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Modelling of integrated vehicle scheduling and container storage problems in unloading process at an automated container terminal

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ABSTRACT

Effectively scheduling vehicles and allocating storage locations for containers are two important problems in container terminal operations. Early research efforts, however, are devoted to study them separately. This paper investigates the integration of the two problems focusing on the unloading process in an automated container terminal, where all or part of the equipment are built in automation. We formulate the integrated problem as a mixed-integer programming (MIP) model to minimise ship's berth time. We determine the detailed schedules for all vehicles to be used during the unloading process and the storage location to be assigned for all containers. A series of experiments are carried out for small-sized problems by using commercial software. A genetic algorithm (GA) is designed for solving large-sized problems. The solutions from the GA for the small-sized problems are compared with the optimal solutions obtained from the commercial software to verify the effectiveness of the GA. The computational results show that the model and solution methods proposed in this paper are efficient in solving the integrated unloading problem for the automated container terminal.

1. Introduction

Containers are large steel boxes with standardised sizes, designed for easily handling and transporting of cargos. Container trade is the fastest-growing freight segment which had an average annual increase of 6.1% in tonnage from 2005 to 2013 (UNCTAD, 2014). Container terminals, performing as the interfaces between seaside and landside, have been playing an important role in global trading. Container terminals are highly capitalised, and the competitions, particularly for those geographically closed terminals, are very intense. Therefore, improving the efficiency of container terminals becomes a vital challenge for all port managers.

Typically, there are two major operation processes in container terminals: unloading process and loading process. During the unloading process, containers (i.e. import containers) are transported from ships to storage yard, before being loaded onto external trucks and/or trains for onward delivery. During the loading process, after being received from external trucks and/or trains, containers (i.e. export containers) are allocated to the storage yard for temporary storing, and then loaded onto the ships. The flow of containers in the unloading and loading processes through a terminal is shown in Fig. 1. This paper will focus on the container handling in the unloading process.

In recent years, there has been a tremendous growing in the investment of automated equipment, i.e. automated vehicles and automated cranes, in container terminals, in order to satisfy the increasing container traffic flows and also reduce labour costs; such container terminals that use automated equipment are called automated container terminals, for example, ECT Rotterdam, CTA Hamburg, PPT Singapore, etc. Among all automated vehicles, the most commonly used is automated guided vehicle (AGV). AGV is a mobile robot that can move on a road-type network that incorporates electric wires or transponders in the ground to control its position. The popularity of using automated vehicles in container terminals is expected to continue since internal transportation in non-automated terminals have been proved to be inefficient and costly (Vis, 2006). Fig. 2 shows an air view of the automated container terminal in Hamburg.

Except AGVs, there are other types of container handling equipment involved in the terminal operations. This paper considers an automated container terminal involving quay cranes (QCs), AGVs and yard cranes (YCs) for container handling. QCs are located along the quayside for unloading containers from the ship to the AGVs; AGVs travel between the quayside and yard side for delivering

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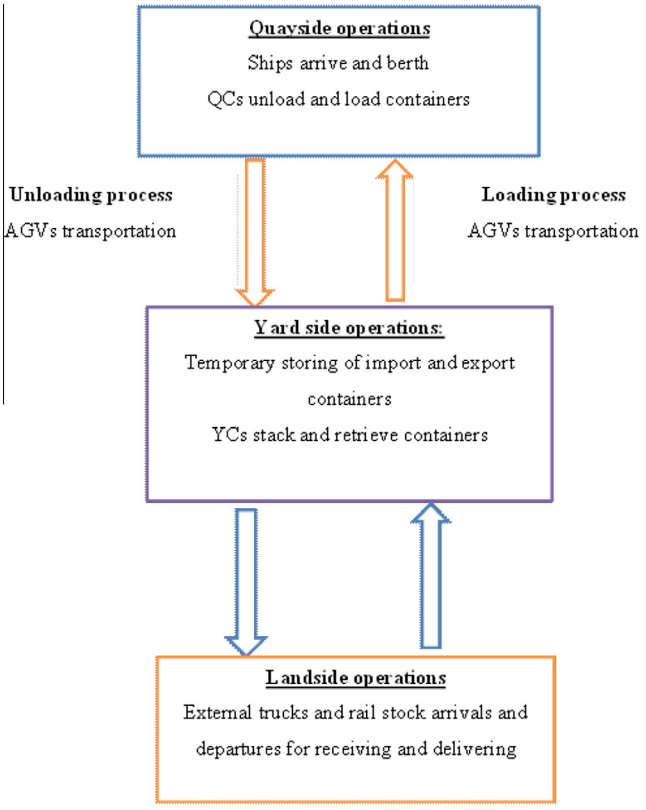

Fig. 1. Unloading and loading processes in a container terminal.

containers; YCs are used to move and stack containers within the yard. The slot in which a container is stored in the yard is called the yard location, and each container has to be assigned to a yard location, which is specified by a series of number (i.e. bay-row-tier).

Scheduling of vehicles has become one of the major planning issues for container terminals as inefficient vehicle schedules will cause delay in container-handling processes and thus affect the productivity of container terminals. In addition, container storage spaces are very limited due to the ever-increasing number of container flows through container terminals. Therefore, both scheduling vehicles and allocating containers are very critical in container terminal operations. Specifically, the vehicle scheduling problem determines delivery sequence and time to handle the containers for each vehicle; container storage problem determines the yard storage location for each container. Significant research has been devoted to the vehicle scheduling and container storage problems separately. The two problems are, however, highly interrelated for several reasons: (1) AGVs act an important role as the link between the quayside and yard side, and they interface the two problems; (2) container storage locations in the yard determine the YCs' schedules, which in turn affect the release time of each container from AGVs; (3) AGVs' schedule specify the time when each container is delivered to a yard location, i.e. where this container will be stored in. Therefore, it is important to address the two problems simultaneously. This paper focuses on the integration of the two problems during the container unloading operation, aiming to minimise the ship's berth time, which is one of the most important factors to evaluate the efficiency of container terminal operations.

The main contribution of this work is that we provide an integrated modelling approach to address the two critical problems, i.e. AGV/YC scheduling and container storage, which has not been considered in the literature. We also develop a novel-designed specialised method based on the genetic algorithm. This paper is organised as follows: Section 2 gives a brief review of previous studies on the AGV scheduling and container storage problems. The problem is described and formulated as a mixed-integer programming model in Section 3. Section 4 proposes a heuristic method, genetic algorithm (GA), which will be used for solving the large-sized problems. Section 5 gives the computational results for both small-sized and large-sized problems. Section 6 concludes this paper and suggests future works.

2. Literature review

Over the past decades, there have been emerging researches devoted on various aspects related to container terminal operations. The first comprehensive classification and review of the literature in the field of container terminals was given by Steenken, Voß, and Stahlbock (2004), followed by an updated paper by Stahlbock and Voß (2008). More recently, Carlo, Vis, and Roodbergen (2014b) presented an in-depth overview of studies on transport operations and analysed the container handling equipment used. A formal classification and overview of container

Fig. 2. Air view of a typical container terminal, Hamburg. source: www.maritimejournal.com