Simulation Modelling Practice and Theory 000 (2016) 1–17

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

An efficient simulation model for rack design in multi-elevator shuttle-based storage and retrieval system

Zhao Ning [a,*], Luo Lei [a], Zhang Saipeng [a], Gabriel Lodewijks [a,b]

[a] School of Mechanical Engineering, University of Science and Technology Beijing, Xueyuan Road 30, Haidian District, Beijing 100083, PR China
[b] Section of Transport Engineering and Logistics, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Mekelweg 2, 2628 CD, Delft, the Netherlands

A R T I C L E I N F O

Article history:
Received 14 August 2015
Revised 16 March 2016
Accepted 21 March 2016
Available online xxx

Keywords:
Warehousing
Shuttle based storage and retrieval system
Multi- elevator tier captive systems
Simulation modeling
Efficiency analysis

A B S T R A C T

A shuttle-based storage and retrieval system (SBS/RS) is a relatively new material-handling facility. A multi-elevator tier-captive SBS/RS is a newly designed subset of such a facility. This new system consists of tier-captive shuttle carriers, multiple elevators with a lifting table, and racks. The storage rack of the system is defined in terms of tiers, columns, and the number and position of the elevators. The aim of this study is to develop an efficient simulation model that can be auto-remodeled for different rack configurations. With this model, it will be easy for warehouse designers to test a large number of rack alternatives and to determine the optimal solution efficiently. Furthermore, the designers can illustrate the solution to shareholders through animation identical to the real system. A simulation case study is presented for a multi- elevator tier-captive SBS/RS containing 81 different rack alternatives. These alternatives are simulated under 15 different retrieval rates within 48 h, and finally, the optimal rack design is found out. We believe that our work will assist warehouse designers in efficiently designing racks of multi- elevator tier-captive SBS/RSs during early technology selection.

1. Introduction

A shuttle-based storage and retrieval system (SBS/RS) is a relatively new material-handling facility, composed of shuttle carriers (vehicle), elevators with a lifting table (lift), and storage racks. The SBS/RS is the subset of an autonomous vehicle storage and retrieval system (AVS/RS). The main difference between an AVS/RS and a traditional automated storage and retrieval system (AS/RS) is the movement patterns of the storage and retrieval (S/R) devices [1]. In an AS/RS, the unit loads are handled by cranes that simultaneously move in horizontal and vertical directions, whereas in an AVS/RS, the unit loads are handled by autonomous vehicles (shuttle carriers) moving horizontally and by an elevator (with lifting table) moving vertically. Therefore, a number of storage and retrieval commands can be performed simultaneously in an AVS/RS (SBS/RS) and better performance may be achieved.

Depending on the vehicle assignment to storage tiers, there are two main rack configurations within AVS/RS: ‘tier-to-tier’ and ‘tier-captive’ [2]. In this paper, a tier-captive configuration type SBS/RS is studied. Theoretically, an SBS/RS can deliver better throughput by using more shuttle carriers. However, the lifting tables are a bottleneck in the tier-captive configuration

* Corresponding author. Tel.: +86 10 62332121.
E-mail address: zhning@sina.com (Z. Ning).

http://dx.doi.org/10.1016/j.simpat.2016.03.007

because the number of elevators is determined by the number of aisles. In order to improve performance, new tier-captive configurations equipped with multiple elevators per aisle have been developed in recent years. Multi shuttle Captive is one such example; it was developed by Dematic and has been used in Europe and China.

It is crucial to design an SBS/RS in such a way that it can efficiently handle different requirements, without any bottlenecks and excess capacity [3]. However, this multi-elevator technology has resulted in more rack alternatives compared to a traditional single elevator SBS/RS. This is because the multi-elevator system allows the introduction of new design variables, such as the number of elevators, the elevator position, and the buffer position. In order to find the appropriate rack configuration, designers have to simulate and evaluate a large number of alternatives. If there are too many alternatives, it is hard to find the best one due to time and money constraints.

In order to simplify the performance evaluation and to facilitate faster rack design, we propose an efficient simulation model, which can be used in the early technology selection or in the conceptualization phase of the system development. Compared to conventional abstract simulation models [3,4,14], the animation of the proposed model is identical to the real system, which can help shareholders to understand the design. More important, the proposed model can be auto-remodeled for different alternatives. Consequently, the tedious manual modeling work can be significantly reduced and a large number of alternatives can be efficiently evaluated in a tolerable period of time. The scientific contribution of our work is enabling wide range performance evaluation of multi-elevator SBS/RS scenarios via simulation.

This paper is organized as follows. Literature related to the performance evaluation of the SBS/RS is presented in Section 2. The rack design of the multi-elevator tier-captive SBS/RS is described in Section 3. The proposed simulation model is presented in Section 4. A simulation case study is presented in Section 5. Finally, conclusions are drawn in Section 6.

2. Literature review

Based on our knowledge, only a few studies are directly related to the SBS/RS, meanwhile a majority of studies pertain to the AVS/RS, which use the same technology as SBS/RS.

Malmborg first analyzed the performance of a tier-to-tier AVS/RS. A queuing model was proposed to estimate the cycle time performance considering the number of columns, tiers, vehicles, and lifts [5].

Following Malmborg's study, Kuo et al. used an M/G/V queue model nested within an M/G/L queue model to estimate the waiting time for a vehicle and a lift [6]. Fukunari and Malmborg developed a network queuing approach to estimate the cycle time [7]. Heragu et al. proposed an open queuing network to analyze both the AVS/RS and AS/RS [8]. Roy et al. proposed a multi-class semi-open queuing network to investigate the tier–to-tier AVS/RS performance impact of rack configurations, allocation of resources to zones, and vehicle assignment rules [9,10]. These studies focused on using an analytical model to evaluate the performance of the design.

Simulation is another method that can be used to evaluate the performance of a specific design. In many cases it yields a more realistic approach compared to the analytical model. This is caused by the fact that a deterministic (analytical) approach normally requires simplifications of the model that are not required in a (stochastic) simulation model. In general analytical models are used to validate the results of simplified simulations [2,6,9,11]. Simulation can be used for performance analysis [3,12]. For example, Ekren and Heragu developed 30 simulation models for six design scenarios using ARENA software; based on the results of the simulations, a regression analysis was carried out to determine the relationship between the rack configuration and the system performance [12]. Ekren and Heragu also used simulation to determine near optimum values for a number of autonomous vehicles and lifts; seven design scenarios and 133 different simulation experiments were performed in the study [3].

The earliest study on SBS/RS was by Carlo and Vis [13]. They studied a type of SBS/RS with two non-passing lifting tables sharing one mast, with the objective of improving the lifting performance. They focused on the lifting table scheduling problem and proposed a look-ahead strategy.

Marchet et al. presented an open queuing network approach to study SBS/RS and compared their experimental results with simulation results [14]. Based on the open queuing network approach, Marchet et al. investigated the main design trade-offs and proposed a comprehensive design framework for an SBS/RS [15].

Lerher studied the energy regeneration models for SBS/RS. The proposed models enable the reduction of the energy consumption, which is another design objective in warehouse designing [16]. Sari et al. conducted the experimental validation of travel time models for an SBS/RS [17].

Recently, Lerher studied the performance evaluation problem and proposed a travel time model for an SBS/RS [18]. Based on the proposed travel time models, the expected cycle time for single- and dual-command cycles of the aforementioned two SBS/RS types can be evaluated. Lerher studied double-deep shuttle-based storage and retrieval systems [19], which is another special design feature of an SBS/RS. A travel time model was proposed, which enables the calculation of the expected cycle time for single- and dual-command cycles. Lerher proposed an approach to calculate the throughput and the energy related performance [20]. Apart from these analytical models, Lerher et al. [21] also conducted a simulation analysis of an SBS/RS. A simulation model using a traditional single elevator SBS/RS was developed and a case study about the performance of 9 design scenarios was conducted. The results of the simulation study showed that the elevator will be a bottleneck if the tier number increased, where the shuttle carrier will be the bottleneck if the column number increased. All the aforementioned studies significantly improved the development of the SBS/RS.

Please cite this article as: Z. Ning et al., An efficient simulation model for rack design in multi-elevator shuttle-based storage and retrieval system, Simulation Modelling Practice and Theory (2016), http://dx.doi.org/10.1016/j.simpat.2016.03.007