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The load planning problem for double-stack intermodal trains

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ABSTRACT

This paper presents a general methodology that addresses the load planning problem for intermodal trains. We propose a model that can deal with single- or double-stack railcars as well as arbitrary containers-to-cars matching rules. Moreover, we model weight and center of gravity constraints, stacking rules and technical loading restrictions associated with specific container types and/or contents. We propose an integer linear programming (ILP) formulation whose objective is to choose the optimal subset of containers and the optimal way of loading them on outbound railcars so as to minimize the resulting loading cost. An extensive numerical study is conducted. It shows that ignoring center of gravity constraints and containers-to-cars matching rules may lead to an overestimation of the train capacity and to select load plans that are not feasible in practice. We also show that we can solve realistic instances to optimality in reasonable computational time using a commercial ILP solver.

1. Introduction

Nowadays, an essential ingredient of a competitive economy is a cost-effective freight transportation system. Intermodal transportation is an important component of this system in which different transport modes are linked in order to move freight from a point of origin to a point of destination. Taking advantage of economies of scale, low volume demands are first shipped to an intermediate point, a consolidation terminal or hub, where traffic is sorted (classified) and grouped (consolidated). Then, the consolidated traffic is moved between hubs by efficient transport modes. In this paper we deal with intermodal railway transportation where containers are consolidated and transported by trains on the long-haul part of their trip. We focus on the North American market and on double-stack trains.

Intermodal transportation relies heavily on containerization because, in addition to decreasing transportation cost, it ensures faster and safer handling as well as transfer between transport modes. Intermodal containers are steel frame boxes designed to move goods across the world using different transport modes without any re-handling of the cargo. The containerized worldwide traffic has risen tremendously over the past decades and North American ports have seen an important annual growth of container traffic. This growth is placing a heavy burden on the entire consolidation-based transportation system, which must provide efficient, reliable and cost-effective services.

Terminals are major components of any intermodal transportation system and thus are critical to the entire international trade. They are special transshipment nodes that provide equipment and space where containers are processed, loaded, unloaded and stored to ensure a seamless transfer between different modes. Carriers, in our case railways, face a number of challenging planning issues, which may be examined according to the classical categorization with respect to the planning horizon, that is strategic, tactical, operational. In this study, we focus on the *load planning problem*, which is an operational problem arising at intermodal railway terminals.

Given a set of containers stored in a terminal and a sequence of railcars, the problem is to determine the optimal subset of containers to load and the exact way of loading them on an optimal subset of railcars while minimizing cost. We address this problem for double-stack trains. This is a challenging problem because the load plan must satisfy a number of complex loading rules that depend on specific container and railcar characteristics. For example, stacking rules depend on container sizes, weights, and contents and on Center Of Gravity (COG) restrictions. While the methodology expounded in this paper is general, the North American market is the main focus of our attention because it is particularly challeng-

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ing. Indeed, there are in North America a large number of railcar types and several more container types and containers than the standard 20 feet and 40 feet.

As we detail in Section 3, with one exception, the existing literature does not address the load planning problem for double-stack trains. Moreover, the simplifying assumptions that are adopted may lead to load plans that violate important loading rules and hence cannot be used in practice. For example, none of the studies model the COG restrictions. The objective of this paper is to propose a general methodology that addresses the load planning problem of double-stack trains taking into account all the different loading rules encountered in actuality.

There are a large number of possible ways – so-called *loading patterns* – in which containers of different sizes may be loaded onto a railcar of a particular standardized type. The multitude of railcar types and the very large cardinalities of several of the associated sets of loading patterns is a key issue. We refer to this problem as *containers-to-car matching*. In connection with this problem, we make a number of contributions. First, we propose a general model that can deal with single- and double-stack railcars that can be of different types and subject to different loading rules. Second, our model accounts for additional loading constraints related to the specific container types, contents and weights as well as to COG restrictions. Third, we present an extensive set of numerical results based on a case study focusing on the North American market.

The numerical results indicate that our model provides an appropriate framework for solving very large instances of the load planning problem in reasonable time using a commercial solver. They also demonstrate that failing to account for containers-to-cars matching as well as COG and stacking restrictions may lead to overestimations of the usable capacity and to suggesting load plans that are not applicable in practice.

The remainder of the paper is structured as follows. Section 2 describes the load planning problem in detail. Section 3 is dedicated to a review of the existing literature on the assignment of containers to railcars and to highlight our main contributions. Section 4 presents the ILP formulation of the load planning problem. Section 5 describes the content of the empirical study and examines its results. Finally, Section 6 draws conclusions and discusses possible directions for future research.

2. The double-stack train loading problem

This section presents a detailed description of the load planning problem for double-stack trains. We examine the ways in which containers and railcars can be physically matched together and explain how these loading possibilities depend on the exact characteristics of the containers and railcars. We start by successively describing the intermodal containers and the rules for stacking them as well as the intermodal railcars. We then present the rules governing the loading of containers onto railcars.

2.1. Intermodal containers

Intermodal containers are characterized by (i) their size (length and height) (ii) their type (iii) their contents and (iv) their weight, filling level and weight distribution. In order to facilitate their handling, sizes are standardized. There are four ISO standard sizes used worldwide: 20 feet high cube, 40 feet low and high cube, 45 feet high cube (the height of low cube containers is 8 feet 6 inches/2.6 meter whereas it is 9 feet 6 inches/2.9 meter for high cubes). This paper focuses on the North American market, where there are two additional sizes of high cubes: 48 feet and 53 feet.

Fig. 1. Examples of container types.

For each size, containers are available in several standardized types. Some are illustrated in Fig. 1. Ninety percent of the global fleet consists of general purpose containers, called “dry containers”, that are steel frame boxes with 6 solid sides (upper left in the figure). Several other types of containers are designed to transport goods for which dry containers are not suitable. For instance, reefers (refrigerated containers) or heated containers are designed to carry goods needing temperature control (bottom left in the figure). During transport, the reefers can either be connected to a genset (power generator set) supplying electrical power to a number of them or can have individual power units. Fig. 1 also shows an open/soft top container without a roof (upper right), an open-side container and a tank container for the transportation of liquids (bottom right). While the designs of these containers are different, their sizes remain standard. Containers can carry hazardous materials in which case special restrictions usually govern their storage and transport.

Containers can be stacked one on top of another. In addition to rules governing the weights and the positioning of containers loaded onto railcars, the stacking of containers must conform to rules prescribing their relative position. In essence, the containers must be positioned so as to ensure that their load is transferred in accordance with the design of their steel frames. Specifically, the container above can be connected to the container(s) below with four Inter Box Connectors (IBC) designed for this purpose and the standard lengthwise distance between the connecting points where these couplings can be installed is 40 feet. This is illustrated in Fig. 2 where the thick lines indicate this 40 feet distance. Hence, a 40 feet container can be loaded on top of two 20 feet but a 20 feet container cannot be loaded on top of a 40 feet one. Since the connecting points are symmetrically located from the mid-length of the containers, a longer container (45, 48, 53 feet) must be centered on top of a shorter one (40, 45, 48 feet) or on top of a pair of 20 feet containers.

Lastly, we assume that there exists a per container cost associated with the failure to load an available container standing for, e.g., customer penalties for late arrival and storage costs in the terminal.

2.2. Intermodal railcars

Intermodal trains consist of a sequence of railcars designed to carry single- or double-stacked containers. Intermodal railcars are characterized by their number of platforms and by the length, weight-carrying capacity and tare weight of each one. Fig. 3 illustrates a five-platform double-stack railcar. In accordance with the