DECISION SUPPORT SYSTEMS FOR RAIL FREIGHT TRANSPORT OPERATIONS

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Abstract

Rail freight is essential to the economic growth of any nation because it provides efficient and cost-effective freight services. Burdened with governmental regulatory frameworks, Rail freight operators (RFOs) should develop relevant and unified operational models for strategic decision-making and operational policy formulation. First, this study examines the synergistic relationships between private investment in railroad and expedited conveyance services. This research focuses on resolving fleet planning issues that RFOs face when moving rakes via express or standard transport services while accounting for turnaround time, fees, demand, customer prioritization, and penalty cost. Furthermore, it is observed that railway organizations are spending on digitizing rail freight transportation for better resource utilization and revenue generation. Today, most of the rakes have GPS devices. Thus, railway train management systems readily provide data to create a dynamic optimization model for RFOs using IoT-based real-time information. Moreover, precise coordination is also vital for optimizing resource management in industrial supply chains. Challenges like single-track sections, manual dispatching, and operational fluctuations lead to inconsistent runtimes and delays in rail freight. Therefore, accurate Estimated Time of Arrival (ETA) predictions are crucial for optimizing decisions and minimizing cost overruns.

First, an integer linear programming model (ILP) is developed for optimal fleet size (number of rakes), rake (freight train) assignment, and scheduling for RFOs. The proposed formulation maximizes revenue by integrating standard and express conveyance services. In addition, for larger networks, we proposed a "Two-phase Greedy Search Heuristic." In addition, with a blended fleet size, rake assignment, and schedule, the model attempts to explain how to accomplish the optimal trade-off between freight prices, turnaround time, and ordinary/express transport service selection. A greedy search rake schedular heuristic produced results for small and medium-sized instances nearly as good as those produced by an exact method (CPLEX). The robustness of the developed mathematical modelling is demonstrated by testing with varied problem instances. Moreover, we concluded from our real-world case study that RFOs should contemplate a combination of express and standard service. Mix transport service can assist RFOs in achieving up to 20% increase in the total of trips taken during a calendar month. The use of express service significantly impacts RFOs' revenue maximization by efficiently fulfilling demand with fewer rakes and minimizing unfulfilled demand. Additionally, the majority of express service should be utilized at the beginning of each month, as this would facilitate early revenue realization and reduce the average monthly turnaround time per trip. The study identified optimal parameter settings that balance customer satisfaction, cost considerations, and revenue generation.

Furthermore, We formulated an integer linear programming (ILP) model that maximises revenue, incorporating optimal rake assignment and scheduling for ordinary transport service. In addition, to incorporate real-time GPS data, we proposed an "IoT-enabled real-time rake schedular-reschedular heuristic" for rescheduling rakes on a real-time basis. The computational investigations exhibit that the proposed heuristic performs effectively both in terms of run time and the quality of the solution. Additionally, our study leverages the power of machine learning and GPS data to develop a data-driven regression predictive model for ETA predictions for RFOs. Initially, we aimed to develop a base predictive model considering the entire origin-to-destination journey as one cohesive trip. Among the nine data-driven machine learning models that underwent assessment, the XGBoost algorithm exhibited superior predictive accuracy, characterized by the lowest Root Mean Square Error value. Nonetheless, its performance limitations were evident during return journeys, mainly when dealing with empty rakes, resulting in an overall reduction in predictive accuracy. To overcome this limitation, we devised an Upgraded predictive model, segregating the two directions - origin to destination as "Loaded" and destination back to origin as "Empty" - into distinct trips. This approach significantly enhances ETA predictions, particularly for the "Empty" direction, while preserving the accuracy of predictions for the "Loaded" direction. In summary, the Upgraded predictive model outperforms the Base model, with the XGBoost algorithm-based prediction model excelling for the "Loaded" direction and the feature-weighted K-Nearest Neighbours algorithm-based prediction model performing best for the "Empty" direction. The models predict an ETA accuracy exceeding 95% at the origin, but as the journey advances, slight declines occur, reducing accuracy to 93% due to delays. These models can potentially enhance revenue generation for RFOs, optimize day-to-day rake operations, and boost customer satisfaction through accurate delivery time estimations.

Keywords: Rail Freight Operator; Fleet planning; Mathematical Optimization; Integer Linear Programming; Heuristics; Express freight train service; Internet of Things (IoT); Real-time Rake Rescheduling; Machine Learning; Predictive Analytics; Estimated Time of Arrival prediction.