Development of a model for operating ship path and speed coupling optimization

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ABSTRACT
The fuel consumption of a ship during navigation is closely related to its speed, path and encountered weather. Ship operating companies always tend to choose the appropriate weather route for fuel consumption saving. When completing a voyage mission, the operating ships are always constrained by the estimated time of arrival (ETA). Under the condition that the total sailing time remains unchanged, different routes will correspond to different speeds. Therefore, for operating ships, the selection of weather route is always a coupling optimization problem of route and speed aimed at minimizing fuel consumption. In this paper, a model for a simultaneous determination of ship’s path and speed with the constraint of ETA is established. The rhumb algorithm is applied to generate path taking in account the influence of the curvature of the earth. The marine environment forecast data provided by a commercial weather forecast company is used to interpolate the weather encountered by ships in different route speed combinations. Subsequently, a self-developed fuel consumption model, which is recognized by operating companies, is applied to calculate the total fuel consumption for the whole voyage. Finally, the optimal path and speed are determined simultaneously by particle swarm optimization (PSO) algorithm. The result shows that the optimized route can reduce fuel consumption by 1.2% compared with great circle route. Besides, the optimized route makes ship avoid the rough sea conditions effectively.

KEY WORDS: Weather route, coupling optimization, fuel consumption.

INTRODUCTION
Shipping is the most important form of transportation in international trade but also a huge fuel consumer. Planning a best route based on weather forecast and specific ship characteristics is an effective way to reduce fuel consumption. This best route is called as weather route (Padhy et al., 2008; Shao et al., 2012). Generally, the route is planned by the chief mate and confirmed by the captain. In most cases, the route is decided by their experiences, which is not the best choice sometimes (Lee et al., 2018). Therefore, it is of great practical significance to develop a route planning algorithm meeting the needs of navigation.

Referring to previous literatures, there have been many research achievements in route planning. Sun et al. (2020) proposed an efficient optimization method for economic ship-routing using the improved A* algorithm. The optimization method effectively integrated high-fidelity theory-based method for wave-added resistance and the air dynamic of wind-assisted rotors. Zhou et al. (2019) developed a proper grid system to find a safe, time-saving route for the ship to cross the ocean by applying modified genetic algorithm. The results show that the algorithm can effectively avoid the dangerous area. Kim et al. (2014) presented a new ARC-Theta, which can create paths in real-time with accommodation for the actual heading angles and steering performance of unmanned surface vessels. Compared with other algorithms, the efficiency of their algorithm is verified. Park and Kim (2015) determined the optimal path in a fixed-speed state by using the A-star algorithm. Then they adjusted the speed on the path by applying geometric programming. Vettor and Soares (2016) developed a ship weather routing system which ship responses are modelled for any sea-state condition. They abstracted the ship route planning problem into a multi-objective optimization problem for which the waypoint and speed are variables. The characteristic of these algorithms is to grid the map and generate paths by connecting adjacent grid centers.

There are also many methods that independent on grid maps. Szlapczynska and Smierzchalski (2007) proposed an adaptation of the isochrone method with area partitioning assuring that the route found by the adopted method would not cross land. Hinnenthal and Claus (2010) established a multi-objective, non-linear and constrained optimization problem in which a suitable compromise can be found between opposing targets. By solving the equations, a new optimization approach to select the most advantageous route is posed. Fang and Lin (2015) applied the three-dimensional modified isochrone method utilizing the recursive forward technique to globally search for the optimum route. Two types of routing strategies, i.e. ETA routing and fuel-saving routing are compared and discussed. Wang et al. (2018) developed a real-coded genetic algorithm to provide decision-making for ship weather routing. The results show that the algorithm can minimize the voyage time and provide a route that does not intersect with dangerous areas, which indicates that it can avoid dangers to some extent.

The above methods have played a role in the development of route planning technology. However, there are still some deficiencies that need to be further improved to better meet the needs of navigation. One of the most important points is that the weather encountered by the ship will change dynamically with the different path and speed. Therefore, the fuel