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The effects of emission control area regulations on cruise shipping

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ABSTRACT

To control SOx, NOx and particulate matter emission from ships, including cruise ships, emission control areas (ECAs) have been defined by the International Maritime Organization (IMO), which influences cruise planning. This paper investigates a mixed integer programming model to re-schedule voyage plans by optimizing speeds, sailing patterns and ports-of-call sequences, hence reducing fuel costs. A tabu search based solution method is developed to solve the model. Computational tests on real-world data of cruise lines are conducted in order to explore the effects of ECA regulations on cruise shipping. The results show that the proposed model can save fuel costs under ECA regulations, and the designed solution method is efficient.

1. Introduction

The modern cruise industry originated in North America in the 1960s (Lawton and Butler, 1987; Hobson, 1993) and has developed into a comprehensive tourism product that provides entertainment, shopping, accommodations, and dining and fitness facilities, such that cruise ships are also known as 'floating resorts'. The rapid economic development of the global cruise has made it one of most active and rapidly developing segments in the modern tourism industry (Sun et al., 2011). From 2005 to 2015, the number of cruise passengers worldwide has increased considerably from 13.24 to 22.06 million (+66.62%). A cruise fleet of 315 ships operated globally in 2016, carrying 23.6 million passengers and generating revenues of 35.5 billion USD (Cruise Industry News, 2017). In recent years, the international cruise industry has maintained its high growth rate. In addition, its center of development has begun to transfer to the Asia-Pacific region. According to the China Cruise and Yacht Industry Association, in 2016, 996 cruise ships and 6.78 million passengers were hosted by ten top ports (Sanya port, Haikou port, Guangzhou port, Xiamen port, Zhoushan port, Shanghai port, Qingdao port, Yantai port, Tianjin port, and Dalian port) in China, which represented increases over the previous year of 58% and 82%, respectively.

The growth of the cruise industry has led to increasing concerns about its environmental impact. Cruise ships generally use heavy oil, which has a complex composition and produces more hazardous substances, such as sulphides. Cruise ship emissions entail different risk and hazard for the environment (Carić and Mackelworth, 2014). Protecting the ecological environment is the foundation and prerequisite for permanently utilizing a tourism resource. For SOx, NOx and particulate matter emissions, the ECAs (Emission Control Areas) designated under MARPOL (International Convention for the Prevention of Pollution from Ships) Annex VI promulgated by the IMO (International Maritime Organization) include the Baltic Sea area, the North Sea area, the North American area and the Unites States Caribbean Sea area. In addition, DECAs (Domestic Emission Control Areas) are defined to improve the air quality of coastal areas, regions along rivers, and in particular, port cities in China. These include the Pearl River Delta area, the Yangtze River Delta area and the Bohai Rim (Beijing, Tianjin, Hebei) area, as shown in Fig. 1.

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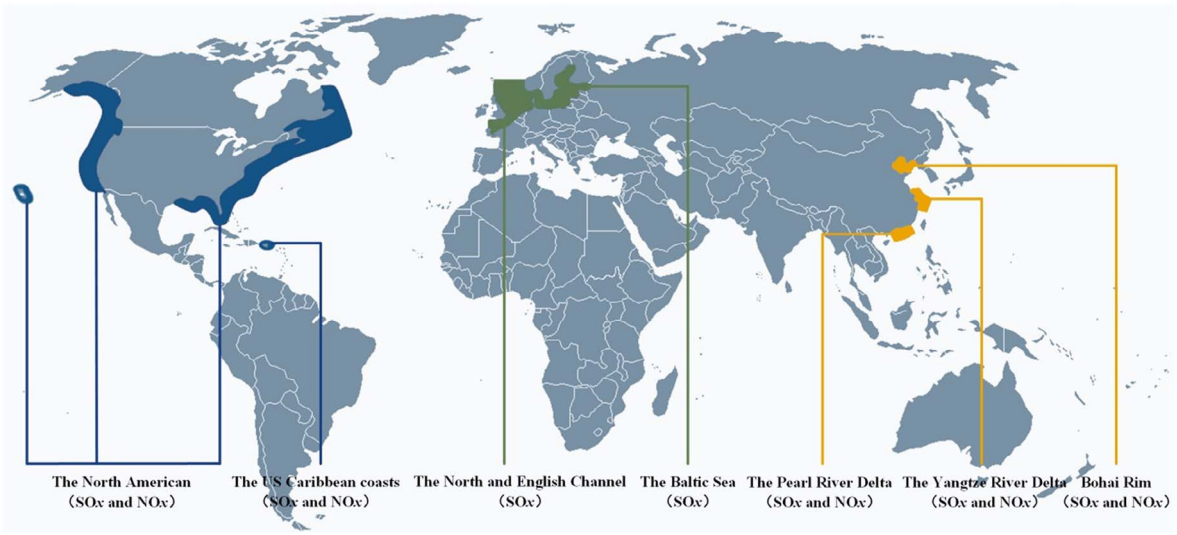

Fig. 1. Map of the emission control areas.

The establishment of ECAs has been remarkably successful in controlling marine pollution but has had certain impacts on the shipping industry. Its side effects are mainly embodied in the following aspects. Fuel costs are the main factor affecting total operational costs, and low-sulphur fuel is more expensive than bunker fuel, so total operational costs have increased. ECA regulations also affect speed and routing decisions, which are critical fuel cost determinants. Cruise lines have three alternatives to satisfy the sulphur standards of ECA regulations (Fagerholt et al., 2015). The first approach is to install a scrubber system that removes the sulphur content from the exhaust, which allows cruise ships to continue using HFO (heavy fuel oil) in the ECAs. The second method is to use LNG (liquefied natural gas) as the fuel to reduce sulphur and nitrogen oxide emissions. The last option is fuel switching, which allows a cruise to convert between burning HFO outside ECAs and the cheaper MGO (marine gasoline oil) inside ECAs. MGO is a clean fuel with extremely low sulphur content (0.1%) and can be used within ECAs. In this paper, we will focus on the most widely used method, which is fuel switching (Gu and Wallace, 2017).

The research contribution is threefold. First, we develop a mixed integer programming model to optimize sailing speeds and ports-of-call sequences of the cruise ship and thereby minimize fuel costs of cruise itineraries under ECA regulations. Second, we conduct computational tests on a realistic cruise itinerary to indicate that ECA regulations have an impact on fuel costs of cruise itineraries and prove that the proposed model can provide optimized ports-of-call sequence and cruise shipping schedule for cruise lines. Third, since some itineraries of cruise lines take months and require visiting a considerable number of ports, which is an instance of large-scale problems; we design a tabu search based solution method is designed to solve such large-scale problems.

The remainder of this paper is organized as follows. Section 2 is the literature review. The problem description is provided in Section 3. Then, a mathematical model is formulated in Section 4. To solve the model, Section 5 addresses a tabu search based solution method. Section 6 presents the data input and the results of numerical experiments, and conclusions are presented in the last section.

2. Related works

Cruise shipping is one of tourism's robust growth engines and an integral part of maritime transportation. However, the academic literature about cruise shipping is limited over the past two decades. One reason for the relative lack of research is that cruise ship tourism began relatively late and accounts for only 2% of world tourism in revenue (Gui and Russo, 2011). Another explanation is that scholars primarily concentrate on freight transportation in terms of maritime logistics (Meng and Wang, 2012; Zhen, 2016; Zhen et al., 2016, 2017).

The prior research has predominantly focused on cruise shipping as a segment of the global service supply chain. Soriani et al. (2009) suggested that vertical integration processes play an important role in affecting competition among cruising ports. In the future, the main challenges will be to effectively integrate port activity with inland resources. Véronneau and Roy (2009) investigated the critical features of the cruise ship supply chain and the most efficient measures in managing global service supply chains through a field study and interviews with cruise company managers. Similarly, Véronneau et al. (2015) further explored the contribution pattern of service suppliers for the cruise industry and the relationships between a major cruise line company and its suppliers to examine service quality creation among suppliers. Rodrigue and Notteboom (2013) studied a specific case of capacity deployment and itineraries in two cruise markets, the Caribbean and the Mediterranean, which are interrelated and interact with each other due to seasonal demand. The above studies contribute to the cruise shipping field, but none of them are quantitative analyses. The above studies have contributed to the cruise shipping field, but none of them provide quantitative analyses. The following scholars have embarked on new attempts to incorporate quantitative research methods and have examined specific problems in the cruise shipping