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Modeling the mixed storage strategy for quay crane double cycling in container terminals

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ABSTRACT

A mixed storage strategy was proposed to improve the efficiency of yard operations and horizontal transportation to corporate with quay crane double cycling. The effects of the mixed storage strategy on terminal operations, including truck travel distance, yard crane operations and the number of required trucks, were analyzed. An approach based on cycle-time models, the queuing theory was proposed to evaluate the performances from long-term run. Results show using the mixed storage strategy, the truck travel distance can be decreased and the number of required trucks and yard crane's operation time can be reduced by 16% and 26% respectively.

1. Introduction

With the development of international trade, the volume of world sea cargo has rapidly increased. Since container terminals are important nodes in the international transport network, their efficiency affects the performance of the global supply chain. To attract more ships, port operators strive to decrease ship turnaround time by implementing new techniques. Double cycling has received increasing amounts of attention in recent years. Using this method, a quay crane (QC) can handle a pair of containers in a cycle, with this pair consisting of an inbound container and an outbound container that are stowed in the same ship bay (Goodchild and Daganzo, 2006). Meanwhile, a truck can carry an inbound container from the quay after delivering an outbound container to the quay. To ensure the efficiency of double cycling, the truck efficiency should be well coordinated with the QCs' efficiency.

Internal trucks transport containers in the terminal and serve as an interface between the quay operations and yard operations. The efficiency of these trucks is affected by the yard cranes (YC) and QCs. Any delay of yard operations will finally result in the delay of ships (Lee et al., 2009; Luo and Wu, 2015). Generally, inbound and outbound containers are stored separately in terminal yards. This storage strategy makes it more convenient for the terminal operators to make yard schedules and decrease the interferences between the internal and external operations (Tao and Lee, 2015; Zhen, 2014). However, with double cycling, the entire container handling system is more complex, consisting of seven stages, as shown in Fig. 1. The cycle time of trucks is longer, and the coordination of trucks and YCs becomes more important to maintain QCs' efficiency. Therefore, the use of YCs and trucks should be further planned.

To achieve a high productivity of double cycling operations, a mixed storage strategy in which outbound and inbound containers are stacked in the same bay but in different rows is proposed (Cheung et al., 2002). Using the mixed storage

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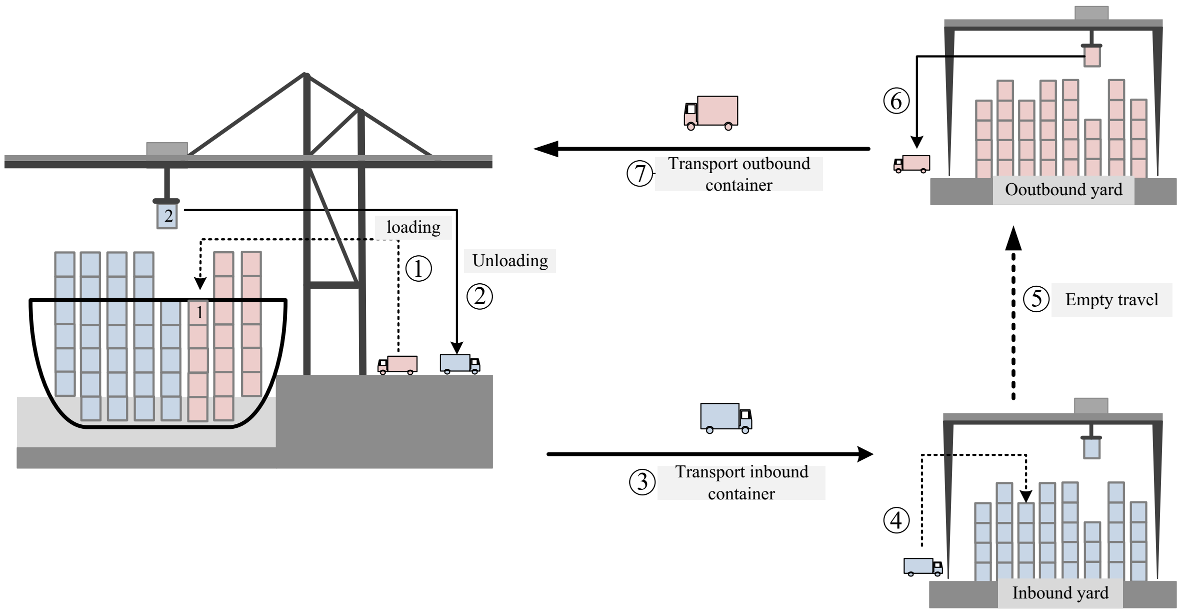

Fig. 1. The double-cycling handling system.

strategy, the unloaded travel of internal trucks between inbound and outbound blocks is eliminated (the fifth stage in Fig. 1). Meanwhile, double cycling operations of YCs are possible, which can increase the operation efficiency of YCs. The changes caused by a mixed storage strategy, such as the yard layout, the truck travel routes and YC operations, are obvious. However, the accurate effects of a mixed storage strategy on terminal operation costs and schedules must be addressed, and knowledge of these effects is necessary to gain insight into a long-term run at a general level.

In this study, the issues associated with modeling the mixed storage strategy for double cycling operations are addressed. The effects of a mixed storage strategy on the average truck travel distance, the required number of trucks and the YCs' operation efficiency are evaluated. Cycle-time models, queuing theory and simulation are used to quantify these effects. Furthermore, stacking strategies are proposed to achieve more benefits. The remainder of the paper is organized as follows. Section 2 provides a review of the existing literature. Section 3 provides a description of the mixed storage strategy, and its performance is evaluated in Section 4. Stacking strategies and lower bounds of YC's handling time are proposed in Section 5. A simulation study to test the validity of the models is provided in Section 6. Conclusions are given in Section 7.

2. Literature review

Container terminal operations have gained a substantial amount of attention from researchers. To increase terminal efficiency, new technologies and methods have been implemented, such as truck appointment system (Zhao and Goodchild, 2010; Chen et al., 2013), cross-docking at yards (Konur and Golias, 2013; Yu and Egbelu, 2008). Double cycling is one of the new techniques used in container terminals, serving to increase QCs' efficiency and optimize truck utilization. The effect of double cycling has been shown via practical implementation (e.g., in the ports of Los Angeles and Tianjin, China (TranSystmes, 2003)) and via theoretical research analysis (Goodchild and Daganzo, 2007). The results indicate that double cycling can reduce the cycling number of QCs by 20% and decrease the operation time by 10%. Furthermore, to increase the double cycling number, Goodchild and Daganzo (2006) optimized the sequence of QCs. Later, Zhang and Kim (2009) extended his model by considering the hatch. Lee et al. (2014) treated the quay crane sequencing model as a flow shop problem and used the Sidney algorithm to solve it. In addition to the effect on the QC's double cycling number, Goodchild and Daganzo (2007) analyzed the effect of double cycling on other operations in the terminal, including the truck travel distance, the number of required trucks and the loading sequence. To increase the operation efficiency, other operations should be incorporated with the quay crane double cycling (Kim and Kim, 1999; Luo and Wu, 2015).

Recently, studies on the integrated scheduling of QCs, trucks and YCs for single cycling have rapidly developed. For example, Kim and Park (2004) developed a dynamic programming model to optimize YC routing. Kaveshgar and Huynh (2015) formulated an integrated schedule of QCs, YCs and trucks as a hybrid flow shop scheduling problem. Cheung et al. (2002) proposed a storage space allocation method. Bish (2003) and Zhang et al. (2003) developed models to optimize the yard crane deployment. Bish et al. (2005) and Ng et al. (2007) studies the truck scheduling in container terminal. For QC's scheduling, many factors were considered to develop the models, such as safety clearance between the QCs (Kim and Park, 2004; Lee et al., 2008; Wen et al., 2010) and the moving time of QCs (Bierwirth and Meisel, 2009). To solve the model, the branch and