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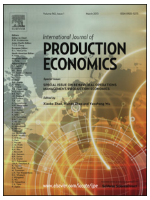

A market-oriented approach for intermodal network optimisation meeting cost, time and environmental requirements

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ABSTRACT

An increasing number of logistics service providers act as freight integrators in offering one-stop solutions to customers in recent years. Most mathematical models of intermodal network design have been developed with a single objective of cost minimisation. This study focuses on developing innovative approaches in the area of enhanced intermodal network design provided by freight integrators. The overall aim of this paper is to demonstrate an original optimisation model that can be employed by freight integrators to address cost minimisation, transit time minimisation, and carbon footprint to better meet market needs. To achieve the aim, this paper develops a bi-objective optimisation model to minimise cost and transit time for the tactical planning of intermodal container flows with constrained carbon emission. The results and analysis of the example of China offer practical insights on the impact of trade-offs between cost and transit time, and the effect of different carbon emission restrictions on intermodal network design.

1. Introduction

Containerisation which was invented about sixty years ago has brought logistics and transportation into a new stage. The way of cargo handling standardisation provides a solution which drives different transportation modes towards a seamless process (Thill and Lim, 2010). Hence the practice of intermodal transportation has become prevalent. Container intermodal transport can be well-described as container transport in multimodal chains which link the original nodes of consignors to the destination nodes of consignees so as to offer door-to-door services to customers. At the same time, the rapid development of supply chain management leads to a deeper integration between logistics services. The demarcation between previously exclusive logistics markets is now unclear. One-stop services achieving integration among various stages in supply chains are well welcomed by customers (Lam and Van de Voorde, 2011). Correspondingly, an increasing number of logistics service providers act as freight integrators in offering more integrated solutions to customers. These companies are eager to obtain a bigger piece of cake in a highly competitive environment to achieve the loyalty of their customers (Perez-Labajos and Blanco, 2004). Innovation plays a key role in the dynamic and competitive logistics market to better serve customers (Flint et al., 2005). Therefore, this study focuses on developing innovative approaches in the area of enhanced intermodal network design provided by freight integrators.

The design of intermodal networks has attracted increasing interests in academia. Nevertheless, there remain major literature gaps in this research domain. First, according to a recent literature survey (Lam and Gu, 2013), most mathematical models of intermodal network design have been developed with a single objective of cost minimisation (e.g. Iannone and Thore, 2010; Wang and Yun, 2013). Only few models integrated transit time as another objective (Jula et al. 2006; Zhang et al. 2009; Yang et al. 2011; Zhang et al. 2011), or included multiple objectives (Erera et al. 2005; Wong et al. 2010). Innovative solution methods should be developed to meet the need of a diversified market as some customers prefer lowest freight rates while some others would rather pay more for a faster delivery. Second, many research works focused on container routing and empty container repositioning in sea transportation. However, very few papers considered both sea and land legs together (Min 1991; Kim et al. 2008; Imai et al. 2009; Infante et al. 2009). Third, the issue of environmental protection has become a key concern in sustainable development in the logistics and transportation industries (Lun et al., 2015). Hence there is a growing need to consider carbon footprint in intermodal network design. To the authors' knowledge, we do not find any intermodal network optimisation model testing the effect of different carbon emission levels. Intermodal networks offer a great potential to improve sustainability because railway and inland barge transport generally incur much lower carbon emissions than trucking (Kim and Van Wee, 2014), which is currently a dominant

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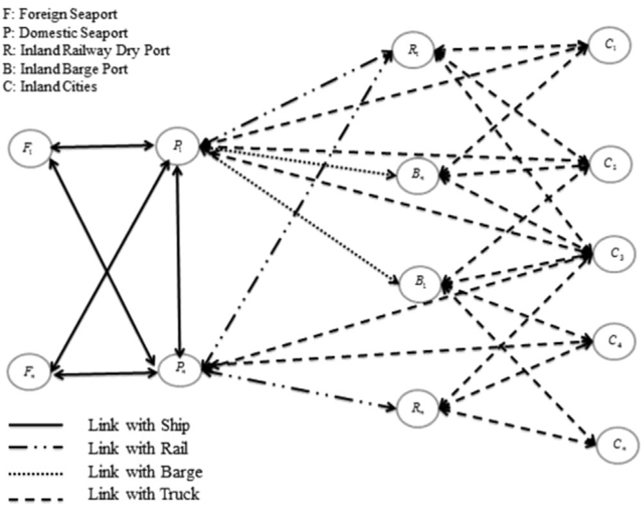

Fig. 1. Port hinterland intermodal container transport network.
Source: Drawn by the authors.

mode in inland transport. This explains why green transport initiatives suggest solutions such as seaports linked with inland dry ports by railway especially double-stack train application, inland barge connections, and using shortest possible initial and final journeys by trucks in intermodal networks (Rahimi et al. 2008; Liao et al. 2009). In general, environmental issues have been increasingly researched, but quantitative models developed to address such significant issues are relatively scarce (Rahimi et al. 2008; Shintani et al. 2010).

In view of the identified research gaps, this paper develops an original optimisation model for the tactical planning of a port hinterland intermodal network. The overall aim of this paper is to demonstrate an enhanced intermodal network design that can be performed by freight integrators to address cost minimisation, transit time minimisation, and carbon footprint to better meet market needs. There are three major inland transportation modes to link shipping, including railway, barge, and truck. These three major transportation modes incur different costs, transit times, and carbon emissions. How to manage the trade-offs among these three aspects is a major challenge to freight and logistics planners, operators and users, because their corresponding management objectives may conflict with each other most of the time (Lam and Lai, 2015; Notteboom, 2010). This study develops an innovative approach to address these trade-offs and to analyse the effect of different carbon emission restrictions on intermodal network design using a case study of China.

The rest of this paper is organised as follows: Section 2 describes the detailed problem and presents model formulation. Section 3 applies the model for a case study regarding China and reports the numerical results. Section 4 discusses managerial implications. Section 5 concludes this research.

2. Problem description and model development

2.1. Port hinterland intermodal network design problem

The model is used for the tactical planning of a port hinterland intermodal network. The detailed network is illustrated in Fig. 1. Containerised freights are shipped from many foreign seaports to many domestic seaports. After containers are discharged at domestic seaports, customs clearance is required before they can be routed through an inland transport network to end-customers' distribution centres at domestic inland cities. Three available inland transportation modes could be chosen, including truck, railway, and barge. Where there are available rail linkages or barge ports nearby, line-haul may be done by rail or barge before last mile delivery by trucking. Without such facilities, containers could also be transported from domestic seaports to end-customers all the way by trucking.

2.2. A bi-objective optimisation model

This model has two objectives: cost minimisation and transit time minimisation. Bi-objective optimisation is more reasonable and practical than single objective optimisation. In real-life situations, decision makers often need to deal with conflicting objectives. Cost and transit time are the two most common considerations in transport planning problems (Lam and Gu, 2013). This model is formulated in a setting that a freight integrator is the decision maker. We assume that the freight integrator uses one type of container ship and there is no capacity constraint for container transport in the sea leg since shipping capacity is not the focus of this study. The main focus is put on the hinterland container transport optimisation and its modal split situation. Also, this assumption fits the current market situation of over-supply in general. Transit times are assumed to be deterministic at all transportation modes. This assumption suits the tactical planning time horizon and the study scope. To analyse the effect of different carbon emission requirements on intermodal network design, carbon emission restrictions set by the government for transport operations are considered as a model constraint. This section presents the model formulation and corresponding explanations are given as follows.

2.2.1. Model formulation

2.2.1.1. Sets.

Set	Description
N	A set of nodes, let $N = F \cup P \cup R \cup B \cup C$, while F stands for foreign seaports, P stands for domestic seaports, R stands for dry ports linked by railway, B stands for barge ports, C stands for inland cities.
A	A set of arcs, let $A = A_{FP} \cup A_{PF} \cup A_{PR} \cup A_{RP} \cup A_{PB} \cup A_{BP} \cup A_{PC} \cup A_{CP} \cup A_{RC} \cup A_{CR} \cup A_{BC} \cup A_{CB}$, For each $(i,j) \in A_{XY}$, (i,j) denotes the arc from $i \in X$ and $j \in Y$, and $X, Y \in \{F, P, R, B, C\}$.

2.2.1.2. Decision variables.

Decision variable	Description
tcm_{ij}	Total container transport quantity from node n_i to n_j in TEUs, $(i,j) \in A$
ecm_{ij}	