Transportation Research Part E 72 (2014) 42–59

Contents lists available at ScienceDirect

Transportation Research Part E

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

A matheuristic for the liner shipping network design problem

Berit Dangaard Brouer[a,*], Guy Desaulniers[b], David Pisinger[a]

[a] Department of Management Engineering, Technical University of Denmark, Produktionstorvet, Building 424, DK-2800 Kgs. Lyngby, Denmark
[b] Department of Mathematics and Industrial Engineering, Polytechnique Montréal and GERAD, C.P. 6079, Succ. Centre-Ville, Montréal, Québec H3C 3A7, Canada

ARTICLE INFO

Article history:
Received 13 May 2014
Received in revised form 26 August 2014
Accepted 27 September 2014

Keywords:
Liner shipping
Network design
Matheuristic

ABSTRACT

We present an integer programming based heuristic, a *matheuristic*, for the liner shipping network design problem. This problem consists of finding a set of container shipping routes defining a capacitated network for cargo transport. The objective is to maximize the revenue of cargo transport, while minimizing the cost of operating the network. Liner shipping companies publish a set of routes with a time schedule, and it is an industry standard to have a weekly departure at each port call on a route. A weekly frequency is achieved by deploying several vessels to a single route, respecting the available fleet of container vessels. The *matheuristic* is composed of four main algorithmic components: a construction heuristic, an improvement heuristic, a reinsertion heuristic, and a perturbation heuristic. The improvement heuristic uses an integer program to select a set of improving port insertions and removals on each service. Computational results are reported for the benchmark suite *LINER-LIB 2012* following the industry standard of weekly departures on every schedule. The heuristic shows overall good performance and is able to find high quality solutions within competitive execution times. The matheuristic can also be applied as a decision support tool to improve an existing network by optimizing on a designated subset of the routes. A case study is presented for this approach with very promising results.

1. Introduction

Liner shipping is the mass transit system of the ocean ways with regular scheduled services of varying capacity between geographical regions. A service is a sequence of port visits sailed by a number of vessels with a designated capacity. It is current practice for the industry to call every port on a service every week on a specific weekday. The weekly frequency of liner shipping services is a historic industry standard due to the advantage of regularity for the customers, using the liner shipping service as a link in their supply chain as well as the organization of berthing times at container terminals requiring not only berth availability, but also personnel and equipment to handle cargo. The weekly frequency is achieved by the deployed vessels sailing exactly one week apart. Liner shipping and containerized transportation of goods over sea is a key component in today's supply chains. Approximately 500 liner shipping services are operated worldwide by a vessel fleet of close to 5000 container vessels (The World Shipping Council (WSC), 2014a). The services are distributed on regional areas as seen in Table 1.

The liner shipping industry transports roughly 52% of international maritime commerce measured by value (The World Shipping Council (WSC), 2014a). The significance and magnitude of the liner shipping network makes the network design an

* Corresponding author.
E-mail addresses: blof@dtu.dk (B.D. Brouer), guy.desaulniers@gerad.ca (G. Desaulniers), pisinger@man.dtu.dk (D. Pisinger).

http://dx.doi.org/10.1016/j.tre.2014.09.012
1366-5545/

important transportation problem. The network has high fixed asset costs in terms of the container vessels deployed and hence capacity utilization and network efficiency is crucial to a competitive liner shipping operation. At the same time maritime transport is accountable for an estimated 2.7% of the world CO_2 emissions, whereof 25% is attributable to container ships alone (The World Shipping Council (WSC), 2014b). Fuel cost is the largest variable cost of operating a liner shipping network (Stopford, 2009). Performing optimization on the liner shipping network can have a huge impact on the trade of liner shipping as maximizing the revenue while considering variable operational cost may ensure a better capacity utilization in the network. Improved capacity utilization will increase profit for liner shipping companies, and give competitive freight rates for global goods. In due time optimization may target reducing the speed of the container fleet to decrease the CO_2 emissions from liner shipping in general as seen in the case of tramp shipping (Fagerholt et al., 2009).

The liner shipping network design problem (LSNDP) is to construct a set of cyclic services to form a capacitated network for the transport of containerized cargo. The network design maximizes the revenue of container transport considering the cost of vessels deployed to services, overall fuel consumption, port call costs and cargo handling costs. Literature on the LSNDP is quite scarce (Brouer et al., 2014) compared to related maritime shipping transportation problems, but recent years showed increased interest in the LSNDP. The works of Agarwal and Ergun (2008); Alvarez (2009); Reinhardt and Pisinger (2012); Brouer et al. (2014); Plum et al. (2014) reveal that the liner shipping network design problem is a very complex optimization problem, where current mathematical formulations and state-of-the-art exact solution methods cannot scale to realistic sized problem instances at the time of writing. Heuristic approaches have been applied to large-scale instances in Alvarez (2009) and Brouer et al. (2014). A core concept in liner shipping is the transshipment of containers. More than 50% of cargoes are transported on more than one service from origin to destination. Models of the LSNDP with transshipments are often formulated as a routing problem for the fleet of vessels with an underlying multicommodity flow problem (MCFP) to determine the transportation of cargo. A given routing of the vessel fleet results in a capacitated network, where the nodes are *ports* and *port calls* by vessels, respectively. Ports and port calls are connected by loading and unloading arcs for commodities, whereas sailing and transshipment arcs connect port calls corresponding to the vessel routings and possible transshipment points. The quality of this capacitated network depends on the possible routing of multiple commodities. If the routing has been decided, the resulting cargo flow problem is an MCFP. In a heuristic algorithm for the LSNDP the search is typically concerned with constructing routings and interconnections between routings facilitating a profitable cargo flow, but to evaluate any routing solution, the MCFP must be resolved. Alvarez (2009) identifies the excessive time used for solving the MCFP to evaluate a given network configuration as a bottleneck in local search methods. As a result, within reasonable computation time the tabu search of Alvarez (2009) only performs a limited search of the solution space for large-scale instances.

In this paper, we present a matheuristic for solving the LSNDP. Matheuristics are an emerging field within optimization and are defined as methods exploiting the synergies of mathematical programming and metaheuristics (Maniezzo et al., 2009). The domain is wide and includes the use of mathematical programming techniques in a heuristic variant as well as deploying mathematical programming methods within a metaheuristic framework (Maniezzo et al., 2009). For a survey of heuristics deploying mathematical programming models and methods see Ball (2011) or the recent survey on matheuristics for routing problems by Archetti and Speranza (2013). In the present paper we develop an improvement heuristic, where we use an integer program to describe our neighborhood designed to capture the complex interaction of the cargo allocation between routes. The solution of the integer program provides a set of moves in the composition of port calls and fleet deployment.

One of the first approaches using a MIP to describe a neighborhood was proposed by De Franceschi et al. (2006) for the distance-constrained capacitated vehicle routing problem. The method has also been explored for split delivery vehicle routing problems by Chen et al. (2007); Gulczynski et al. (2010), for the split delivery capacitated team orienteering problem by

Table 1
Worldwide services from The World Shipping Council (WSC) (2014a). Notes: Services may be counted on more than one route. Source: Drewry, Container Forecast Q1 & Q2 2013.

Routes	Services
Far East- North America	73
North Europe- Far East	28
Far East- Mediterranean	31
North Europe- North America	23
Mediterranean- North America	21
Europe- Mid- East/ South Asia	40
North America-Mid-East/South Asia	10
Far East- Mid- East/South Asia	72
Australasia	34
East Coast South America	26
West Coast South America	48
South Africa	24
West Africa	60
Total	490