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Method for a simultaneous determination of the path and the speed for ship route planning problems

Sung-Min Lee [a], Myung-Il Roh [b,*], Ki-Su Kim [a], Hoeryong Jung [c], Jong Jin Park [c]

[a] Department of Naval Architecture and Ocean Engineering, Seoul National University, Republic of Korea
[b] Department of Naval Architecture and Ocean Engineering, Research Institute of Marine Systems Engineering, Seoul National University, Republic of Korea
[c] Central Research Institute, Samsung Heavy Industries, Republic of Korea

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ABSTRACT

Recently, the need for a more efficient method for ship route planning was raised due to the financial crisis in the shipping industry, a strengthening of emission regulations, and the limitations of the existing methods. So far, numerous ship route planning methods have been developed, but most of them do not correctly reflect the effect of a change of the ship speed in the path-determination stage. For this study, a ship route planning problem was formulated as an optimization problem. To solve this, a method for a simultaneous determination of the path and the speed of a ship is proposed. To check the efficiency and the applicability of the proposed method, sensitivity analyses and a comparative test regarding some other methods was performed. The proposed method was applied to various examples of ship route planning and the results show that the proposed method can reduce the total fuel consumption compared with the other methods.

1. Introduction

1.1. Research background

Ship route planning is generally the responsibility of the captain and the chief mate. In most cases, they decide the route depending on their experience at the time of planning, and while this does not necessarily cause any problems, it can be improved. Path-finding methods and commercial programs can be of assistance, and many methods can be used. Many of the methods, however, have not fully satisfied user expectations.

While the available methods and programs for the determination of the optimal route are numerous, the existing methods are limited in terms of speed optimization; that is, an optimization method for which the path and the speed are considered at the same time is absent. For these reasons, a new method for ship route planning for which the path and the speed are considered simultaneously is proposed in this study.

1.2. Related studies

Several of the existing methods can be divided according to cell usage, including cell-based and cell-free methods. Here a cell means a small region generated from a grid. Table 1 shows a comparison of cell-based and the cell-free methods. The cell-based method generates a path by connecting the center points of the cells. On the other hand, the cell-free method does not use any cell to generate a path. It is inevitable that the cell-based method must limit the searching direction because the cell shapes are fixed; therefore, when cell-based methods are used, the path is rough and angled-shaped, and post-treatments are consequently needed to smooth the route. Further, the concept of time is not contained in the cell-based method, so the speed optimization should be operated separately. Alternatively, the cell-free methods such as the isochrone method do not limit the searching direction, and the application of speed optimization into the method is relatively easy.

Many ship route planning studies use a cell-based method, and the path optimization and the speed optimization are accordingly separated. Joo et al. (2012) found the optimal path in a fixed-speed state by using the so-called "A-star" algorithm, and they modified the path in consideration of the weather conditions by using the Dijkstra algorithm; afterward, the speed on the path was adjusted. Similarly, Bang and Kwon (2014) found the optimal path in a fixed-speed state by using the A-star algorithm, but they modified the found path in consideration of the weather conditions by using an evolutionary strategy; and lastly, they adjusted the speed on the path. Choi et al. (2015) targeted the ship route planning for the Arctic Sea. Since the weather condition included constant hourly ice changes, they developed an ice model in consideration of

* Corresponding author.
E-mail address: miroh@snu.ac.kr (M.-I. Roh).

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Table 1
Comparison of the cell-based algorithm and the cell-free algorithm.

Use of cell	Methods	Limitation on searching direction	Speed optimization	Computation time
Cell-based	Dijkstra algorithm (Dijkstra, 1959)	Limit	Relatively hard to apply	Relatively long
	A-star algorithm (Hart et al., 1968)			Relatively short
Cell-free	Isochrone method (Hanssen and James, 1960) Dynamic programming (Cormen et al., 2001) Genetic algorithm (Goldberg, 1989)	No limit	Relatively easy to apply	Case-by-case

Table 2
Summary of related studies in relation to this study.

Category	Related studies	Path optimization	Speed optimization
Cell-based (rough route)	Joo et al. (2012)	A-star and Dijkstra algorithm	Evolutionary strategy
	Bang and Kwon (2014)	A-star and evolutionary strategy	Evolutionary strategy
	Choi et al. (2015)	A-star algorithm	–
	Park and Kim (2015)	A-star	Geometric programming
	Kim et al. (2016)	Hybrid directional A-star algorithm	–
	Vettor and Soares (2016)	Evolutionary algorithm and Dijkstra algorithm (ES-Dijkstra)	
Cell-free (smooth route)	Roh (2013)	Improved isochrone method	–
	Wei and Zhou (2012)	3D dynamic programming	
	Chen (2013)	3D dynamic programming	
	Zaccone et al. (2016)	3D dynamic programming	
	Zaccone and Figari (2017)	3D dynamic programming	
	EN-Saver (SHI, 2016)	Improved isochrone method	Genetic algorithm
	Eniram ROUTE (Eniram, 2017)	Empirical method	
	This study	Genetic algorithm	

Table 3
The information required for ship route planning.

Category	Items [unit]
Ship specifications	After draft [metres], Forward draft [metres]
Departure and arrival ports	Latitude [degrees], Longitude [degrees]
ETA (Estimated Time of Arrival)	Time [days]
Geographic information	Binary value of each cell [1: Land, 0: Sea]
Weather conditions	Wind direction [degrees], Wind speed [knots], Wave direction [degrees], Wave height [metres], Wave period [seconds], Swell direction [degrees], Swell height [metres], Swell period [seconds], Current direction [degrees], Current speed [knots]
Miscellaneous	Time duration [hours] for the segment

ice-behavior uncertainties. They proposed a method for the determination of the optimal path under a time-varying weather condition with the use of the A-star algorithm; however, they did not perform a speed optimization on the path. Park and Kim (2015) found the optimal path in a fixed-speed state by using the A-star algorithm, and then adjusted the speed on the path by using geometric programming. Kim et al. (2016) used the hybrid A-star algorithm to find the optimal path without any adjustment of ship speed. The studies of Joo et al. (2012), Bang and Kwon (2014), and Park and Kim (2015) implemented speed optimization with a separation stage. For each of the studies, a different optimization method was used, but for all three, the shortest path was identified in the first stage, followed by the adjustment of the speed on the path in the second stage. Vettor and Soares (2016) formulated a ship route planning problem in terms of a multi-objective optimization problem for which the positions and speeds are design variables. They mainly used the evolutionary algorithm for the formulation of a route that comprises several nodes, and specifically, the Dijkstra algorithm was used to calculate the objective functions between the neighbor nodes. This method was therefore named the "ES (Evolution Strategy)-Dijkstra Method" due to its similarity to the Dijkstra algorithm, whereby the speed can be changed at each segment between the nodes.

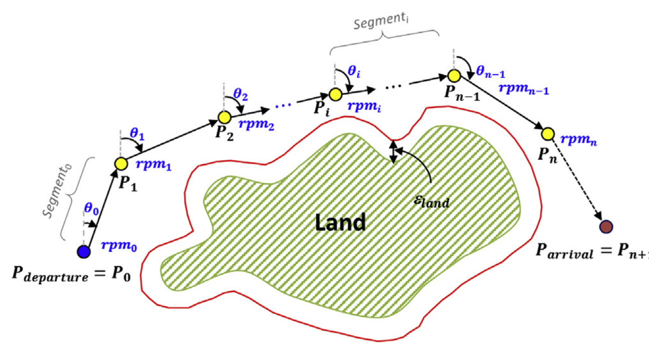

Fig. 1. Design variables of the ship route planning problem of this study.

Several cell-free methods have been developed. Roh (2013) proposed an improved isochrone method for ship route planning, whereby obstacles such as land are considered. Wei and Zhou (2012) used Three-Dimensional (3D) dynamic programming to propose a method for ship route planning that is similar to the isochrone method. Similarly, Chen (2013) developed a program that is based on 3D dynamic programming. 3D dynamic programming has been used in many studies since then. Zaccone et al. (2016) used 3D dynamic programming to perform the optimization of path and speed profile. Zaccone and Figari (2017) complemented the part of ship response modeling in the previous study to optimize the path and speed of the ship. Developed by SHI (2016), EN (Energy)-Saver is a commercial program for ship route planning that finds the path by using an improved isochrone method, and then performs speed optimization using a genetic algorithm. Eniram ROUTE (Eniram, 2017) is a commercial program that uses empirical data that are based on the actual ship route.

In this study, a method that is a type of cell-free method is proposed to determine the path and the speed simultaneously to overcome the limitations of the existing methods. Table 2 is a summary of the related studies.

2. Method for a simultaneous determination of path and speed

2.1. Problem definition

Solving a ship route planning problem is finding the route from the departure to arrival ports. The route can be referred to as the combination of the path and the speed. In shipping operations, the path is determined by a series of ship directions, while the speed is determined by a series of engine Revolutions Per Minute (RPM) settings. Meanwhile, the route is determined by numerous criteria such as the Fuel-Oil Consumption (FOC), sea keeping, operability, etc. Among these criteria, the Total Fuel-Oil Consumption (TFOC), which indicates the monetary