Collaborative Optimization Method of Route and Speed for A Mini Polar Cruise Ship

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ABSTRACT

In order to effectively improve the energy efficiency of ships, a collaborated optimization method of route and speed is investigated in this paper. Firstly, a hybrid engine/battery/cold ironing propulsion system mathematic model is established based on a mini polar cruise ship. Then, the collaborative problem consisting of optimization objective, variables, and constraints is mathematically described. Finally, the particle swarm optimization algorithm (PSO) is employed to solve the optimization problem. A simulation comparison is carried out to verify the effect of the proposed method. The result shows that fuel consumption can be saved by 7.20%.

KEY WORDS: Collaborative optimization; fuel saving; speed optimization; route optimization; sea states.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ECMWF</td>
<td>European center for medium-range weather forecasts</td>
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<tr>
<td>EMS</td>
<td>Energy management strategy</td>
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<td>ES</td>
<td>Evolution strategy</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<td>IMO</td>
<td>International Maritime Organization</td>
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<td>MEPC</td>
<td>Maritime Environment Protection Committee</td>
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<td>PSO</td>
<td>Particle swarm optimization algorithm</td>
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<td>SOC</td>
<td>State of charge</td>
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INTRODUCTION

With the development of polar resources, polar tourism has gradually become a new fashion (Shijin, Yaqiong et al. 2020). However, the polar regions are relatively cold and the ecological environment is fragile. Human activities have caused great threats to the polar environment, such as garbage, marine fishing, exhaust emissions, and noise pollution. Among them, greenhouse gas (GHG) emissions which strongly correlate with fuel consumption can cause the average global temperature to rise and sea ice to melt. Hence, it is necessary to reduce the fuel consumption of polar cruise ships. The Maritime Environment Protection Committee (MEPC) set a global shipping industry decarbonization target in 2018 (MEPC73 2018). Compared with the level of the shipping industry in 2008, MEPC expects to cut GHG emissions by 30% in 2030, and 50% in 2050, and stop GHG emissions by 2100. For ships that have already been built, energy efficiency optimization is an effective way to reduce GHG emissions from fuel consumption. Hence, how to improve the energy efficiency level of ships in complex and changeable sea states is the key to the problem.

To improve the energy efficiency of ships equipped with conventional diesel engine power systems. Route optimization and speed optimization have been extensively studied. The authors in (Szlapczynska and Szlapczynski 2019) used the evolutionary multi-objective optimization method to find the best trade-off between passage time, fuel consumption, and safety. To minimize the financial cost and remove the GHG footprint, Gkerekos and Lazakis (2020) proposed a novel route optimization method. The fuel consumption of the main engine was predicted by a data-driven mode, and the optimal route is obtained by Dijkstra's algorithm. The authors in (Du, Li et al. 2022) modified the PSO algorithm to improve its convergence, then they used the modified PSO to select the optimal route based on a VLCC oil tanker, the result showed that the profit ratio increased by 10.15%. In addition to route optimization, speed optimization had also attracted the attention of scholars. According to (Ronen 1982), The fuel consumption of a ship is almost proportional to the cube of the speed. That is to say, a slight change in speed will cause a significant variation in fuel consumption. Therefore, adjusting the speed has great potential in improving the energy efficiency of ships. The author in (Lindstad, Asbjørnslett et al. 2011) investigated the potential of fuel saving by speed reduction, the results showed that 19% of emissions could be reduced. Besides, the authors in (Wang, Yan et al. 2016) proposed a speed decision method based on different working conditions, their results showed that about 19.04% of fuel consumption was saved. In (Wang, Wang et al. 2022), the speed was optimized according to the different sea conditions. The authors divided the environment into different categories which corresponded to different speeds. The results showed that fuel consumption could be saved by 3.38%. However, the above studies simply considered the route or speed in the optimization process, which brought certain limitations to the improvement of ship energy efficiency.

During the actual voyage, the relationship between route and speed is very close. The sea states encountered by the ship is depending on the choice of the route, and the corresponding optimal speed is also different. Therefore, simply optimizing the route or speed may not be able to fully improve the energy efficiency of the ship. To solve this problem, the authors in (Vettor and Guedes Soares 2016) regarded the ship's position and speed as optimization variables and proposed the ES