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Modelling of dual-cycle strategy for container storage and vehicle scheduling problems at automated container terminals

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ABSTRACT

This study proposes a new approach to determine the dispatching rules of AGVs and container storage locations, considering both unloading and loading processes simultaneously. We formulate this problem as a mixed integer programming model, aiming to minimise the ship's berth time. Optimal solutions can be obtained in small sizes, however, large-sized problems are hard to solve optimally in a reasonable time. Therefore, a heuristic method, i.e. genetic algorithm is designed to solve the problem in large sizes. A series of numerical experiments are carried out to evaluate the effectiveness of the integration approach and algorithm.

1. Introduction

Introduced about half a century ago, containers are large steel boxes of standard dimensions designed for easy and fast handling of cargos. Containers are eight feet wide, and come in three standard lengths – 20 feet, 40 feet or 45 feet. They have a height of either 8.5 feet or 9.5 feet. A 20-foot container carries up to about 28 tonnes of cargo with a volume up to 1000 cubic feet (Christiansen et al., 2007). Before the introduction of containerisation, cargo was transported piece by piece, which made the transportation of goods very expensive and inefficient. One of the most significant benefits resulting from the introduction of containers is the resulting decrease in the potential risk of damage to goods, and the reduction in the need for re-packing between different transportation modes. Today, over 60% of the world's deep-sea general cargo is transported in containers; on some routes, particularly those between economically strong and stable countries, containerisation is up to 100% (Steenken et al., 2004).

With the development of material handling and information technology, a number of terminals, such as Europe Combined Terminal (ECT) in Rotterdam, the Container Terminal Altenwerder (CTA) in Hamburg, the Thames Port in the UK, the Pasir Panjang Terminal (PPT) in Singapore, the Patrick Container Terminal in Brisbane and the Pusan Eastern Container Terminal, have started to employ automated container-handling equipment so as to satisfy the customers' growing demands and lower the labour costs (Luo, 2013). Among quite a few types of automated vehicles, automated guided vehicles (AGVs) are the most representative (Bae et al., 2011). AGVs are robotics that are able to drive on a road-type network which incorporates electric wires or transponders in the ground to control the position of the AGVs. The recent development

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of automated container terminals has led to an increasing interest in studying the scheduling problems in such terminals. This is because the automated container terminal represents the on-going trend of the traditional terminal, in which all or some of the container-handling equipment is automated. Since, in the case of automation, there is a lack of physical human input, efficient scheduling and coordination of different resources (handling equipment, yard locations, etc.) are crucial to improve the overall performance of the automated container terminal.

In a typical automated container terminal, there are three main container handling equipment involved: quay cranes (QCs), automated guided vehicles (AGVs) and yard cranes (YCs). QCs are engaged for unloading/loading containers from/onto the ship at the quayside; AGVs are built with advanced technology to transport containers between the quayside and the storage yard on the pre-defined paths; the storage yard is for temporarily storing of containers before they are further transferred by trucks/trains. During the unloading process, a QC discharges a container onto an AGV, which will deliver the container to the storage yard; then a YC collects the container from the AGV and stack it in the assigned slot. The loading process is the reverse of unloading process. Fig. 1 shows the handling processes in container terminals. In this work, we consider the unloading and loading operations simultaneously, which is called the dual-cycle strategy.

Most of the existing literature considers the scheduling of one single type of equipment and the storage allocation problem of containers separately (Kim and Bae, 2004; Ng and Mak, 2005; Nishimura et al., 2005; Ng et al., 2007). However, vehicle scheduling and container storage are two highly interrelated decision problems faced by container terminals. AGV plays a role of interface between quayside and storage yard to coordinate the operations of QCs and YCs. On the other hand, container storage locations determine the YCs' handling sequences and routes in the yard. Therefore, this study concerns with the integration of AGV scheduling and container storage problems, in order to achieve the optimal performance of an automated container terminal.

The main contribution of this study is to provide an integrated modelling approach for AGV, YC scheduling problem and container storage allocation in the dual-cycle strategy, which considers the unloading and loading operations at the same time. We have also provided a novel designed solution method to solve the problem in practical sizes.

The paper is organized as follows. After introduction, Section 2 gives a brief review of the related literature. Section 3 precisely describes the integrated problem considered in this study and develops a mathematical formulation of it. We design a novel genetic algorithm particularly for this integrated problem in Section 4. Section 5 discusses several numerical experiments to evaluate the performance of the integration approach and the efficiency of GA. Section 6 concludes this study and suggests some extensions of this work.

2. Literature review

Researches related to container terminal operations are receiving more and more attentions due to the increasing importance of marine transportation system. Comprehensive classifications and reviews were provided by Steenken et al. (2004)

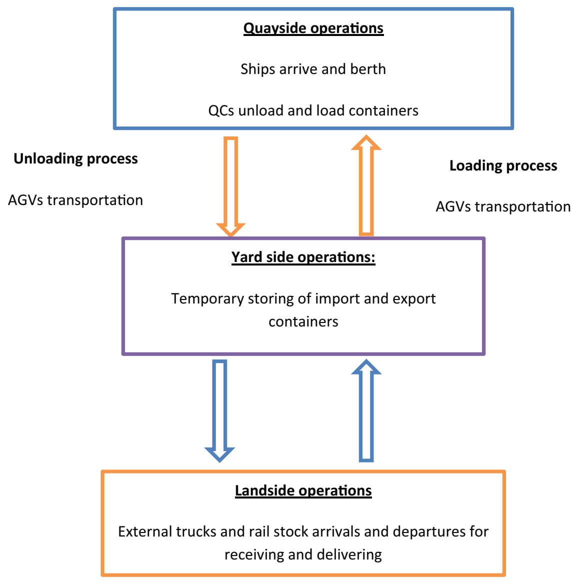

Fig. 1. Unloading and loading processes in an automated container terminal.