Learning-Enhanced Metaheuristics For Stochastic Service Network Design Using Graph Neural Networks

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Logistic Service Providers (LSPs) operate in complex and highly dynamic transport systems, where decisions are influenced by uncertainty, interactions with multiple stakeholders, and large-scale networks. Supporting effective planning and adaptability in such environments remains a key challenge, so efficient optimization algorithms are needed. This research focuses on the Service Network Design (SND) problem faced by an LSP, integrating tactical planning with dynamic operational decisions. The proposed approach considers a complex operational setting, including uncertain travel times and demand, dynamic replanning decisions, and interactions between the LSP and carriers. An agent-based simulation model is developed to capture these complexities and is coupled with a metaheuristic to solve the SND. To overcome the high computational cost of simulation, a Graph Neural Network (GNN) is introduced as a surrogate model. The GNN, trained with simulation-generated data, leverages the network structure to predict both global performance (profit) and node-level indicators, which are used to guide the search process. Numerical experiments show that the proposed framework produces high-quality solutions with scalable computational effort, particularly for large-scale instances. The results highlight the potential of integrating optimization and machine learning to address complex freight transport planning.