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Design of an enhanced multi-aisle order-picking system considering storage assignments and routing heuristics

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ABSTRACT

Order-picking is the activity to retrieve items from the shelves to fulfill customers' orders. Order-picking is one of the most costly operations in warehousing accounting for 50–75% of total operating costs. This paper presents a novel model that is motivated by the normative order-picking algorithm known as "bucket brigades" to address multiple aisles in warehouses where workers have finite walk-back velocities and are allowed to pass successors. In order-picking operations, the majority of the previous research works have applied bucket brigades over a single-line (serial) system. The contributions of this research work are as follows. (1) A summary of an updated literature review of bucket brigades using a state-of-the-art-matrix. (2) A novel multi-aisle order picking model motivated by the normative single-aisle bucket brigade, which represents a more comprehensive and realistic scenario in order fulfillment warehouses. (3) A comparison between the single-line and multi-aisle models in order to analyze the difference in performance in terms of average system utilization, order cycle time and throughput. (4) A sensitivity analysis of different parameters and scenarios in order to identify the best routing heuristic, storage assignment and order type that maximizes utilization, minimizes cycle time and maximizes throughput in multi-aisle order picking systems. The results of the simulation studies are reported and analyzed. The proposed model is flexible and easily scalable to include other real-life warehousing considerations.

1. Introduction

Order-picking refers to the operations where items are retrieved from shelves to fulfill customer orders. It accounts for 50–75% of total operating costs of a warehouse [1]. Thus, maximizing the throughput of an order picking system has the effect of relieving some of the operating costs. Bucket brigades is a viable solution as it yields a high throughput and has been implemented in a multitude of functions particularly in order-picking and assembly operations.

Bucket brigades have effectively emerged into a functional management model with several applications in industry since the first time the concept was introduced by Bartholdi et al. [2]. The simplicity of this model, its self-balancing nature and independence from managerial supervision serves to its practicality and makes it a desirable option to use in manufacturing, warehousing, and assembly operations. Since the normative bucket brigades model was introduced; it has been predominantly represented as a single line. A few papers modified the normative bucket brigades model and presented hybrid forms of bucket brigades suitable for practical industrial applications [3–6]. However, there is a need for scholarly research of order-picking bucket brigade systems in a multi-aisle warehouse, which is a more representative scenario in real life operations.

Potential limitations of the normative bucket brigade system are blocking and the assumption of negligible walk-back time. Blocking tends to increase the average cycle time and the infinite walk-back velocity is an assumption that may skew the estimation of cycle time for large warehouses. This paper presents a multi-aisle order-picking model inspired by the normative single-aisle bucket brigade. This novel multi-aisle model overcomes these limitations by allowing passing and considering finite walk-back velocity. The proposed model allows modeling real-life scenarios in warehouses. For a fair comparison, the single-line model (used as a benchmark) has the same considerations. Additionally, the multi-aisle model extends the backward rule of the normative model so that workers do not have to maintain their relative positions when looking for more work. This extended rule is expected to result in reduced average cycle time, increased average system utilization and increased average throughput.

After testing the performance of the multi-aisle order-picking model against the single-line model in terms of average system

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utilization, cycle time and throughput in phase I; we will study how management's storage assignment and routing heuristics affect the average system utilization, cycle time and throughput of a multi-aisle order picking system in an order fulfillment warehouse in phase II. To the best of our knowledge, the impact of storage and routing policies on the performance of a multiple-aisle order picking system has not been studied.

This paper is organized as follows: Section 2 summarizes the related literature and presents a state-of-the-art-matrix which highlights all the literature related to bucket brigades. Section 3 discusses the single-aisle and multi-aisle model rules and assumptions. Section 4 explains the methodology which is divided into two phases: (1) comparison of the single-line versus multi-aisle models and (2) sensitivity analysis of the multi-aisle model. Section 5 examines the simulation results and presents an optimization technique based on Pareto efficiency condition to find the non-dominated solutions. Finally, Section 6 presents concluding remarks, managerial implications and future research directions.

2. Literature review

The idea of bucket brigades was inspired by the Toyota Sewn Production Management System (also known as TSS) production lines in the 1970s, registered mark of Aisin Seiki Co. Ltd. (www.aisin.com) [7–9] where the workers were sequenced from slowest to fastest, and were independent of where they exactly began [2].

Bartholdi and Eisenstein [7] discussed the idea of bucket brigades in detail, how the deterministic model works, and the dynamics of the workers. It was found that when the workers are arranged from slowest to fastest according to their work velocities, the hand-off points between two consecutive workers converge to a fixed point [7]. This is the self-balancing feature of bucket brigades.

There have been several papers that have discussed bucket brigades under various scenarios and applications. Bratcu and Dolgui [10] present a literature review with descriptions on the different mathematical modeling assumptions made in research and discuss several real-life applications. Quader and Castillo-Villar [11] present an updated literature review in the form of a state-of-the-art matrix which shows the different categories that bucket brigades can be split into as shown in Fig. 1. The matrix has been split into four main categories. The basic model category corresponds to introductory papers which discuss the normative model and the dynamics of it. The extensions of bucket brigades category consists of different dynamics and scenarios the normative bucket brigades model can be applied to. The hybrid models of bucket brigade category includes bucket brigades models which have been modified and enhanced using concepts from other types of models. Finally, applications category consists of papers that discuss real-life applications of bucket brigades.

One area of interest is the behavior of bucket brigades in a stochastic setup. Bartholdi et al. [12] have discussed the concept of stochastic work content and found using simulation that with an increase in the number of discrete stations, the stochastic model behaves very similar to the deterministic one.

Categories	Basic Model	Extensions of bucket brigades									Hybrid forms of bucket brigades			Applications
Subgroups / Year		Asymptoptic behavior of 2-3 worker model	Stochastic models (introducing random work content, other variability etc)	Hybrid dynamic systems	Testing convergence condition	Passing/ blocking scenarios	Introduction of new worker	Analysis of hand-off points	Finite walk-back velocity	Conditions that maximize throughput	In-tree assembly	Zoned	Cellular	
1995	Bartholdi et al.													
1996	Bartholdi & Eisenstien													
1999		Bartholdi et al.								Bartholdi et al.				
2001	Bunimovich		Bartholdi et al.	Bratcu et al.	Bratcu et al.									Bartholdi et al.
2002				Bratcu	Bratcu		Munoz & Villalabos							Anderson et al.
2005	Lim		Lim	Bratcu & Dolgui		Lim					Lim			Bartholdi & Eisenstien
														Bratcu & Dolgui
2006	Parthasarathi		Parthasarathi		Hirotani et al.	Hirotani et al.					Bartholdi et al.			
						Armbruster & Gel								
2007			Bartholdi et al.		Bartholdi et al.	Armbruster & Gel	Armbruster & Gel							
2008								Koo et al.						
2009			Bartholdi et al.		Bartholdi et al.	Bartholdi et al.		Guromoorthy et al.	Bratcu & Dolgui	Lim & Yang		Koo		
					Hirotani et al.									
2010			Bartholdi et al.			Hirotani et al.	Hirotani et al.			Hirotani et al.				
						Bartholdi et al.								
2011													Lim	
2012										Webster et al.			Lim	Lim

Fig. 1. State-of-the-art matrix [11].

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