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Effect of entrance channel dimensions on berth occupancy of container terminals

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ABSTRACT

This paper explores the effect of entrance channel dimensions on berth occupancy of a container terminal when making master planning for a new container terminal, to avoid possible bottlenecks for port's future performance. Therefore, a process-interaction-based simulation model is first developed to simulate container terminal operation, especially ship operation in entrance channel. Then a series of simulation experiments are conducted, in which dozens of container terminals with different numbers of berths and channel dimensions are considered to reproduce the microscopic, stochastic, real-time environment. Finally, simulation results show that the berth occupancy depends on entrance channel dimensions, and more berths, two-way traffic channel and less travel time in channel have higher berth occupancy given the same port service level. So that the effect of entrance channel dimensions, especially very long one-way traffic channels, on berth occupancy should be quantified when determining berth capacities at the master planning stage. Moreover, the analysis and simulation model presented in this paper may help port authorities and the planners to achieve a harmonized overall design in practice.

1. Introduction

Coastal entrance channels, connecting the shipping lanes with seaports, are navigable channels for ships in and out of ports safely and efficiently. Rapid increase in number and size of ships calling at ports recently, puts a premium on minimizing time in port, which leads to further pressures on entrance channels (PIANC, 2014). Even coastal entrance channels in the world, especially very long one-way traffic channels, have already become the bottleneck and have to be expanded to improve port performance (Song et al., 2012; Tang et al., 2014a). For example, the Houston Ship Channel was periodically expanded to accommodate ever-larger ships by widening to 530 feet from 400 feet and deepening to 45 feet from 40 feet (ICIS, 2005; Tang et al., 2014a); Guangzhou Port Group proposed an investment of $484 million to expand the deep-water channel into two-way transportation for large vessels, and about 41.38 miles of channel will be expanded to 421 yards wide and 55 feet deep (Angela, 2015). Therefore, to avoid that the entrance channels would block the future development of ports, the effect of channel dimensions (e.g., the number of traffic lanes and travel time in channel) on berth occupancy should be explored at the master planning stage.

When planning a container terminal, an important consideration is to provide a sufficient annual container-handling capability (terminal capacity). According to Chinese mandatory Design Code of General Layout for Sea Ports (MTPRC, 2014), berth occupancy, a measure of facility utilization, is an important parameter to estimate the capacity of a container terminal. So it is essential for the terminal planners to determine an appropriate berth occupancy. However, when estimating the berth occupancy of a container terminal, the main problem is that many factors must be taken into account. For example, this obviously includes number of berths, arrivals of container ships, berth service time, entrance channel and the acceptable level of service provided by a terminal. Therefore, the number of factors, as well as their diversity, turn the selection of berth occupancy and then the calculation of berth capacity into a highly complex task. UNCTAD (1985) states that berth occupancy depends on the probability distributions of ship arrivals and of berth service time as well as the number of berths. After that, most researches have focused on exploring the effects of import factors (e.g., the number of berths, ship arrivals and berth service time) on berth occupancy, and choose average waiting time/average service time ratio (AWT/AST) as a measure to determine the berth occupancy at the master planning stage. For example, UNCTAD (1985) suggests that an $M/E_k/S$ queue (M for Markovian or random arrivals, E_k for Erlang k berth service time, and S for number of berths) are applied to deduce a relationship between the berth occupancy, the number of berths,

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and AWT/AST. Chaudhry and Templeton (1983), Radmilovich (1992, 1994), Jovanovich et al. (2003) and Thoresen (2003) apply multichannel queueing system to determine AWT/AST ratio depending on berth occupancy, number of berths, number of containers in group and other ship-berth link operating performance measures. Yang and Wei (2004) derive the similar relationships by an $M/E_3/S$ queue and to provide the recommend berth occupancies for Chinese container terminals. Generally speaking, the queuing system in marine terminal can be analytically evaluated under some conditions. However, as the data and the queue configuration are more sophisticated, the researchers have to resort to simulation, such as a growing number of studies dealing with ship-berth link planning (SBL) (Imai et al., 2001, 2005; Wanke, 2011). Traditionally, the ship-berth link is one of most critical aspects to be managed at port operations. Until now, simulation models for SBL planning have considered assigning inbound ships to berthing positions and scheduling quay-cranes (Meisel and Bierwirth, 2009), the yard operations (Chang, 2005; Tu and Chang, 2006), railway lines and congestion level of truck gates (Parola and Sciomachen, 2005), transport systems and their interaction with handling equipment (Duinkerken et al., 2006; Ottjes et al., 2006) and etc. To improve the competitiveness of a port, the major task of SBL operation is to allocate a limited number of berths among inbound ships (Wanke, 2011) to reduce the waiting time of ships. So Dragovic et al. (2005) examine the impact of assigning priorities on the improvement of average number of ships in queue and average time a ship spends in queue; Wanke (2011) tests the impact of different berth allocation policies and queue priorities on SBL performance using simulation as a research tool; Kia et al. (2002) investigate the role of computer simulation in evaluating the performance of a container terminal in relation to its handling techniques and their impact on the capacity of terminal; Wu (2011) use computer simulation to get the berth occupancy of Dayaowan container terminal considering the stochastic distribution of ship arrivals; Hartmann et al. (2011) focus on the container ship arrivals and quay occupation. These researches provide invaluable information and insights regarding methodologies how to describe the stochastic characteristics of ship arrivals and berth service, how to evaluate terminal's service level, and how to simulate the SBL operation. However, SBL operations in most researches above cover berthing area, container yard and gates (Casaca, 2005), but the entrance channel is not considered as an important part of a system. And the average ship waiting time, as an important measure of port performance, is defined as the average ship waiting time for a free berth (i.e., the average difference between ship arrivals and berthing time of the ship) in these researches. In fact, it should be stressed that waiting times are not only caused by berth occupancy, but also by occupancy of the entrance channel system (PIANC, 2014).

Therefore, the effect of entrance channel dimensions should be evaluated when determining berth occupancy of container terminals at the master planning stage, to avoid possible bottlenecks for port's future performance. So in this contribution, we implement a process-interaction based simulation model for ship operation in Java, which simulate the ship traffic in and out of a port via entrance channel. And a series of simulation experiments are conducted, in which dozens of container terminals with different numbers of berths and channel dimensions are considered to reproduce the microscopic, stochastic, real-time environment.

The remainder of this paper is organized as follows. In Section 2, we describe the relationship among berth occupancy, port performance and entrance channel dimensions in greater detail. Section 3 implements a simulation model for ship operation in entrance channels. Section 4 describes the setups of simulation experiments including the characteristics of design container ships, container terminals and entrance channel dimensions, and Section 5 presents the simulation results, and explores the effect of entrance channel dimensions on berth occupancy. Concluding remarks are made in Section 6, and at last, possible extension for future research is also addressed.

2. Problem description

2.1. Berth capacity and berth occupancy

Berth capacity usually refers to the maximum number of containers (or TEU) that can be discharged from and loaded onto a berth per year without the vessel service level being reduced below a commonly accepted level. In China, the planners have to follow the mandatory Design Code of General Layout for Sea Port (MTPRC, 2014), to determine the capacity of a n-DWT berth, P_t at the master planning stage. And the expression of a n-DWT berth capacity is:

$$P_t = \frac{T \cdot G}{\frac{G}{p \cdot t_g} + \frac{t_f}{t_d}} \cdot \rho \tag{1}$$

$$p = n_{qc} \cdot p_1 \cdot K_1 \cdot K_2 \cdot (1 - K_3) \cdot K_4 \tag{2}$$

where P_t is the berth capacity in TEU of a n-DWT berth (n is the berth tonnage, i.e., the tonnage of maximum ships that may be moored); ρ is the expected berth occupancy, which is determined if the required service level (e.g., in terms of acceptable AWT/AST), is available (MTPRC, 2014); G is the number of containers (TEUs) needed to be discharged from and loaded onto a design ship; T is 365 days in a year; t_d is 24 h in a day; t_g is the number of daily working hours, which is a value between 22 h and 24 h; t_f is the sum of hours of auxiliary operation for handling container and of berthing and deberthing, which is a value between 3 h and 5 h; n_{qc} is the number of quay cranes required to serve a class of design ships; p_1 is the design efficiency of a quay crane (Container/h); K_1 is the ratio of 40′ to 20′ containers; K_2, K_3 are the reduction coefficients in handling efficiency caused by the simultaneous operation of quay cranes and container re-shuffling; K_4 is the multiplication coefficient in handling efficiency caused by using new highly efficient quay cranes, a value recommended between 1.05 and 1.25; p is the design containers-handling efficiency (TEU/h) of each class of container ships, depending on n_{qc}, p_1, K_1, K_2, K_3 and K_4.

As noted in MTPRC (2014), when calculating the berth capacity, G and K_1 should be derived from terminal or port statistics. If no statistics are available, the value of G for each design ship is suggested to be a random value between G_{max} and G_{min} (seen in Table 1), and K_1 being a value between 1.1 and 1.9. The recommended values of other parameters, including n_{qc}, p_1, K_2 and K_3 are also given in Table 1, which are excerpted from MTPRC (2014). Therefore, once the values of other parameters are estimated from terminal statistics or MTPRC (2014), the berth occupancy is the key to determining the capacities of berths, and the terminal capacity depends on the product of number of berths, n_{bth} and berth occupancy, ρ (i.e., $n_{bth} \cdot \rho$, which is called terminal capacity coefficient).

It has become a common practice to define and compute berth occupancy on the basis of average waiting time/average service time ratio (AWT/AST). The acceptable levels of waiting time generally determine permissible berth occupancy ratios (Warwar, 1980). In the case of a container terminals, a ratio of 10% between waiting time and service time is generally accepted.