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Service type assignment and container routing with transit time constraints and empty container repositioning for liner shipping service networks

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ABSTRACT

A decision tool is developed for a liner shipping company to deploy its fleet considering vessel speeds and to find routes for cargos with repositioning of empty containers and transit time constraints. This problem is referred as the simultaneous Service type Assignment and container Routing Problem (SARP) in the sequel. A path-flow based mixed-integer linear programming formulation is suggested for the SARP. A Branch and Bound (BB) algorithm is used to solve the SARP exactly. A Column Generation (CG) procedure, embedded within the BB framework, is devised to solve the linear programming relaxation of the SARP. The CG subproblems arises as Shortest Path Problems (SPP). Yet incorporating transit time requirements yields constrained SPP which is NP-hard and solved by a label correcting algorithm. Computational experiments are performed on randomly generated test instances mimicking real life. The BB algorithm yields promising solutions for the SARP. The SARP with and without transit time constraints is compared with each other. Our results suggest a potential to increase profit margins of liner shipping companies by considering transit time requirements of cargos.

1. Introduction

Containerized cargo constitutes approximately 22.7% of the world dry cargo trade and it has a value of more than 50% of the world seaborne trade in terms of dollars in 2013 (UNCTAD, 2014). Over past several decades, world's containerized trade expanded from 102 million tons in 1980 to 1.5 billion tons in 2013 which implies a growth of almost 15 times (UNCTAD, 2014). Liner shipping constitute the backbone of the maritime container transportation. A fierce competition is currently going on in ocean container transportation (see Fransoo and Lee, 2013). Due to limited service differentiation, shipping liner industry is mainly competitive on cost-based. Hence, liner shipping companies need to operate efficiently in order to maintain their competitiveness.

Liner shipping companies provide weekly (or bimonthly) regular services over a shipping service route. A shipping service route consists of a given sequence of port visits to ensure the shipment of cargos among them. The structure of the service routes often constitutes a circular shape and ships' journey starts and finishes at the same port after visiting all other ports

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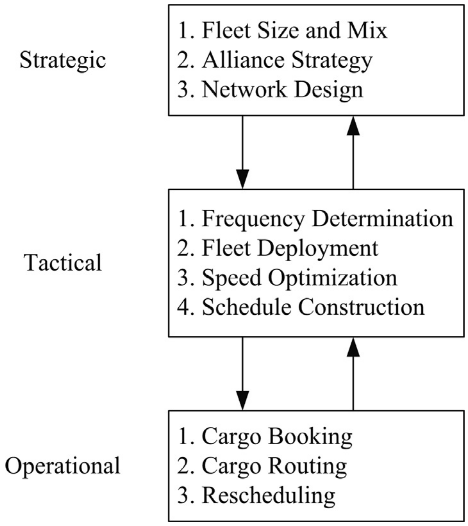

Fig. 1. Three levels of decision making in liner shipping companies. *Source*: Meng et al. (2014).

in their routes. Mostly, ship schedules of liner shipping companies are announced a few months before the realization of the port visits. Decisions made by the liner shippers can be categorized in three levels: strategic, tactical and operational level (Meng et al., 2014). Fig. 1 shows these decisions and the relationship among them. Notice that we use the same nomenclature of the work by Meng et al. (2014) and do not repeat those necessary definitions to be precise here.

In this work, our focus is on the fleet deployment and speed optimization decisions at the tactical level and cargo routing decision at the operational level. We assume that strategic level decisions are already made and the service routes, fleet size and mix of the liner shipping company are given. At the tactical level, it is assumed that a weekly service frequency is provided and detailed ship schedules will be determined depending on fleet deployment and speed optimization decisions afterwards. In what follows we present some of the challenges affecting decisions of liner shipping companies, the objective and contribution of our work.

There are three main elements affecting decisions of the liner shippers: transshipment operations, empty container repositioning and transit time requirements of shippers. Among a total of 159 coastal countries, 82.3% of the pair of countries in the world are not directly connected by a liner shipping service which indicates at least a transshipment is required for the containerized cargo for those country pairs (UNCTAD, 2012). In particular, more than 80% of the container flow in Singapore port, one of the busiest ports in the world, is part of transshipment (Petering, 2011). Besides, with increasing usage of mega container vessels of 18,000 TEUs or more (Maersk, 2011; MSC, 2014), cargo consolidation at transshipment ports is now more important than hitherto.

Another challenge stems from the world's trade unbalance among different continents. Notteboom and Rodrigue (2008) states that 11.1 million TEUs of imbalance is recorded between Asia and Europe in 2005. Furthermore, 70% of the capacity of the containerships leaving US was not used in 2005 (Notteboom and Rodrigue, 2008). This flow unbalance results in an accumulation of empty containers in Europe and North America, and an excessive need for empty containers in Asia. Theofanis and Boile (2009) state that reducing repositioning and container management costs by 10% may yield a potential of 30–50% increase in the profits of liner shipping companies.

Shippers demand shorter transit times which in turn contradicts with the goals of the liner shipping companies since it increases their costs. Bunker costs adds up to 60% of the total ship operating costs (Notteboom and Vernimmen, 2009). Indeed, faster services significantly raise the bunker costs of the liner shipping companies. Liner shipping companies set up slow-steaming policies after a dramatic increase in the oil prices in 2008 to cut their operating costs. When the bunker costs are above USD 200 per TEU, increasing the number of vessels deployed from 8 to 10 can be recompensed by low speed steaming policy (Notteboom and Vernimmen, 2009). On the other hand, higher speed levels are now possible after the sharp decline of the oil prices in 2014. In other words, increasing the sailing speed of vessels may provide better service times and hence gives a chance to gain advantage over competitors.

To sum up, in order to increase the efficiency and effectiveness of global maritime supply chain, fleet deployment and container routing decisions should be made taking into account i) transshipment operations, ii) empty container repositioning together with the laden cargo and iii) transit time requirements of customers.

The objective of this paper is to develop a decision tool for liner shipping companies to simultaneously deploy its fleet considering vessel speeds, and find routes for cargos with repositioning of empty containers under transit time requirements imposed by the shippers. This problem is called as the simultaneous Service type Assignment and container Routing Problem (SARP) in the sequel. For that purpose, we propose a path-flow based multi-commodity flow formulation for the SARP with