Order picking problem: Exact and heuristic algorithms for the Generalized Travelling Salesman Problem with geographical overlap between clusters

Farzaneh Rajabighamchi; Stan van Hoesel; Christof Defryn
Maastricht University, School of Business and Economics
Department of Quantitative Economics
e-mail: {f.rajabighamchi; s.vanhoesel; c.defryn}@ maastrichtuniversity.nl

Within modern warehouses, identical items are often located in multiple locations throughout the warehouse to improve the efficiency of collecting customers' orders. Since only one of these locations needs to be visited to collect a specific item, the problem is modeled as a Generalized Travelling Salesman Problem (GTSP). GTSP is an extension of the traveling salesman problem (TSP) where the set of nodes is partitioned into clusters, and the salesman must visit exactly one node per cluster.
In this research, we apply the definition of the GTSP to an order picker routing problem with multiple locations per product. As such, each product represents a cluster and its corresponding nodes are the locations at which the products can be retrieved. The objective is to find the shortest tour in the clustered graph starting and ending at the depot such that exactly one node of each cluster is visited.
As all products are scattered throughout the warehouse, the product clusters are not separated geographically, which is a more general form of GTSP, and there exists only paper in the literature taking this aspect of the problem into account and assumes such a definition of clustering. To the best of our knowledge, the only research having considered both were proposed by [1]. The researchers highlight the importance of considering overlapping clusters due to their applications in modern warehouses with multiple picking locations for the same item. They propose a Conditional Markov Chain Search, which, based on a pool of heuristic components, automatically generates a meta-heuristic specifically for warehouse order picking. While this paper considers the topology of a warehouse to calculate the distance between items, it does not address various warehouse configurations. More specifically, their instance generator and computational results are based on a fixed grid and do not account for various warehouse sizes with numerous configurations of aisles and cross-aisles.
We propose an ILP formulation of the problem and present a heuristic solution method for obtaining high-quality pick tours. The heuristic is based on a variable neighbourhood search metaheuristic, embedded in a guided local search framework. Furthermore, in order to to illustrate the efficiency of the exact model and

the solution methods, we implemented them on different size benchmark problems from [2] and [3] consisting of 9 different scenarios: three different number of aisles (5,15,60), three different number of cross aisles (3,6,11) and three different number of products in the order (15,60,240).
All algorithms presented in this paper have been implemented in Java, and the ILP formulations have been solved with IBM CPLEX 22.1.0 with default parameters. The time limit for the exact algorithms has been set to 3600 seconds. Testing has been carried out on a Macbook Air with an Apple Silicon M1 chip and 16GB of RAM.
The computational results demonstrate that the proposed algorithm provide better solution quality compared to existing methods for solving GTSP in a shorter amount of time including on larger GTSP instances.
with the increase in cluster sizes and accordingly the instance sizes, our proposed MILP is not able to give us a feasible solution within the time limit of one hour. However, our meta-heuristic algorithm is able to solve the problem and give us a good solution in a very short time (for our biggest instance with 4800 nodes, the run time is 52.5 seconds which is less than one minute and it is incredibly fast). For the cluster size 1,2 and 5, our proposed MILP can provide optimal or feasible solutions but for the larger instances, the model is not able to give any solutions within 60 minutes. The other notable point in these tables is the comparison between our proposed MILP and the existing MILP in the literature. In average, the run time of our proposed MILP is 20% less than the other MILP in the literature, and the quality of the solutions generated by our MILP is in average 15% better than the existing MILP.
Comparing the solutions of GLS with VNS, we can see that implementing GLS and penalising the features of the solutions has an improvement of 15% in average and this percentage is higher for bigger instances compared to the small instances with 2 products in each cluster which this average improvement is 4%.
for the smaller cluster size (2), the Furthermore, in the smaller instances (cluster size 2 and 5) the run time of GLS is in average 80% less than the run time of VNS, and this value drops to 50% for larger instances with 10 and 20 products in each cluster. These numbers show the efficiency of our proposed GLS algorithm and its significant improvements both in run time and the quality of the solutions.

References

[1] Nalivajevs, O., & Karapetyan, D. (2019, September). Conditional Markov Chain Search for the Generalised Travelling Salesman Problem for Warehouse Order Picking. *In 2019 11th Computer Science and Electronic Engineering (CEEC)* (pp. 75-78). IEEE.

[2] Pansart, L., Catusse, N., & Cambazard, H. (2017). Exact algorithms for the order picking problem. *arXiv preprint arXiv:1703.00699.*

[3] Theys, C., Bräysy, O., Dullaert, W., & Raa, B. (2007). Towards a metaheuristic for routing order pickers in a warehouse. *Evolutionary methods for design, optimization and control*, 385-390.