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MILP formulations and an Iterated Local Search Algorithm with Tabu Thresholding for the Order Batching Problem

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ABSTRACT

In this work we deal with the Order Batching Problem (OBP) considering traversal, return and midpoint routing policies. For the first time, we introduce Mixed Integer Linear Programming (MILP) formulations for these three variants of the OBP. We also suggest an efficient Iterated Local Search Algorithm with Tabu Thresholding (ILST). According to our extensive computational experiments on standard and randomly generated instances we can say that the proposed ILST yields an outstanding performance in terms of both accuracy and efficiency.

1. Introduction

We consider the Order Batching Problem (OBP) which is shown to be $\mathcal{NP}$-hard by Gademann and Van de Velde (2005). Given both a list of customer orders and an order picking routing policy, the OBP deals with constructing batches of customer orders such that the total travel distance of all pickers is minimized. Order picking is the process of retrieving products from their storage locations in a warehouse in order to satisfy customer requests. Among several warehousing functions order picking is known to be the most labor intensive and costly one (Drury, 1988). Order picking costs are estimated to be as much as of 65 percent of the total warehouse operating expenses (Tompkins, White, Bozer, & Tanchoco, 2003).

Broadly speaking, order-picking systems can be grouped in two categories according to the material handling equipments used: picker-to-parts systems and parts-to-picker systems. In picker-to-parts systems, order pickers travel along the warehouse and retrieve the requested items. On the other hand, in parts-to-picker systems the requested items are handled and transported by automatic storage and retrieval systems (AS/RSs) to order pickers (de Koster, Le-Duc, & Roodbergen, 2007; Wäscher, 2004). Particularly, there exist two types of picker-to-parts systems: low-level and high-level picking systems. In low-level picking systems, the pickers travel along the aisles in order to pick the requested items from the storage bins or racks. In high-level systems, the pickers drive a truck or crane to reach the pick locations. In this work, we address low-level picker-to-parts picking systems employing human pickers. de Koster et al. (2007) have claimed that 80 percent of all order-picking systems in Western Europe are of this type.

In order picking systems, the service level basically consists of order delivery time, order integrity and accuracy. Order delivery time is closely related with the travel time of the picker. As pointed out by Tompkins et al. (2003) almost half of the order pickers' time is wasted while traveling. Although other activities, such as order searching, picking and setup for the routes, require a considerable amount of the picker's time (Hall, 1993; Petersen, 1997; Roodbergen & de Koster, 2001), the travel activity is seen as the most time consuming one (de Koster et al., 2007). Furthermore, the travel time has a substantial role in customer satisfaction since the shorter the travel time is; the sooner the requested items are ready for shipping. Hence, among several objective functions that can be taken into consideration the minimization of pickers' total travel distance, which will be also addressed in this paper, is the most widely considered one (de Koster et al., 2007).

In the literature, several order picking routing policies have been introduced: traversal (Goetschalckx & Ratliff, 1998), return, midpoint, largest gap (Hall, 1993), composite and optimal (Ratliff & Rosenthal, 1983) routing policies. Petersen (1997) has argued that the traversal, return and midpoint routing policies are simpler than the largest gap, composite and optimal routing policies. According to the experiments by Petersen (1997), the optimal routing policy is the winner at the expense of its disadvantages such as discernible pattern and the routes with backtracks. Indeed, complex routing policies may yield congestion problems when several pickers share long, narrow and two-way aisles. Simple routing policies may arise to be useful especially for complex order picking systems with many pickers.

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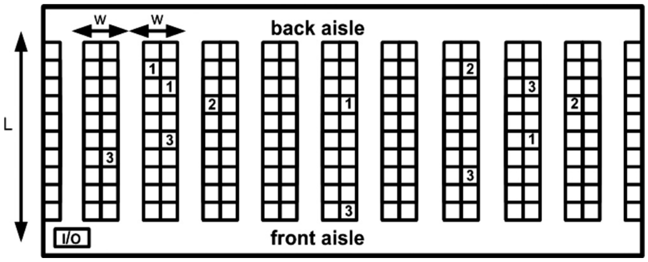

Fig. 1. Layout of a rectangular warehouse.

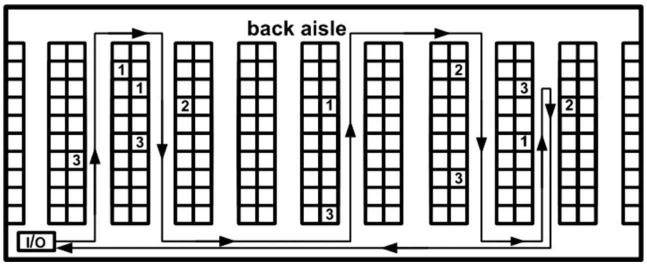

Fig. 2. Traversal routing policy.

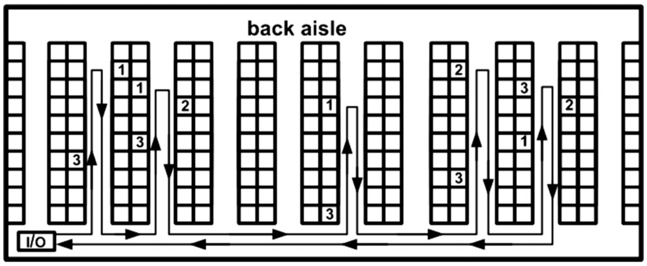

Fig. 3. Return routing policy.

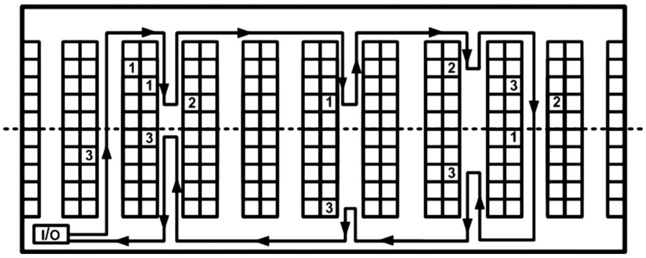

Fig. 4. Midpoint routing policy.

For the sake of clearness, Fig. 1 presents an illustration of one of the warehouse layout types considered in this work. Here, we have totally three orders, i.e. order 1, order 2 and order 3 which include 4, 3 and 5 items, respectively. Note that, the location of these items are indicated with order numbers. The shape of the warehouse is assumed to be rectangular with parallel storage. *L* denotes the distance between the front aisle and the back aisle and *w* stands for the horizontal distance between aisles. The warehouse totally incorporates 10 parallel aisles which are numbered in increasing order starting from the leftmost aisle. In this configuration, the I/O point is situated in front of the leftmost aisle, i.e. the aisle number 1. The picking area has the capacity to store 200 items. Each order must be assigned into a batch and each order consists of at least one item. We assume that the locations of items are known a priori and a sufficient number of pickers with homogenous capacities and constant travel speeds are available at the I/O point. The amount of items which belong to the orders assigned into a batch should not exceed the picker's capacity. We assume that order splitting is not allowed and the quantity to be picked up of each item is one unit. Lastly, we assume that the horizontal distance within stocking aisles is negligible and the picker does not need an additional time for entering and leaving the aisles.

We concentrate on the OBP considering traversal, return and midpoint routing policies. In the traversal routing policy the picker starts from the I/O point, traverses each aisle entirely where an item is required to be picked up and returns the I/O point. The picker enters an aisle from one end and leaves from the opposite end. In case the number of aisles that must be visited is odd then the picker enters the rightmost aisle which must be visited and returns whenever it retrieves the item situated in the deepest location. Note that, only in that case the picker does not need to traverse the aisle entirely. In the return routing policy, a picker starts from the I/O point and proceeds along the front aisle. The picker enters each aisle where an item has to be picked up and travels along that aisle as far as the deepest location where an item must be retrieved, then turns back and leaves that aisle from the same end. The midpoint method divides the warehouse into two areas by drawing a horizontal line. The order picker traverses entirely the leftmost aisle which it has to pick up an item and then reaches the back aisle. The items which are located in the back half of the warehouse are accessed from the back aisle. Next, the picker traverses the rightmost aisle entirely and enters the front aisle. Then all items situated in the front half of the warehouse are reached from the front aisle before the picker returns the I/O point. Figs. 2–4 depict the routes of a picker serving all three orders considering traversal, return and midpoint policies, respectively.

The motivation of this study is two-fold. First, we develop Mixed Integer Linear Programming (MILP) formulations for the OBP considering traversal, return and midpoint routing policies. To the best of our knowledge, these are the first MILP formulations for these three variants of the OBP. Second, we suggest an efficient Iterated Local Search Algorithm with Tabu Thresholding (ILST) for the OBP. We compare the performance of the MILP formulations and the ILST with the savings algorithm, named as C&W(ii) in the work by de Koster, Van Der Poort, and Wolters (1999) and the iterated local search heuristic, namely the ILS-2, devised by Henn and Wäscher (2012). We have also adopted the parametric enhancement of the saving algorithm proposed by Paessens (1988) in the context of the Vehicle Routing Problem. According to our computational experiments, we have observed that the proposed ILST outperforms the ILS-2 in terms of both accuracy and efficiency.

The rest of this paper is organized as follows. Section 2 introduces a brief literature survey on the OBP. Next, in Section 3 we give three MILP formulations of the OBP considering traversal, return and midpoint routing policies, respectively. The ILST approach is presented in Section 4, followed by the computational results in Section 5. Finally, concluding remarks are given in Section 6.

2. Literature survey

To the best of our knowledge, there are a few studies addressing the exact solution of the OBP. In their early work, Gademann, Van den Berg, and Van der Hoff (2001) have designed a branch and bound algorithm for the order batching with the objective of minimizing the maximum travel time of the pickers. The OBP has been formulated as a Set Partitioning Problem (SPP) by Gademann and Van de Velde (2005) where the authors have devised a branch and price algorithm and they have reported the optimum solution of problems with up to 32 customer orders. Recently, Henn and Wäscher (2012) have claimed that after generating all feasible batches they were able to solve OBP instances with up to 40 customer orders by solving the SPP formulated by Gademann and Van de Velde (2005). We should point out that a disadvantage of this approach is that it requires extensive efforts in the preprocessing phase to generate all feasible batches.

For a revised version of the OBP considering the traversal routing policy, Bozer and Kile (2008) have proposed a Mixed Integer