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Koza, David Franz; Desaulniers, Guy; Røpke, Stefan

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Integrated Liner Shipping Network Design and Scheduling, or: Solving a large service network design problem

D.F. Koza[a], G. Desaulniers[b], S. Ropke[a]

[a] Department of Management Engineering, Technical University of Denmark,
`dakoz@dtu.dk, ropke@dtu.dk`

[b] GERAD & Department of Mathematics and Industrial Engineering, Polytechnique Montréal, Canada,
`guy.desaulniers@gerad.ca`

Global container liner shipping networks are composed of *services* and each service represents a roundtrip that connects a set of ports following a published schedule. The majority of services is operated at a weekly frequency, and each port on a service is visited at the same time each week. Commonly, all vessels deployed on a service are of the same capacity. Liner services are connected through common port calls that allow liner network operators to move cargo from one service to another. The movement of containers between services is called *transshipment* and enables large liner shipping companies to transport containers between almost any possible pair of ports around the globe.

Current state-of-the-art models and methods (e.g. Karsten et al., 2017) for liner shipping network design problems only determine the routes and sailing speeds for individual services, but approximate transshipment times by a constant. In practice, the transshipment time between two services depends on how well the schedules of the individual services are synchronized. In the network of the world's largest overseas cargo carrier, around half of all transported containers are transshipped, and the transshipment times may significantly affect the total *transit time* of containers between their origin and destination port.

The Integrated Liner Shipping Network Design and Scheduling Problem (LSNDSP) extends the classic liner shipping network design problem by defining schedules for all services, and by considering the interdependency between these. The goal is to construct a network of scheduled services and to determine feasible container routes through the network such that the revenue from transporting cargo minus the cost of operating the services and handling cargo is maximized. A service is defined by the deployed vessel class and its capacity, a cyclic route and a schedule. The schedule implicitly defines the sailing speed on each sailing leg. The length of a service is required to be a multiple of a week and the number of vessels operating the service is equal to its duration to ensure a weekly frequency. A demand represents a weekly quantity of containers for a particular origin-destination pair of ports. Each demand is associated with a unit revenue. Additionally, transit time limits apply, reflecting a demand's time-sensitivity. Cargo can be transshipped between services, but every transshipment implies additional costs

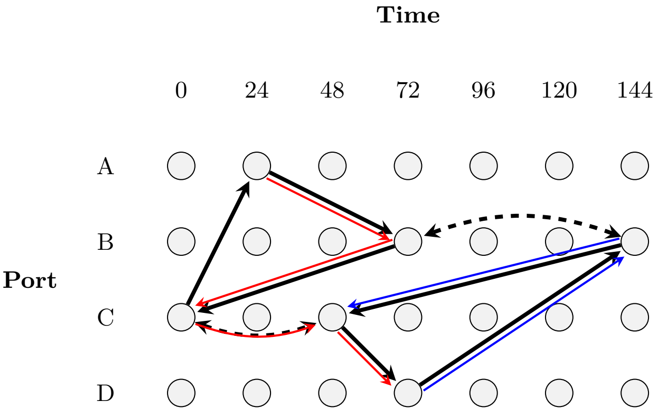

Figure 1: Illustration of a time-space graph G. Solid arcs represent sailings between ports and dashed arcs represent transshipments. The colored arcs denote examples of cargo paths; the blue path from port D to port C is direct, whereas the red path from port A to port D requires a transshipment at port C. Backward arcs represent sailings or transshipments that end in the following week.

for cargo handling at the transshipment port. The transshipment time depends on the schedules of the unloading and the loading service. If a minimum transshipment time is not met, cargo may have to wait one week for the next vessel to arrive. A limit on the number of transshipments may be defined for a demand, reflecting the shippers preference towards direct shipping routes. A demand can, but does not have to be served by the cargo carrier, and it can be fulfilled partially.

We model the problem over a directed time-space graph $G(V, A)$, with vertices V representing a port at a particular time within a week (168h), and arcs A representing sailings (A^S) or transshipments (A^T). Figure 1 illustrates a solution over a small time-space graph of four ports and a time discretization of 24 hours. The problem formulation over graph G is a variation of service network design problems, which are generalizations of (capacitated) fixed-charge network design problems (Crainic, 2000). The LSNDSP is $\mathcal{NP}$-hard in the strong sense.

To solve the problem we propose a column-and-row generation (CRG) matheuristic that combines linear programming techniques with heuristics. The method can be used to construct new liner networks or to extend or improve existing liner networks. In our talk we will discuss some

Instance	**Graph $G(V,A)$**				**Model**	
	$\lvert V\rvert$	$\lvert A\rvert$	$\lvert A^S\rvert$	$\lvert A^T\rvert$	**constraints**	**binary vars**
Baltic	168	7,812	5,460	2,352	5,988	8,652
WAF	280	42,168	38,248	3,920	39,127	51,016
Mediterranean	546	108,206	101,108	7,644	103,660	165,816
Pacific	630	542,262	534,072	8,820	537,948	1,044,708

Table 1: Graph and model properties for each data instance under a time discretization of 12 hours.

Instance		**CRG matheuristic**		**Karsten et al. (2017)**
		exact transship. time	48h transship. time	48h transship. time
Baltic	Best	$-2.84\cdot10^5$	$-2.84\cdot10^5$	$-0.05\cdot10^5$
	Average	$-2.24\cdot10^5$	$-2.08\cdot10^5$	$1.74\cdot10^5$
WAF	Best	$-5.92\cdot10^6$	$-5.90\cdot10^6$	$-5.48\cdot10^6$
	Average	$-5.76\cdot10^6$	$-5.77\cdot10^6$	$-4.89\cdot10^6$
Mediterranean	Best	$2.54\cdot10^6$	$2.11\cdot10^6$	$2.19\cdot10^6$
	Average	$2.73\cdot10^6$	$2.33\cdot10^6$	$2.65\cdot10^6$
Pacific	Best	$2.69\cdot10^6$	$-0.33\cdot10^6$	$1.13\cdot10^6$
	Average	$3.71\cdot10^6$	$1.06\cdot10^6$	$3.44\cdot10^6$

Table 2: Best and average objective function values (cost in USD) per instance, comparing results obtained by the CRG matheuristic under exact and approximated (48h) transshipment times with results from Karsten et al. (2017)

of the applied linear and integer programming techniques in detail.

We tested the method on data instances from the publicly available LINER-LIB benchmark suite, which was developed in collaboration with a large liner shipping company (Brouer et al., 2014). Table 1 shows the resulting graph and model size for the four considered instances.

Table 2 displays the objective function values obtained by the CRG matheuristic for the LSNDSP as well as for the LSNDSP under the simplifying assumption of constant transshipment times. The displayed values represent cost minus revenues, thus lower values reflect better solutions. In the third column, the objective function values found by the solution method for the liner shipping network design problem by Karsten et al. (2017) are reported. Under equal assumptions, the proposed CRG matheuristic consistently finds better solutions for all addressed instances. We further observe that a 48-hours approximation of transshipment times may result in an overestimation of profits.

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