Optimizing the Vehicle Routing Problem with Heterogeneous Fleets and Loading Constraints Using Machine Learning

1st Elsa Silva
ALGORITMI Research Center/LASI, Portugal
University of Minho
Braga, Portugal
elsa@dps.uminho.pt

2nd Leonor Ribeiro
ALGORITMI Research Center/LASI, Portugal
University of Minho
Braga, Portugal
pg52588@alunos.uminho.pt

3rd João N. C. Gonçalves
Católica Porto Business School, Research Centre in Management and Economics
Universidade Católica Portuguesa
Porto, Portugal
jngoncalves@ucp.pt

***Abstract*—The transportation of goods is a critical component in logistics operations, directly impacting costs and supply chain efficiency. The growing complexity of delivery systems, characterized by fleet heterogeneity and loading constraints, renders traditional optimization methods insufficient to guarantee high-quality solutions within acceptable computational time. This work addresses the Two-Dimensional Heterogeneous Fleet Vehicle Routing Problem (2L-HFVRP) through a hybrid framework that integrates a Mixed-Integer Linear Programming (MILP) model with Supervised Machine Learning (ML) techniques. The optimization layer ensures a representation of operational and structural constraints, while the predictive layer estimates client–vehicle assignment variables, enabling anticipatory decisions and feasible solutions when the solver alone fails to converge within practical time limits. Six variable-fixing strategies are designed, differentiated by their degree of prescription and the balance between fleet capacity and diversity. Experimental results demonstrate that predictive integration substantially accelerates the resolution process and ensures consistent solutions across instance sizes. This is particularly evident for instances with 25 customers, where the standalone MILP yielded no feasible solution within one hour, while the hybrid MILP+ML approach solved all tested instances. Among the proposed strategies, capacity-conditioned fixing achieves the best trade-off between computational efficiency and solution quality, whereas more prescriptive approaches, while faster, tend to incur higher operational costs. These findings highlight the potential of combining mathematical optimization with machine learning to overcome the scalability limitations of exact methods, advancing the practical applicability of vehicle routing models with loading constraints in real-world logistics settings.**

***Index Terms*—Vehicle Routing Problem, Two-Dimensional Loading, Heterogeneous Fleet, Mixed-Integer Linear Programming, Machine Learning, Hybrid Optimization**