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Liner shipping cargo allocation with service levels and speed optimization

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ABSTRACT

The cargo allocation problem is a key strategic problem that determines the profitability of a liner shipping network. We present a novel mixed-integer programming model for this problem that introduces service levels for transit time requirements and optimizes the vessel speed on each leg of a service. These extensions to the cargo allocation problem greatly increase its realism and value for carriers. We evaluate our model on realistic data from the LINER-LIB and perform a sensitivity analysis of transit times versus bunker costs. Furthermore, we show how carriers can use our model to make data driven decisions in their operations.

1. Introduction

In 2013, more than 9.57 billion tons of cargo were transported by sea, which is more than 80% of the global merchandise trade (UNCTAD 2013). Of this, 1.58 billion tons (16%) were transported in containers. Additionally, more than 50% of the worldwide seaborne value was transported in standardized containers by liner carriers (UNCTAD 2013).

Liner carriers operate networks that are built from one or more services, each calling a predetermined port sequence that forms a cycle. Cargo is sent from a loading port to a destination port in a specific equipment type (container type and size). These cargo movements are called *cargo flows* and can either be transported directly on one service or be transhipped between services at ports. Transhipment is an important aspect in liner networks because it can increase network utilization (Brouer et al. (2013), Notteboom (2006)).

According to Notteboom (2006), Panayides and Song (2013) and Wang and Meng (2014) the "time factor" is a fundamental requirement of practical liner shipping networks. Key time factors in liner shipping are: Service frequency[1] (how frequently is each port visited by a vessel), vessel speed, port durations and the maximum duration for each cargo flow, called the *transit time*. Providing competitive transit times is an important goal for liner carriers. Transit time requirements vary for each customer and depend on what kind of cargo they are shipping, with perishable commodities and short life cycle products, for example, requiring short transit times (Notteboom (2006)).

The cargo allocation problem asks how to allocate cargo flows to specific services in a predetermined network. We formulate a mathematical model to solve this problem including cargo flow specific transit times (service levels), vessel speed optimization and empty container repositioning. We extend the state-of-the-art by performing speed optimization in an

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[1] This work assumes round trips of constant length, but makes no assumption regarding the frequency (e.g., weekly, bi-weekly, etc.).

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integrated manner, which introduces a trade-off between reducing the vessel speed (slow-steaming, see, e.g, Meyer et al. (2012)) to save fuel costs and satisfying the required duration of the cargo. Without considering transit times, the strategy to perform (super) slow-steaming due to high bunker prices can lead to decreased competitiveness (see Christiansen et al. (2012)). To summarize, our model includes the following novel components:

1. Cargo transit time restrictions
2. Per leg speed optimization with transhipment durations and variable port stays
3. Empty container repositioning

The mathematical model presented in this paper is defined as the cargo allocation problem with service levels and speed optimization (CAPSLSO). The model we present targets a strategic and tactical planning horizon because it assumes deterministic and (regular) weekly cargo flows. The process of determining in which time slot a vessel should visit a particular port is complicated for carriers, involving significant amounts of manual work and phone calls to container terminals. Although our model does not specifically prescribe time slots, it can be used to support negotiations with terminals and to help plan berthing times based on the recommended sailing speeds on each leg. Speed optimization for each leg in a service is a particular advancement over the state-of-the-art, in which an average speed for the entire service is usually used (Álvarez, 2009). This flexibility allows carriers to meet transit time requirements for time-critical cargo, while at the same time saving money through slow-steaming on non-profitable legs. Furthermore, our model can be extended to solve cargo allocation in an operational perspective by including tide dependent port drafts, berth window service synchronization and up-to-date schedules. Finally, the model allows for the evaluation of new cargo flows. Typically, a liner shipping network already serves thousands of containers per week. In operations, cargo is accepted from the spot market to increase the operational vessel utilization. With the help of the model, the impact of spot cargo on the whole network can be analyzed on a monetary basis, which can help to determine an appropriate price for a specific service level.

This paper is organized as follows: In Section 2, related work in the field of cargo allocation in liner shipping is presented. Section 3 presents the CAPSLSO, Section 4 provides our mathematical model and Section 5 gives numerical results for transit time optimized networks based on the LINER-LIB problem instances from Brouer et al. (2013). In Section 6, a case study and sensitivity analysis are presented. Section 7 concludes the paper and provides an outlook on future work.

2. Literature review

Work in the field of cargo allocation (also called cargo routing in the literature) can be separated into work that focuses solely on allocation and work that integrates the problem into the more complex liner shipping network design (LSND) problem. In the scope of network design, cargo allocation determines the efficiency and utilization of a network and provides the overall profit and costs (such as for bunker usage and transhipment fees).

An early work on LSND is the work of Powell and Perkins (1997), which presents an optimization approach for vessel routes using the cost model presented in Perakis and Jaramillo (1991). However, cargo transhipment and transit times are not considered. Cho and Perakis (1996) present a model and solution approach to deploy vessels to a predetermined set of routes. The vessel speed is fixed per route and no transhipment is included in their model. Fagerholt (2004) presents a model to design optimal vessel routes based on the vehicle routing problem. Each vessel steams at a predetermined speed and transhipment is disallowed in this model. Shintani et al. (2007) introduce the container shipping network design problem that considers empty container repositioning. They solve the problem in two steps by first determining profitable port groups and, secondly, specific port sequences. The vessel cruising speed is optimized per route, and no transhipment or transit times are included. Fagerholt et al. (2009) present a case study for the fleet deployment problem without transhipment and cargo transit times.

The first publication on LSND that considered transhipment operations is Agarwal and Ergun (2008). However, no transhipment costs are considered in their work. These are added by Álvarez (2009) in the context of the joint routing and fleet deployment problem, which decides which port rotation should be served by which vessel. The main contribution of Álvarez (2009) is a case study and the consideration of container transhipment costs in a realistic sized network with 120 ports. Reinhardt and Pisinger (2010) provide an exact model to solve the liner shipping network design problem, not only on simple, but also on "butterfly" routes, which are routes in which the same port is visited twice. Their mixed integer program incorporates the cargo allocation problem with transhipments, but lacks leg dependent speed optimization and transit time requirements. The solution approach of Álvarez (2009) for solving the LSND problem is extended in Brouer et al. (2013) to allow (bi) weekly frequencies and butterfly rotations. Furthermore, they introduce a benchmark suite to evaluate algorithms solving the network design and cargo allocation problem. This benchmark, called the LINER-LIB, includes real-world data, such as transit times, but does not prescribe which data should be used in a given LSND model. Song and Dong (2013) solves the liner service route design problem with butterfly routes and empty container repositioning. A maximum duration between ports is included in their model, with speed optimization being performed on a per route basis. Song and Dong (2013) consider transhipments for empty containers and their processing time at the ports on the long-haul services. Laden containers are not allowed to be transhiped on these services. Song and Dong (2013) propose a non-linear optimization problem and a hierarchical solution process to solve the model.