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Vessel transportation scheduling optimization based on channel–berth coordination

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ABSTRACT

Channels and berths are important resources for vessels in port operation. This study aims to improve the efficiency of vessel transportation scheduling by coordinating channels and berths. Therefore, in consideration of scheduling order, travel direction and distance of the berth, a mathematical model with minimum total waiting time as the objective function is established. Furthermore, it applies a simulated annealing and multiple population genetic algorithm (SAMPGA) to solve the proposed model for vessel transportation scheduling in port. This study simulates numerical examples for 10 and 20 vessels. Calculations indicate waiting and total scheduled times of 485 min and 342 min, respectively, for 10 vessels and 1731 min and 456 min, respectively, for 20 vessels. Compared with the simple genetic algorithm (SGA) and the "first come, first served" (FCFS) method, the total waiting time, scheduled time, and maximum waiting time are decreased significantly through SAMPGA. The results show that the proposed model and algorithm can ensure safety and improve the efficiency of vessel transportation scheduling simultaneously.

1. Introductions

Presently, vessels in port have expanded considerably, thus leading the relevant departments to pay attention to the safety and efficiency of vessel operation in port; some scholars have also examined this issue. In practice, vessel transportation scheduling is performed manually in most ports. Therefore, they need a method to improve the safety and efficiency of vessel operation at present. Currently, studies on vessel transportation scheduling in port mainly either develop a simulation model of the vessel transportation system or establish a mathematical model for optimal vessel transportation scheduling.

Regarding simulation models, Liu and Wen (2009) proposed a channel transit capacity model on the basis of a vessel's behavior by simulating the actual traffic flow and aimed to assess or predict the channel transit capacity and Dai et al. (2009) proposed a ship domain model to calculate the throughput capacity for a limited port channel. The simulation model for channel capacity calculations has theoretical value and practical significance in the calculation, assessment, and prediction of channel capacity (Shabayek and Yeung, 2002). To evaluate the potential for marine traffic congestion of North Harbor in Busan Port, Yeo et al. (2007) analyzed the effects of ship traffic conditions in the year 2011 using the AWE-SIM simulation program. Colley et al. (1984) developed a model to simulate traffic flow and collision avoidance through the main south-west bound lane of the Dover Strait traffic separation scheme. Merrick et al. (2003) created a simulation model to estimate the number of vessel interactions in the system and predicted increases for three alternative expansion plans, and the output of the model represented the level of congestion under each alternative. To provide guidance on achieving time efficiency and accuracy in the modeling of ship traffic and the calibration of container port simulation models, Pachakis and Kiremidjian (2003) proposed a modeling methodology based on statistical analysis of ship traffic characteristics.

The simulation model is mainly used to analyze the port capacity, forecast traffic flow and evaluate navigation safety. They are mainly used to evaluate port performance and guide port construction but cannot provide particular guidance for vessel transportation scheduling solutions. To provide a particular scheduling solution for vessel transportation, some scholars have established mathematical model for vessel operation in port.

Regarding mathematical models, studies involve channel usage efficiency, berth allocation, and quay crane and other resource scheduling. Hsu et al. (2008) investigated berth distance, vessel size, vessel type, vessel draught, etc. as weighting factors and used

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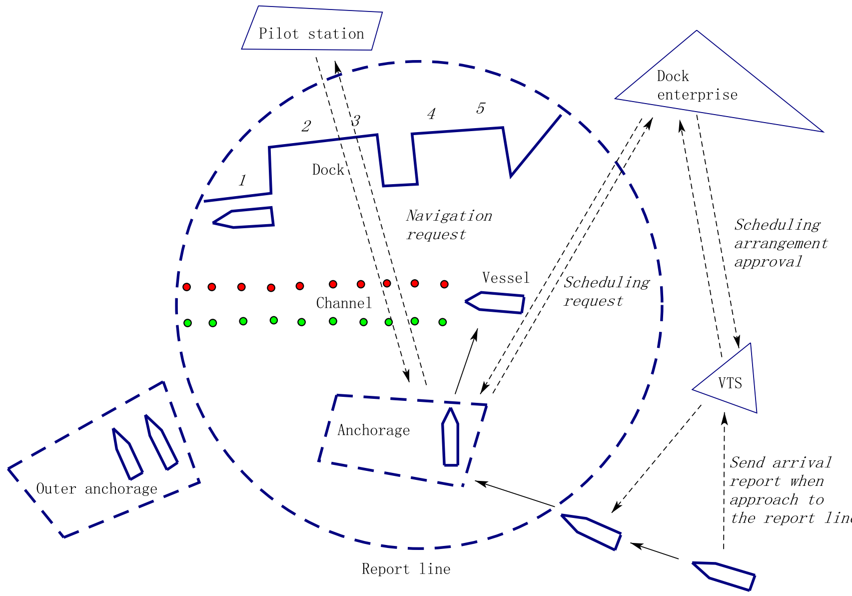

Fig. 1. Method of vessel scheduling in a port.

these to propose an optimal sequence model for vessels entering and leaving port on a one-way channel. On the basis of the fundamental rules of the Strait of Istanbul, Ozgecan and Tutun (2011) developed a scheduling algorithm involving the relevant specific considerations to aid decisions on sequencing vessel entrances and giving way to vessel traffic in either direction. Verstichel et al. (2011) defined the navigation lock scheduling problem as a parallel machine scheduling problem and adopted mixed integer linear programming methods as a solution. Berth, where vessels charge or discharge, is the most important resource in port operation. However, Jannes omitted the berth operation, which will reduce the berth usage efficiency. By contrast, some scholars have performed studies on berth operation. For example, Imai et al. (2003, 2005) researched berth allocation in container ports. In addition, the efficiency of operations and processes on the ship-berth link has been analyzed using the basic operating parameters for Pusan East Container Terminal (Dragovic et al., 2006). Jin and Li (2011) studied the quay crane dynamic scheduling problem based on berth schedules in a container terminal. The main focus of these studies, however, was on berth operation; they did not consider channel throughput time, which may lead to congestion on the channel.

In summary, studies on the vessel transportation scheduling solution for entering and leaving ports have largely focused on a single aspect of channel usage efficiency or berth operation. However, few have considered coordination between channel and berth resource demands. Assuming that berth has been allocated, a simplified mathematical model based on security and efficiency was established (Lin et al., 2014). This model suggests that it is possible to improve the efficiency of vessel scheduling in the port through coordinating channel and berth resources. Therefore, this study improves the mathematical model with channel–berth coordination based on a one-way channel.

Several algorithms have been employed to solve some of the mathematical models. Kim and Moon (2012) proposed a berth distribution model based on a simulated annealing algorithm for minimizing the number of fines received due to delays in the departure of vessels and the extra container handling costs caused by unreasonable berth position. Nishimura et al. (2001) employed a genetic algorithm to solve the problem of determining a dynamic berth assignment for vessels in the public berth system. Chuang et al. (2010) designed fuzzy genetic algorithms for solving the route scheduling optimization model, which can provide auxiliary support for route scheduling. However, the existing algorithms were designed for solving mathematical models of berth operation, which is not used for modeling based on channel–berth coordination. To solve the proposed mathematical model, a simulated annealing and multiple population genetic algorithm (SAMPGA) is designed. Furthermore, numerical examples are used to validate the model and algorithm.

2. Problem statement

The purpose of vessel transportation scheduling is to enable as many vessels as possible to pass a channel as soon as possible in order to reduce vessel delay and improve the efficiency of vessel transportation. Generally, vessel operation in port is performed under the guidance of vessel transportation service (VTS) staff, in accordance with port navigation rules and its operation plan. Safety and efficiency are the two principles of vessel transportation in port. The scheduling of vessels involves three major resources: anchorage, berth and channel. Anchorage is usually not in short supply. In general, as a one-way channel, it will become a bottleneck for port traffic when the port traffic flow is near to its capacity. In such a case, it will reduce vessels' waiting time and improve transportation efficiency if anchorage is coordinated with channel and berth. The port vessel scheduling method is illustrated in Fig. 1. In general, the dock enterprise will allocate berths for vessels entering the port before they arrive at the port. Vessels are supposed to send an arrival report to the VTS to request a schedule when approaching the report line. Then, the VTS will coordinate scheduling arrangement approval according to the report, the berth and the condition of other resource services, as well as the traffic on the channel based on safety and efficiency. Vessels will leave anchorage for the channel if they are permitted to dock at the berth. At the same time, a pilot will embark for the vessel if necessary. For the reason that vessel operations in port are continuous, the time the vessel arrives at some points (such as the channel and berth) are certain if the vessels' current position, the distance between current position and the destination points, and the time they start are according to schedule and speed. For safety considerations, a particular distance between two successive vessels is required during vessel travel. Through space to time