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The Intermodal Truck and Container Problem

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Introduction

Intermodal freight transportation moves containerized goods by combining different means of transportation, including trucks, trains, and ships. Given the immense scope and complexity of logistics operations that span vehicle and container fleets, a geographically distributed infrastructure, and a wide range of products, efficient coordination of routing and scheduling is vital yet incredibly difficult. The main goal of this study is to improve drayage operations for intermodal freight operations.

Drayage refers to all short-haul truck-based pickup and delivery operations that connect locations within an intermodal network, such as seaports, rail stations, storage locations, and customer locations. Drayage operations are complex problems that have various operational constraints and require scheduling, routing, and resource allocation. The potential for improvements, aiding future planners, is presented by the fact that the majority of intermodal providers currently rely on manual methods for their drayage operations.

This study is written in collaboration with Van den Bosch B.V. (VdB), a prominent European intermodal logistics service provider focused on containerized transportation. VdB plans to integrate their truck routing department with their container planning department in order to enable smart and sustainable operations as they continue to grow.

Problem Definition

This research addresses a complex specialized vehicle routing problem with multiple complexities reflective of issues faced in practice:

• Loading requests representing regional exporters wanting to ship freight using intermodal transport to non-regional recipients using containers;
• Unloading requests corresponding to incoming full containers that have already arrived at regional recipient locations via intermodal transport and require a truck-based action;
• Time windows constraining when feasible pickup and delivery can occur at customer sites;
• Differentiated truck chassis configurations restricting which container sizes can be transported based on specific truck-container pairings;
• Various container sizes (e.g. 20ft, 30ft, 40ft, etc.) requiring compatible chassis to move;
• Commodity types differentiating containers based on prior loads to prevent contamination. Namely, certain products cannot be shipped in containers that have carried other products previously;
• Dispersed initial positioning of assets like trucks and containers across the transportation network based on operations from the previous day;
• Truck parking location restrictions forcing a return to certain hubs or terminals at the end of routes;
• Empty container allocation to balance container resources across the network;
• Intermodal delivery options with varying costs versus time trade-offs for long-haul transportation between regions.

With distributed transportation resources, heterogeneous loading and unloading requests, and interdependent planning decisions, identifying optimal operational plans is an extremely challenging undertaking. This motivates the development of an optimization methodology tailored to this problem to assist human planners. Determining low-cost planning solutions balancing asset utilization, costs, and operational constraints across intermodal networks with hundreds of nodes and resources represents a knowledge gap this research aims to help address

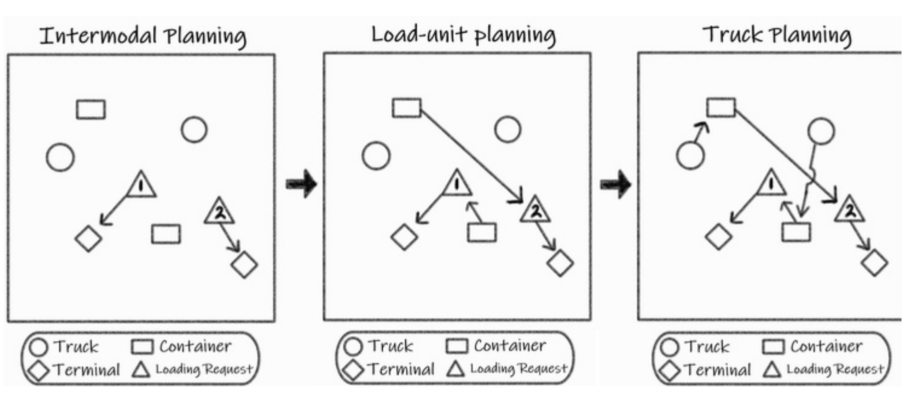

Figure 1: Current planning strategy

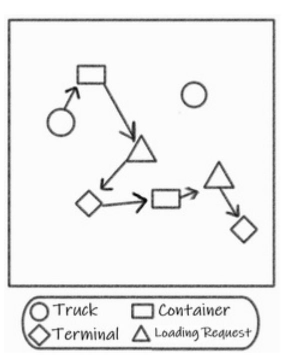

Figure 1: Optimal planning

Exact Model

A novel integer linear programming (ILP) optimization model is formulated to determine optimal routing capturing all the operational constraints. The model is presented in a modular, progressive fashion to highlight how the various extensions expand or constrain the solution space. First, a base vehicle routing problem formulation is introduced representing the standard pickup and delivery problem. Extensions are then added to incorporate, container management, intermodal delivery options, and other constraints, culminating in the final problem formulation.

Metaheuristic Model

Despite improvements, the integrated problem's scale and complexity still limit the exact optimization method to small or moderately-sized instances. Yet real-world problem sizes often involve hundreds of nodes and resources, necessitating an efficient heuristic method. To address this, a metaheuristic algorithm is designed leveraging ant colony optimization (ACO) concepts tailored to the problem structure.

The approach utilizes a multi-ant search strategy to balance exploration and exploitation across iterations while optimizing allocations and routing. Two ant types with distinct objectives are coordinated: container-ants focus on optimally allocating empty containers to meet loading requests while adhering to constraints, and truck-ants serve the resulting container routes while minimizing their non-revenue generating movements. The probabilities for ant path selections combine the attractiveness of an option (distance) with the desirability of an option (pheromone levels). A novel PacMan-inspired algorithm drives the truck-ant routing.

Numerical Results

Both optimization methodologies are tested on a diverse set of benchmark instances ranging in size from 1 to 130 nodes (i.e. exporters, storages, terminals, hubs, and recipient locations) and 2 to 240 transportation resources (i.e. trucks and containers). The metaheuristic is able to find good feasible solutions quickly across varying problem instances, while the exact ILP model can only solve small to medium case sizes before becoming unsolvable due to the problem complexity.

Detailed analysis verifies the metaheuristic can effectively handle intermodal planning problems at real-world scale and adapt to different operating conditions like export versus import dominant regions. The approach is further validated through a case study at VdB by comparing model results with their current planning approach. This case study considers a 48-hour planning horizon for the BeNeLux region (Netherlands, Belgium, Northern France, and Ruhr Germany) focused on liquid chemicals transport orders. Experiments quantify substantial cost savings from 5-25\% by integrating truck and container management using the optimization methodology rather than VdB's current sequential planning approach.

Results

The key results and contributions of this thesis research are summarized as follows:
• Novel integer linear programming (ILP) formulation created to model the intricate intermodal operational planning problem with synchronized truck routing and container management;
• Custom metaheuristic optimization algorithm design using ant colony optimization concepts and a novel PacMan-inspired truck routing method to provide an efficient heuristic tailored to the problem characteristics;
• Incremental exact model presentation highlighting how progressive extensions represent the complex constraints and trade-offs faced in practice;
• Rigorous computational testing quantifying metaheuristic solution quality and scalability on a diverse set of benchmark instances with varying problem sizes, resources, and operating conditions;
• Real-world logistics case study based on operational data highlighting specific planning process improvements;
• Quantification of significant transportation cost reductions from 5-25% by integrating truck and container optimization compared to current sequential planning approaches;

In summary, this study proposes an integrated optimization methodology for intermodal transportation planning spanning truck routing, container allocation, and intermodal transfers. The study improves the current state of logistics planning by offering both a tailored MILP formulation and a metaheuristic algorithm. Furthermore, both a numerical and a case study demonstrate the potential of integrating truck and container routing. Lastly, the research extends the field of vehicle routing problems, enabling cost and sustainability benefits for the industry. Opportunities remain for future research to build on the modeling foundations and algorithmic approach developed in this study.

Acknowledgements

This research was conducted at the TU/e in collaboration with Van den Bosch. I would like to thank Albert and Rolf from the TU/e and Teun from Van den Bosch for their guidance and support during this project

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