Transportation Research Part E 118 (2018) 1–19

Contents lists available at ScienceDirect

Transportation Research Part E

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

Community structure based global hub location problem in liner shipping

Jianfeng Zheng[a,*], Jingwen Qi[a], Zhuo Sun[a,*], Feng Li[b]

[a] Transportation Engineering College, Dalian Maritime University, Dalian 116026, China
[b] State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing 100044, China

ARTICLE INFO

Keywords:
Global hub location problem
Liner shipping
Community structure

ABSTRACT

This paper proposes a global hub location problem (GHLP) in liner shipping considering community structure. A two-stage optimization method is developed to solve the proposed problem. In the first stage, ports are partitioned into different communities by using a community detection algorithm. In the second stage, we determine the location of hub ports for various communities, respectively. The optimal hub location solution for each considered community can be independently determined. Then the problem size can be sharply decreased. More importantly, we find that it forms a community structure based optimal solution of the GHLP by combining the optimal hub location solutions for all considered communities. Numerical experiments are carried out to account for the effectiveness of our two-stage optimization method.

1. Introduction

In liner shipping, many containers are often transshipped at the hub ports in order to benefit from economies of scale on transporting containers through the consolidation of containers. The location of hub ports is a very important problem that significantly affects decision making in container routing and ship routing, especially in liner hub-and-spoke (H&S) shipping network design. Generally, large ships are usually deployed to serve the hub ports, and small ships often serve some feeder ports. In the conventional hub location problem (Alumur and Kara, 2008), flows are routed from origin nodes to destination nodes through an H&S structure. Hence, the hub location problem is often regarded as a special H&S network design problem (or a hub network design problem). Most of the previous studies on liner H&S shipping network design (e.g., Fagerholt, 1999, 2004; Sambracos et al., 2004; Imai et al., 2009; Karlaftis et al., 2009; Gelareh et al., 2010; Gelareh and Pisinger, 2011; Meng and Wang, 2011a; Zheng et al., 2014, 2015b) often consider a region or a subnetwork of the global shipping network, such as an Asia-Europe-Oceania shipping network. This paper investigates the location of hub ports in a global shipping network, which is called global hub location problem (GHLP), from a single liner carrier point of view. As a strategic level for certain liner carrier, the decision-making of the GHLP is helpful for determining liner shipping network design from a global optimization perspective. This is because long-haul shipping service routes (or main lines) basically serve the hub ports and some major ports, while feeder lines serve the feeder ports. In practice, many liner carriers provide global shipping services for their customers. Based on a region or a subnetwork of the global shipping network considered in the previous studies, a local optimization hub location solution may be obtained for certain liner carrier providing global shipping services. This motivates us to investigate the GHLP, based on which a global optimization hub location solution can be obtained.

* Corresponding authors.
E-mail addresses: jfzheng@dlmu.edu.cn (J. Zheng), mixwind@gmail.com (Z. Sun).

https://doi.org/10.1016/j.tre.2018.06.009
Received 13 May 2018; Accepted 26 June 2018
1366-5545/

In the last century, certain liner shipping company provided some around-the-world shipping service routes, each of which visits the ports around the world, such as Evergreen Marine Corp. Ltd. (https://www.evergreen-marine.com/tw/tbi1/jsp/TBI1_History.jsp). Due to the ship size limitation at Panama Canal, large vessels cannot be deployed on the around-the-world shipping service routes. Hence liner shipping companies cannot benefit from economies of scale. As a result, around-the-world shipping service routes are not common nowadays. Due to global warming, the Arctic shipping service routes may be opened in the near future, it may be another chance to provide around-the-world shipping service routes. In practice, many liner shipping service routes are serving between two continents, classified by different trade lanes, such as Trans-Pacific, Trans-Atlantic and Asia-Europe. There are interactions between different liner shipping service routes serving different trade lanes. This is because, there are many overlaps between different liner shipping service routes. For example, there are some overlaps between Trans-Pacific and Asia-Europe trade lanes, leading to some identical ports (or hub ports). Because of these identical hub ports, containers are often transshipped between different liner shipping service routes serving different trade lanes. Hence, it is very necessary to investigate hub location from a global optimization perspective.

Obviously, the GHLP can be completely equivalent to the conventional hub location problem (see Alumur and Kara, 2008), which is an NP-hard problem. The difficulties in solving the GHLP lie in that the GHLP is a large scale problem and there are a great number of integer decision variables. Hence, it is a big challenge to directly solve the GHLP by using the previous algorithms on the hub location problem. The main work of this paper is to propose a proper method to efficiently solve the GHLP.

In the conventional hub location problem (Alumur and Kara, 2008), different nodes are directly connected by links. The link distance is often measured by the Euclidean distance. In maritime transportation, ships sail along the waterways. The distance between any two ports should be calculated based on the waterways and the spherical distance. Generally, any two ports cannot be simply connected via a link. Instead, we consider that ports are directly connected to the waterways, following Sun and Zheng (2016).

In order to efficiently solve the GHLP, this paper makes use of community structure, which is a common property in many realistic networked systems (Girvan and Newman, 2002; Newman and Girvan, 2004). Namely, the network divides into groups of nodes with dense connections internally and sparser connections between groups. Each group is a single community. Generally, a liner H&S shipping network has community structure. Any feeder shipping service network composed of a hub port and its associated feeder ports can form a community. This is because, within any community there are many connections between a hub port and its associated feeder ports, while between different communities there are only a few connections among various hub ports. As shown in Sun et al. (2012), the global shipping network has community structure.

Based on community structure, this paper develops a two-stage optimization method to efficiently solve the GHLP. In the first stage, ports are partitioned into different communities by using a community detection algorithm. In the second stage, we determine the location of hub ports for various communities, respectively. The optimal hub location solution for each considered community can be independently determined. The problem size can be sharply decreased.

Sung and Jin (2001) proposed a hub network design problem under a non-restrictive policy, which is called cluster hub location problem (CHLP) in Wagner (2007). In Sung and Jin (2001), nodes are partitioned into some predetermined clusters, which are called communities in this paper. The main differences between the GHLP and the CHLP are as follows. Firstly, the GHLP mainly considers economies of scale on some major waterways, while the CHLP considers economies of scale on the hub-level network (i.e., inter-hub flows), following the conventional hub location problem. Secondly, the CHLP assumes that only one hub is established for each cluster, while the GHLP considers one or more hubs to be established for each community. More importantly, the GHLP can be efficiently solved by using our two-stage optimization method, as will be shown later.

1.1. Literature review

The hub location problem was initiated by Goldman (1969), followed by O'Kelly (1986, 1987). In the conventional hub location problem, economies of scale are often measured by a constant discount factor (see Alumur and Kara, 2008, and references therein). Later, O'Kelly and Bryan (1998) considered a flow-based cost function for describing economies of scale. Racunicam and Wynter (2005) investigated the intermodal hub location problem, and Meng and Wang (2011b) studied the intermodal H&S network design problem, both of which considered the flow-based cost functions. Tanash et al. (2017) proposed an exact algorithm to solve the modular hub location problem with single assignments, in which the flow-based cost functions are considered for economies of scale. Gelareh and Pisinger (2011) and Asgari et al. (2013) studied the hub location problem in a liner shipping network, in which the discount factor is considered for economies of scale. This paper considers different cost functions on discount factor to reflect economies of scale. Namely, a constant discount factor and ship type based discount factor are considered in this paper.

Researchers have proposed many different hub location problems and models (see Alumur and Kara, 2008, and references therein), including the p-hub median problem, the hub location problem with fixed costs, the p-hub center problem and hub covering problems. In addition, Campbell et al. (2005a,b) studied the hub arc location problems. Yaman (2009) and Alumur et al. (2012) investigated the hierarchical hub location problems. Kim and O'Kelly (2009), Cui et al. (2010) and An et al. (2014) explored the reliable hub location problems. Contreras et al. (2011) studied a dynamic hub location problem. Asgari et al. (2013) studied a network design approach for hub ports-shipping companies' competition and cooperation, each of which is formulated by a hub location problem. Recently, Teye et al. (2017a,b) employed the method of entropy maximization to combine a logit mode choice model with a facility location problem to investigate the development of urban intermodal container terminals for port cities. Zeng et al. (2017) investigated the impact of the Carat Canal on the evolution of hub ports under China's Belt and Road initiative. For more hub location problems and models, please refer to the review papers, i.e., Alumur and Kara (2008), Campbell and O'Kelly (2012) and Farahani et al. (2013).