ARTICLE IN PRESS

Transportation Research Part E xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

A strategic model of port-hinterland freight distribution networks

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ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form 25 May 2016
Accepted 30 May 2016
Available online xxxx

Keywords:
Port-hinterland network
Distribution network
Freight model
Port connectivity
Policy analysis
Facility location model

ABSTRACT

This paper presents a strategic model for port-hinterland freight distribution networks. The approach utilizes a combination of a multi-objective optimization model to estimate locations and networks of distribution centers and an assignment model that recognizes distributed service level preferences. Our example application concerns the European continent and is transferable to other regions. The model calibration is able to explain the European port-hinterland distribution structures satisfactorily. We compute novel performance measures that take into account port-hinterland distribution structures. The measures include port-hinterland transport cost, port-hinterland transport time, and distribution center-hinterland transport time. These measures can provide inputs for port-connectivity studies.

1. Introduction

In the past decades, international trade has grown substantially due to flourishing interregional economic cooperation and international economic competition. Established and emerging economic blocks such as ASEAN (Association of South East Asian Nations), AANZFTA (ASEAN, Australia, and New Zealand Free Trade Area), EFTA (European Free Trade Association) the EU (European Union), RCEP (Regional Comprehensive Economic Partnership), TPP (Trans-Pacific Partnership), BRICS (Brazil, India, China, Russia and South Africa) and IBSA (India, Brazil, South Africa) are increasingly aware of the need to stimulate and facilitate trade among their member states.

Advances in the efficiency of global freight logistics systems play a key role in supporting the growth of international trade, specifically trade taking place between major economic blocks and continents. Major developments such as containerization and the emergence of global maritime shipping networks have reduced maritime transport cost to an unprecedented level. Logistics services in the maritime component of the global freight transportation system have become very efficient. The efficiency of the global shipping system stands in stark contrast to lack of efficiency of inland freight distribution systems. Inland freight distribution systems, which connect the maritime shipping system to both production and consumption sites, still face profound efficiency challenges.

Hinterland transport costs, on average, constitute 80% of the total transport cost of intermodal shipments, while hinterland transport covers only 10% of the total transport distance (Rodrigue and Notteboom, 2012). Port-hinterland transport costs are both a strong measure of port connectivity, as well as the highest cost component in global freight transport chains. Improvements in port-hinterland distribution systems will positively impact the connectivity of ports to hinterland

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http://dx.doi.org/10.1016/j.tre.2016.05.014

destinations, while simultaneously substantially reducing transport costs in global shipping networks. In fact, port-hinterland connectivity plays a very important role in the port choice of the shippers and hence the routing and volumes of transported goods (Halim et al., 2015).

Unlike maritime freight transport, hinterland freight transport is much more resistant to changes due to the involvements of many actors, and the strong path dependency in infrastructure developments. A salient example is the tension between the slowly developing port-hinterland infrastructure, and the rapidly growing demand for hinterland freight transport (Notteboom, 2008). Over the past couple of decades, there has been a steady increase of port related flows on inland transportation networks. This has caused traditional direct shipments using trucks to face problems such as congestion, negative environmental impacts, and economic losses due to prolonged transport time.

Logistic service providers respond to the tension between transport demand and transport supply by dynamically adapting their services and strategies, ensuring that producer, product, and client service level requirements are met. They make strategic decisions about the selection of the right modes of transport, the location of distribution centers, and the connections between distribution center locations and modes of transport, in an effort to continuously reduce generalized logistics cost. Regular updates of these decisions by shippers and logistics service providers will follow the fast paced changes in trade flows. These strategic decisions by shippers and logistic service providers shape the way seaports are connected to hinterland destinations, and thus strongly affect port connectivity.

Our paper focuses on the quantitative modeling of port-hinterland distribution systems, aimed at providing support for strategic decisions for improving the efficiency of port-hinterland infrastructures and services. Strategic changes in hinterland networks affect large regions such as the European Union. The geographic scope of the model, therefore, is that of a continent, which covers the hinterland of a major maritime port; a scale at which port competition and port-hinterland connectivity typically is studied. The model can be used to study the impact of various developments including demand growth, changes in infrastructure networks, and changes in transport pricing. In particular, the model supports the assessment of changes in port-hinterland connectivity as it calculates advanced measures of port-hinterland transport costs and transport time. As such, the presented model describes a critical component of models of global transport chains. Furthermore, when this model is combined with a global container network choice model such as the World Container Model (Tavasszy et al., 2011), it can also support the assessment of impact of changes in port-hinterland connectivity on port choice.

So far, only few models have been developed to describe port-hinterland distribution systems. The majority of port-hinterland literature has aimed at building the taxonomy and conceptualization of port-hinterland distribution systems (Dooms et al., 2015; Notteboom, 2008, 2010; Notteboom and Rodrigue, 2005; Rodrigue and Notteboom, 2010; Veenstra et al., 2012). Structures of port-hinterland logistic systems are only rarely assessed quantitatively through the application of an empirically valid modeling approach. Studies that do apply quantitative modeling approaches typically aim to optimize the performance of individual companies (Goetschalckx et al., 2002), rather than focusing on the aggregate port-hinterland distribution system. There are a few models that explicitly address the design of port-hinterland intermodal connections, such as Thore and Iannone (2012) and Lam and Gu (2013). These models suggest normative designs of intermodal connections in the port-hinterland network and do not recognize behavior and preferences of different actors, nor do they account for distribution centers in these logistics networks. Typically, therefore, port-hinterland connectivity studies (see e.g. Ferrari et al., 2011; Wang et al., 2016; Thill and Lim, 2010) use simplified cost measures, which do not account adequately for the structure of port-hinterland logistic systems. We intend to fill these gaps.

In our paper, we present a novel approach to descriptively model complex port-hinterland distribution networks. The approach utilizes an integrated multi-stage logistics network model for aggregate agents, recognizing heterogeneous service preferences and including locations of distribution centers that serve port-hinterland flows. Specifically, we model the freight distribution network that connects seaports, distribution centers (DCs), and consumption regions. There exist many definitions of what a DC is. In this research, we consider a DC to be either a warehouse where containers are stripped and the contents are stored or cross-docked, or a container depot where goods wait inside the container to be called by a factory nearby. Our approach also allows for calculating port-hinterland connectivity using advanced measures of port-hinterland transport costs and transport time, which account for these complex port-hinterland distribution networks. To demonstrate the feasibility of the model, we present an application to the European port-hinterland distribution network, for which data are readily available. We consider 1445 regions at the NUTS-3 (The European nomenclature of territorial units for statistics) level as consumption regions, 309 regions as potential DC locations, and 121 seaports in Europe, as the origins and destinations of the port related flows.

The remainder of the paper is organized as follows. In Section 2, we position our approach in the freight modeling literature. Section 3 presents the model, including the solution algorithms and the approach for model calibration. Section 4 provides the results of the application of the model to the European port-hinterland logistics network involving seaports, distribution centers, and consumption regions. Section 5 presents our conclusions and recommendations.

2. Literature review

Our port-hinterland model builds on the existing literature in the field of freight transport modeling. In this section we review the literature relevant for the development of the model, paying specific attention to the scale and perspectives (i.e. normative/optimization-based model, or descriptive/exploration-based model) employed in the model.