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Intermodal freight transport planning – A receding horizon control approach

Le Li [a,*], Rudy R. Negenborn [b], Bart De Schutter [a]

[a] Delft Center for Systems and Control, Delft University of Technology, 2628 CD Delft, The Netherlands
[b] Department of Maritime and Transport Technology, Delft University of Technology, 2628 CD Delft, The Netherlands

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ABSTRACT

This paper investigates intermodal freight transport planning problems among deep-sea terminals and inland terminals in hinterland haulage for a horizontally fully integrated intermodal freight transport operator at the tactical container flow level. An intermodal freight transport network (IFTN) model is first developed to capture the key characteristics of intermodal freight transport such as the modality change phenomena at intermodal terminals, physical capacity constraints of the network, time-dependent transport times on freeways, and time schedules for trains and barges. After that, the intermodal freight transport planning problem is formulated as an optimal intermodal container flow control problem from a system and control perspective with the use of the proposed IFTN model. To deal with the dynamic transport demands and dynamic traffic conditions in the IFTN, a receding horizon intermodal container flow control (RIFC) approach is proposed to control and to reassign intermodal container flows in a receding horizon way. This container flow control approach involves solving linear programming problems and is suited for transport planning on large-sized networks. Both an all-or-nothing approach and the proposed RIFC approach are evaluated through simulation studies. Simulation results show the potential of the proposed RIFC approach.

1. Introduction

1.1. Motivation

In global freight transport, major deep-sea ports typically act as gateways for both import and export cargoes for certain geographical areas, for instance the Port of Rotterdam for North and West Europe. These geographical areas are considered as the hinterlands of deep-sea ports. Hinterland haulage refers to freight transport between deep-sea ports and the origins or destinations of cargoes in the hinterlands, and has become an important component in modern logistic systems. An efficient and sustainable hinterland haulage will benefit freight transport operators and freight forwarders by reducing their operational costs, shippers by providing high quality transport services and guaranteeing low transport costs, deep-sea ports by enhancing their competitiveness, and the society by developing a sustainable freight transport system.

However, hinterland haulage has been facing challenges from increasing cargo volumes, limited capacities of transport infrastructures, traffic congestion on freeways, traffic emission issues, etc. Another major challenge for hinterland haulage

* Corresponding author. Tel.: +31 1527 83593; fax: +31 1527 86679.
E-mail addresses: l.li-1@tudelft.nl (L. Li), r.r.negenborn@tudelft.nl (R.R. Negenborn), b.deschutter@tudelft.nl (B. De Schutter).

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is one emerging practice known as ‘slow steaming’ in international shipping lines. Slow steaming refers to the phenomenon that an existing deep-sea vessel goes slower than its design speed for the sake of reducing fuel consumption and consequently emissions (Psaraftis and Kontovas, 2013). The effect of this phenomenon is a longer maritime transportation time and thus a tighter schedule for hinterland haulage. These challenges necessitate an efficient and innovative way to organize hinterland haulage.

Crainic and Kim (2007) defines intermodal freight transport as “the transportation of a load from its origin to its destination by a sequence of at least two transportation modes, the transfer from one mode to the next being performed at an intermodal terminal.” In hinterland haulage, intermodal freight transport strives to organize freight transport with the integrated use of different modalities (e.g., trucks, trains, barges) over an intermodal freight transport network (IFTN). An IFTN is a network consisting of different single-mode transport networks, e.g., the freeway network, the railway network, and the inland waterway network. These single-mode transport networks connect each other at intermodal terminals. An intermodal freight transport operator is a special organization or enterprise that owns or hires transport vehicles, e.g., trucks, trains, and barges, and provides shippers with intermodal container transport services over an intermodal freight transport network. The objective of intermodal freight transport planning is to select intermodal routes and determine container flow assignments over the IFTN such that a user-supplied objective function given by intermodal freight transport operators is minimized, while considering a number of transport demands, the physical capacities of transport connections, the transport network properties, and the traffic conditions. A typical example of such an operator is European Gateway Services (http://www.europeangatewayservices.com/), which offers frequent rail and barge connections between the Port of Rotterdam and a growing network of inland terminals in the hinterland of the port. Freight trucks are also available at terminals for transporting containers. Operators (such as European Gateway Services operator) provide an additional motivation for the work on the transport planning problem of intermodal freight transport operators as presented in this paper. The paper van Riessen et al. (2015) investigated the service network design problem for the European Gateway Services network using a path-based and minimum flow network formulation. In this paper, we will investigate container flow control problem in intermodal freight transport planning with a developed IFTN model.

1.2. The scope of the problem

This paper investigates intermodal freight transport planning problems among deep-sea terminals and inland terminals in hinterland haulage for a horizontally fully integrated intermodal freight transport operator (similar to carriers) at the tactical container flow level. The operator is assisted with an efficient ICT system. We assume that this ICT system can measure real container transport information regarding its own operations, timely exchange freight transport related information with the ICT systems of other parties involved (e.g., obtaining the measurements of traffic conditions on freeways from the traffic management system on the road network), integrate real freight transport related information from different sources, and further facilitate the freight transport planning done by the intermodal freight transport operator.

In maritime-based intermodal freight transport chains, hinterland haulage involves two steps: main haulage and pre-haulage or end-haulage (or collection or distribution). In this paper, we limit our scope to the main haulage, and therefore investigate intermodal freight transport planning problems among deep-sea terminals and inland terminals in hinterland haulage for intermodal freight transport operators.

Intermodal freight transport involves multiple stakeholders e.g., shippers, carriers, terminal operators, producers, consumers. There are typically two types of collaboration among these stakeholders: horizontal collaboration and vertical collaboration. This paper investigates the freight transport planning problem for a horizontally fully integrated intermodal freight transport operator, and considers other stakeholders (e.g., shippers, terminal operators) as either the customers or the service providers of this intermodal freight transport operator. This comes with the following underlying assumptions: shippers are the customers of the intermodal freight transport operator; the producers and consumers of the cargoes can be interpreted as the origins and destinations of containers, which will be specified by shippers when they make the container transport orders; terminal operators provide container handling services to the intermodal freight operator, and these container handling services are characterized by container storage capacities, container loading and unloading capacities, and times needed and cost charged for changing modalities at intermodal terminals.

Based on the decision horizon of planning problems, research efforts on intermodal freight transport are categorized into three decision-making levels: strategic level, tactical level, and operational level (see the review papers Crainic and Kim (2007), Macharis and Bontekoning (2004), Jarzemskiene (2007), Caris et al. (2008, 2013), and SteadieSeifi et al. (2014)). For an intermodal freight transport operator, strategic decisions concern the infrastructure investments, e.g., whether to increase or reduce the size of intermodal transport network that this operator works on, whether to purchase more transport vehicles or rent vehicles from leasing companies; tactical decisions consider aggregated container flows and are typically about service network design and network flow planning to optimally utilize the given infrastructure, e.g., modal choice and capacity allocation on each service, service frequencies and the timetables of trains and barges, equipment planning, and container flow assignment; operational decisions consider the optimal routing of each individual container over certain service networks, e.g., intermodal routing, itinerary replanning. The operational freight transport planning problem faced by intermodal freight transport operators is typically a mixed integer optimization problem in which individual containers are directly modeled and scheduled in the planning. This problem is NP-hard and requires huge computational efforts to solve it as the number of shipments or the size of the IFTN increase.