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Simulation-Based Performance Analysis of a Miniload Multishuttle Order Picking System

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Abstract

In today's fluctuating business environment, flexibility, responsiveness, and reconfigurability in the field of warehousing systems are key characteristics as well as the level of automation, cost effectiveness and maximum throughput. The miniload multishuttle system represents relatively a new scalable automated storage and retrieval solution which provides considerable flexibility for adapting throughput capacity to meet market needs. The miniload multishuttle system comprises autonomous vehicles (shuttles), lifts, and a system of rails that facilitate movement of the vehicles in the x and y dimensions in a tier. In this new technology, the shuttles can be moved between different tiers by means of shuttle lifts. Especially in large and complex material flow systems, the modeling problem arises with the interactions between transactions and the collisions between shuttles. An agent-based simulation approach that differs from discrete-event simulation (DES) offers an alternative way to model the autonomous control of the multishuttle system. This research develops a simulation model for the miniload multishuttle order picking system using the multi-agent modeling approach. The main objective of this paper is to create a detailed simulation model and to evaluate the performance of the system in order to support in design process of miniload multishuttle order picking systems.

Keywords: Flexibility; Miniload multishuttle; Multi-agent simulation

1. Introduction

Intralogistics systems are defined as a combination of organization, controlling, execution and optimization of the in-house material and information flow [1]. Classical criteria in the design process of intralogistics systems are minimization of costs (by means of e.g. maximal utilization of resources), quality of service (order lead time, timeliness, error levels), flexibility (ability to cope with changing process parameters, such as order structure or article structure) and scalability (ability to grow with increasing system load) [2]. All of these design criteria in the field of intralogistics are key challenges for the industry, especially in dynamic and uncertain environments. This dynamic environment is characterized by a wide variety of products, fluctuations in demand, and increased customer expectations in terms of quality and delivery time. To deal with these increasingly challenging issues, firms need to develop strategies that provide the flexibility to succeed in uncertain environments. However, it seems to be difficult to achieve within the rigid, specific and specialized world of automated material handling systems [3] which offers static and inflexible hardware solutions for the main functions of intralogistics systems. At this point, autonomous vehicles have been widely adopted as a key component to intralogistics systems in order to improve adaptability by physical flexibility in disposition, routing and space consumption.

Automated storage and retrieval systems (AS/RSs) are major material handling systems that have been widely used in warehousing for storing and retrieving finished products and parts [4]. In its most basic depiction, the basic components of an AS/RS are storage racks, a crane (or, equivalently, S/R machine), and input/output (I/O) stations. The benefits of AS/RSs include low labor cost, enhanced space exploitation, improved material tracking and high system throughput [5]. Although AS/RS technology can

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achieve high throughput and fast response times in many material handling applications, classic AS/RS systems have limitations, such as limited flexibility and autonomy by the physical build-up of the system. The traditional design is a single shuttle that can carry a pallet or handling unit. In order to increase the throughput capacity of the system, multishuttle AS/RSs have been developed in recent years [6]. The miniload multishuttle system represents relatively a new scalable AS/RS solution which provides considerable flexibility for adapting throughput capacity to meet market needs. While there is usually just a handful of an automated crane in conventional AS/RS, there are a higher number of coordinated vehicles in the multishuttle system to fulfil the storage and retrieval orders.

Especially in large and complex material flow systems, numerous questions arise both on the design and control levels. From a design perspective, the system configuration is often complicated by large varieties of products needing storage, varying areas of required storage space and drastic fluctuations in product demand [7]. Large-scale, complex or highly dynamic environments make the systems too complex to be evaluated analytically. Especially, automated storage and retrieval systems are difficult to model analytically because they incorporate interactions of many subsystems [8]. For this reason, simulation is used as an important decision support tool to analyze all the processes and interactions of the warehouse that are complex, dynamic and stochastic in nature. Most of research on warehouse simulation ([9], [10], [11]) uses discrete-event simulation approach to model the operations of a warehouse or the dynamic behaviors of the system are expressed using mathematical techniques. However, using such models, it is difficult to model the autonomous vehicle's control. Multi-agent systems [12], which are composed of different interacting computing entities called agents, offer an alternative way to design and implement simulation of intralogistics systems based on multishuttles and autonomous control.

In this paper, we develop a multi-agent simulation model to evaluate the performance of a miniload multishuttle order picking system. The main objective of our research is to introduce the application of a statechart-based model for the new generation multishuttle systems in which the shuttles can be moved between different tiers. The remainder of this paper is organized as follows. In Section 2 the architecture of the system and control structure is presented. We describe the multi-agent simulation model of miniload multishuttle order picking system in Section 3. Finally, details of the implementation and evaluation results are given in Section 4.

2. System description and control structure

Since throughput capacity is a concern with AS/RS, multishuttle systems have been developed for automated storage and retrieval of cartons or small parts in order to increase the throughput capacity of a system. This system comprises autonomous vehicles (shuttles), lifts, and a system of rails that facilitate movement of the vehicles in the x and y dimensions in a tier. In this new technology, the shuttles can be moved between different tiers by means of shuttle lifts. Figure 1 illustrates an example of a multishuttle with lift and one aisle rack system used in the storage area.

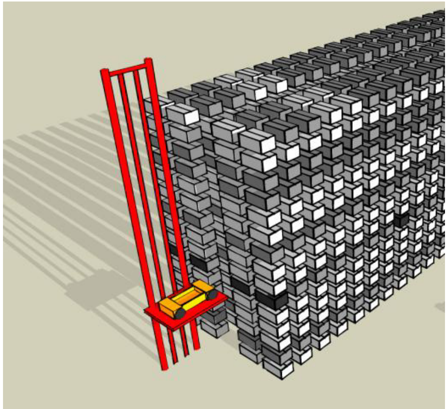

Fig. 1. The multishuttle automated storage/retrieval system

Figure 2 shows the structure of the miniload order picking system under study (mentioned in [13] and [14]). The order picking system can be classified as a part (or product)-to-picker system. Three main areas can be distinguished, namely the storage area, workstations, and conveyor. At the workstation, the picker picks a number of required items from the product tote based on customer order and puts them in an order tote. A conveyor loop is used to transport the product totes between the storage area and workstations.

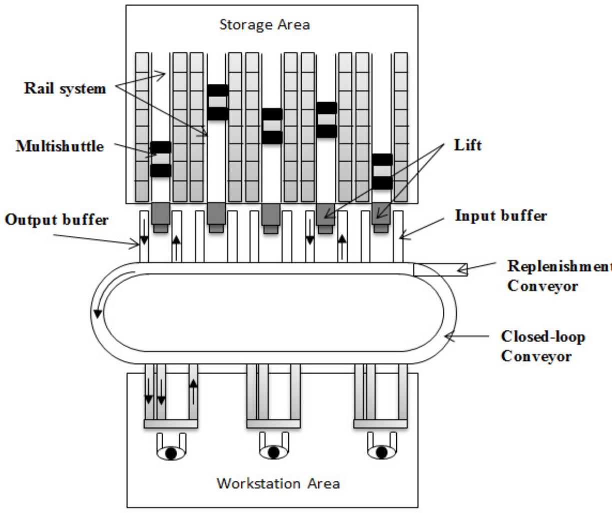

Fig. 2. Miniload multishuttle order picking system

The storage area consists of multiple levels of racking, shuttles, and buffer conveyors. It is essentially automated with multishuttles to serve two main functions, namely the storage and retrieval of product totes. Multishuttle system is an important goods to person material handling technology. Currently, one storage crane works all vertical levels within the storage aisle in conventional AS/RS. However, in next generation of multishuttle technology, each vertical level in the storage system is concurrently serviced by an autonomous