Ocean Engineering 137 (2017) 382–393

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

# Key influencing factors on improving the waterway through capacity of coastal ports

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ARTICLE INFO

*Keywords:*
Port management
Waterway
Waterway through capacity
Simulation model

ABSTRACT

This paper aims at solving the problems of how to improve the waterway through capacity and how much each influencing factor can improve the capacity quantitatively. The problems are figured out by building a simulation model of the ships' navigation operation system. First of all, the definition of waterway through capacity and the elements of the ships' navigation operation system are discussed comprehensively. Then, a complicated simulation model, which considers the influencing factors, such as rules of ships entering and leaving port, navigation rules and inner anchorage scales, is constructed. After that, the simulation model is verified to ensure its reliability and effectiveness. Finally, various simulation experiments are designed according to a real bulk cargo port area in China and how much each influencing factor can improve the waterway through capacity is obtained, which provides a theoretical foundation for waterway construction and port management.

## 1. Introduction

The waterway, which is the way for ships' entering and leaving a port, is one of the most important part of the port. With the continuous increase of ship traffic volumes, the waterway is becoming the bottleneck of port development. For example, Yangshan Port expands the waterway to a two-way traffic waterway in 2013, since the waterway restricts the development of the port with the increment of the throughput (about 14.15 million TEUs) and the number of ships (about 100 international liner ships per week). However, due to the high cost of construction and dredging for the waterway, it's mostly uneconomical or even impractical to build a new waterway or expand an existing waterway to a two-way traffic waterway. Therefore, it has generated considerable attention on how to improve the waterway through capacity in respect of management without expanding the waterway these years, which is the problem we concern in this paper.

For improving seaport waterway through capacity, Ning et al. (2008) proposed the tentative construction standard of the two-way traffic channel and tried to see if it can improve the waterway capacity. Later, my group did a lot of work on how to improve the waterway capacity. For example, Guo et al. (2010) and Wang et al. (2015) gave the definition of seaport waterway through capacity and analysed the influence of port service level or safety level on waterway through capacity, respectively; Wang et al. (2012) studied the impact of three types of ship traffic rules on port service level in Y-type waterway intersection water, which included First Come First Serve Rule, Larger Ship Priority Rule and Ship Leaving Port Priority Rule; Wang et al. (2013a) and Wang et al. (2013b) studied the influence of anchorage number or operation days on waterway capacity in coastal bulk cargo port area, respectively; Tang et al. (2014a) chose the annual average turnaround time, average waiting time, and average waiting time/average service time ratio as the performance measures of port service to explore the feasibility of building a ships-passing anchorage and its dimensions; Tang et al. (2014b) discussed the optimal channel dimensions problem with limited dredging budget constraints in an integrated way; Tang et al. (2016) explored the relationship between entrance channel dimension and berth occupancy of container terminals. Besides, Lin et al. (2014) developed a mathematical model to minimize the weight of ship's waiting time for the channel and applied Genetic Algorithm to solve the model; Zhang et al. (2016) aimed at improving the efficiency of vessel transportation scheduling by coordinating channels and berths, and used the simulated annealing and multiple population genetic algorithm to solve the proposed model; Liu et al. (2016) proposed dynamic ship domain model that take into consideration navigation waterway condition, ship behaviors, ship types and sizes and operators' skill, to estimate the capacity of restricted water channels.

The above literatures involve various aspects of the research on promotion measures of waterway through capacity, which provide a strong foundation for further studies. However, the research mostly considers one aspect of the promotion measure of waterway through

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http://dx.doi.org/10.1016/j.oceaneng.2017.04.013
Received 18 January 2017; Received in revised form 20 March 2017; Accepted 9 April 2017
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capacity. Some of them only discuss the problem from qualitative analysis angle and lack the quantitative study on promotion measures of waterway through capacity, which are not suitable for being used to solve the proposed problems in this paper directly.

Besides, due to the complexity and randomness of the seaport operation system, there are so many random factors, which include arriving time of ships, inclement weather conditions, unload time of ships and so on, having impact on system working, numerical methods fail to obtain analytical solutions (Clausen and Kaffka, 2016). And because of the advantages on dealing with such complex systems, simulation technology has been generally applied in port design and management these years (Longo et al., 2013).

Sun et al. (2012) introduced a general simulation platform, named MicroPort, which aimed to provide an integrated and flexible modeling system for evaluating the operational capability and efficiency of different designs of seaport container terminals; Longo et al. (2013) developed a simulation model to recreate the complexity of a medium-sized Mediterranean seaport and analyse the performance evolution of such system with particular reference to the ship turnaround time; Kavakeb et al. (2015) studied the impact of using a new intelligent vehicle technology on the performance and total cost of a European port compared with existing vehicle systems by simulation technology; Petering (2015) analysed how the overall productivity of an RTG-based seaport container terminal depended on the system used for automatically selecting storage locations for export containers in real time as they enter the terminal by a fully-integrated discrete event simulation model; Zhao et al. (2015) proposed a simulation-based optimization method for the storage allocation problem of outbound containers in automated container terminals; (Clausen and Kaffka, 2016) used simulation method to optimize the operations in an overall system with all its stochastic influence and interactions, which may create an experimental model and identify the best recommended course of action; Ngoc et al. (2016) developed a method to optimize the time slot assignment for individual trucks by discrete event simulation, aiming at minimizing total emissions from trucks and cranes at import yards; Peng et al. (2016) modeled the energy replacement problem with the purpose of minimizing the carbon emissions by combining an allocation resource mathematical model and a simulation model of the whole transportation network together, to solve the problem of allocating limited resources for yard cranes; Zhou et al. (2016) proposed a simulation-based optimization framework to obtain a cost-effective and reliable design solution to the physical layout and equipment deployment strategy of the yard at a mega container terminal.

The above research shows the superiority of simulation method in analyzing complex systems design, management and monitoring, which also provides important references for the problem proposed in this paper.

Based on the analysis of the elements of ships' navigation operation system comprehensively, this paper studies the influencing factors on improving the waterway through capacity in respect of management without expanding the waterway, which can provide theoretical basis for port plan and management. Therefore, in the rest of the paper, we first describe some terms including seaport waterway through capacity and its several influencing factors in Section 2. After that, a simulation model of the ships' navigation operation system is constructed and verified in Section 3. Numerous simulation experiments and analysis are carried out in Section 4 to study the influences of rules of ships entering and leaving port, navigation rules and inner anchorage scales on waterway through capacity, respectively. Finally we conclude the paper in Section 5.

## 2. Term explanations

In this section, we first introduce the definition of the seaport waterway through capacity, and then the key influencing factors are discussed in detail in Section 2.2.

### 2.1. Seaport waterway through capacity

Since seaport waterway through capacity is affected not only by the natural conditions, waterway dimensions, navigation rules, etc., but also by handling operations and port management, which is not easy to define. Thus, although many researchers have proposed kinds of different definitions of seaport through capacity, none of them has become standardization. Refer to *Design Code of General Layout for Sea Port,* the definition of seaport waterway through capacity we choose in this paper is relatively accepted, which defines seaport waterway capacity for a given waterway of a certain seaport under normal operating status as the total annual tonnage of ships going through it at a specified port service level (Guo et al., 2010).

Waterway through capacity, which is a characterization of ultimate carrying capacity of waterway, should reflect the service quality of the waterway for ships. According to *Port Development: a Hand Book for Planners in Developing Countries* (United Nations, 1985), we introduce *AWT/AST* as the evaluation indicator of port service level in this paper. *AWT* refers to ships' average waiting time including the time waiting for both waterway and berth, and *AST* is the average service time of ships at berth. The smaller the value of *AWT/AST* is, the higher the port service level is.

### 2.2. Key influencing factors of waterway through capacity

There are plenty of factors affecting the waterway through capacity, we mainly analyse three key aspects in the field of port management, which are rules of ships entering and leaving port, navigation rules of ships going through waterway and the scale of inner anchorage.

#### 2.2.1. Rules of ships entering and leaving port

Rules of ships entering and leaving port refer to that arrival ships should report ships' status to Vessel Movement Center (*VMC*) at a specific time and place based on the requirements of a port, so that *VMC* can determine the sequence and organization of ships before the ships are going to pass the waterway according to certain rules, in which the certain rules are called the rules of ships entering and leaving port.

On the one hand, when the quantity of arrival ships is relatively large, ships need to wait for berth or waterway in queue, which may lead to congestion and bring great economic losses. One the other hand, it can make ships pass the waterway more efficiently and safely when the ships obey proper rules entering and leaving port, which may improve waterway through capacity at the same time. Therefore, it's vital to choose rational rules of ships entering and leaving port.

According to the investigation of the rules of ships entering and leaving port used in main port areas, the rules considered in this paper are expressed as follows.

a) First Come, First Service (*FCFS*) Rule

Ships enter the waterway based on the sequence of the ships' arriving time at the port area.

*FCFS* rule reflects the equity of different ships and treats all ships without difference. Since *FCFS* rule is one of the most common rules and easy to realize, it's treated as the basic rule of ships entering and leaving port in this paper.

b) Large-ton-Ship First Service (*LSFS*) Rule

The priorities of ships with large tonnage are higher than smaller ones. When ships with different tonnage arrive the port area simultaneously, large ships enter the waterway prior to small ships. Ships with same tonnage still obey *FCFS* rule.

In actual situation, the costs caused by waiting for berth or waterway of large ships are more than those of small ships, thus many ports adopt *LSFS* rule because of the similar quantities of large ships and small ships arriving the port area.

c) Ships Entering and Leaving port in Cluster (*SELC*) Rule

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