessel speed reduction zones (VSR) as specific geo-referenced spatial objects with explicitly defined limits on permissible emissions or velocity limitations.
5. Expanding the list of possible optimization variables. Here, in addition to the trajectory and engine power level, additional variables need to be introduced. One such variable could be the fuel type (really, many modern vessels can switch quite quickly from diesel to LNG, for example, while passing through specially protected natural areas). The temporary switching to purely electric motion on certain sections of the route using energy accumulated on previous sections could also be considered here. The choice of current propulsion from several alternative options could also be a new optimization variable for new-generation vessels. The latter could significantly change the optimal route obtained in weather routing (Sun et al., 2025). While traditional vessels currently strive to avoid storm zones, it's entirely possible that future unmanned vessels equipped with rotor sails will, conversely, seek out strong wind zones to maximize their energy efficiency. All of these potential improvements fit within the semantics of the special discrete optimization variables already implemented in our algorithm—the so-called "statuses". This concept is currently used in the service to find the optimal movement mode for double-action vessels in ice, i.e. fore- or stern forward (Topaj et al., 2019). However, it appears to be completely suitable for the prospective system modifications described above.

4 CONCLUSIONS

The mentioned improvements and extensions should make vessel routing software systems a powerful and user-friendly tool that is in demand in the real practice of sustainable and decarbonization-oriented shipping.

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