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# A column generation approach to solve the Joint Order Batching and Picker Routing Problem including picker congestion

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## 1 Introduction

Order picking is one of the most important processes in warehouse operations and deals with the preparation of different customer orders. The tasks associated with the order picking process are usually performed by human operators who push a trolley around the warehouse to collect the required products. At the operational level, the two main decisions taken by managers are the batching of orders and the routing of pickers. The order batching problem (OBP) consists in determining the set of orders assigned to each picker. The picker routing problem (PRP) is to define the minimal distance tour to collect all the products of a given set of orders. In an integrated approach, the joint order batching and picker routing problem (JOBPRP) considers both decisions jointly and can be solved to optimality with a branch-and-cut approach [1]. In the literature, a common assumption is the non-existence of congestion produced by pickers. In this work, we propose to include the effect of congestion as a delay in the nominal travel times.

## 2 Modeling and solving the JOBPRP including picker congestion

We consider a warehouse with several parallel aisles, each of them divided into several sub-aisles. To quantify the delay produced by congestion, the planning horizon is divided into homogeneous time intervals, and the number of pickers visiting each sub-aisle is computed. If more than one picker visits a sub-aisle during the same time interval, all these pickers incur a delay in their travel time.

The delay function increases with the number of pickers. To mathematically formulate the problem, we propose an extended formulation in which variables (or columns) represent possible picking routes. Each column is associated with information about the total time and level of congestion in each visited sub-aisle at each time period.

To solve the model, a heuristic column generation approach is proposed. First, the resolution of the linear relaxation of the extended formulation is performed using a column generation algorithm. In each iteration, for a given set of columns, the restricted master problem is solved, and then a set of negative reduced cost columns are added by solving the dedicated pricing sub-problem. Once the relaxation is solved (there are no more negative reduced cost columns to add), the integer problem is solved with the columns obtained in the previous step, in order to provide an upper bound. The value of the linear relaxation is a lower bound, and we can thus report performance guarantee.

### 3 Pricing columns through a labeling algorithm

One of the most important components of the algorithm is the production of negative reduced cost columns with a pricing algorithm. In the case of the JOBPRP with congestion, using a commercial solver for pricing is not relevant since the non-linearity of congestion is difficult to model, and optimal solutions can be obtained in reasonable time only for very small size instances. The pricing problem can be formulated as a dynamic program, and in this work, we developed a label correcting algorithm to solve it. The principle of this algorithm is to associate a label to each feasible partial picker route. Each label has a set of attributes that indicate the consumption of different resources in the partial route: the total time including delays imposed by congestion, the collected items and orders, the arcs used in the route, and the congestion charge in the visited sub-aisles. We consider a graph where nodes represent the picking locations where items have to be collected, and arcs represent a shortest path in the warehouse to travel between the corresponding locations. To each node are associated the labels that represent a partial picker route ending at the corresponding location. The algorithm iteratively extends labels associated to a node to its successor nodes. At the end of the algorithm, we keep all labels associated to the end depot with a negative reduced cost. It can be noticed here that, contrary to usual label correcting algorithms we do not use dominance rules to eliminate labels because of the congestion aspect of the problem.

To evaluate the entire solving process, several experiments on instances from the literature were performed, and the relevance of the obtained solutions is discussed.

## References

- [1] Cristiano Arbex Valle, John E. Beasley, and Alexandre Salles da Cunha. Optimally solving the joint order batching and picker routing problem. *European Journal of Operational Research*, 262(3):817–834, November 2017.