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Anticipatory freight selection in intermodal long-haul round-trips

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ABSTRACT

We consider the planning problem faced by Logistic Service Providers (LSPs) transporting freights periodically, using long-haul round-trips. In each round-trip, freights are delivered and picked up at different locations within one region. Freights have time-windows and become known gradually over time. Using probabilistic knowledge about future freights, the LSP's objective is to minimize costs over a multi-period horizon. We propose a look-ahead planning method using Approximate Dynamic Programming. Experiments show that our approach reduces costs up to 25.5% compared to a single-period optimization approach. We provide managerial insights for several intermodal long-haul round-trips settings and provide directions for further research.

1. Introduction

In a world with increasing trade and environmental consciousness, Logistic Service Providers (LSPs) are looking for better ways of organizing their long-haul transportation processes. Nowadays, LSPs aim towards network efficiency while maximizing profitability. This aim brings various challenges, one of which we study in this paper. We investigate the challenge faced by a Dutch LSP that transports containers from the Eastern part of the country to the Port of Rotterdam, and vice versa, in daily long-haul round-trips. Each day, a barge transports containers from a single inland terminal to different deep-sea terminals within the port. While delivering containers, the same barge picks up containers from the same, and other terminals, and transports them back to the inland terminal where it started. Alternatively, the LSP has trucks to transport containers. The challenge consists on how to assign the new containers that arrive for both parts of the round-trip, either to the barge or to trucks, to achieve the best network performance over time.

Ideally, the barge would visit as few terminals in the port as possible and trucks would be seldom used. However, the variability in the amount and type of containers that arrive each day makes the ideal situation hard to achieve. Each day, the LSP must choose which containers to consolidate and which to postpone, in order for its operations to be as close to ideal over time. For example, postponing the transport of a container to, or from, a given terminal today can reduce the number of terminals visited today without increasing the number of terminals visited tomorrow. Also, transporting a container that has a long time-window today can reduce the number of terminals that need to be visited tomorrow. The proper balance of consolidation and postponement in each round-trip will result in a better performance over a period of time.

In general terms, we study the decision problem of selecting freights for transportation in long-haul round-trips, periodically. In every period, a single round-trip is performed. In each round trip, freights are transported (i) from a single origin to

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multiple locations within a far away region and (ii) from locations in that region back to the origin, using a high capacity vehicle. The region is far away from the origin, but locations within the region are close to each other. As a result, the long-haul is the same in every round-trip and every period, and differences in costs arise due to the locations visited in the round-trip corresponding to each period and the use of an alternative transportation mode. The alternative transportation mode is more expensive than the high-capacity vehicle per freight. New freights, with different characteristics, arrive each period. Each freight has a given destination, a release-day, and a due-day. Although the number of freights, and their characteristics, vary from day to day, there is information about their probability distribution. The objective of the decisions is to reduce the total costs over a multi-period horizon (i.e., sum of transportation and handling costs over all modes and over all days) while transporting all freights.

Decisions that minimize the costs over a multi-period horizon are complex for three reasons. First, the freights that arrive in each period are uncertain. The uncertainty is not only on the number of freights that arrive, but also on their characteristics. Second, freights have different time-windows, which restrict the periods in which they can be consolidated and to which they can be postponed. Third, the cost advantage of consolidating the maximum number of freights in the high capacity vehicle, can be conflicting with the objective of minimizing costs over a multi-period horizon. To overcome these challenges, we model the optimization problem as a Markov Decision Process (MDP), and propose an Approximate Dynamic Programming (ADP) algorithm to solve it.

Our goal in this paper is twofold: (i) to model the stochastic and time dependent nature of the problem and design a solution approach that is applicable to solve realistic instances in reasonable time and (ii) to provide insight into the effect of various problem characteristics on the anticipatory freight selection decisions. With anticipatory, we mean making decisions today in anticipation of what might happen tomorrow. More specifically, we aim to answer the following two research questions: (i) how to design a proper look-ahead decision approach, i.e., a decision approach that incorporates information about future costs in current-day decisions and (ii) what performance can be expected from this look-ahead approach, with respect to costs savings under different stochastic freight characteristics, such as time-windows and destinations.

The remainder of this paper is structured as follows. In Section 2, we briefly review the relevant literature and specify our contribution to it. In Section 3, we introduce the notation and formulate the problem as an MDP. In Section 4, we present the ADP solution algorithm. In Section 5, we evaluate various designs for the ADP algorithm, and provide a comparison with optimal and heuristic solution approaches. Finally, we conclude this paper in Section 6 with insights about modeling and solving anticipatory freight selection problems in intermodal long-haul round trips, and provide directions for further research.

2. Literature review

The literature on freight consolidation in intermodal transportation networks is vast. In this brief review of it, we focus on two problem classes: (i) problems concerning assignment of freights to modes in an intermodal network and (ii) problems concerning anticipatory and dynamic selection of loads in transportation. In the first class, we summarize the key points and shortcomings of models and solution approaches proposed for Dynamic Service Network Design (DSND). In the second class, we provide examples on how the dynamic and stochastic nature of demand in transportation has been captured in routing and transportation problems, and what kind of solutions have been proposed. For an extensive review on research about the first problem class, we refer the reader to Crainic and Kim (2007) and SteadieSeifi et al. (2014); and for the second class, to Pillac et al. (2013) and Powell et al. (2007).

Decision problems in DSND involve the choice of transportation services for freight, over a multi-period horizon, where at least one problem characteristic varies over time (SteadieSeifi et al., 2014). However, two of the shortcomings in most DSND studies are that: (i) they do not incorporate time dependencies such as time-windows and information about pre-announced orders (Crainic and Kim, 2007) and (ii) they assume deterministic demand (SteadieSeifi et al., 2014). Furthermore, it seems that studies that tackle these shortcomings do so one at a time. For example, studies that model time dependencies, such as Andersen et al. (2009b), and consolidation opportunities, such as Moccia et al. (2011), assume deterministic demand. Recently, optimization studies that model multiple time dependencies in intermodal freight transportation networks, such as Li et al. (2015) and Nabais et al. (2015), use approaches based on receding horizons and model predictive control to take advantage of information that becomes known over time. Although these two studies do not explicitly incorporate probability distributions to capture uncertainty, they establish the benefits of including dynamic information in optimization models. Research that models uncertainty in the demand, such as Hoff et al. (2010), is usually developed for single mode. Furthermore, models that incorporate random variables, such as Lium et al. (2009), yield one initial plan that is robust to all realizations of the random variables. Only a few of these models, such as Bai et al. (2014) and Lo et al. (2013), include both planning and re-planning of a single transportation mode, in a two-stage approach.

One of the reasons why shortcomings have been tackled one at a time lies in the solution approaches used. Graph theory and meta-heuristics, which have been often proposed to solve DSND problems (SteadieSeifi et al., 2014; Wieberneit, 2008), are less suitable for dealing with time-dependencies and stochastic demands. To deal with time-dependencies, mathematical programming techniques such as cycle-based variables (Andersen et al., 2009a), branch-and-price (Andersen et al., 2011), digraphs formulations (Moccia et al., 2011), and decompositions (Ghane-Ezabadi and Vergara, 2016) have been used. However, these techniques are computationally expensive. Consequently, meta-heuristics, such as those based on Tabu Search (Crainic et al., 2000; Verma et al., 2012), have been used for larger problems (SteadieSeifi et al., 2014). Integrating

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