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Batch picking in narrow-aisle order picking systems with consideration for picker blocking

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ABSTRACT

This paper develops strategies to control picker blocking that challenge the traditional assumptions regarding the tradeoffs between wide- and narrow-aisle order picking systems. We propose an integrated batching and sequencing procedure called the indexed batching model (IBM), with the objective of minimizing the total retrieval time (the sum of travel time, pick time and congestion delays). The IBM differs from traditional batching formulations by assigning orders to indexed batches, whereby each batch corresponds to a position in the batch release sequence. We develop a mixed integer programming solution for exact control, and demonstrate a simulated annealing procedure to solve large practical problems. Our results indicate that the proposed approach achieves a 5–15% reduction in the total retrieval time primarily by reducing picker blocking. We conclude that the IBM is particularly effective in narrow-aisle picking systems.

1. Introduction

Most distribution centers (DCs) operate under constant pressure from management to reduce costs and increase efficiency. According to a recent warehouse operations survey (Napolitano, 2008), the warehousing industry has three major sources of cost: inventory, capital investment, and order processing. Tradeoffs between these sources of cost are common. For example, rising inventories often force warehouses to store more goods in less space (Gue et al., 2006; Napolitano, 2009). Narrow-aisle picking systems are one alternative to increase space utilization with minimal investment costs, but the narrow-aisle characteristic can actually increase DC operational costs related to order picking time due to both longer routes and more congestion (Gue et al., 2006). Small order sizes exacerbate the problem because they require more trips. Congestion in the form of picker blocking has traditionally been difficult to control in order picking systems (OPS), often causing significant operational performance loss (Gue et al., 2006; Parikh and Meller, 2010). An OPS can be designed with wide aisles to create less blocking, or can be operated using zone picking, with each zone containing a single picker. However, additional space, labor, or planning requirements can negatively affect both of these solutions.

To our best knowledge, there are no control policies for batching that explicitly quantify the effects of both travel distance and congestion, nor does the academic literature address policies to trade off travel distance and time blocked. The two objectives of this paper are: (1) develop an order batching framework to directly mitigate both travel distance and time blocked; and (2) present a practical solution procedure to solve the integrated batching and sequencing problem. We describe a new batching framework that includes the sequencing problem formulated as a mixed integer program (MIP). Since the formulation can only be solved optimally for small scale problems, we also develop a simulated annealing heuristic to solve large scale problems.

The remainder of the paper is organized as follows. Section 2 briefly reviews related studies. In Section 3, a concise batching framework to handle blocking is developed. The framework considers a picking area with one-way aisles and uses insights from flow-shop scheduling problems to identify strategies to reduce picker blocking. Section 4 develops an indexed batching framework to address in-the-aisle picker blocking. Section 4 also addresses the sequencing of batches, the extension to multiple aisles, and the effects of a picker retrieving multiple batches within the same pick wave. Sections 5 and 6 formulate a MIP and develop a simulated annealing heuristic approach. Section 7 summarizes the experimental results and notes several important insights. Section 8 concludes this paper.

2. Literature survey

When warehouse space is limited, *narrow-aisles*[1] are a common design characteristic. However, narrow-aisles can create congestion

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[1] A typical example of narrow-aisles in Napolitano and Gross & Associates (2003) is 8 feet wide, which makes two-way traffic impossible. A typical regular-aisle is 12 feet wide.

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depending on the picking equipment used. To alleviate congestion, alternative OPS configurations or order picking strategies, such as wide-aisles OPS or zone order picking, can be used when feasible (De Koster and Yu, 2008). If picker blocking is a concern in the narrow-aisle setting, yielding at aisle entrances, rerouting, and distance-based batching strategies are the only solutions currently available in the literature (Gue et al., 2006; Hong et al., 2012; Zhang et al., 2009). We review the previous studies and classify them based on three modeling methodologies: (1) analytical models; (2) routing methods; and (3) order batching. We focus on methods that directly address picker blocking.

Gue et al. (2006), Hong et al. (2010), and Parikh and Meller (2010) introduce analytical models to quantify narrow-aisle picker blocking. They determine the relationship between throughput and pick density to demonstrate the significance of picker blocking. The results indicate that batch picking strategies in narrow-aisle OPS are advantageous when the pick density is either very low or very high (Gue et al., 2006). Parikh and Meller (2010) and Hong et al. (2010) find significant picker blocking in narrow-aisle OPS when the variation of the pick density is high. Hong et al. also use simulation models to determine efficient batch formations under various batching algorithms, storage policies, and sorting strategies.

There are a few studies about controlling or reducing picker blocking while routing. Ratliff and Rosenthal (1983) present a polynomial-time method to optimally solve the order picking problem when the objective is to minimize travel distance. Hall (1993) surveys routing heuristics for practical purposes, and concludes that S-shape and largest-gap strategies are reasonable strategies for minimizing travel distance. However, these studies only attempt to minimize travel distance and do not address additional travel distance or time delays due to picker blocking. Gue et al. (2006) discuss practical routing methods to avoid picker blocking, e.g., allowing a trailing picker to pass while the leading picker unloads collected items, or forcing a blocked picker to exit the current aisle and use an empty aisle to continue to traverse the pick area when significant blocking is expected. Zhang et al. (2009) include the identification and sizing of alternative paths in the layout design problem.

Ruben and Jacobs (1999) suggest that some implementations of batch picking increase picker blocking; however recent studies show the possibility of less picker blocking in a batch picking situation (Gue et al., 2006; Hong et al., 2012). In general, most of the literature on batching algorithms ignores picker blocking or considers only a single order picker (De Koster et al., 1999; Gademann and Van de Velde, 2005; Gademann et al., 2001; Ho and Tseng, 2006; Hsu et al., 2005; Pan and Liu, 1995; Won and Olafsson, 2005). Ruben and Jacobs (1999) show the relationship between the batching algorithm and the storage policy, indicating that it can increase congestion, picker blocking, and delays. Gue et al. (2006) introduce an industry batch picking case with less picker blocking when pick density is very high. A distance-based batching algorithm using a route-packing based order batching procedure (RBP) in Hong et al. (2012) produces less picker blocking as an auxiliary benefit, but does not explicitly control picker blocking.

3. Problem definition

3.1. Narrow-aisle order picking system and batch picking

We consider a narrow-aisle OPS where pickers circumnavigate one-way aisles to retrieve items from shelves and place them on a cart. When an order picker has no items to retrieve in a particular aisle, the aisle can be skipped to shorten the travel distance, provided that the unidirectional characteristic of aisles is maintained. The order size is relatively small compared to the cart capacity; thus, consolidating many orders into one trip ("batch picking") is implemented to improve order picking throughput. Each item in an order is stored in only one pick location. A sort-while-pick strategy is used so that the size of a batch is constrained by the number of orders that will fit on the cart. Other sorting strategies are discussed in Section 7.1.

3.2. Multiple pickers and in-the-aisle picker blocking

In general, multiple pickers gather items for a set of orders received prior to their order picking shift, i.e. wave picking. A picker completing a trip through the picking area returns to the original starting position and begins picking a new batch without delay. When multiple pickers work in an OPS, they will encounter congestion while travelling and accessing pick faces. A narrow-aisle layout encounters additional congestion created by the no passing policy (Gue et al., 2006).

In a narrow-aisle OPS, picker blocking is classified into two types as depicted in Fig. 1. First, when two-way traversal of a narrow-aisle is possible, a deadlock occurs if a picker enters an aisle in which another picker is already present and moving towards the entering picker (Fig. 1a). To avoid deadlocks, the approaching picker can be ordered to wait before entering, but then becomes idle. One-way traversal routing with a dedicated travel direction in each aisle is popular for avoiding this type of idleness and deadlock.

Second, congestion can occur when pickers are moving in the same direction and the trailing picker would like to overtake the former picker (Fig. 1b) or when the trailing picker's next pick-location is occupied by the former picker so that the trailing picker is blocked until the former picker moves. Gue et al. (2006) call this "in-the-aisle picker blocking". Blocking at the aisle entrance due to occupancy by the picker at the first pick face is also called in-the-aisle picker blocking. Our paper assumes that all pickers travel at the same speed (Parikh and Meller, 2010), which is generally a valid assumption in practice, particularly with the use of mechanical order picking equipment. We develop a batching and sequencing procedure that explicitly incorporates in-the-aisle picker blocking into the retrieval time.

3.3. Performance criterion considering picker blocking

Our goal is to *minimize total retrieval time*, i.e., maximize throughput. The total retrieval time is expressed by the sum of the cart loading (LDT) and unloading time (ULDT), pick time (PT), walk time (WT), and delay time (DT) of all batches. Hence, the following objective is minimized:

$$Min \sum_{\text{batches}} (\text{LDT} + \text{ULDT} + \text{PT} + \text{WT} + \text{DT})$$

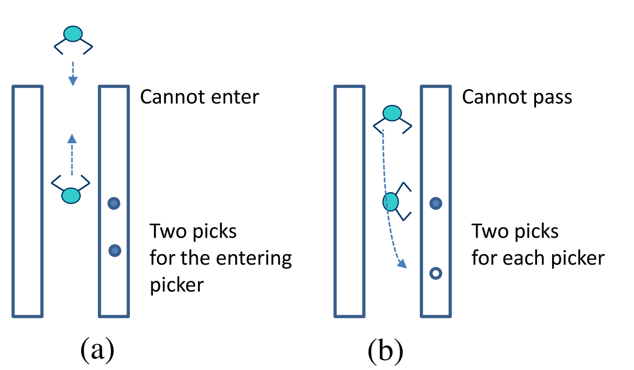

Fig. 1. Types of picker blocking in a narrow-aisle OPS: (a) aisle entrance picker blocking; and (b) in-the-aisle picker blocking.