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Free balancing for a shuttle-based storage and retrieval system

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A B S T R A C T

Shuttle-based storage and retrieval systems (SBS/RSes) – a type of automated storage and retrieval system (AS/RS) – have recently been developed to increase throughput capacity. An SBS/RS can increase throughput by using multiple shuttles as storage and retrieval machines (SRMs), while traditional AS/RSes are limited because they use a single stacker crane as an SRM to handle multiple jobs. However, when setting up an SBS/RS, a significant investment is required to integrate a shuttle for each tier in the storage construction. To lower costs, a reduction in the number of shuttles is an adequate solution if the SBS/RS can maintain the designated throughput. However, this could also lead to operational problems. Namely collision prevention and workload balances could be affected because each shuttle would be able to travel to any tier for pickups and drop-offs. Thus, shuttle position control is important when the system operates with a mismatch between the number of shuttles and tiers. Ideally, free balancing should be achieved. When free balanced, each shuttle's position is monitored to prevent collisions or blockages, as well as to make sure jobs are evenly assigned and the required throughput is maintained. This paper suggests system controls to prove the effectiveness of free balancing, and it runs a simulation analysis to verify the system with the suggested controls. As a result, free balancing shows better performances in terms of throughput and utilization compared to a basic system control. Specifically, in our case, free balancing can achieve targeted throughput with less number of shuttles.

1. Introduction

Automated storage and retrieval systems (AS/RSes) are the most well-known automated warehouse technology. These systems offer significant benefits over non-automated systems; they save workforce costs and floor space, increase reliability and lower error rates [23]. However, transaction mechanisms have recently changed, and there is now a tendency toward smaller quantities in terms of orders and production batches. This requires technology advances.

As one of these advanced technologies, shuttle-based storage and retrieval systems (SBS/RSes) have been developed to process more loads and achieve higher speeds than mini-load crane-based automated storage and retrieval systems (CBAS/RSes). The latter systems are not suitable for loads that require frequent transactions because the storage and retrieval machine (SRM) consists of a single stacker crane. In contrast, an SBS/RS is able to satisfy the new transaction mech-

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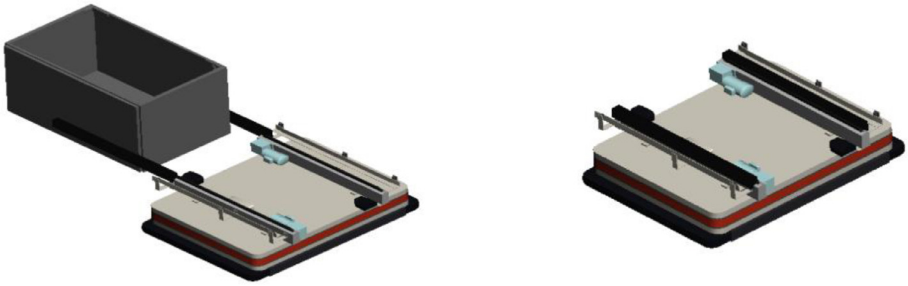
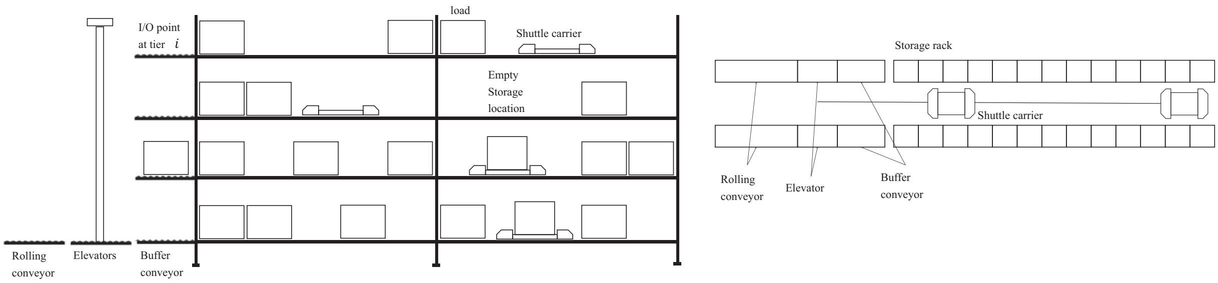


Fig. 1. SBS/RS shuttle carrier simulation display.



(a) Side view of SBS/RS

(b) Top view of SBS/RS

Fig. 2. Physical configuration of a shuttle-based storage and retrieval system.

anisms because the SRM employs multiple shuttles that service multiple tiers. Fig. 1 describes the SBS/RS shuttle carrier in a simulation, and Fig. 2 shows the physical configuration of the SBS/RS.

There are two main SBS/RS configurations – one with tier-captive shuttles and the other with tier-to-tier shuttles. In a tier-captive SBS/RS, an individual shuttle carrier is configured for each tier. One of the significant drawbacks of this system is its low flexibility. Although efficient tier-captive SBS/RSes have been constructed with high throughput capacities and short cycle times in numerous industries, they rely on fixed configurations and cannot simply adjust to rapid changes confronting storehouse management. To overcome this drawback, tier-to-tier SBS/RSes have been employed. These systems achieve greater flexibility than their tier-captive counterparts by adding or eliminating extra shuttles.

Despite the advantages of tier-to-tier SBS/RSes, they suffer from operational issues. Because the number of shuttles changes to achieve flexibility, the system requires inter-tier movement that does not occur in tier-captive SBS/RSes (Fig. 3). In SBS/RSes using bi-directional guide paths, this inter-tier movement can cause operational difficulties as well as system failures due to shuttle collisions. As a result, tier-to-tier SBS/RSes can exhibit significant differences in system performance according to operational method. In other words, the efficient use of tier-to-tier SBS/RSes is very important in achieving cost-effective operations.

This paper defines the problems inherent in tier-to-tier SBS/RSes and presents free balancing as a solution. In free balancing, the system is dynamically operated by controlling each shuttle and load position to prevent inefficiencies such as blocking delays and collisions. To analyze the effects of free balancing, this paper compares the performance of free balancing and non-free balancing operations by exploring several examples of transaction process logic and load assignment policies in a simulation. The detailed simulation is modeled using AutoMod®.

This study is organized as follows. Section 2 provides a review of the literature on AS/RSes, SBS/RSes and automated guided vehicles (AGVs). In Section 3, the details of the tier-to-tier SBS/RS and shuttle collision prevention are explained. Section 4 describes the main assumptions of this paper and exhibits a comprehensive simulation model. The results of the experiments and analyses are presented in Section 5. Section 6 discusses the conclusions of this research.

2. Literature review

AS/RSes have been discussed by a lot of researchers. Roodbergen and Vis [23] have provided a review of AS/RSes. According to their paper, AS/RS design decisions can be divided into two categories – physical designs and control policies. The physical design determines the physical configuration, including factors such as the number of cranes per aisle. In contrast, control policies determine the actions conducted by the system. A control policy is composed of storage assignments, batching, sequencing and dwell points.