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A tabu search approach to solving the picking routing problem for large- and medium-size distribution centres considering the availability of inventory and K heterogeneous material handling equipment

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ABSTRACT

This paper formulates and solves the picking routing problem for large- and medium-size distribution centres (DCs) considering a set of *n* products to be collected from *m* storage locations given a level of inventory and a fleet of heterogeneous material handling equipment. The problem is solved using a generic tabu search (TS) and two hybrid variations of the TS, called TS 2-Opt Insertion and 2-Opt Exchange. This paper makes a contribution to the scientific literature by modelling the availability of inventory and considering the existence of a fleet of heterogeneous material handling equipment in the problem. Numerical experiments were analysed with the split plot design, which made it possible to validate the problem and study the performance of the developed metaheuristics. In addition, a genetic algorithm and a simulated annealing were implemented as benchmark to assess the performance of the proposed hybrid tabu search metaheuristics. The statistical analysis showed that TS 2-Opt Insertion provided better performance than a generic tabu search, TS 2-Opt Exchange, a generic genetic algorithm (benchmark) and simulated annealing outperforming them by between 1% and 9.12%.

1. Introduction

Order picking is one of the most important operations of a distribution centre (DC) and warehouse [20,22]. The main goal of DCs is to serve the customers' demand at the lowest possible cost [14]. It must be noted that this operation accounts for between 55% and 65% of DC operating costs [7]. Order picking systems can be divided into two groups: manual and automated [16]. A manual order picker involves human operators on a large scale and heterogeneous material handling equipment (MHE) such as forklifts, order pickers and pallet jacks, among others [14]. On the other hand, automated order picking uses machines and robots as an AS (automated storage)/RS (retrieval system) [16].

In this paper, a picker-to-part system for large- and medium-size distribution centres (DCs) is represented. In this type of system, the order picker drives one of the heterogeneous MHE to pick products from their storage locations [10]. MHE is classified as heterogeneous because different types of MHE can have different capacities, travel speeds and lift heights. In addition, DCs can be categorized as large- and medium-size processes based on whether these have at least four aisles and two hundred storage locations [9,1,3,17]. The size of a DC has a direct impact on not only the design and management of the operations but also the identification and selection of the approach to solving the optimization model, making metaheuristics be an adequate technique for solving the corresponding problem of the logistic process. Indeed, quantitative models are chosen to solve problems such as order batching, slotting or picking routing problems. Based on the results in the scientific literature, it has been found that such optimization models have been implemented for sorting picking order batching or routing problems with approximately 40 storage locations, 40 order costumers and a picking list formed by a maximum of 20 prod-

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ucts in the DC or warehouse [15,11,13]. These authors prove that the optimization model generated long computational processing times due to the quantity of variables and constraints modelled. Therefore, these types of problems can be solved using metaheuristics such as the following: tabu search, genetic algorithm, and ant colony simulated annealing, among others [1,11,14,16,7]. Although metaheuristics cannot guarantee the optimal solution, for cases of large- and medium-size DCs, its implementation is necessary to obtain an adequate solution in the required timeslot.

According to Caron et al. [5] and Henn and Wäscher [14], a picker-to-part system can be divided into three sub-problems, i.e., the slotting (put-away) problem, the order batching problem and the picking routing problem. This paper focuses on the picking routing problem. Within the picking operation, the picking routing states the sequences for collecting the products from their storage locations in the shortest time possible [27]. Picking routing depends on several factors such as the warehouse layout, the storage policy, the inventory policy, the levels of storage location, the available inventory, the location of the depot, the types of products and the fleet of heterogeneous equipment [16,6]. This amount of factors of the problem increases the complexity of the modelling and its solution.

Most of the scientific literature does not consider factors such as the inventory policy, the available inventory, the types of products and the fleet of heterogeneous MHE. Only Daniels et al. [9] represent the inventory in their paper, although the other described factors are not modelled. Additionally, Albareda-Sambola et al. [1], Chen et al. [6] and Chen et al. [7] represent K homogeneous MHE (same load capacity and travel speed). However, these papers do not consider the inventory availability or the constraints among the MHE, the products to be picked and their storage locations. Furthermore, homogeneous MHE only execute horizontal movements between aisles.

The scope of our work covers the limitations noted above. We consider *K* heterogeneous MHE, different types of products, alternative storage locations and the inventory availability in a large- and medium-size distribution centre. This approach emerges as one of the first capable of integrating all of these factors in the scientific literature. Consequently, the aim of this paper is to formulate and solve the picking routing problem, in which a set of picking routes is simultaneously formed taking into account different types of products, the storage location (different height levels), the inventory availability and *K* heterogeneous MHE. This approach increases the ability to represent real operational conditions and also contributes with the modelling of inconstant operation times, which depend on the types of products, the height level of the storage location and the assigned MHE.

The paper proposes different tabu search approaches. The first approach is a generic tabu search, whereas the second is a hybrid tabu search that integrates two diversification strategies called 2-Opt Exchange and 2-Opt Insertion. It should be noted that the hybrid between metaheuristic tabu search and 2-Opt is a novel approach to solving this picking routing problem and has not been previously proposed in the scientific literature. The reasons for choosing tabu search as the metaheuristic to tackle the problem are due to its good performance and computational efficiency for solving other picking and DC problems (e.g., [9,16,14,13]. In addition, a genetic algorithm and simulated annealing are implemented to compare the performance of the hybrid tabu search metaheuristics.

The remainder of the paper is organized as follows. Section 2 presents an overview of the literature related to the picking routing problem. In Section 3, we describe the problem and its formulation. In Section 4, three tabu search approaches to solving the problem are presented. Section 5 presents the experimental study, including its statistical analysis and discussion. Finally, Section 6 draws conclusions and suggests further research topics.

2. Literature review

This section presents a literature review that analyses the different approaches and characteristics to tackle the picking routing problem. The review presents the paper grouped into different sets according to the considered constraints and limitations. The main considered variations are as follows: i) the consideration of a fleet of K heterogeneous material handling equipment (MHE), ii) the consideration of setup and handling times, iii) constraints considering multilevel storage systems with *n* products, *m* storage locations and *K* heterogeneous MHE, and iv) the consideration of the availability of inventory.

Table 1 depicts the classification according to the previous specifications. In addition, the table include the type of solution approach.

First, it must be noted that none of the reviewed papers present a fleet of heterogeneous material handling equipment (MHE). Consequently, our paper fills this gap in the scientific literature.

Most of the papers consider only one MHE with or without consideration of the limited load capacity [23,9,28,11,16,13,2,8,19]. Only two papers present a fleet of homogeneous MHE (considering the same load capacity, travel speed and maximum height lift). It should be noted that a fleet of heterogeneous MHE can be formed by pallet jacks, truck lifts, and order pickers, among others, which can be used according to the picking operation requirements in a distribution centre (DC). Hence, the importance of representing a fleet of heterogeneous MHE in the picking routing problem is relevant, and its consideration becomes significant for the scientific literature on the picking routing problem.

The constraints that address a multilevel storage system by considering *n* products and *m* storage locations together with a fleet of *K* MHE have been partially tackled by Battini et al. [2] and Lin et al. [19]. These authors model a constraint between products and storage locations without taking into consideration the specifications of the available MHE (e.g., load capacity and maximum lift height, among others). However, the feasibility of a set of picking routes is commonly constrained by the capability of the MHE to retrieve products from storage locations considering constraints such as available load capacity and maximum lift height, among others. Consequently, these types of constraints linked to MHE availability are very relevant for real-world problems.

In the objective function of the picking routing problem, the setup and handling times are only taken into consideration by Rubrico et al. [26], Henn [11] and Chen et al. [7]. It must be noted that the handling time is critical in a picking operation because it typically depends on the characteristics of the products to be collected (e.g., weight and volume, among others), in addition to the height of the storage locations to be visited. In addition, the setup times represent the reality of the operation of many picking operations, including a set of actions to take previously to start the route.

Regarding the availability of inventory condition, it is only represented by Daniels et al. [9]. This condition is relevant because it conditions the feasibility of the picking routes. It is raised because, if there is no inventory available in the visited storage location, then the picking route will be unfeasible.

Although real picking systems should consider all of the considerations and constraints noted above, to the best of our knowledge, papers encompassing all of them have not been identified in the literature review. This situation is our main reason for conducting this research and formulating an entire problem that simultaneously takes into account a fleet of K heterogeneous MHE to pick *n*