Int. J. Naval Archit. Ocean Eng. (2013) 5:210~226
http://dx.doi.org/10.2478/IJNAOE-2013-0128

Simulation of optimal arctic routes using a numerical sea ice model based on an ice-coupled ocean circulation method

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ABSTRACT: *Ever since the Arctic region has opened its mysterious passage to mankind, continuous attempts to take advantage of its fastest route across the region has been made. The Arctic region is still covered by thick ice and thus finding a feasible navigating route is essential for an economical voyage. To find the optimal route, it is necessary to establish an efficient transit model that enables us to simulate every possible route in advance. In this work, an enhanced algorithm to determine the optimal route in the Arctic region is introduced. A transit model based on the simulated sea ice and environmental data numerically modeled in the Arctic is developed. By integrating the simulated data into a transit model, further applications such as route simulation, cost estimation or hindcast can be easily performed. An interactive simulation system that determines the optimal Arctic route using the transit model is developed. The simulation of optimal routes is carried out and the validity of the results is discussed.*

KEY WORDS: Sea ice model; Ice-coupled ocean circulation; Ice transit model; Arctic sea route; Weighted Dijkstra algorithm.

INTRODUCTION

Due to the tremendous increase of energy consumption and worldwide political instability, oil prices have been on the rise. As an effort to overcome the unprecedented high oil prices, many countries have concentrated their efforts in finding energy sources in the Arctic region. To access the abundant natural resources in that region, passage across the Arctic must be established.

Recent global warming has accelerated the melting phenomenon of the Arctic ice and as a result this situation has allowed the human access to the Arctic area. The Northern Sea Route (NSR) along Russia and the Northwest Passage (NP) located near Canada were finally open, allowing fast navigation between the Pacific and the Atlantic oceans. The importance of those two routes can be explained by the enormous amount of natural resources buried in the northern region of Russia and Canada.

Geometrically, the NSR or NP routes are the shorter paths, compared to the conventional route passing through Suez Canal route (Ostreng et al., 1999), which noticeably saves time and expenses. Nonetheless, navigating the NSR or NP is hard to carry out, not only because of the harsh environment but also the restrictions implicitly imposed for political reasons. In particular, the harsh environment results in many technical difficulties that would make it hard for a year-round commercial shipping route.

Simulating possible navigational routes is difficult and challenging but extremely beneficial to the shipping companies. Therefore, before dispatching the icebreakers or ice-strengthened vessels to the Arctic region, they want to simulate the technical and economical feasibilities based on precise ice and environmental data.

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One of the crucial requirements required to overcome the technical challenges along the Arctic route is the accurately predicting the environmental conditions in the region. Traditionally, obtaining the environmental data such as ice concentration, thickness, strength, visibility, and so forth has not been an easy task. The traditional method of observation is not only obsolete but also unreliable. Recent development of technical equipment utilizing electromagnetic device, satellite, or sonar has upgraded accuracy and effectiveness in measuring the environmental condition. These high tech methods, however, still have many problems with respect to reliability.

To compute the navigational route, it is necessary to have a so-called transit model, which describes every piece of information required for navigation. La Prairie et al. (1995) suggested a transit model to estimate the cost by considering the relationship between the thrust of a ship and ice resistance. Their model is very complicated to use. Another big leap started with the launch of the International Northern Sea Route Programme (INSROP). It is a numerically analyzed model that determines the optimal route by estimating the distance, speed, and icebreaker fee (Patey and Riska, 1999; Kamesaki et al., 1999). Unfortunately this collaborating work was discontinued in 1999. On the other hand, CRREL (U.S. Army Cold Regions Research and Engineering Laboratory) developed a NSR transit model (Mulherin et al., 1996). They described the ice model using probabilistic distribution and utilized Monte Carlo iteration to find routes. A modified CRREL model was suggested by the authors (Choi et al., 2010; Ha et al., 2011). This model basically adopted the concept suggested by CRREL, but included more practical data omitted in the CRREL model. It used a direct method to compute the route instead of the lengthy Monte Carlo approach.

A critical disadvantage encountered in the previous efforts is that the user must provide accurate data of sea ice along the routes in NSR and NP. The data must be updated on a regular basis prior to voyages. Real-time update of ice and environmental data transferred from a satellite, for example, may be the most desirable scenario but can be risky and unreliable.

An approach to overcome the above disadvantage is to prepare a more versatile model that accurately and dependably describes the sea ice condition. Possible candidates of those models would include an analytical model obtained by solving a governing equation or a numerical model by simulating the current data. Although it would be premature to assert that these models fully describe the ice condition with accuracy, they provide an introductory step in accommodating a comprehensive transit model.

Another goal of the work is to establish a simulation system that computes the optimal routes in the Arctic region. Obtaining an optimal route requires a systematic approach in setting up a computerized system that encompasses various different techniques such as database, graphical user interface, graph theory, and the concept of simple user interaction. A simulation system built upon the basic technical tools is developed. The organization and internal process of the simulation system are illustrated in Fig. 1.

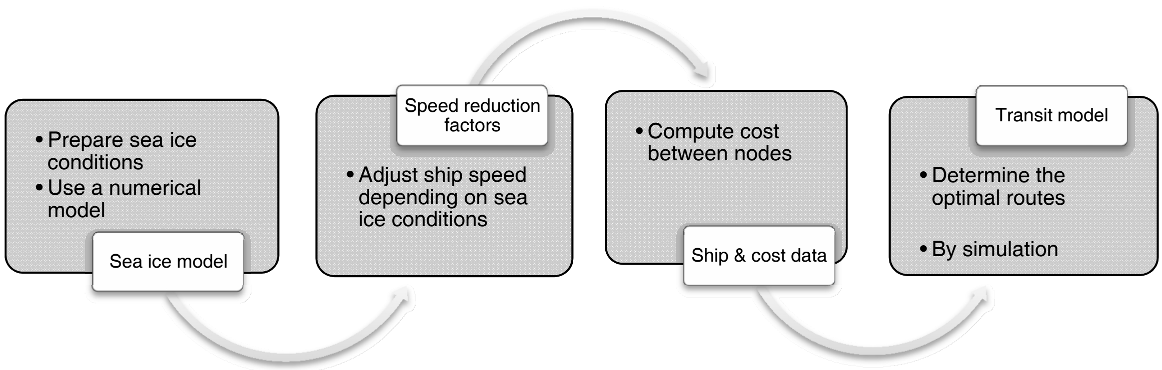

Fig. 1 Organization of simulation system developed.

In this paper, a simulation system based on a sea ice model that solves a general circulation method is presented. Each major concept shown in the Fig. 1 will be dealt with. Establishment of a numerical sea ice model that will be used in the transit simulation is explained in the upcoming section. Construction of a huge database for ice and environmental data is addressed and followed by the discussion of a method that finds an optimal route. The simulation of the transit model is executed and its results are analyzed.