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Daily berth planning in a tidal port with channel flow control

Lu Zhen[a,*], Zhe Liang[b], Dan Zhuge[c], Loo Hay Lee[d], Ek Peng Chew[d]

[a] School of Management, Shanghai University, Shanghai, China
[b] School of Economic and Management, Tongji University, Shanghai, China
[c] Department of Logistics and Maritime Studies, Hong Kong Polytechnic University, Hong Kong, China
[d] Department of Industrial and System Engineering, National University of Singapore, Singapore

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A B S T R A C T

This paper studies an operational-level berth allocation and quay crane assignment problem (daily berth planning) considering tides and channel flow control constraints. An integer programming model is proposed for this problem. Then a column generation solution approach is developed on a set partitioning based reformulation of the original model. Computational study is conducted on 30 test cases constructed from real-world data to validate efficiency of the proposed solution approach. Results show that this simple but practical solution approach can optimally solve the daily berthing planning problem instances with up to 80 vessels, 40 berths, and 120 quay cranes within one hour, which is reasonable and acceptable for the real-world applications. The proposed decision model and the solution approach could be potentially useful for some tidal ports with (or without) navigation channels.

1. Introduction

Due to the offshoring of manufacturing activities in Asia (particularly in China), the amount of container transportation has been growing by about three times the world's GDP growth during the past three decades (Meng et al., 2014). The actual throughputs in ports have grown even faster as more and more containers are transshipped in mega-ports of the world (Fransoo and Lee, 2013; Lee and Song, 2017). It is an urgent task to increase efficiency of port operations so as to maximize the throughput of ports. As port operators are usually paid by a handling charge per container, the indicator of throughput is essential for port operators' revenue. Port operators usually have great interest in berth planning since it is the start point of port operations planning. The planned berth locations for vessels are subsequently used as the key input for yard storage, personnel, and equipment deployment planning.

The berth planning process can be categorized into three different levels based on their planning horizon. (1) *Monthly berth planning*: vessels' monthly arrival plans (e.g., estimated import and export throughput, estimated port stay) and physical characteristics are sent from shipping lines to a port operator; then they are fed into the CITOS (Computer Integrated Terminal Operation System) of the port operator. (2) *Weekly berth planning*: the estimated arrival time and departure time of vessels is updated by the shipping lines. The port operator assigns a berth number to each vessel without the exact berthing start time and end time. Based on the assigned berth numbers, the yard planning can be conducted. (3) *Daily berth planning*: the shipping lines send the relatively accurate time of arrival and departure as well as actual import and export

* Corresponding author.
E-mail address: lzhen@shu.edu.cn (L. Zhen).

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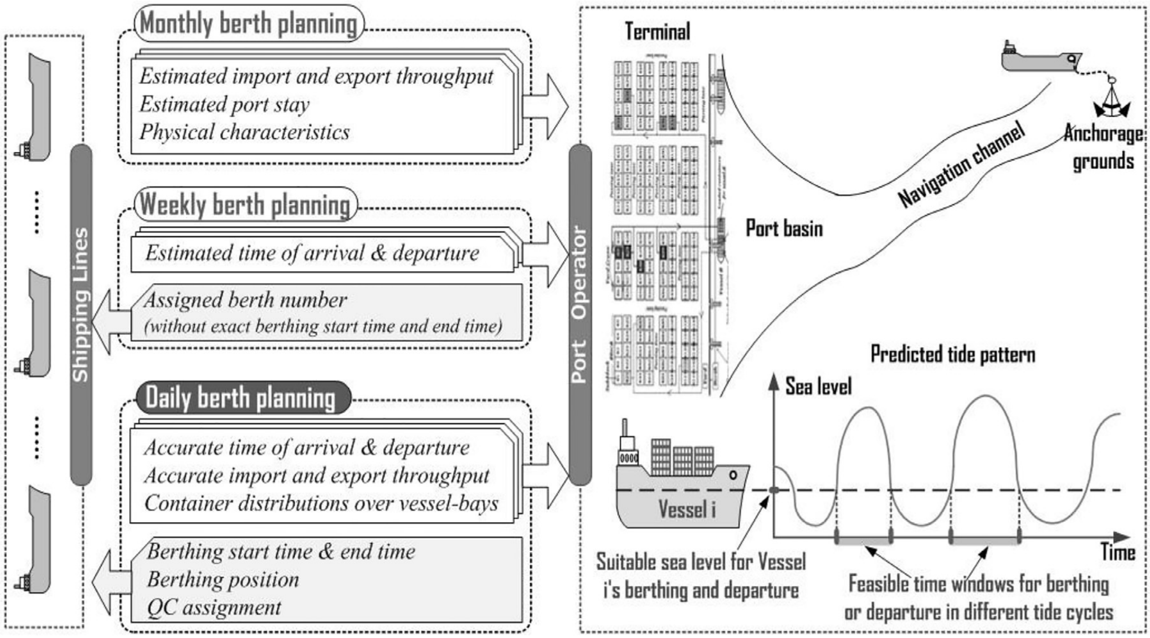

Fig. 1. An illustration on daily berth planning in a tidal port.

throughput to the port operator, who will decide the actual berthing position as well as the start and end berthing time. In addition, quay crane (QC) assignments for vessels are also decided in this critical step. The left part of Fig. 1 shows the above three levels of berth planning activities before mooring a vessel.

Among the three levels of berth planning, port operators are most interested in the daily berth planning because this problem is based on relatively accurate information. Therefore, this study investigates the daily berth planning process and designs models as well as solution approaches to improve the berthing efficiency. The above described daily berth planning is usually called by 'integrated planning of berth allocation and QC assignment problem' in related literature (Bierwirth and Meisel, 2010 and 2015). Most of current studies overlook the factors of tides and navigation channel flow control when solving the berth planning problem. Some mega-ports (e.g., Port of Shanghai, Port of Antwerp, and Port of Hamburg) are tidal ports. For an example in Port of Shanghai, the water depth in the Waigaoqiao area is about 12.5 m, which leads to that mega-vessels can only navigate the route when tide is sufficiently high (SHMSA, 2016). For another example in Port of Hamburg, a vessel with a draft of more than 12.8 m needs to consider the tidal factor when it passes through the navigation channel (Port of Hamburg, 2016). In Port of Antwerp, around 70% of arriving vessels were influenced by tide fluctuations before the dredging of Scheldt River in 2010 (Du et al., 2015). Although berths and port basins of these mega-ports are deep enough to moor mega-ships, the navigation channels are relatively shallow. The tide in a port usually fluctuates following a pattern as shown in the bottom-right part of Fig. 1. Mega-ships need to take advantage of the tide so as to pass through the channel, and the berthing and departure time of these mega-ships depends on the tide pattern. So the tide pattern is very critical for making the daily berth planning decision. The feasible tidal time windows for each vessel can be determined in advance according to the predicted tide pattern and the drafts of vessels.

Another critical factor that affects the berth planning is the navigation channel, which is usually surrounded by islands, archipelagos, and hidden reefs. For the safety concern, the pilot station of a port has strict regulations for vessels' sailing in the channel. Vessels are usually guided by some pilot ships so as to guarantee the safe sailing routes and speed. The daily berth planning has to consider the navigation channel flow control or channel restrictions, which may stem from (i) bottleneck resources such as a limited number of the pilot ships, (ii) locks of channels, e.g., in Port of Antwerp, (iii) spatial conditions like the depth, length, and width of the channels (or rivers connecting a port and open sea, e.g., in Port of Hamburg), (iv) channel sharing with some neighbor terminals. All of the above channel restrictions may impact the berth allocation in a port.

On the basis of the traditional daily berth planning problem, the factor of the tide imposes some feasible berthing and departure time windows for vessels. In addition, due to the factor of the channel flow control, the pilot station also proposes some additional berthing and departure time constraints for the incoming and outgoing vessels. Therefore, an intuitive improvement is to integrate the above issues and to optimize them simultaneously. A more rigorous name of the problem proposed in this study should be 'the integrated problem on berth allocation and QC assignment with consideration of tide and navigation channel' . In this paper we first present an integer programming (IP) model, in which the decisions on berth, QC, tide windows, and service time are represented by different variables. However, we cannot obtain even a feasible solu-