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A process algebra based simulation model of a miniload-workstation order picking system

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ABSTRACT

A modular discrete-event simulation model for a miniload-workstation (ML-WS) order picking system has been developed using a process algebra based simulation language. The proposed model is structured systematically such that distinctions between areas and operational layers can be clearly identified. Furthermore, subsystems and decentralized controls are applied in the model architecture. We demonstrate the modularity of the model by experiments, in which some control heuristics and the number of miniloads are altered. A realistic, industrial scale distribution center is used as the reference case for the simulation study. The resulting model architecture allows easy implementation of various system structures, design parameters, and control heuristics.

1. Introduction

The state-of-the-art technology in material handling systems has turned automated storage/retrieval systems (AS/RS) into common practice for distribution centers. An AS/RS is a comprehensive material handling system that typically comprises storage racks, storage/retrieval cranes, input/output (I/O) locations, and conveyors. The system is able to handle the storage, retrieval, and transportation of unit loads without interference of human operators. A large variety of system options for AS/RS is currently available in the industry. Recently, Roodbergen and Vis [1] provided a thorough overview of AS/RS systems.

In this paper we discuss a special class of AS/RS namely the *end-of-aisle systems* with *totes* as the unit loads. In such an end-of-aisle AS/RS, *product totes*, which contain items belonging to the same Stock Keeping Unit (SKU), are retrieved from the storage racks and are sent to the order picking workstation. At the workstation, an operator picks the required amount of items from a product tote and puts them into another tote, known as the *order tote*. Afterwards, the product tote is sent back to the storage rack if the tote is not empty. This system is also referred to as the miniload-workstation order picking system.

Most of the literature on AS/RS simulation is directed towards performance analysis. One of the earliest of such studies was done by Houshyar and Chung [2] who analyzed the performance of a small AS/RS warehouse under different scenarios. Lee et al. [3] conducted a simulation study in a larger scale AS/RS warehouse with rail-guided vehicles (RGVs) to determine the strategy that yields the optimal number of RGVs, the utilization of the crane, and the maximum throughput of the system. Potrč et al. [4] considered the performance analysis of a multi-shuttle AS/RS. Meller and Mungwattana [5] investigated the effect of dwell-point strategy for a highly utilized AS/RS.

Typically, simulation models are exclusively created for specific, pre-defined system configurations. In this case, altering the system structure (for example adding/subtracting the number of aisles, cranes, order picking stations, *etc*) or design parameters (for example control heuristics, order pattern, replenishment policy, *etc*) may require much time and effort before the model is fully functional. Also, many simulation models are simplified such that model architecture and control structure become less of an issue.

Studies discussing the development of model and control structures for AS/RS are very limited. We argue, however, that model architecture and control structure are crucial for simulation studies of industrial scale AS/RS. After all, one of the main strengths of simulation in AS/RS research is to compare numerous designs, taking into account more design aspects in combination with

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control policies so as to obtain more information on good design practice [1]. For this purpose, a profound model architecture and control structure are needed.

In this paper we propose a novel approach towards building a simulation model for a comprehensive miniload-workstation order picking system based on *process algebra*. The contribution of this study is twofold. First, we show the applicability of a process algebra based simulation language, χ (Chi), in modeling a realistic, industrial scale miniload-workstation order picking system. Second, we propose a modular model architecture with regards to system structure and design parameters.

The remainder of this paper is organized as follows. The miniload-workstation system under study is described in Section 2. In Section 3 we provide some related works on detailed modeling of AS/RS using Petri net. Section 4 provides a brief overview of process algebra and the language χ. Subsequently, the overal architecture of the proposed simulation model is presented in Section 5. An example of modeling using χ is explained in Section 6. Section 7 provides experiments to show the modularity of our model. Finally, Section 8 concludes the paper.

2. Description of the ML-WS system

The miniload-workstation order picking system elaborated in this study is based on an existing distribution center. In Section 2.1 we present the physical structure, while in Sections 2.2 and 2.3 we describe respectively the storage and retrieval, and the item picking. Fig. 1 shows the overal structure of the system.

2.1. Physical structure

The miniload-workstation order picking system can be divided into three areas, namely *miniloads*, *workstations*, and *conveyors*. Miniloads provide temporary storage spaces for product totes. At the workstation, items are picked from product totes and put into order totes. Conveyors connect the miniload area to the workstation area, and the other way around, for moving the product totes.

Miniloads are automated storage racks equipped with cranes to serve two functions, namely the storage and retrieval of product totes. Each miniload consists of two single-deep racks with a single crane in the middle to access product totes. Each crane is capable of holding up to four product totes simultaneously. The cranes move horizontally along the aisle between the racks, while the holder of product totes move vertically to store or retrieve the totes. There are five miniloads present in the system and a total of 31 250 storage locations for product totes.

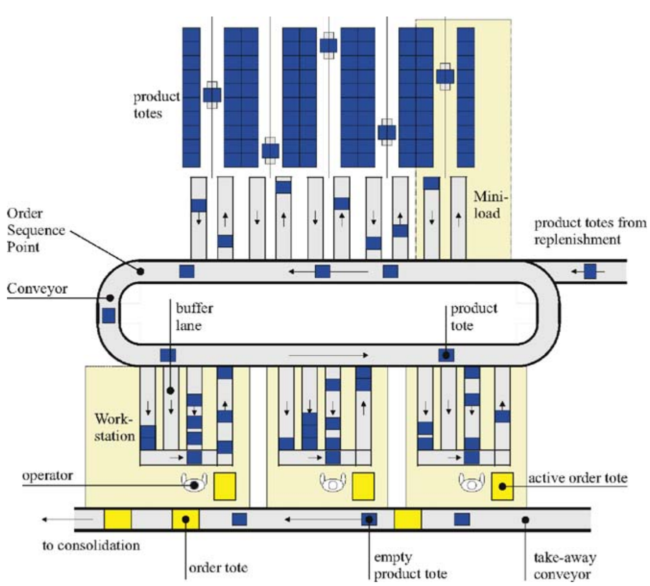

Fig. 1. Miniload-workstation order picking system.

Each of the three workstations in the system consists of three input buffers and one output buffer (see Fig. 1). There are maximal three suborders active at the same time at a workstation, and thus maximal nine suborders are active in the whole workstation area. An operator works on one suborder at a time, putting all items picked from the product totes belonging to one suborder into the order tote(s). The operator is not allowed to start working on the next suborder when not all items for the current suborder have been picked.

The central conveyor loop transports product totes from the miniload area to the workstation area, and the other way around. As there is only a limited number of positions on the conveyor, only product totes that have successfully reserved a position are allowed to enter the conveyor.

The operation of the miniload-workstation order picking system is triggered by orders that enter the system at any time. An order consists of several suborders. Each suborder can contain up to 316 order lines. An order line represents an SKU type and the required amount of items for that SKU. In total, 1624 SKUs are handled in this order picking system. Three main operations in the system are *storage*, *retrieval*, and *item picking*.

2.2. Storage and retrieval

Storage happens when a product tote needs to be kept temporarily in the miniload until it is required to fulfill an order. Two types of product tote exist, namely *replenishment* and *returning* product totes. A replenishment product tote is a new tote that is full of items. A returning product tote is a tote that has just finished being picked at the workstation but still contains some items left. This type of tote has a higher priority for fulfilling an order than a replenishment tote.

Retrievals take place at the miniload and start when the miniload controller has chosen the next suborder to be completed from a list of all arriving suborders. The chosen suborder is further divided into jobs, which specify the SKU type and the required number of items to be picked. These jobs are then assigned to the five miniloads. When a miniload is assigned with a retrieval job, it reserves a number of product totes until the required quantity of items is covered by the items in the reserved tote(s). Once a product tote is reserved for a job, items in that tote can only be used to fulfill that particular job and may not be used for other jobs. The reserved totes are retrieved by the miniload cranes and are put on the output buffer of the miniload. The totes wait until they get access to the central conveyor loop to be sent to one of the workstations. Note that the inventory position (IP) of each SKU is continuously updated. IP serves as the base for the replenishment process, that is, ordering additional items from the suppliers. In this system, an order-up-to level replenishment policy (s, S) is used (see [6]).

Two queues can be distinguished for the miniload operation. *Storage* queue q_s is a physical queue at the miniload input buffer, while *retrieval* queue q_r is a virtual queue of totes at the miniload controller. The trigger for storage or retrieval action is either $q_s \geq 4$ or $q_r \geq 4$. That is, the miniload crane waits until a batch of four totes is formed. However, if after a delay of 120 seconds (a so-called *time out*) no batch of four totes has been formed either in q_s or q_r, then a storage or retrieval action will still be triggered.

The decision on which of the two actions is executed depends on the position of the miniload crane at that moment. Two positions are possible, namely *inside* and *outside* the miniload racks. When the miniload crane is inside the racks, then it is ready to retrieve (Fig. 2(a)). Otherwise, if the miniload crane is outside