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Interfaces with Other Disciplines

Impact analysis of maritime cabotage legislations on liner hub-and-spoke shipping network design ☆

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ABSTRACT

Maritime cabotage is a legislation published by a particular coastal country, which is used to conduct the cargo transportation between its two domestic ports. This paper proposes a two-phase mathematical programming model to formulate the liner hub-and-spoke shipping network design problem subject to the maritime cabotage legislations, i.e., the hub location and feeder allocation problem for phase I and the ship route design with ship fleet deployment problem for phase II. The problem in phase I is formulated as a mixed-integer linear programming model. By developing a hub port expanding technique, the problem in phase II is formulated as a vehicle routing problem with pickup and delivery. A Lagrangian relaxation based solution method is proposed to solve it. Numerical implementations based on the Asia–Europe–Oceania shipping services are carried out to account for the impact analysis of the maritime cabotage legislations on liner hub-and-spoke shipping network design problem.

1. Introduction

In International Law, "Cabotage" is identified with coasting – trade so that is means navigating and traveling along the coast between the ports thereof (Igbokwe, 2001). Cabotage has however come to be known as "coastal trade" or "coasting trade" or "coastwise shipping", meaning carriage of goods and persons by ships between ports on or along the same coast or between ports within the same country and the exclusive rights of a country to operate sea traffic within its coasts, or to operate air traffic, road traffic or rail traffic within its territory (Igbokwe, 2001). In this regard, there is cabotage in different modes of transportation. This paper is concerned with the maritime cabotage.

A maritime cabotage law is a legislation published by a particular coastal country, to exclusively conduct its domestic shipping operations. The strict and relaxed maritime cabotage legislations (Igbokwe, 2001) have been used by different coastal countries in order to favor the national interests and to control local coastal trades. In the former legislation of a coastal country, the domestic shipping is strictly restricted to those ships built, owned and operated by citizens of this country. The latter one relaxed one or some of the above three restrictions. One example for the strict maritime cabotage legislation is known as "the Jones Act" (Whitehurst, 1985) implemented in the United States (US). The relaxed maritime cabotage legislations are applied in coastal countries, such as India, Philippines, Australia, and Malaysia.

In order to benefit from the economies of scale in ship size, large ships are deployed by liner shipping companies to serve the major or hub ports and small ships are used to consolidate cargoes (e.g., containers) from some feeder ports, leading to a hub-and-spoke (H& S) shipping manner. For example, Maersk line, which is the world's largest liner shipping company, ordered 10 mega ships with the capacity of 18,000 twenty-foot equivalent units (TEUs) each in 2011 and these mega ships will be deployed on the Asia–Europe trade lane. Furthermore, the liner shipping company provides the maximal transit time between a pair of ports on the website as an important factor to evaluate the level of service, called the transit time constraints. The purpose of this study is to quantify the impact of the strict maritime cabotage legislation on a liner shipping company in designing its H& S shipping network subject to the transit time constraints by developing a proper mathematical model and a solution method.

1.1. Literature review

Different maritime cabotage legislations have been implemented in different coastal countries, and there are a number of studies for its qualitative impact on maritime industry and economy of the coastal country. Aspinwall (1987) analyzed the impact

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of American cabotage law on the outer continental shelf operations. Francois, Arce, Reinert, and Flynn (1996) explored the effects of the Jones Act on welfare and on production, trade, and employment in important upstream and downstream sectors. Recently, Mak, Sheehey, and Toriki (2010) discussed the application of Passenger Vessel Services Act (PVSA) of 1886 to the US cruise ship industry. The PVSA is also a maritime cabotage law, which attempts to shield US maritime shipping from foreign competition. Cavana (1994) provided a brief review of the costal shipping industry in New Zealand and an overview of international cabotage laws. Later, Cavana (2004) discussed a qualitative analysis of reintroducing maritime cabotage legislation onto New Zealand's coasts. The main conclusion drawn from the stakeholder analysis was that to reintroduce the maritime cabotage legislation onto New Zealand's coast would appear to have an overall net negative impact on the New Zealand economy. This is mainly because: (i) maritime cabotage would result in increased domestic and international freight rates, reduction in competition and choice of transport services, job losses in the manufacturing and agricultural sectors, and loss of exports; (ii) there would be an overall increase in fuel usage and adverse effects on the environment since the international vessels were currently moving along the coast. Hohlfelder and Vann (2000) investigated the maritime cabotage legislation at Aperlae in ancient Lycia based on observations arising from the continuing survey of Aperlae. They concluded that the maritime cabotage legislation is the secondary port's enduring lifeline. Similar to the maritime cabotage, Zou (2002) investigated the navigation of foreign vessels within Chinese jurisdictional waters. Giannopoulos and Aifandopoulou-Klimis (2004) gave a comprehensive review of the inland maritime transport system of Greece before the application of full liberalization in the provision of transport services and the lifting of maritime cabotage restrictions that existed until 2002. Very recently, Lazarus and Ukpere (2011) studied the maritime cabotage legislation, Cabotage Act of 2003, which came into force in 2004 and aimed at reserving the coastal shipping for Nigeria nationals.

There have been many studies on the network design of H& S operations in the literature. O'Kelly (1987) proposed the first recognized mathematical formulation given as a quadratic integer programming problem. Later, Campbell (1992, 1994) presented linear integer programming models for single and multiple allocation, respectively. Moreover, there are also many extended models for the H& S network design problem, such as Skorin-Kapov, Skorin-Kapov, and O'Kelly (1996), O'Kelly, Bryan, Skorin-Kapov, and Skorin-Kapov (1996), Ernst and Krishnamoorthy (1996), Sohn and Park (1998), Ebery (2001), Alumur, Kara, and Karasan (2009). For more studies, please refer to a review paper by Alumur and Kara (2008) and the references therein.

There are also many works on the H& S network design in liner shipping. Fagerholt (1999, 2004), Sambracos, Paravantis, Tarantilis, and Kiranoudis (2004), Karlaftis, Kepaptsoglou, and Sambracos (2009) focused on investigating a feeder ship route design problem, which can be formulated as a vehicle routing problem (VRP). Given two hub ports located at two regions, Imai, Nishimura, Papadimitriou, and Liu (2006, 2009) studied the H& S operations and multi-port-calling (MPC) operations. Based on a set of candidate ship routes, Meng and Wang (2011) formulated the liner shipping network design problem with combined H& S and MPC operations as a mixed-integer linear programming model, which can be efficiently solved by CPLEX. Recently, Gelareh, Nickel, and Pisinger (2010) investigated the liner H& S shipping network design problem under a competitive situation. Later, Gelareh and Pisinger (2011) introduced the ship fleet deployment into the liner H& S network design problem, where the discount of transportation cost is assumed to be dependent on the size of the deployed ship. Different from H& S network design, many studies have been carried out for ship routing and scheduling problems in liner shipping, please refer to some review papers such as Christiansen, Fagerholt, and Ronen (2004, 2013) and Meng, Wang, Andersson, and Thun (2013), and the references therein.

1.2. Objectives and contributions

This paper quantifies the impact of maritime cabotage legislations on a liner shipping company in designing its H& S shipping network. It proposes a two-phase mathematical programming model for the liner H& S shipping network design problem subject to the maritime cabotage legislations and transit time constraints. The first phase determines the hub port location and feeder port allocation subject to the maritime cabotage legislations, by solving a mixed-integer linear programming model. The second phase designs main and feeder ship routes with ship fleet deployment subject to the transit time constraints, which is formulated as a vehicle routing problem with pickup and delivery (VRPPD). A Lagrangian relaxation based solution method is proposed to solve it.

The contributions of this paper are threefold. Firstly, a more practical liner H& S shipping network design problem subject to the maritime cabotage legislations is proposed. Secondly, a two-phase mathematical programming model is built for the proposed problem. Thirdly, an efficient solution method is developed to solve our problem.

The rest of this paper is organized as follows. Section 2 gives the notation and problem description. Section 3 proposes a two-phase mathematical programming model. Section 4 provides a Lagrangian relaxation based solution method. Section 5 carries out the numerical experiments based on Asia–Europe–Oceania shipping service. Finally, a summary is given in Section 6.

2. Notation and problem description

2.1. Maritime cabotage legislations

To incorporate maritime cabotage legislations, we assume that ships considered in this paper are built, owned and operated by citizens of a country a. We will implement different scenarios by considering different a. Let $\mathcal{P}$ represent the set of ports, which can be further classified into two disjoint subsets: the set of hub ports denoted by $\mathcal{P}^{\mathrm{H}}$ and the set of feeder ports denoted by $\mathcal{P}^{\mathrm{F}}$. The maritime cabotage legislations in liner H& S shipping network design can be simply described by introducing an indicator δ_{ij}^{a} for each pair of port i and port j $(\forall i, j \in \mathcal{P})$. If ships of country a are allowed to directly transport containers from port i to port j, δ_{ij}^{a} is equal to 1; otherwise δ_{ij}^{a} is 0. Let $\boldsymbol{\delta}^{a}$ denote the set of $\left\{\delta_{ij}^{a}\right\}(\forall i, j \in \mathcal{P})$.

In order to take the maritime cabotage legislations of the different coastal countries into account, this paper assumes that China and Japan published the strict maritime cabotage legislations. We further assume that two liner shipping companies, i.e., COSCO in China and APL in Singapore will provide the shipping services, respectively. Due to the Japanese maritime cabotage legislation, COSCO cannot provide the direct shipping services among the ports in Japan. As for APL, both Chinese and Japanese maritime cabotage legislations will function for their local ports, respectively.

2.2. Main and feeder ship routes

Generally, the liner shipping company publishes the regular shipping services among a group of ports. Each shipping service can be described as the port calling sequence by a ship, which is referred to as a ship route. Let $\mathcal{R}$ denote the set of all feasible ship routes. Let $\mathcal{V}$ denote the set of all available ships. Since not all ships