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Using a hybrid approach based on the particle swarm optimization and ant colony optimization to solve a joint order batching and picker routing problem

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ABSTRACT

Order picking is the most costly activity in a warehouse, because it is labor-intensive and repetitive. However, research on order picking has mainly focused on either order batching or picker routing alone; both of which are NP-hard problems. Therefore, considering the characteristics of existing logistics centers, namely, that order products and items are few but diverse, picking vehicles in logistics centers are limited, and batch amounts have upper limits in carrying capacity, this study proposes an efficient hybrid algorithm for solving the joint batch picking and picker routing problem to determine the batch size, order allocation in a batch, and the traveling distance. The core of the hybrid algorithm is composed of the particle swarm optimization (PSO) and the ant colony optimization (ACO) algorithms. PSO finds the best batch picking plan by minimizing the sum of the traveling distance. ACO searches for the most effective traveling path for each batch. The experimental results show that the hybrid algorithm is more efficient in terms of both solution quality and computational efficiency as compared with the known optimal solution and the current practices in industry. This method would improve picking performance and allow customer demands to be met rapidly.

1. Introduction

Warehouse management is a primary issue for logistics companies. Warehouse activities include the movement of all goods related to purchases, storage, inventory, picking, distribution processing, shipping, and delivery. Among these activities, picking is one of the key operations that incur high labor cost as well as one of the most complex actions (Hwang et al., 1988; Rana and Vickson, 1991). Therefore, the development of efficient picking methods and the optimization of picking operations have significant effects on the overall operational efficiency of the warehouse. Order picking is the process in which the items that were ordered by customers are selected from the warehouse. These items are then distributed and other related work is performed. Picking involves five actions: pre-action, picking, searching, transport, and others. Tompkins et al. (2003) indicated that transport time accounts for 50% of the total picking time, whereas searching time for products accounts for 20%. Thus, the majority of studies have focused on how to reduce the transport and searching times.

Order picking arises because incoming articles are typically received and stored in (large-volume) unit loads while internal or external customers order small volumes (less-than-unit loads) of different articles (Henn and Wäscher, 2012). A customer order is composed of order lines, where each order line consists of a particular article (item type) and the corresponding requested quantity. Those order lines which should be processed together are summarized in a pick list. This list may enclose the order lines of a single customer order (pick-by-order) or of a combination of customer orders (pick-by-batch). Moreover, the list guides the order pickers through the picking area. The tours of the order pickers (who start at the depot, proceed to the respective storage locations, and return to the depot) are usually determined by routing strategies (Henn and Schmid, 2011). Order picking is a warehouse function dealing with the retrieval of articles from their storage locations in order to satisfy a given demand specified by customer requests (Petersen and Schmenner, 1999).

Studies that aim to reduce the picking time in the warehouse can be categorized into those that focus on better storage space planning, order batching, or the optimization of picking paths

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(de Koster et al., 2007). Better storage space planning can efficiently reduce the time expended on picker searching, classification, and moving, thereby increasing the picking efficiency. Using the order batching method, items in an order with proximate storage spaces are placed in the same batch. Thus, pickers do not have to travel long distances to pick up goods for the same order. The order batching method increases staff utilization and reduces labor costs for picking. Pickers adopt various picking paths when performing picking operations. Consequently, different picking sequences and paths are used, which influence the picking path distances and picking efficiency. The majority of studies have focused on the use of order batching and picking path optimization to reduce picking time, thereby increasing picking efficiency. However, order selection influences picking path planning. Most studies have resolved only order batching or optimal routing methods. Won and Olafsson (2005) proposed a two-phase heuristic algorithm that was combined from joint order batching and sequencing problems to resolve the scheduling architecture. A small-sample experiment was used in their study for comparison. Although its calculation was comparatively complex, substantial improvements were gained.

Order batching methods divide selected orders into a set of batches. Each order is assigned to a specific batch and then picked. When an order requires the picking of a large quantity of products, each product is treated as a single batch and can be picked independently. However, when a number of orders have a small quantity of products, these small orders can be picked simultaneously, thereby reducing the overall picking time. Hwang et al. (1988) considered the order batch processing problem as a clustering problem. Three similarity measures were used to develop six cluster classification algorithms and to resolve order batching problems. The experimental results indicated that merging orders with higher degrees of similarity significantly improved picking efficiency. Gademann et al. (2001) addressed the problem of batching orders in a parallel-aisle warehouse, with the objective to minimize the maximum lead time of any of the batches. They presented a branch-and-bound algorithm to solve this problem exactly.

Picker routing is a traditional traveling salesman problem (TSP). Assuming that there are n locations; when pickers know the distances between each storage space, each storage space should only be visited once to pick up goods. Pickers plan how to visit each storage space using the shortest path before returning to the starting point. Expressing this process using a mathematical model involves $n(n+1)/2$ decision variables and $2n+2$\widehat$n$ constraints. The goal of picker routing is to plan the order pickers to complete the order picking operations in minimum travel distance (Hsieh and Huang, 2011). As the number of locations increases, the solution time to obtain the optimal solution is intractable. A number of heuristic methods to obtain the shortest picking distances are presented (Charles and Petersen, 1997; Roodbergen and de Koster, 2001). Charles and Petersen (1997) considered the returning characteristic, such that pickers enter the aisle to collect the items required from the aisle, exit from where they entered, and travel to the subsequent aisles in succession. de Koster et al. (2007) applied the midpoint method, wherein pickers enter from one end of an aisle to pick goods, and turn to another aisle in succession as each aisle is finished. The proposed largest gap method involves comparing the distances between the goods that must be picked in the aisle and the bottom aisles on both sides. The shorter path is then chosen. If the distance between the goods and the two bottom aisles is shorter than the shortest distance between goods, pickers immediately turn around.

Dorigo et al. (1996) compared the ant colony system (ACS), genetic algorithm (GA), and simulated annealing heuristic algorithms using the traveling salesman problem library (TSPLIB) international sample questions. Their obtained results with the ACS were superior to those of other algorithms. The errors of their optimal solution were less than 3.5%. Won and Olafsson (2005) proposed two efficient heuristic algorithms to resolve both order batching and picking order problems. Although this method necessitates complex calculations that increase the implementation time, the performance was exceptional. Kulak et al. (2012) developed a cluster-based tabu search algorithm, which uses cluster analysis methods to determine the correlation for the products that must be picked for each order based on their storage space proximity. The tabu search method was then used for path improvement to obtain a near-optimum path.

Previous research on order picking has mainly focused on either order batching or picker routing alone; both of which are NP-hard problems. In this study, considering the characteristics of existing logistics centers, namely, that order products and items are few but diverse, picking vehicles in logistics centers are limited, and batch amounts have upper limits in carrying capacity, we propose an efficient hybrid algorithm for solving the joint batch picking and picker routing problem to determine the batch size, order allocation in a batch, and the traveling distance. The core of the hybrid algorithm is composed of the particle swarm optimization (PSO) and the ant colony optimization (ACO) algorithms. In the first stage, PSO determines the order in which batches are to be picked. In the second stage, the ACO algorithm identifies the shortest picking distances for each path and sums them to provide iteration adaptation values for the first-stage PSO. A combination of near-optimum order batches and picking orders is then obtained.

The rest of the paper is organized as follows: Section 2 explains the joint order batching and picker routing problem. Section 3 formulates a mixed integer programming model. Section 4 develops a two-stage hybrid algorithm from PSO and ACO to obtain the near-optimal solution because of the computational complexity; Section 5 demonstrates the performance of the proposed two-stage algorithm through a computational study and the empirical data from real industries. Finally, Section 6 presents the concluding remarks.

2. Joint order batching and picker routing problem

Order numbers are high during picking operations in logistic centers. Products and items offered for order are complex and diverse to satisfy the demands of various customers. However, picking cars in logistic centers are limited. Batches are likewise limited by their carrying capacity, and picking cannot be completed at one time. Thus, we must consider order batch combination methods in this study. After grouping orders with items that are stored in proximate locations in the same batch, the picking of the said batch is performed to reduce the picking distances.

As shown in Fig. 1, the locations for items in Orders 3 and 4 are relatively near each other, similar to the locations for items in Orders 1 and 2. Suppose that the maximum carrying capacity, that is, the maximum number of orders that a batch can carry is three. In this four-order situation, picking can be performed in two batches. Order batching methods can be divided into two types. The first batching method involves placing Orders 1 into Batch 1, and Orders 2, 3, and 4 into Batch 2. The second batching method involves placing Orders 1 and 2 into Batch 1, and Orders 3 and 4 into Batch 2. Fig. 1 shows that the picking distances indicated by the second batching method are superior to those of the first batching method. Therefore, we need to design each batch combination to minimize the overall picking distances.

In addition to not exceeding the maximum batch carrying capacity, assigning each order to a batch while determining how to pick the batch is what we aim to resolve in this study. Therefore, the following problems are addressed in this study:

1. Determining order batching methods.
2. Determining picking order.

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