Efficient Move Evaluation and Large Neighborhood Search Algorithm for Integrated Optimization of Order Picking Problems

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1 Introduction and related literature

Within warehousing activities, Order Picking (OP) is largely considered as the most resource-intensive. In manual picker-to-parts warehouses, where a walking human operator performs the picking, the OP activity alone represents 50-75% of the total operating costs [1]. Efficient solution methods have been developed for single OP planning problems, however, recent researches have highlighted the potential gains from integrating several level of decisions [3]. In this talk we study the *Picker Routing Problem* (PRP), which consists in finding a minimum length tour in a warehouse, and the integrated problems that jointly optimize other decisions with the PRP. The methodological results we introduce are generic and apply to all integrated problems where the objective is to minimize a function that is cumulative on aisle traversals (e.g., traveled distance, picking time). Among them, we test our methodology on the *Joint Order Batching and Picker Routing Problem* (JOBPRP) that aims at grouping customer orders in consolidated batches retrieved by a single route.

The OP literature uses two different modeling paradigms to design efficient algorithms. The most straightforward option models a picking route as a tour between the visited locations, as it is classically done in the routing literature. In this case, the elementary modeling unit is the *visit* to a location, and its position in a route. This approach benefits from the prolific literature on routing problems. The second option is to model a picking route as a succession of aisle traversals, thus exploiting *problem-specific knowledge* on the warehouse layout structure. The seminal work of Ratliff and Rosenthal (1983) [2] is the first to use the *aisle* as the elementary modeling unit, disregarding the visit order in a route, and introduces a polynomial-time *Dynamic Programming* (DP) algorithm for the PRP in a single block warehouse. It is important to emphasize that the two paradigms lead to very different models and algorithms. Nowadays, most mathematical-programming based methods with state-of-the-art results use the aisle modeling, for instance Wahlen ad Gschwind (2023) [4] for the JOBPRP. In terms of metaheuristics, however, most studies do not fully exploit problem-specific knowledge.

To the best of the authors knowledge, there exists no study aiming at designing efficient move evaluation using problem-specific knowledge for integrated OP problems. Since neighborhoods can get pretty complex for OP problems (i.e. several position inserted in a route, or several routes modified), the efficient computation of insertion costs is far from being a computationally easy task. In this talk, we aim at addressing this gap by introducing three main methodological contributions : *1.* A novel constructive heuristic for the PRP coined the *Aisle First Cross Second* (AFCS) heuristic. The AFCS provides upper and lower bounds for the route distance within a very reasonable time complexity. This heuristic is used as a surrogate objective function for move evaluation for integrated problems. *2.* A neighborhood exploration scheme that relies on several move underestimation and overestimation routines (including the AFCS bounds) to efficiently prune the neighborhood search. *3.* A generic Large Neighborhood Search (LNS) algorithm that is tested on benchmark instances from the JOBPRP literature with promising results.

2 Methodology

The AFCS is a 2-step heuristic that builds first the aisle traversals, then constructs the cross aisle traversals. Both steps are optimally solved, that is with the minimum cost increment. A lower bound for the PRP is derived from the first step of the AFCS heuristic, and the second step returns a valid solution, that is an upper bound. From these bounds we derive an approximation ratio for the heuristic that only depends on the geometry of the layout. Furthermore, we prove that the AFCS runs in linear time complexity.

Since exact move evaluation can be costly for integrated OP problems, we introduce a move underestimation and two overestimation procedures. The AFCS provides lower and upper bounds for the PRP, which can be used to evaluate moves. Furthermore we introduce an additional move overestimation procedure based on the dynamic programming algorithm of Ratliff and Rosenthal (1983) [2]. From these results, we propose a generic neighborhood exploration scheme that uses the bound information to efficiently prune dominated parts the search space.

A LNS algorithm is developed to evaluate the performances of the proposed neighborhood schemes on integrated problems. The algorithm uses several removal operators (i.e. random, related, and aisle removal) and several insertion operators (i.e. best element best insertion, random element best insertion, largest element best insertion and k-regret). An important feature that differs from LNS applied to the routing literature is the consideration of the *size* of a move. Indeed, inserting an order in the solution may modify add several visits in one route, so that ignoring move size leads to all the challenging elements being left in the pool for the end of the algorithm, when their insertion would be more challenging. The LNS algorithm is then enhanced by local search to improve its intensification capabilities.

3 Conclusion

Preliminary experiments on classical JOBPRP instances show very promising results. The main objective of this study has been met, as the algorithm performs a large number of LNS iterations within a limited computation time. Although our method does not quite reach the running times reported in [4], it proves to scale better on large instances with longer routes.

Références

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