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Scheduling two lifts on a common rail considering acceleration and deceleration in a shuttle based storage and retrieval system

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ABSTRACT

Shuttle based storage and retrieval systems (SBS/RS) attract continuous research attention because of their ability to achieve a high throughput. In an SBS/RS system, lifts are regarded as the bottleneck that hinder reaching higher throughput and therefore require subtle control polices. In this paper, the scheduling of two non-passing lifts on a common rail SBS/RS has been studied with consideration of the acceleration and deceleration of the lifts. Lift scheduling includes storage and retrieval requests sequencing, assignment of lifts, and collision avoidance. The main objective of the lift scheduling is minimizing the makespan of the moves. Different with the traditional constant velocity lift scheduling approach is that new collisions emerge when the acceleration/deceleration of the lifts are taken into consideration. This makes the scheduling different. In this paper a collision free lifts trajectory predicting approach with acceleration/deceleration is presented. Combined with the collision-free method, request sequencing and assignment are carried out by a proposed genetic algorithm. Experimental results with several SBS/RS practical working scenarios provide evidence that the proposed scheduling approach achieved on average 12.2% and 6.4% improvement in makespan compared with the constant velocity approach when the maximum velocity of the lifts is 1.5 m/s and 2 m/s respectively.

1. Introduction

1.1. Background

More and more companies that utilize warehouses like to employ automated material handling facilities to store and retrieve unit loads. The implementation of automated material handling facilities provides many advantages, such as the saving of labour and floor space, and an improvement of the work efficiency and storage capacity. Automated storage and retrieval systems (AS/RS) and shuttle based storage and retrieval systems (SBS/RS) are the two main configurations that have been widely accepted by the logistics industry. The key distinction between AS/RS and SBS/RS is the movement patterns of the storage/retrieval (S/R) devices (Fukunari & Malmborg, 2009). In AS/RS, horizontal and vertical movements of unit loads are simultaneously carried out by aisle-captive cranes. Differently, the S/R devices in SBS/RS are composed of multiple lifts and tier-captive shuttle carriers (Lerher, 2015). The lifts conduct the vertical movement of the unit loads whereas the shuttle carriers conduct the horizontal movement. With this decoupling of vertical and horizontal movement of the unit loads, SBS/RS have the advantage in throughput because it has a fleet of shuttles (Fukunari & Malmborg, 2009) and lifts (Zhao, Luo, Zhang, & Lodewijks, 2016) where an AS/RS has only one aisle-captive crane in the basic configuration (Kung, Kobayashi, Higashi, Sugi, & Ota, 2014). For this reason, SBS/RS have a brighter future in the highly competitive logistics industry (Lerher, 2015; Marchet, Melacini, Perotti, & Tappia, 2013).

Malmborg (2002) was the first who studied autonomous vehicle storage and retrieval systems (AVS/RS), which use the same technology as SBS/RS. In AVS/RS, each autonomous vehicle (AV) can reach every storage unit in the rack and the number of autonomous vehicles (AVs) can be adjusted based on the specific configuration. Different rack configurations and vehicle numbers lead to different system performance. Therefore, the prediction of system performance is critical in the design phase of AVS/RS. A queuing model was proposed by Malmborg to predict the cycle time performance accounting for the number of columns, tiers, vehicles, and lifts. Many researchers followed Malmborg's study and employed a different methodology to estimate

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different performance indicators of AVS/RS. Kuo, Krishnamurthy, and Malmborg (2007) proposed a M/G/V and a M/G/L queuing model to estimate the waiting time of a vehicle and a lift. Fukunari and Malmborg (2008) proposed a network queuing approach to predict the cycle time of storage and retrieval transactions. Roy, Krishnamurthy, Heragu, and Malmborg (2012) proposed a multi-class semi-open queuing network to investigate the impact of rack configurations, allocation of resources to zones, and vehicle assignment rules. Ekren, Heragu, Krishnamurthy, and Malmborg (2010) developed simulation models and carried out a regression analysis to determine the relationship between the rack configuration and the system performance. Ekren and Heragu (2011) investigated the optimal number of vehicles and lifts using simulation. Ekren, Heragu, Krishnamurthy, and Malmborg (2013) proposed a semi-open queuing network model to determine the system performance.

In general, the main key performance criterion in the AVS/RS design is the throughput (Roy et al., 2012). To increase the throughput, a SBS/RS is designed as a special configuration of an AVS/RS. In SBS/RS, each AV services one exclusive tier of storage racks and the number of AVs is the same as the number of tiers. For this reason, the AVs only conduct tier captive movement and are renamed shuttles. Marchet, Melacini, Perotti, and Tappia (2012) presented an open queuing network approach to estimate throughput and cycle times of an SBS/RS. Based on the open queuing network approach, Marchet et al. (2013) investigated the main design trade-offs and proposed a comprehensive design framework for an SBS/RS. Lerher (2013) studied the energy regeneration models for SBS/RS. The proposed models enable the reduction of the energy consumption, which is another performance indicator in warehouse design. Lerher (2015) proposed a travel time model for an SBS/RS. Based on the proposed travel time models, the expected cycle time for single- and dual-command cycles of SBS/RS can be estimated. Lerher (2015) conducted a simulation analysis of an SBS/RS. The result of the simulation study showed that the lift is the bottleneck in most of the cases. Lerher (2016) proposed an estimating model to calculate the throughput and the energy consumption of SBS/RS. Lerher, Borovinsek, Ficko, and Palcic (2017) also developed a parametric simulation model to optimize rack configuration.

Except the study of the performance of a basic version of SBS/RS, many researchers focused on special configurations or special control policies recently. For example, Lerher (2015) proposed a travel time model of double-deep shuttle-based storage and retrieval systems, which expands the storage capacity. Shuttle-based compact systems are other special configurations that can dramatically increase the storage capacity. Tappia (2017) proposed a novel queuing network model to estimate its performance. D'Antonio, Maddis, Bedolla, Chiabert, and Lombardi (2017) proposed analytical models for evaluating performances of deep-lane AVS/RS. Zou, Xu, Gong, and De Koster (2016) focused on the study of parallel movement of lifts and shuttles. He proposed a parallel processing policy and gained significant improvement of performance. All the aforementioned studies significantly improved the design and performance of the SBS/RS.

1.2. Multi-lift SBS/RS

Lifts are always the bottleneck of an SBS/RS and determine the performance of the whole system (Carlo & Vis, 2012; Lerher, 2013, 2015). The reason is that only one lift is used whereas multiple shuttles are used in the basic version of one aisle SBS/RS. In order to change this situation, Ning (2016) proposed a multi-lift SBS/RS system with multiple lift mast (Fig. 1). In this system, the lifts occupy storage space and conduct parallel vertical movement of unit loads. Conveyor belts move the unit loads from or to the multiple input/output (I/O) points. Simulation results show that great throughput improvement can be achieved by this system because the improvement of the lift capacity.

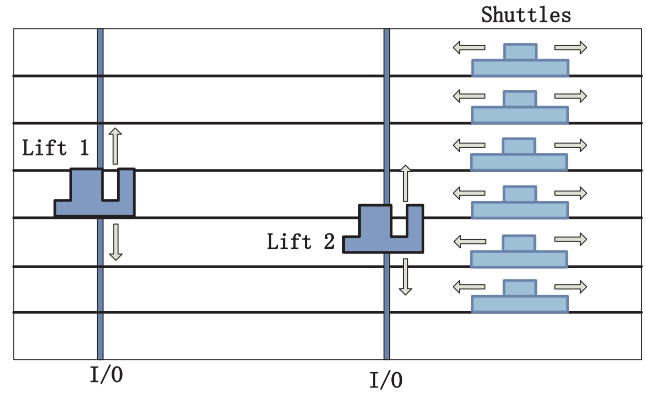

Fig. 1. Schematic representation of an SBS/RS with multiple lifts in different masts (Ning, 2016).

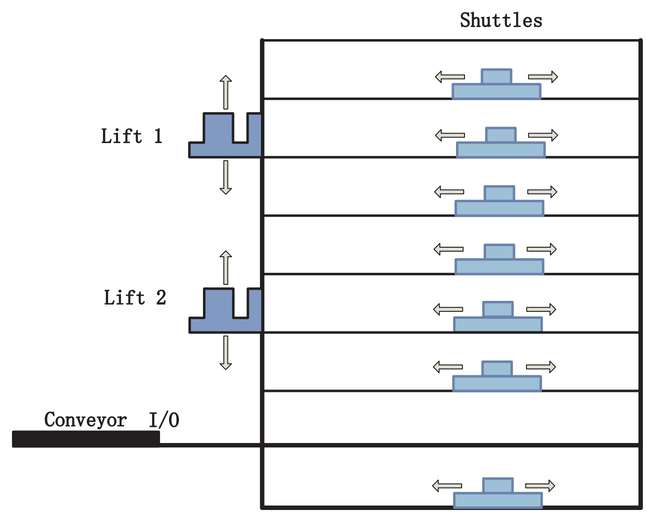

Fig. 2. Schematic representation of an SBS/RS with multiple lifts on a common mast (Carlo and Vis, 2012).

On the other hand however, the implementation of multiple lift masts results in a reduction of storage capacity and adds complexity to the conveyor belt layout in the I/O point.

Fig. 1 shows a schematic representation of an SBS/RS with multiple lifts in different masts (Ning, 2016). Carlo and Vis (2012) first studied a multiple lift system with a common mast (Fig. 2). Only one I/O point exists at level 0 on the interface between conveyor and the lifts. The two lifts share a common mast to transport the load from the interface between the I/O and the shuttles. Obviously, collision avoidance of the two lifts emerges as a key problem and elaborate lifts scheduling is essential. Carlo and Vis proposed a look-ahead scheduling strategy that showed a great advantage compared with some earlier used priority rules. Carlo and Vis' work got a significant improvement on the multi-lift configuration of an SBS/RS and showed potential value in throughput increase. However, in their work the acceleration and deceleration of the lifts was neglected and it was assumed that lifts had a constant velocity. This neglect will result a deviation from the actual system performance since lift acceleration and deceleration do exist in the real world. Moreover, the proposed scheduling solution that neglects lift acceleration/deceleration may not be a good solution when acceleration/deceleration is taken into consideration. Carlo and Vis (2012) also listed the consideration of acceleration/deceleration as the primary part of their future work. For this reason, we continue Carlo and Vis (2012)'s work and present an elaborate scheduling method that does take lift acceleration/deceleration into account.