Transportation Research Part E 97 (2017) 38–68

Contents lists available at ScienceDirect

Transportation Research Part E

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

Quay crane scheduling with draft and trim constraints

Lingxiao Wu, Weimin Ma *

School of Economics and Management, Tongji University, Shanghai 200092, China

ARTICLE INFO

Article history:
Received 9 May 2016
Received in revised form 22 October 2016
Accepted 24 October 2016

Keywords:
Container terminals
Quay crane scheduling
Draft and trim constraints
Branch and bound
Genetic algorithm

ABSTRACT

This paper discusses the quay crane scheduling problem with draft and trim constraints (QCSPDT), an extension to the current quay crane scheduling problem. We propose a linear mixed integer programming model with the objective to minimize the total handling time for the considered problem. A branch and bound method and a hybrid genetic algorithm are developed to solve the studied problem with different sizes. Computational experiments are conducted to examine the proposed model and solution algorithms. The computational results show that the solution methods are effective and efficient in solving the QCSPDT.

1. Introduction

Maritime transportation forms the backbone of international trade. As reported by UNCTAD (2015), maritime transport handles over 80% of the volume of global trade. An overwhelming majority of seaborne cargoes are containerized. As annual international trade grows rapidly, container terminals (CTs) which serve as the interface between inland and seaborne transportation are now facing an immense increase of service demand. Besides, competition among CTs, especially geographically close ones has become fiercer than ever. In order to improve customer satisfaction and achieve competitive advantages, container terminals must enhance their efficiency by reducing the turn-around time of ships. Up to present, many studies related to container terminal operations have focused on berth allocation, quay crane scheduling, container truck dispatching and storage planning. Comprehensive surveys for these problems are provided by Stahlbock and Voß (2008), Bierwirth and Meisel (2010), Carlo et al. (2015) and Bierwirth and Meisel (2015).

In this paper, the quay crane scheduling problem (QCSP) is studied. Quay cranes (QCs) are the most important equipment in container terminals which are used for loading or discharging containers onto or from ships. In reality, the operation of QCs is often the bottleneck for improving the turn-around time of ships. The QCSP as shown in Fig. 1 is to assign loading and unloading tasks to a group of QCs and determine the sequence of tasks of each QC (Daganzo, 1989). According to the definition of a task, studies on the QCSP can be generally divided into two distinctive classes. In the first class, the QCSP is considered for complete ship-bays where a task consists of all loading and unloading operations on the same ship-bay. In the second class, the QCSP is studied with container groups, and a task is defined as a group of containers with the identical operation (either loading or unloading) on the same ship-bay. Given that tasks of the QCSP are always non-preemptive both in practice and in most relevant studies, the QCSP with container groups which allows a more balanced division of tasks among QCs outperforms the QCSP with complete ship-bays in terms of QC efficiency and total handling time.

The general objective for the QCSP is to minimize the completion time of ship handling known as makespan. A number of constraints have to be factored into the QCSP and some of them have been well discussed in previous studies. For example, as

* Corresponding author at: NO.1239 Siping Road, Shanghai 200092, China.
E-mail address: mawm@tongji.edu.cn (W. Ma).

http://dx.doi.org/10.1016/j.tre.2016.10.011
1366-5545/

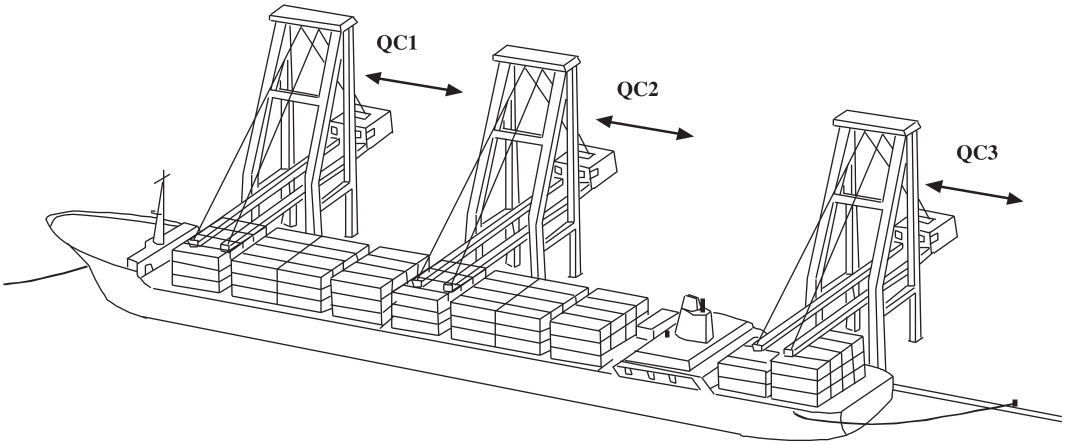

Fig. 1. A representation of QCs working on a vessel (Kim and Park, 2004).

cranes are rail mounted equipment, they cannot cross each other. Also, a minimum distance between cranes is necessary to ensure handling safety. However, although draft and trim of ships are key factors ensuring safety and efficiency of ship operations, constraints on them were rarely studied in previous research on this subject.

Containerships are handled in berths where water depth is quite limited when compared with open seas. As shown in Fig. 2, for the safety of ship hull, a minimum under-keel clearance (UKC), which is measured by the distance between the bottoms of the hull and the berth is required for the whole process of ship operation (see House (2007) for details). The UKC is directly affected by the draft of ships under handling. And as the draft varies due to loading and unloading of containers, the UKC also changes frequently during handling. To ensure sufficient UKC, the draft must be kept less than a certain upper bound. For berths with relatively sufficient depth, such an upper bound of draft may have little impact on the ship handling. However, for those with limited depth (for example, some terminals are only accessible for vessels during high-water periods (Xu et al., 2012), the limitation on draft could significantly influence the ship handling.

As shown in Fig. 3, containerships may tilt longitudinally as a result of uneven distribution of the weight of loaded containers which is caused by poor handling sequences. Such tilt is measured by the trim of ships. Trim is an important factor affecting ship handling and abnormally large trim may result in a series of problems:

- Difficulties in both lashing and unlashing of containers;
- Difficulties for quay cranes to grasp and put containers in place;
- Greater risk of collision caused by a decreased UKC;
- Greater risk of capsizal for ships (Pike, 2013).

Therefore, the trim of a containership must be remained at zero or at least in a narrow range around zero during handling. Although ballast can be used in some cases to avoid problems caused by trim, it only works within a limited range and moreover, the pumping or discharge of ballast may be prohibited in some ports due to IMO conventions (for example, the *International Convention for the Control and Management of Ships Ballast Water and Sediments*) or regulations of port authorities.

The goal of our work is to solve the quay crane scheduling problem with draft and trim constraints (QCSPDT). Handling tasks in this paper are defined as container groups. Therefore, our work acts as an extension to the current QCSP, especially

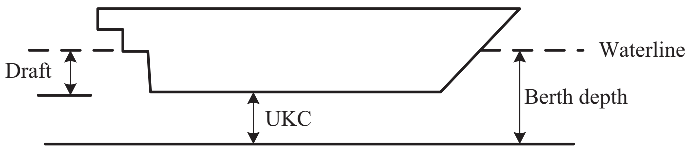

Fig. 2. An illustration of draft, berth depth and UKC.

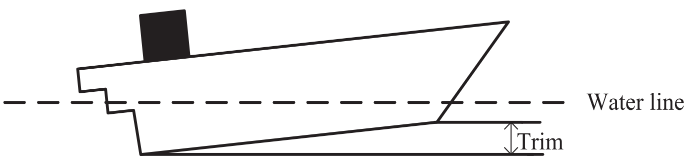

Fig. 3. An illustration of trim.