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Cargo routing and empty container repositioning in multiple shipping service routes

Dong-Ping Song [a,*], Jing-Xin Dong [b,1]

[a] International Shipping & Logistics Group, School of Management, University of Plymouth, Drake Circus, Plymouth PL4 8AA, UK

[b] Logistics Institute, Business School, University of Hull, Cottingham Road, Hull HU6 7RX, UK

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ABSTRACT

This paper considers the problem of joint cargo routing and empty container repositioning at the operational level for a shipping network with multiple service routes, multiple deployed vessels and multiple regular voyages. The objective is to minimize the total relevant costs in the planning horizon including: container lifting on/off costs at ports, customer demand backlog costs, the demurrage (or waiting) costs at the transhipment ports for temporarily storing laden containers, the empty container inventory costs at ports, and the empty container transportation costs. The laden container routing from the original port to the destination port is limited with at most three service routes. Two solution methods are proposed to solve the optimization problem. The first is a two-stage shortest-path based integer programming method, which combines a cargo routing algorithm with an integer programming of the dynamic system. The second is a two-stage heuristic-rules based integer programming method, which combines an integer programming of the static system with a heuristic implementation algorithm in dynamic system. The two solution methods are applied to two case studies with 30 different scenarios and compared with a practical policy. The results show that two solution methods perform substantially better than the practical policy. The shortest-path based method is preferable for relatively small-scale problems as it yields slightly better solution than the heuristic-rules based method. However, the heuristic-rules based method has advantages in its applicability to large-scale realistic systems while producing good performance, to which the shortest-path based method may be computationally inapplicable. Moreover, the heuristic-rules based method can also be applied to stochastic situations because its second stage is rule-based and dynamical.

1. Introduction

Container shipping has grown rapidly in the last two decades. The annual growth rate of the world container traffic has been well above the world trade growth rate largely due to the containerisation of more commodity types and the deployment of larger containerships and more containers (ci-online.co.uk). A container shipping company usually operates a number of shipping service routes, which form an inter-connected shipping service network. A shipping service route refers to a fixed sequence of ports, in which a fleet of container vessels is deployed to provide regular service (normally weekly service).

* Corresponding author. Tel.: +44 (0)1752 585630; fax: +44 (0)1752 585633.
E-mail addresses: dongping.song@plymouth.ac.uk (D.-P. Song), jingxin.dong@hull.ac.uk (J.-X. Dong).
[1] Tel.: +44 (0)1482 347512.

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These vessels make round-trips (voyages) along the service route repeatedly. It is a common practice that shipping companies publish their service routes and schedules on the Internet several months before the actual journey.

To provide the transportation service, shipping companies are usually responsible for providing required empty containers to their customers. These containers are either owned by shipping company or leased from container lessors. Empty containers may be stored in an inland depot or port depot. Customers can pick up the required empty containers from the depots, consolidate their cargoes into the containers, and move the laden containers back to depot or ports waiting for vessels. These laden containers are then lifted on a vessel in the booked shipping service. There may involve one or two other shipping services for transhipment before the laden container finally reaches the destination port. Then the laden container will be discharged from the vessel and transported to the cargo receiver or a depot for unpacking. After unpacking, the empty container can either be moved/stored in an inland depot or a port for reuse in the future, or be repositioned to other ports in the shipping networks to meet customer demands there. It can be observed that container shipping involves two supply chains: the forward supply chain of laden container flows, and the backward supply chain of empty container flows. A unique characteristic of container shipping is that both laden and empty containers have to be moved and stored in the same shipping network using the same resources (e.g. vessels and facilities), which implies that these two supply chains are interwoven and difficult to separate.

Due to expensive handling costs at ports, repositioning empty containers has been a huge burden for many shipping lines. Drewry Shipping Consultants reported that empty containers have accounted for at least 20% of global port handling activity ever since 1998 (Drewry, 2006). It is estimated that the cost of moving empty containers around the globe exceeds US$15 billion in 2002 (Song et al., 2005). At the operational level, empty container repositioning is closely related to laden container (or cargo) routing. The former concerns arranging the movements of empty containers in the shipping network in order to better position the movable resources, whereas the latter concerns determining the physical routes of laden containers in the shipping network in order to better satisfy customer demands. To a large degree, the movements of empty container are driven by the movements of laden containers.

In the literature, the studies of cargo routing in maritime transportation mainly focus on tramp and industrial shipping sectors (Christiansen et al., 2004). Rather limited number of studies have addressed the cargo/container routing in the liner shipping sector (Agarwal and Ergun, 2008). Song et al. (2005) propose an aggregated pipe network to model the global container-shipping network and assign the world container trade over the shipping network heuristically. Agarwal and Ergun (2008) investigate the cargo routing problems together with ship scheduling and network design. Alvarez (2009) considers a joint routing and deployment of container vessels with an implicit consideration of container routing and transhipment. Yan et al. (2009) develop a network flow model for the problem of the joint ship scheduling and container shipment planning over a time–space network in short-term operations. They do not consider empty container movements. Bell et al. (2011) present a frequency-based assignment model to allocate full and empty containers over shipping services by minimizing the sailing time plus container dwell time at the original port and any intermediate transhipment ports. Meng and Wang (2011c) consider the intermodal hub-and-spoke network design problem with multiple stakeholders and multi-type containers, in which the route choice is implied. Wang and Meng (2011) study the schedule design of the liner routes and container routing problem by minimizing the sum of the total transhipment cost and penalty cost associated with the transit time and the market-level transit time. Their main focus is on schedule design and the container routing is selected from a given set of practical container shipment plans. The majority of the above studies concentrate on the tactical or strategic decision level, and the operational level constraints such as container availability and daily vessel capacity are not considered explicitly. At the tactical or strategic level, the customer demands, the laden and empty container flows are often treated by averaging over a medium or long period, whereas the day-to-day changes of demands, backlogs and flows are not incorporated. Therefore, although the vessel capacity is satisfied at the tactical or strategic level, it is not guaranteed at the operational level. Transhipment is an important phenomenon in container shipping, which has been well recognized in the above studies. However, the maximum number of transhipping times for a shipment is often not specified and utilized. Note that in practice it is rare for a laden container to be transhipped for more than twice in the shipping network mainly due to the high lifting on/off costs. By specifying the maximum number of container transhipping times, the models could be significantly simplified but remain realistic.

In the area of empty container repositioning, numerous studies have been carried out. They may be classified into three groups according to the research context. The first group focuses on empty container repositioning in seaborne shipping networks; the second group focuses on inland or intermodal transportation networks; whereas the third group tackles the empty repositioning problem as a sub-problem or a constraint under other decision-making problems. In the first group, some studies consider a single service route or a service network with specific structure. For example, Lai et al. (1995) use a simulation model and some heuristic search methods to find cost-effective ways to reposition empty containers from Middle East ports to Far East ports in a Europe–Asia service route. Du and Hall (1997) propose a threshold control policy to allocate empty equipment in a hub-and-spoke transport network. Li et al. (2004) and Song and Zhang (2010) establish the optimality of the threshold-type inventory-based control policy in a single port subject to uncertain demands. Song (2007) and Lam et al. (2007) investigate the optimal empty container repositioning policies in two-port systems. Li et al. (2007) extend the threshold control policy to multiple port systems. Feng and Chang (2008) present a two-stage linear programming model for an intra-Asia shipping service. Dong and Song (2009) employ simulation-based optimization and inventory-based policy to deal with the joint optimization problem of container fleet sizing and empty container repositioning. Song and Dong (2011) present flow balancing-based empty repositioning policies in shipping service routes with typical topological