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Using a TSP heuristic for routing order pickers in warehouses

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ABSTRACT

In this paper, we deal with the sequencing and routing problem of order pickers in conventional multi-parallel-aisle warehouse systems. For this NP-hard Steiner travelling salesman problem (TSP), exact algorithms only exist for warehouses with at most three cross aisles, while for other warehouse types literature provides a selection of dedicated construction heuristics. We evaluate to what extent reformulating and solving the problem as a classical TSP leads to performance improvements compared to existing dedicated heuristics. We report average savings in route distance of up to 47% when using the LKH (Lin–Kernighan–Helsgaun) TSP heuristic. Additionally, we examine if combining problem-specific solution concepts from dedicated heuristics with high-quality local search features could be useful. Lastly, we verify whether the sophistication of 'state-of-the-art' local search heuristics is necessary for routing order pickers in warehouses, or whether a subset of features suffices to generate high-quality solutions.

1. Introduction

In most modern warehouses, order picking is one of the main activities to be performed. The process typically involves the collection of stock keeping units which are demanded by customers, from a number of locations in the warehouse. Order picking accounts for no less than 55% (Bartholdi and Hackman, 2006) to 65% (Coyle et al., 1996) of the total operational warehouse costs. Furthermore, research has shown that order picking represents up to 60% of a warehouse's total job package (Drury, 1988) of which more than 55% is related to travelling (Bartholdi and Hackman, 2006). As such, warehouse design (including decisions on where the stock keeping units (SKUs) are to be located within the warehouse) and efficient policies for picking (allocation of items to pickers) and routing (determination of the route of a single picker) within warehouses hold a large potential for cost savings. Previous work has shown that picking and storage strategies are closely interrelated, implying that decisions on the storage policy have a major influence on order picking performance (see e.g. Petersen, 1999; Petersen and Aase, 2004). Although we will discuss the impact of two relatively straightforward storage policies on order picking performance, this paper mainly focuses on the actual order picking process. For an extensive overview of storage policies, we refer to De Koster et al. (2007).

For a given storage and picking policy, this is when all SKUs have been assigned to storage locations and all items to be picked are already allocated to one or more pickers, one still needs to calculate the order picker's route through the warehouse. So far, procedures for this particular routing problem have been analyzed for four types of warehouse systems (see Gu et al., 2007). The most common type of order picking warehouse system, the conventional multi-parallel-aisle system (multiple-block warehouse), is the subject of this research. Other variants are the automated storage and retrieval systems (AS/RS), both the man-on-board AS/RS and the unit-load AS/RS, and the carousel systems. The heuristics developed for the operational process of routing order pickers in multi-block warehouses are fairly simple construction heuristics which construct a feasible solution, without attempting any improvement by means of local search or metaheuristic search. Based on the impressive results obtained by (meta)heuristic search for reducing distance in the classical travelling salesman problem (TSP) and other traditional routing problems such as the vehicle routing problem (VRP) and the vehicle routing problem with time windows (VRPTW), further research on routing order pickers seems appropriate (for extensive literature reviews on metaheuristic search for the VRP(TW), see e.g. Bräysy and Gendreau, 2005a,b; Golden et al., 2008).

In this respect, Makris and Giakoumakis (2003) propose to use a TSP-based *k*-interchange method for the problem of routing order pickers in single-block warehouses. Their procedure is compared to the well-known S-shape heuristic (see Section 2) and outperformed the latter in seven out of eleven examined cases. Renaud

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and Ruiz (2007) discuss the results of a study performed on the product location and order picking activities in a Canadian distribution centre of a snack-selling company. Prior to the study, order pickers followed a predetermined route along a conveyor belt. The authors illustrate for this DC that solving a TSP in combination with using a modified storage policy could reduce order picking distances. Both studies clearly motivate the use of TSP algorithms for the order picking problems, although some questions still remain unanswered. Are the findings for routing in single-block or conveyor-equipped warehouses also valid in conventional multi-parallel-aisle warehouses, or does the adoption of problem-specific features make dedicated multiple-block order picking heuristics more efficient? How do the performances of TSP-based heuristic solution techniques compare to those of the dedicated heuristics (other than S-shape) that have been proposed in literature, and can they still be improved?

In light of the above, this paper aims at answering three research questions. First, we analyze whether a state-of-the-art heuristic for the classical TSP is able to outperform well-known dedicated heuristics for routing order pickers in conventional multiple-block warehouses (RQ1). We therefore reformulate the routing and sequencing problem of order pickers in conventional multi-parallel-aisle systems as a classical TSP and adjust an efficient TSP algorithm to meet the specific features of this routing problem. Secondly, we verify whether combining certain problem-specific solution concepts from dedicated heuristics with high-quality local search features could be useful in further improving the solution quality (RQ2). Thirdly, we evaluate if the sophistication of ‘state-of-the-art’ local search heuristics is necessary for routing order pickers in warehouses, or whether a subset of local search features suffices to generate improved results (RQ3).

The remainder of this paper is structured as follows. In the next section, we give a problem description and briefly review related work. In Section 3, we discuss the methodology to answer the research questions. Computational experiments are presented in Section 4, while Section 5 provides conclusions and suggestions for further research.

2. Problem description and literature review

Conventional multi-parallel-aisle warehouse systems are characterized by their rectangular layout (Fig. 1). Stock keeping units are stored in longitudinal pick aisles. Cross aisles are located perpendicular on the pick aisles and allow for an efficient movement from one pick aisle to the next. By assumption cross aisles do not contain any stock keeping units. Furthermore, two adjacent cross aisles determine a so-called block. A warehouse with n cross aisles therefore has $n-1$ blocks. The parts of pick aisles which are located within a certain block are the block’s subaisles. The main decision to be made in the order picking process is designing the route that the picker has to follow on its way through the warehouse, starting and ending at a depot. This depot can either be centrally or decentrally located.

The problem of sequencing and routing order pickers in conventional multi-parallel-aisle systems classifies as a *Steiner* TSP (see e.g. Cornuéjols et al., 1985; Roodbergen, 2001; De Koster et al., 2007). The aim of the Steiner TSP is finding a minimum-length Steiner tour, where each non-Steiner node is visited at least once. The problem can be represented by a graph $G = (N, A)$ with node set $N = S \cup R$ and edge set A. Node subset $R = \{1,\ldots,n\} + \{0\}$ contains all n order items that need to be picked up in the warehouse, as well as the depot which is represented by node 0. Node subset $S = \{n+1,\ldots,n+p\}$ contains the Steiner nodes indicating all p “crossing nodes” between two or more aisles, where p equals the product of the number of cross aisles and the number of pick aisles in the warehouse. Edge set $A \subseteq R \times R$ represents all travel possibilities between order items and between order items and the depot. Fig. 2 illustrates the concept by means of a warehouse with five pick aisles and three cross aisles ($p = 15$) where 20 items and the depot location need to be visited ($n = 20$). Node subset $R = \{0,1,\ldots,19,20\}$ then contains all nodes that explicitly need to be visited at least once, since they are either an order item or the depot. The Steiner nodes in $S = \{21,22,\ldots,34,35\}$ do not necessarily have to be part of an order picker’s route. As a result of the special (rectangular) structure of the warehouse, they might, however, be visited while visiting nodes in R.

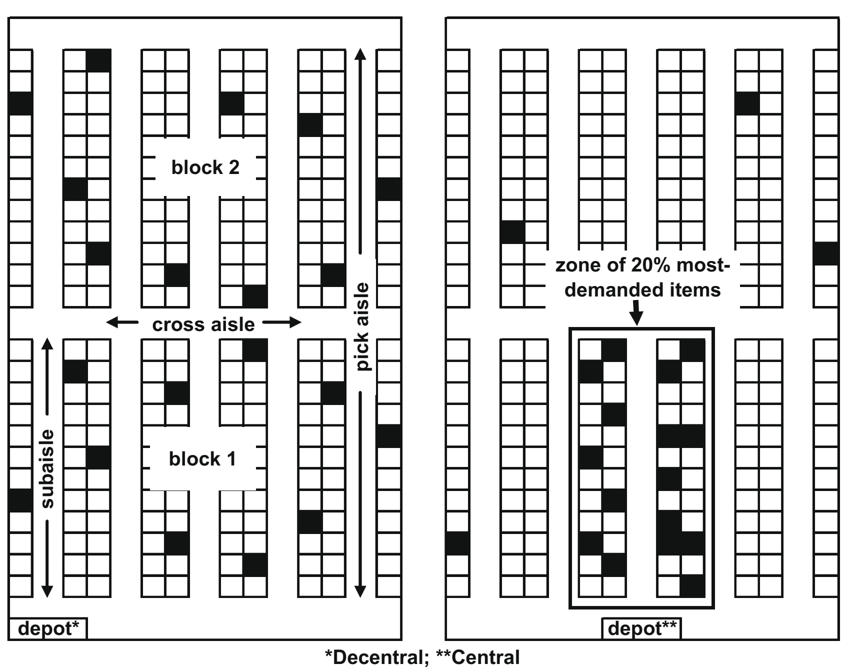

Fig. 1. Conventional multi-parallel-aisle warehouse system with random storage (left) and volume-based storage (right) policy.