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An efficient hybrid algorithm for integrated order batching, sequencing and routing problem

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ABSTRACT

This study discusses the integrated order batching, sequencing and routing problem (IOBSRP) in warehouses. Distinguished from the past studies, a comprehensive nonlinear mixed integer optimization model is developed to simultaneously determine three decisions, including order batching, batch sequencing, and picker's routing, under the consideration of the minimum total tardiness of customer orders. The IOBSRP can be proven as a NP-Hard problem. Consequently, an algorithm integrating hybrid-coded genetic algorithm and ant colony optimization is developed to efficiently tackle the proposed nonlinear IOBSRP model. The hybrid-coded genetic algorithm is responsible for searching the near-optimal solutions of order batching and batch sequencing decisions by the hybrid-coded chromosome design and the evolutionary processes. For the picker routing decision of each batch, the ant colony optimization adopts the shortest path strategy to calculate the minimum of total travel time and its completion time. In order to exhibit the merits of the proposed algorithm, illustrative examples and sensitivity analysis were performed with various demands, batch capacity, and items per order. The experimental results show that the proposed hybrid algorithm has more advantage in the light of solution quality as compared with multiple-GA and due-date first approach.

1. Introduction

Warehouse operations have a strong influence on total logistics costs which include both investment and direct operational costs. Particularly order picking is seen as the most labor intensive warehouse operation as it often causes 60–70% of the total operating cost of a warehouse. In other words, the efficiency of order picking operations mainly impacts the operational performance and the cost effectiveness of a warehouse (Kulak et al., 2012). Therefore, the development of efficient picking methods and the optimization of picking operations have significant effects on the overall operational efficiency of the warehouse (Hwang et al., 1988; Rana and Vickson, 1991).

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). Picking involves five actions: pre-action, picking, searching, transport, and others. Among these components, the transport time is of outstanding importance, since it consumes the major proportion (at least 50%) of the total processing time (Tompkins et al., 2003). 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).

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

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studies have focused on the use of order batching and picking path optimization to reduce picking time, thereby increasing picking efficiency (de Koster et al., 2007).

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.

In practice, customer orders have to be completed by certain due dates. In distribution warehouses, e.g. due dates have to be met in order to guarantee the scheduled departure of trucks, which deliver the requested items to the external customers (Gademann et al., 2001). In material warehouses which provide the input to a production system (internal customers), on-time retrievals from the warehouse are vital in order to avoid production delays. In these cases, instead of measuring the quality of a solution by means of the total processing time, the batching of customer orders into picking orders has to be evaluated with respect to the tardiness of the customer orders (Elsayed et al., 1993). The tardiness of a customer order is defined as the positive difference between the completion time of a customer order and its due date. The point in time when the order picker returns from his/her tour to the depot after having collected all items is called (batch) completion time. The completion time of a customer order is identical to the completion time of the batch the order is assigned to. The composition of the batches, the sequence according to which the batches are processed and the corresponding release times (i.e. the points in time when the various batches are started) determine whether and how due dates can be met. The described situation gives rise to the following problem, order batching and sequencing problem (OBSP) (Henn and Schmid, 2011).

Hwang et al. (1988) dealt the order batch processing problem as a clustering problem. In their study, the items required for picking the orders were defined as attribute vectors. 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. Tsai et al. (2008) considered an order batching and sequencing problem where the total costs (depending on the total travel time) have to be minimized and both earliness and tardiness are penalized. The batching problem is solved by means of a genetic algorithm. In their implementation, a solution is represented by a sequence of integers. This sequence contains the indices of the batches to which the items requested in the customer order have been assigned. In order to determine the fitness of the generated solutions, a traveling salesman problem is solved by another genetic algorithm. The authors permit the splitting of orders; therefore, the items required by a single customer order may be collected on different tours. The order batching problem considered in Henn and Wäscher (2012) deals with the question of how a given set of customer orders should be combined into picking orders such that the total length of all picker tours necessary for all of the requested items to be collected is minimized. For the solution of this problem the authors suggest two approaches based on the tabu search principle. The first is a classic tabu search (TS), and the second is the attribute-based hill climber. In a series of extensive numerical experiments, these approaches are benchmarked against other solution methods put forward in the current literature. It is demonstrated that the proposed methods are superior to the existing methods and provide solutions which may allow distribution warehouses to operate more efficiently.

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. 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. Won and Olafsson (2005) proposed two heuristic algorithms to resolve both order batching and picking routing problems, to increase the efficiency of logistics centers, and to promptly respond to consumer demand. The first algorithm was used to determine order batching. The second algorithm was used to determine the picking sequence. They used a simple example to indicate that although this method necessitates complex calculations that increase the implementation time, the performance was exceptional. 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 isle in succession as each isle 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. Tsai et al. (2008) presented a multiple-GA method. In the first stage of the GA, the order batches that are required for picking are identified. The second stage of the GA determines the shortest picking paths for these batches. The paths are then used to resolve complex batch picking problems in the warehouse systems. 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 by the end of the iterations.

Amorim et al. (2013) studied the joint production and distribution planning at the operational level. They proved the importance of lot sizing for make-to-order systems when perishability is explicitly considered. The value of considering lot sizing versus batching is further investigated per type of production scenario. Overall, results indicate that lot sizing is able to deliver better solutions than batching. The added flexibility of lot sizing allows for a reduction on production setup costs and both fixed and variable distribution costs. Adacher and Cassandras (2014) extended a stochastic discrete optimization approach so as to tackle the lot-sizing problem in manufacturing systems. The lot sizing determines the number of parts batched together for production. They utilize the queueing approach that evidences the existence of a convex relationship between batch size and waiting time (including processing). In this paper, they considered the surrogate method and the stochastic comparison algorithm. Noblesse et al. (2014) studied the lot sizing decision in a production/inventory setting, where lead times are determined by a queueing model that is linked endogenously to the orders placed by the inventory model. Assuming a continuous review (s, S) inventory policy, they develop a procedure to obtain the distribution of lead times and the distribution of inventory levels, when lead times are endogenously determined by the inventory model.

In the past literature, most research on order picking has mainly focused on either order batching or picker routing alone; both of which are NP-Hard problems. However, in this study, we discuss the integrated order batching, sequencing and routing problem (IOBSRP) in warehouses. A comprehensive nonlinear mixed integer optimization model is developed to simultaneously

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