

# A Pattern-Mining-Driven Hybrid Method for Large-Scale CVRP Boosted via Reduction to NEARP Subproblems

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## 1 Introduction

The Capacitated Vehicle Routing Problem (CVRP) is a fundamental combinatorial optimization problem that involves finding a set of minimum-cost routes to deliver goods from a central depot to a set of customers while respecting vehicle capacity constraints. Although metaheuristics have reached a high level of maturity for small and medium-sized instances, solving large-scale CVRP instances with thousands of nodes remains computationally challenging.

Recent advances have introduced high-performance heuristics such as the Adaptive Iterated Local Search (AILS-II), which utilizes carefully designed to handle large-scale CVRP instances [2]. This report describes a hybrid method that integrates the MineReduce approach [1] with AILS-II to perform strategic problem size reduction during the search process.

## 2 Methodology

The proposed method enhances the AILS-II framework by incorporating a data-mining-driven reduction phase that simplifies the problem instance when the search stagnates. The framework consists of three primary stages: elite set management, pattern mining for problem reduction, and specialized subproblem resolution.

### Elite Set and Stagnation Detection

The algorithm maintains an elite set  $E$ , which stores the best solutions found during the execution of AILS-II. Stagnation is detected if the elite set  $E$  remains unaltered for a threshold of  $\delta = 1000$  AILS-II iterations.

### Pattern Mining and Problem Size Reduction

Upon reaching the stagnation threshold, the method triggers a pattern mining procedure. Applying the MineReduce approach [1], it extracts maximal frequent itemsets (paths) that appear together in a significant number of elite solutions. In this hybrid method, frequent paths are identified as sequences of nodes that consistently appear together in high-quality solutions.

The original CVRP instance  $I$  is then reduced to a new instance  $I'$  categorized as a Node, Edge, and Arc Routing Problem (NEARP), also known as the Mixed Capacitated General Routing Problem (MCGRP) [3]. The reduction is performed as follows:

- Each frequent path identified by the miner is replaced by a single required edge.
- The demand associated with each required edge is the sum of the customers' demands in the corresponding path.
- The cost associated with each required edge is the sum of distances between consecutive customers in the corresponding path.
- Customers not included in frequent paths remain as required nodes in the NEARP formulation.

## Subproblem Resolution and Solution Expansion

To solve the reduced NEARP instance, the method uses the Hybrid Genetic Search for Capacitated Arc Routing Problems (HGS-CARP) [4]. HGS-CARP is chosen for its efficiency in joint sequencing and orientation decisions. The time limit allocated for this phase is proportional to the number of services in the reduced instance:  $n = |V_R| + |E_R|$ , where  $|V_R|$  is the number of required nodes and  $|E_R|$  is the number of required edges.

Once HGS-CARP finishes, the solution to  $I'$  is expanded back into the original solution space. This expansion replaces each required edge with its corresponding original path. AILS-II then resumes its search from the expanded solution.

## Motivation

The proposed hybridization leverages the strengths of three distinct methodologies. AILS-II provides a robust and adaptive mechanism for exploring the global solution space of large CVRP instances. MineReduce addresses search stagnation by identifying reliable clusters of nodes (frequent paths), thereby significantly reducing the effective size of the decision space by merging elements in a condensed, yet equivalent representation. HGS-CARP effectively handles the routing of a joint set of required nodes and edges in reduced NEARP instances.

By transforming the CVRP into a reduced NEARP instance and utilizing HGS-CARP, the orientation and sequencing of fixed paths are efficiently optimized, potentially breaking through complexity barriers faced by standard CVRP heuristics on very large graphs.

## References

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