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A hybrid local search method for the two-dimensional loading capacitated vehicle routing problem

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1 Introduction

The rapid pace of urban expansion and the continuous rise in consumer expectations have placed unprecedented pressure on modern logistics systems. Among the numerous challenges that arise in this context, the Two-Dimensional Loading Capacitated Vehicle Routing Problem (2L-CVRP) stands out for its complexity and practical relevance. This problem seamlessly combines two fundamental aspects of combinatorial optimization, vehicle routing and two-dimensional loading, thereby capturing the dual nature of real logistics operations.

We propose in this work a hybrid GLS-ALNS methodology to address the 2|UO|L version of the problem. The proposed GLS-ALNS method was evaluated on established benchmark instances from the literature and successfully achieved best-known solutions for the majority of test cases. Particularly, our approach identified 8 new best-known solutions, demonstrating its effectiveness in solving this complex optimization problem.

2 Problem description

Over the years, research on the 2L-CVRP has witnessed significant progress, with numerous studies addressing both its routing and packing aspects. Owing to the inherent combinatorial complexity of the problem, a wide spectrum of solution paradigms has been investigated, spanning exact methods [4], contemporary metaheuristics [3], and learning-based approaches [5]. This methodological diversity underscores the richness of the 2L-CVRP and its practical and theoretical relevance across both academic and industrial domains.

The 2L-CVRP is a combinatorial optimization problem with multiple facets that combines two classic fields in an attractive way: the Capacitated Vehicle Routing Problem (CVRP) and the Two-Dimensional Bin Packing Problem (2D-BPP). In addition to the classical CVRP constraints, each customer requests a set of rectangular items, where each item is characterized by its length and width. The goal is to determine a set of routes and an associated two-dimensional packing for each route that collectively minimize the total routing cost while considering a set of constraints like *Orthogonal loading*, where items must be placed on the vehicle's loading surface orthogonally, *Complete shipment*, where all items required by a customer must be loaded onto the same vehicle and *No overlap*, where all items assigned to a vehicle must be properly arranged on without overlap. We study in this work the 2|UO|L version of the problem, where the loading is restricted to be orthogonal and no item rotation is allowed. Also, there is no constraint on item positioning in the container, which means in practical cases that re-arrangements of the items in the vehicle at the customers' sites are allowed.

3 Solving approach

We propose a hybrid solution framework, which explicitly separates the routing and packing tasks while incorporating coordination and repair mechanisms. The method begins by generating good quality routes through an initial optimization phase inspired by the GLS approach of [1]. Subsequently, the main optimization phase is executed iteratively. At each iteration, a GLS step is first applied to optimize the routes, independent of packing constraints. This ensures that the resulting routes are promising in terms of travel cost and customer sequencing. Following route construction, two packing heuristics are applied in parallel to each route. Nonetheless, due to potential conflicts between routing and spatial constraints, the packing phase may occasionally fail, either because of insufficient space or suboptimal item grouping.

To handle cases where the packing heuristics fail, we apply a soft variant of the Best Fit heuristic to the affected routes. The goal is to include the maximum number of customers in the packing solution while preserving the route’s cost efficiency. Customers whose items cannot be accommodated are subsequently removed from their respective routes. We further incorporate an Adaptive Large Neighborhood Search (ALNS) repair phase, which applies repair operators to improve packing outcomes. This mechanism dynamically adjusts customer sequences or reassigns items across routes, guided by feedback from the packing feasibility checker.

We evaluated our approach on the standard 2L-CVRP instances originally generated in the work of [2]. The dataset comprises 180 instances, organized into five classes, each containing 36 instances. Our method matches the best-known solution for 167 instances and finds new better solutions for 8 instances. The improvements on a single instance starts from 0.28% and reaches 1.82%.

4 Conclusion

We present in this work a hybrid method to address the 2L-CVRP problem. We examined the 2|UO|L version of the problem. The method includes a GLS component for the routing phase, packing heuristics for the packing phase, and ALNS repair heuristics to address situations when the packing heuristics fail. Future directions for our work will involve incorporating learning components into our framework to better guide the resolution method through the solution search space. The primary objective is to determine the feasibility of a packing for each vehicle’s routing solution without relying on packing heuristics. Another goal is to assist the repair component in quickly identifying where to place unassigned customers. We also want to extend our framework in order to solve multiple versions of the 2L-CVRP problem.

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