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Mixed-width aisle configurations for order picking in distribution centers

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ABSTRACT

Space required for the order picking area and labor required to perform the picking activity are two significant costs for a distribution center (DC). Traditionally, DCs employ either entirely wide or entirely narrow aisles in their picking systems. Wide aisles allow pickers to pass each other, which reduces blocking, and requires fewer pickers than their narrow-aisle counterpart for the same throughput. However, the amount of space required for wide-aisle configurations is high. Narrow aisles utilize less space than wide aisles, but are less efficient because of the increased likelihood of congestion experienced by pickers. We propose a variation to the traditional orthogonal aisle designs where both wide and narrow aisles are mixed within the configuration, with a view that mixed-width aisles may provide a compromise between space and labor. To analyze these new mixed-width aisle configurations, we develop analytical models for space and travel time considering randomized storage and traversal routing policies. Through a cost-based optimization model, we identify system parameters for which mixed-width aisle configurations are optimal. Experimental results indicate that annual cost savings of up to $48,000 can be realized over systems with pure wide or narrow aisle configurations.

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1. Introduction

A vital operation in a distribution center (DC) is order picking, the fulfillment of customer orders by retrieving customer requested items from storage locations. Order picking is arguably the most expensive operational activity constituting upwards of 50% of a DC's total operating costs (Tompkins, White, Bozer, & Tanchoco, 2003). Additionally, the layout of the picking area is critical to efficient operations and customer service (Coyle, Bardi, & Langley, 1996). In the ongoing quest to maximize profits, decision makers would naturally look to their order picking system (OPS) for any opportunity to increase efficiency and lower costs. One such opportunity, which ultimately leads to a cost effective OPS, comes in the form of an optimally designed picking area.

Designing an optimum OPS for a DC depends on several system parameters, such as aisle layout, storage system configuration, storage policy, picking method, and picking strategy. From an aisle layout standpoint, traditional DCs utilize either entirely wide or entirely narrow aisles in their picking systems. Wide aisles allow pickers to pass each other, reducing blocking and requiring fewer pickers to meet the required system throughput (orders/hour or items/hour). The space required for wide-aisle configurations is, however, relatively high. Narrow aisles utilize less space than wide aisles, but are less efficient because of the high likelihood of congestion experienced by pickers. Space required for the picking area and labor required to perform picking are, therefore, two significant costs for a DC's OPS. Through our conversations with warehouse managers we have observed that traditional approaches focus on minimizing either space (when the cost of land is high and the cost of labor is low) or labor (when the cost of land is low and the cost of labor is high), instead of integrating the two objectives.

In the past few years alternate aisle arrangements have been proposed that improve upon the traditional layout of the picking area. The Fishbone and Flying-V layouts designed by Gue and Meller (2009) potentially offer higher throughput or reduced costs by adding non-horizontal (or vertical) cross-aisles. These designs are beneficial to unit-load warehouses where only one item is picked during a pick tour, but do not offer significant improvements when picking a batch of orders resulting in multiple items per pick tour. For such OPS, we propose a variation to the traditional orthogonal aisle designs where both wide and narrow aisles are mixed within the system (see Fig. 1). This specific layout incorporates both narrow- and wide-aisle sections (A–E) in each of the four aisles (1–4). We anticipate that the mixed-width aisles may provide a good compromise between space and labor; i.e., less blocking compared to pure narrow aisles due to the ability of pickers to pass each other in the wide sections and less space compared to pure wide aisles due to the inclusion of narrow sections.

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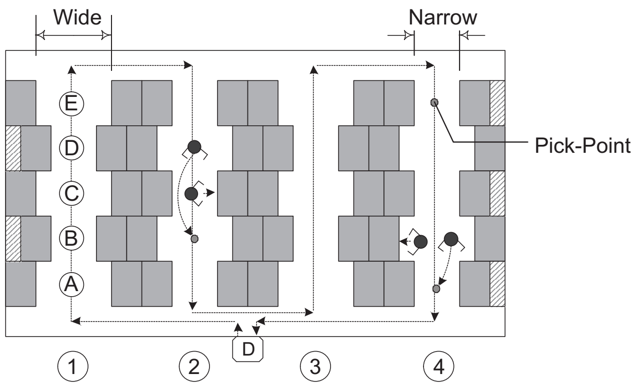

Fig. 1. Mixed-width aisle configuration.

Through this research we evaluate the potential savings in total cost that could be realized through the use of mixed-width aisles. Our research is of significance to OPS designers and managers because it not only provides general analytical models that can be used to determine the optimal aisle width (whether wide, narrow, or mixed), but it also helps compare the three alternatives.

The remainder of this paper is organized as follows. We begin by reviewing existing research in Section 2 and develop rules to identify feasible mixed-width aisle configurations in Section 3. In Sections 4 and 5, we discuss our analytical space and throughput models. We present an optimization model and a solution approach for identifying the optimal aisle configuration in Section 6. Section 7 discusses our experimental results and Section 8 offers managerial insights. We summarize our findings in Section 9.

2. Related research

Extensive research has been performed in the area of order picking system design and operation. Rouwenhorst et al. (2000) discussed order picking design and control problems in terms of long, medium, and short term decisions such as sorting systems for long term, layout, equipment and workforce capacity for medium term, and workforce assignment for short term. In the situation where the probability of visiting every aisle for one or more picks is close to 1.0, traversal routing policy is close to optimal under randomized storage policy (Petersen & Aase, 2004). Roodbergen and Vis (2006) developed a model to optimize the layout for a warehouse's order picking area while minimizing the average distance a picker traveled. This model was based on fixed routing policies and found that for high pick densities, the traversal routing policy was best suited for layouts with an even number of aisles. The review article by Gu, Goetschalckx, and McGinnis (2007) identified order picking planning problems relating to batching, routing and sequencing, and sorting and provided various decision support models and solution algorithms to aid in the design process. De Koster, Le-Duc, and Roodbergen (2007) indicated that most current research points at travel as the component which takes up the majority of a picker's time, and as such, continued to discuss layout designs, storage assignments, zoning, batching and routing methods in terms of minimizing distances. Roodbergen, Sharp, and Vis (2008) considered systems that utilized cross-aisles and developed a model that minimized a picker's travel distance by optimizing the layout of one or more blocks of parallel aisles. This model was developed for systems that employed a randomized storage policy and a traversal routing policy.

A critical factor that could affect the total travel time is picker congestion, typically modeled as picker blocking. Blocking is attributed to either the inability of the pickers to pass each other in the aisle (because the aisles are narrow) or not being able to pick at a pick-column when someone else is picking there. The former is referred to as *in-the-aisle blocking*, while the latter is referred to as *pick-column blocking*. Gue, Meller, and Skufca (2006) were the first to evaluate the impact of varying pick densities on in-the-aisle blocking in a picking system that was comprised of pure narrow aisles. They found that as the pick density increased, or picking became busier, congestion decreased. Skufca (2005), a co-author on Gue et al. (2006), extended these blocking models by developing analytical expressions to estimate blocking with k workers traveling at an infinite speed in a continuous loop and picking at most one stock keeping unit. Pan and Shih (2008) investigated picking operation performance in a system that involved multiple pickers in a warehouse. Using their proposed throughput model, they found that a random storage policy generally utilizes the picking area more uniformly (as compared to a policy that places less frequent items in more distant locations), thus increasing throughput.

Parikh and Meller (2009) developed analytical models which estimated picker blocking in systems with aisles wide enough for passing. They considered two cases, deterministic pick time (where only one SKU is picked at a pick-column) and non-deterministic pick time (where one or more SKUs are picked at a pick-column), and concluded that blocking is significantly less in wide aisles than in narrow aisles. For narrow aisles with non-deterministic pick time, Parikh and Meller (2010a) indicated that blocking experienced by pickers could actually be a concern as the system gets busier. Using these models, Parikh and Meller (2010b) developed a cost-based optimization model to determine the optimal height of a one-pallet-deep storage system for order picking systems that employ person on-board order picking equipment (e.g., an order picker truck).

Hong, Johnson, and Peters (2012a) argued that decreasing travel length does not guarantee a shorter retrieval time due to picker blocking. They subsequently developed a route selecting order batching model to solve large scale order batching problems in multi-picker systems. Building upon their previous work, Hong, Johnson, and Peters (2012b) developed an integrated batching and sequencing procedure for narrow aisle systems that minimizes both travel distance and time blocked. Experimental results showed that the consideration of blocking in their models offered substantial benefits and played a vital role in maximizing picker utilization. Recently, Hong, Johnson, and Peters (2013) revisited the Markov chain modeling framework used previously in the literature, and were able to derive closed-form expressions for blocking for the case when walk speed is infinite.

Pan and Wu (2012) argued that previous studies on the evaluation of the throughput time that measure order picking efficiency by travel distance are only adequate for single picker operations because congestion never takes place in such systems. Realizing that blocking can be an issue in multiple picker systems, they developed a throughput model for a picker-to-parts narrow aisle system accounting for the likelihood of picker blocking. They concluded that the concentration of high demand items in certain aisles inevitably causes congestion in a multiple picker environment, significantly affecting the efficiency of the picking process. In another work, Pan, Shih, and Wu (2012) addressed the storage assignment problem in a picker-to-parts narrow aisle system. They presented a storage assignment policy that improves the order picking efficiency by considering congestion resulting from multiple pickers in a warehouse.

While current literature discusses optimal storage and travel policies, very little literature exists that addresses optimal aisle-width, and none that addresses the notion of mixed-width aisles within a single picking area. We expect to fill this gap by proposing this novel aisle configuration and developing analytical models for space and travel-time. Additionally, we present an optimization