AI-DRIVEN OPTIMIZATION OF FREIGHT TRANSPORTATION AND GREEN CORRIDOR FORMATION IN MANUFACTURING ENTERPRISES

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Abstract. The thesis analyzes an approach to optimizing freight transportation in manufacturing enterprises using artificial intelligence and to forming green corridors. Demand and travel-time forecasting, route and load optimization based on the Vehicle Routing Problem with Time Windows (VRPTW), and the role of reinforcement learning are discussed. A Green Corridor Index (GCI) is proposed to score routes by CO_2 emissions, delivery time, and vehicle load factor. Based on a literature analysis, the potential of AI to reduce empty runs, improve vehicle utilization, and lower emissions is shown, along with limitations related to data quality and uncertainty.

Keywords: freight transportation, artificial intelligence, route optimization, VRPTW, reinforcement learning, green corridor, manufacturing logistics, CO_2 emissions.

Introduction

Freight transportation is one of the main cost items in the logistics of manufacturing enterprises and accounts for a considerable share of fuel consumption and CO_2 emissions. When inbound raw-material deliveries, inter-shop transfers, and outbound shipments are planned separately, empty runs, partially loaded vehicles, and waiting times at loading points increase. As a result, both economic and environmental efficiency decline.

In this thesis, a "green corridor" means a coordinated, low-emission route that consolidates freight flows and is served with priority. Justifying such a corridor requires data-driven assessment rather than intuitive decisions. Compared with classical optimization methods, artificial intelligence offers greater adaptability, scalability, and support for multi-objective optimization [5]. The aim of the study is to substantiate a methodology for optimizing intra-enterprise and regional freight flows with AI and for identifying routes that can be designated as green corridors.

Methods

The study is conceptual and analytical: recent reviews were analyzed, and an integrated system structure was proposed on that basis. The system has four layers: (1) data collection (shipment volumes, vehicle telematics, loading and unloading schedules, fuel consumption, traffic conditions); (2) forecasting (gradient boosting and LSTM models for demand and travel time); (3) optimization; (4) evaluation and selection of routes by the green corridor index.

Route and load optimization is formulated as a VRPTW: total cost is minimized subject to vehicle capacity and the time window of each loading point. Because the VRP is NP-hard, a hybrid of metaheuristics (e.g., a genetic algorithm) and reinforcement learning is recommended for practical problem sizes; recent reviews show that the main directions are to formulate the VRP as a Markov decision process solved with deep RL, and to integrate RL with heuristic or metaheuristic methods [2, 3]. The environmental and economic priority of a route is scored with the following index:

$$GCI = w_1 \cdot (1 - E/E_0) + w_2 \cdot (1 - T/T_0) + w_3 \cdot LF$$

where E is CO_2 emissions per tonne-kilometre, T is delivery time, E_0 and T_0 are the corresponding values under current (baseline) planning, LF is the vehicle load factor (from 0 to 1), and w_1, w_2, w_3 are weighting coefficients ($w_1 + w_2 + w_3 = 1$). Routes with a high GCI that also concentrate freight volume are candidates for green corridors.

Results

The literature analysis yields the following findings. First, a review of 129 studies from 2015 to 2025 reports that RL and deep RL show strong potential for generating near-optimal solutions to the NP-hard VRP [3]; another review classifies machine-learning-based VRP methods by application constraints and technical details, focusing mainly on RL [2]. Second, accounting for uncertainties such as demand variability and travel-time fluctuations is important for dynamic routing, yet few RL-based studies explicitly incorporate stochastic uncertainties [4]. Third, AI-supported logistics optimization can improve fleet utilization, reduce empty runs, and support the operational integration of low-emission trucks, but AI is not a green solution on its own [6]. Predictive analytics can also reduce unnecessary trips and inventories [5], and collaborative freight distribution has been reviewed as a way to lower greenhouse gas emissions [1].

The interrelation of the proposed system components is given in the table.

System components and their control

Component	Function	Main risk	Control measure
Forecasting (gradient boosting, LSTM)	Advance estimation of demand and travel time	Low data quality, abrupt demand changes	Regular model retraining and validation
Route optimization (VRPTW, metaheuristic + RL)	Planning of routes and loads	Computational complexity, real-time requirements	Hybrid method, regular re-planning
Green Corridor Index (GCI)	Scoring routes by emissions, time, and load factor	Subjective choice of weights	Sensitivity analysis of weights
Real-time monitoring (telematics, IoT)	Detecting deviations from the plan	Fragmented information systems	Unified data platform

Discussion

The analysis shows that forecasting and optimization should be treated as a single loop: an inaccurate forecast reduces the benefit of routing, while a forecast without optimization brings no practical gain. The GCI provides a transparent criterion for comparing routes by emissions, time, and load factor, but its weights must be chosen to match enterprise priorities and checked with sensitivity analysis. The proposed approach is so far conceptual: its effectiveness must be confirmed on an enterprise's real data against a baseline. Later stages envisage a pilot project, IoT-based real-time monitoring, and extension to multimodal transport.

Conclusion

AI-based optimization of freight transportation in manufacturing enterprises requires combining forecasting, VRPTW-based routing, and a green corridor index in one system. The literature analysis shows that RL and hybrid methods are promising for large problems, while data quality and handling of uncertainty remain open issues. The proposed GCI helps identify green corridor candidates in terms of lower emissions, fewer empty runs, and higher vehicle load.

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