Operational planning for many-to-one-to-many freight transportation

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Extended abstract submitted for presentation at the 11th Triennial Symposium on
Transportation Analysis conference (TRISTAN XI)
June 19-25, 2022, Mauritius Island

April 12, 2022

Keywords: M1M systems; Operational planning; Look-ahead model; Rolling horizon framework; Adaptive large neighborhood search heuristic

1 INTRODUCTION

Transportation and Logistics (TL) systems that provide movements of freight and passengers over regional, national, or international networks are essential to society's development and achievements. Traditionally, freight transport systems are managed by multiple stakeholders that organize the movement of goods over part of the TL chains independently without information and resource sharing, which causes empty travels, low capacity utilization, high transportation costs, delay in deliveries, and heavy carbon emissions. With the development of information and communication technologies and intelligent transport system technologies, new TL business models, such as City Logistics (Savelsbergh & Woensel, 2016), Physical Internet (Pan *et al.*, 2017), and Synchromodality (Giusti *et al.*, 2019), have been proposed to address these issues. The common feature of these innovative systems is to provide efficient, effective, and sustainable services through the coordination and cooperation of stakeholders, the consolidation of shipment flows, and the synchronization of operations in integrated networks driven by intelligent 'decision-making' platforms.

To answer the needs in more than one application environment, this paper proposes a *many-to-one-to-many* (M1M) freight transport system that integrates first/last mile urban distribution and long-haul multimodal transportation for shipments with standard loading units (e.g., π-containers). On the one side of the M1M system, *many shippers* (e.g., producers, wholesalers, and distributors) make *shipment requests* for cost and time-efficient transportation of their product loads. Each shipment needs to be transported from a given shipper location to a consignee location within given time windows. On the other side, *many carriers* (e.g., transportation service providers), of diverse modes and types (full or less-than-truckload motor carriers, railroads, airlines, and river and ocean navigation, etc.), make *service offers* for urban and long-haul transportation and request profitable loads. Each service provides a limited transport capacity on a specific route with or without time schedules, served by one or multiple vehicles with the same or different modes. In the middle, *the one* - using the *Intelligent Decision Support Platform* (IDSP) for 'automated' planning and optimizing operations - aims to profitably and simultaneously satisfy the needs of both categories of stakeholders. The IDSP receives requests and offers continuously over time and optimizes in time and space the selection of shipment requests and service offers, shipment-to-service assignments, shipment itineraries, and service schedules through consolidation of shipments of different shippers into the same vehicles and synchronization of activities in an interconnected transportation network, as illustrated in Figure 1. The recent developments in information technologies such as cloud computing and Internet of Things allow real-time monitoring of shipments' and vehicles' status and information sharing among stakeholders, which facilitates the adoption of such a platform in practice.

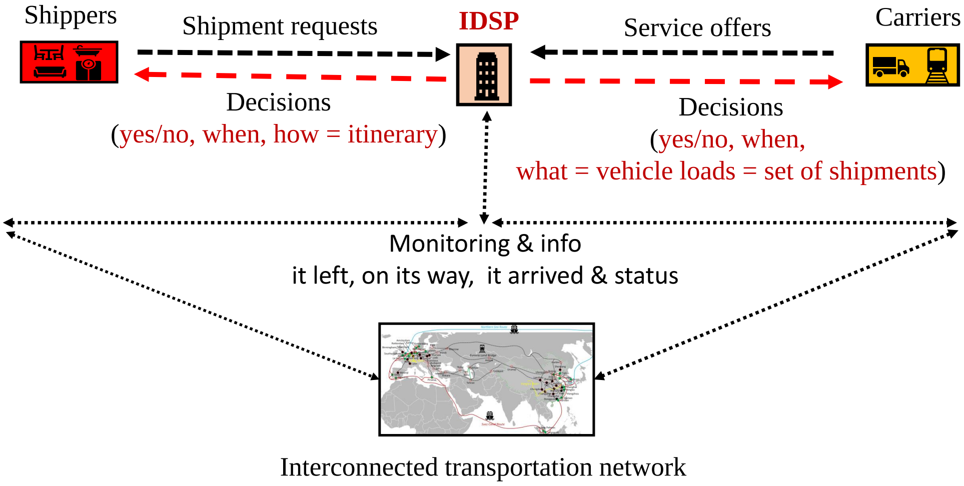

Figure 1 – *M1M system structure, stakeholders, communications & decisions*

To the best of our knowledge, this is the first paper that considers the selection of shipment requests and service offers simultaneously in freight transportation at the operational level. To bridge this gap in the literature, the first contribution of this paper is that we introduce a platform that integrates the decisions on acceptance or postponement of shipment requests and service offers, and decisions on shipment-to-service assignments, shipment itineraries, and service schedules for accepted requests and offers. Besides, we consider both requests and offers arrive at the platform dynamically. The decisions made now may have an impact on the future, what happens in the near future may also influence the decisions we take now. To reflect the interplay between current decisions and future outcomes, we develop a look-ahead model that integrates predicted requests and offers into decision processes. Thanks to the development of data analytics, the platform can obtain trusted predictions of near-future events. Furthermore, the decisions made at each time are not all to be put into practice. This paper designs a rolling horizon framework to control the implementations and re-optimize the decisions when new requests and offers are received. To produce good-quality solutions rapidly, an adaptive large neighborhood search (ALNS) heuristic algorithm is designed to solve the optimization problems at each decision time. Finally, we conduct extensive numerical experiments to evaluate the performance of the look-ahead model in comparison to a myopic model that does not take into account future outcomes, and assess the efficiency of the ALNS heuristic in terms of computation time and solution quality.

2 METHODOLOGY

2.1 Look-ahead model

The evolution of the M1M system is indexed by a discrete time variable $t \in [0, ..., \infty)$. We denote time period $t \in [1, ..., \infty)$ as the duration from time $t-1$ to time t. Requests and offers received during time period $(t-1, t]$ will be kept until decision time $t \in [1, ..., \infty)$.

Under the look-ahead context, at any time t, decisions are made over a planning horizon T based on known as well as predicted information. We denote H as the length of the prediction horizon, $H \leq T$. The decisions made at any time t can be divided into four groups: 1) acceptance decisions, which indicate whether active or predicted requests/offers are accepted or postponed at time $k \in \{t, ..., t+T\}$; 2) assignment decisions, which indicate whether a shipment is assigned to a service segment at time k; 3) service schedules, which indicate the departure times of time-flexible services at their origins; 4) shipment schedules, which indicate the time a shipment is picked up, unloaded, crossdock moved, stored, loaded, and delivered over the planning horizon.

The objective of the look-ahead model is to maximize the total profits for known and predicted requests and offers over the planning horizon, including: the fare for accepted requests; the fixed costs for accepted offers; the transportation costs; the pickup costs at origins; the delivery costs at destinations; the unloading, crossdock movement, storage, and loading costs at intermediate terminals; and the penalty costs for early and later delivery of shipments. The constraints of the model can be classified into four sets: 1) acceptance constraints, which ensure each request/offer can be accepted at most once within its feasible acceptance horizon; 2) flow constraints, which ensure an accepted shipment will be picked up at its origin and delivered at its destination within given time windows in addition to flow conservation at intermediate terminals; 3) service scheduling constraints, which ensure each time-flexible service will depart from its origin within its start time window; 4) capacity constraints, which ensure the loads at service segments and activities at terminals will not exceed the maximum capacity limitations.

2.2 Rolling horizon framework

At any time t, decisions suggested by the optimization model are not all to be implemented. We distinguish between the current implementation and the look-ahead components of the planning horizon. The acceptance decisions made at time t are generally implemented, that is, they are not to be changed in the follow-up periods, and are transmitted to the appropriate stakeholders and departments of the IDSP's firm for execution; but the decisions regarding shipment-to-service assignments, shipment itineraries, and service schedules made at time t are changeable if the shipment will not be picked up before time $t+1$ and the service will not depart before time $t+1$. Period $t+1$ thus belongs to the current implementation component of the planning horizon. The following periods, from period $t+2$ to period $t+T$, belong to the look-ahead component. Most decisions of these periods are temporary in nature, they are not to be actually put into practice and executed.

Based on the decisions made at time t, for accepted requests that will depart before the next decision time $t+1$, shipments' itineraries and schedules are fixed. The platform thus needs to book the transport, loading, unloading, crossdock movements, and storage capacities required for the shipments; for time-flexible services that are assigned to shipments whose itineraries are fixed, their time schedules will also be fixed, the platform thus needs to inform carriers the scheduled departure, arrival and return times. After implementing the fixed decisions made at time t, the platform achieves a new state at time $t+1$. Such a procedure is used repeatedly, as time advances and the planning horizon is pushed into the future, as shown in Figure 2. This is called the rolling horizon procedure.

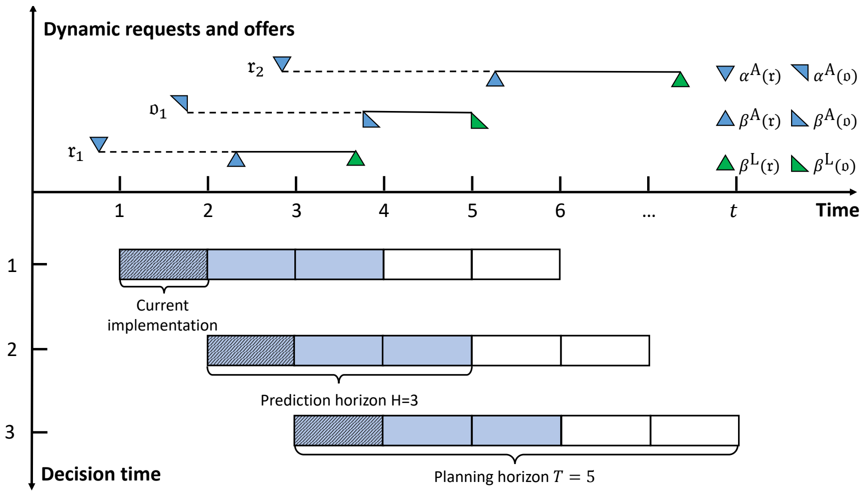

Figure 2 – *Rolling horizon framework for the operational planning of the M1M system*

2.3 Adaptive large neighborhood search heuristic

Due to the computational complexity, we design an adaptive large neighborhood search (ALNS) algorithm to solve the optimization problems at each decision time. The ALNS algorithm consists of two layers: the first layer selects requests and offers; the second layer decides shipment itineraries and service schedules. Based on the properties of the M1M problem, we design adapted removal and repair operators to improve the solutions at each layer.

3 RESULTS

The performance of methodologies is tested under a comprehensive set of instances. Specifically, we compare the look-ahead model with a myopic model which does not consider future outcomes; we compare the ALNS heuristic with the CPLEX solver.

4 DISCUSSION

At the conference, we will introduce the operational planning problem of the M1M systems in which an intelligent decision support platform aims to provide optimal decisions on acceptance or postponement of shipment requests and service offers, and decisions on shipment-to-service assignments, shipment itineraries, and service schedules for accepted requests and offers. We will discuss the look-ahead model that integrates forecasted requests and offers into decision processes. A rolling horizon framework will be proposed to control the implementation and reoptimization of decisions. Finally, we will show the adaptive large neighborhood search algorithm that solves the optimization problems at each decision time. The performance of methodologies will be discussed under a comprehensive set of instances.

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