Transportation Research Part B 72 (2015) 1–19

Contents lists available at ScienceDirect

Transportation Research Part B

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

A tailored branch-and-price approach for a joint tramp ship routing and bunkering problem

Qiang Meng [a,*], Shuaian Wang [b], Chung-Yee Lee [c]

[a] Department of Civil and Environmental Engineering, National University of Singapore, Singapore 117576, Singapore
[b] Strome College of Business, Old Dominion University, Norfolk, VA 23529, USA
[c] Department of Industrial Engineering and Logistics Management, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

ARTICLE INFO

Article history:
Received 23 April 2013
Received in revised form 12 November 2014
Accepted 13 November 2014
Available online 4 December 2014

Keywords:
Maritime transportation
Ship routing and scheduling
Bunkering
Tramp shipping
Branch-and-price

ABSTRACT

This paper deals with a practical tramp ship routing problem while taking into account different bunker prices at different ports, which is called the joint tramp ship routing and bunkering (JSRB) problem. Given a set of cargoes to be transported and a set of ports with different bunker prices, the proposed problem determines how to route ships to carry the cargoes and the amount of bunker to purchase at each port, in order to maximize the total profit. After building an integer linear programming model for the JSRB problem, we propose a tailored branch-and-price (B&P) solution approach. The B&P approach incorporates an efficient method for obtaining the optimal bunkering policy and a novel dominance rule for detecting inefficient routing options. The B&P approach is tested with randomly generated large-scale instances derived from real-world planning problems. All of the instances can be solved efficiently. Moreover, the proposed approach for the JSRB problem outperforms the conventional sequential planning approach and can incorporate the prediction of future cargo demand to avoid making myopic decisions.

1. Introduction

Seaborne transportation, a main freight transportation mode, is one of the cost effective ways of transporting large volume of cargoes between continents. UNCTAD (2012) reported that approximately eight billion tons of cargoes are carried by sea each year. Seaborne transportation can be classified into three different modes of operation: industrial, tramp, and liner. In industrial shipping, shippers own ships and aim to minimize the total shipping costs of transporting their cargoes. In tramp shipping, ships do not have a fixed itinerary and they operate only when there is cargo demand. Usually, a ship transports a cargo for a single customer at a time. The tramp shipping operation is similar to industrial shipping, except that in tramp shipping the objective is to maximize the profit by only transporting the profitable cargoes. Liner shipping can be equated with bus services: ships have fixed itineraries and schedules, and transport cargoes (containers) for many customers. Optimization methods should be very helpful in seaborne transportation management and operations given the large volume of cargoes transported by sea.

This study aims to optimize the shipping operations for a tramp shipping company with a fleet of heterogeneous ships to carry bulk cargoes in the spot shipping market. The company negotiates with shippers (consigners, consignees, or their agents) regarding cargo volumes, loading and discharge ports, loading and discharge time windows, and freight rates;

* Corresponding author. Tel.: +65 6516 5494; fax: +65 6779 1635.
E-mail address: ceemq@nus.edu.sg (Q. Meng).

http://dx.doi.org/10.1016/j.trb.2014.11.008

and it will definitely choose the most profitable cargoes if there are several cargoes available and the ship fleet capacity is insufficient. To evaluate the profitability of a cargo, the company first examines which ships are suitable for the cargo. A ship can be a candidate to transport a cargo if the ship is available to carry the cargo at the loading port by the requested loading time and the ship capacity is large enough to hold the cargo. If there is more than one ship suitable for the cargo, and/or there is more than one cargo suitable for the ship, the company needs to determine which ship to carry which cargo in order to maximize its total profit.

The total costs of a ship fleet consist of ship costs (manning, maintenance, and chartering cost) and bunker costs. As a result of high bunker prices, bunker costs may constitute more than 50% of the total costs for a tramp shipping company. In fact, the maritime transportation industry has over the last decade experienced an increased awareness of the effect of bunker usage on operational costs and on environmental emissions. The bunker prices at different ports can be substantially different. For example, Fig. 1 shows the price for IFO 380 (Intermediate fuel oil with a maximum viscosity of 380 Centistokes), which is commonly used as the bunker for main engines of ships, at different ports on 15 April, 2011. The price difference can be as large as 200 USD/ton, which translates into 6000 USD's daily cost if the daily bunker consumption is 30 tons. Therefore, the bunker price at the loading port of a cargo is an important factor that must be taken into account when evaluating the profitability of the cargo. In general, a ship tries to purchase as much bunker as possible when it visits a port with a low bunker price, and vice versa. The joint ship routing and bunkering (JSRB) problem aims to determine the optimal routing and bunkering strategies for ships to maximize the total profit.

1.1. Literature review

Ronen (1983, 1993), Christiansen et al. (2004, 2007, 2013) and Meng et al. (2014) have provided a comprehensive coverage on the routing and scheduling problems in seaborne transportation. We give a brief review on models developed for both tramp and industrial shipping operations since they share many common characteristics. One of the pioneering works on ship routing is contributed by Appelgren (1969, 1971) who defined a typical tramp ship routing problem. Most of the cargoes are contracted and must be shipped by the ship fleet. However, some optional cargoes may become available in the market, and they can be carried by the fleet when profitable. The ships in the fleet are restricted to carry only one cargo at a time. Many tramp ship routing problems are extensions of the work done by Appelgren (1969, 1971). Brown et al. (1987) examined a ship routing problem with full shipload crude oil. Perakis and Bremer (1992) considered a similar topic. Fisher and Rosenwein (1989) studied the pickup and delivery of various bulk cargoes in a setting where at most one cargo is on a vessel at any time. Psaraftis (1988) and Thompson and Psaraftis (1993) have considered a ship routing and scheduling problem where several cargoes are allowed to be on-board a ship at the same time and each cargo consists of a designated number of units of a product. Fagerholt and Christiansen (2000a) examined a multiproduct scheduling problem while including the allocation of cargoes to different flexible cargo holds. Christiansen and Fagerholt (2002) presented a real ship scheduling problem by incorporating the possibility that ports are closed at night and over weekends and allowing for long loading or unloading operations. Korsvik et al. (2011) and Andersson et al. (2011a) have examined a ship routing and scheduling problem with split loads. A ship scheduling problem with flexible cargo sizes was studied by Brønmo et al. (2007a), Brønmo et al. (2007b) and Korsvik and Fagerholt (2010), where the cargo size is flexible and the shipping company can choose the actual load quantity that best fits its fleet and schedule. Bausch et al. (1998), Sherali et al. (1999), Fagerholt and Christiansen (2000a, 2000b), and Jetlund and Karimi (2004) have addressed problems with multiple non-mixable products where the allocation of products to the various tanks/holds must be accounted for. Andersson et al. (2011b) introduced a project shipping problem with cargo coupling and synchronization constraints.

In the abovementioned studies, the bunker price has been assumed to be constant rather than a decision variable, and therefore it makes no difference at which port to purchase bunker. Besbes and Savin (2009) formulated a stochastic optimization model for maximizing the profit of a single tramp ship with bunkering considerations. They used Markov chain to model the bunker price and assumed that the profit to travel from one port to another is a random variable with a known probability distribution function for each time period. Their model can be employed to estimate the long-term profitability but is not suitable for an operational-level planning problem in which more than one ship is involved and the bunker price

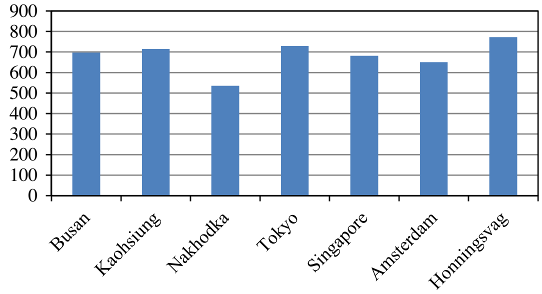

Fig. 1. Prices of IFO 380 (USD/ton) at different ports on 15 April, 2011. Source: NASCO (Singapore) Shipping Company.