

Decision Optimization for Inland Waterways Transportation Network Design Problem

Abstract:

Efficient freight transportation enables viable supplier-buyer links within complex supply chain networks. Integrating road, rail, and inland waterways through multimodal transportation (MMT) systems can mitigate logistics expenses and environmental externalities. Inland waterways transportation (IWT) networks hold massive yet underutilized potential for fostering sustainable economic growth. However, research has traditionally prioritized seaports over optimizing IWT operations and enhancing hinterland connectivity. The literature review reveals gaps regarding shallow-draft IWT, dryport and vehicle heterogeneity impacts, and incorporating social aspects when designing MMT networks. The models described in this thesis address these gaps by encompassing understudied facets like shallow-draft inland waterways and constituent interactions for greener hinterland connectivity. They provide granular insights to overcome multimodal supply chain bottlenecks while aligning optimization objectives with shipper and carrier requirements.

This thesis examines critical planning and performance issues in IWT through integrated modelling approaches spanning tactical and operational frameworks. The first objective develops a comprehensive port selection framework encompassing diverse cargo types and multidimensional performance indicators across operations, infrastructure, financials, and socioeconomics. It constructs a unified Port Performance Index leveraging secondary data from major Indian ports. The standardized index aims to facilitate informed decision-making by shippers and carriers for port selection, ensuring relevance in real-world application. Overall, it lays the foundation for data-driven assessment and comparison of port performance across critical aspects.

Subsequent objectives formulate integrated MMT network design optimizations with IWT. The second objective optimizes inland port operations within a multimodal transportation framework from a shipper's perspective. It addresses real-world challenges like water fluctuations and negative externalities while integrating shallow-draft waterways. The model explores operational and tactical decisions across integrated road-rail-inland waterway supply chains, utilizing dryports to enhance hinterland connectivity. A multi-echelon, multi-commodity network is designed incorporating heterogeneous vehicle types and social factors. By evaluating various scenarios, the study provides granular insights into overcoming bottlenecks toward efficient hinterland freight movement. A case study demonstrates large-scale practical implementation.

The third objective optimizes inland port decisions from a carrier perspective to maximize revenue through integrated operational and tactical strategies. It formulates a mixed-integer non-linear model encompassing barge routing, empty container balancing,

heterogeneous fleet deployment, and stringent turnaround time constraints within a bidirectional shipping network. By exploring distinct revenue management tactics and providing granular analysis, the study enhances understanding of optimizing inland waterway operations and profit maximization strategies.

The fourth objective incorporates uncertain spot demand alongside regular customers in optimizing revenue management from a carrier viewpoint. A stochastic model handles unpredictable shipping needs through recourse optimization while imposing turnaround time limits reflecting real-world dynamics. By addressing complexities of empty container balancing, heterogeneous fleet mix, and storage leasing, it develops strategies to tackle uncertainty. The computational studies demonstrate large-scale practical implementations and sensitivity analysis conveys operational and policy impacts on critical efficiency metrics.

The problem complexity is handled through exact and linearization solution approaches including decomposition techniques. A key contribution is utilizing Benders decomposition for large-scale exact solution derivation, enabling practitioners to solve intricate optimization problems. The findings of this study summarize operational and policy insights related to vessel planning, network design, fleet allocations, and infrastructure development. The conclusion summarizes contributions and outlines future work to enable data-driven IWT advancement by integrating constituent perspectives in sustainable transportation planning.

The research documents the significance of IWT in India's policy landscape and validates its relevance through case studies on National Waterways-II. The index and models constructed fill knowledge voids by encompassing understudied dimensions toward establishing standardized performance measurement coupled with optimization tools for informed decision making. By addressing complex challenges involved in optimizing IWT operations, this thesis expands the current understanding of inland waterways transportation. It provides actionable insights for diverse stakeholders to enhance productivity and environmental sustainability, while boosting profitability and minimizing operations cost across interconnected supply chain networks. The data-driven frameworks offer a launch pad for future investigations to ensure the proliferation of affordable and responsible freight transportation through integrated modelling approaches.

Keywords: Port performance index; Benchmarking, Inland waterways network design; Shallow draft inland waterways transportation; Network flow optimization; Empty container balancing.