Network Design, Scheduling and Deployment Planning in Shipping Applications

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Introduction

The recent decades have seen continued globalization with a resulting increase in the international trade of which the majority of the total ton-mileage is carried by ocean going vessels. In particular, the last few years have seen an increased tendency of consolidation in the manufacturing industries resulting in larger actors with higher influence when it comes to securing favorable shipping contracts. Combined with increased competition on the shipping market this has reduced the profit margins (Christiansen et al. (2004) [2]). In response to these trends, shipping companies are seeking to strengthen their positions through acquisitions and mergers resulting in larger companies with very large vessel fleets.

With increases in fleet sizes as well as the number of ports covered by the service network within the individual shipping companies, the task of planning and scheduling is becoming increasingly complex. To further complicate planning and execution, there is a growing trend where customers are demanding end-to-end service in their supply chains as well as high-quality secure and reliable transports (Hingorani et al. (2005) [3]). The combination of these factors is the motivation for seeking alternative planning methods such as those provided by operations research in general and mathematical programming in particular.

The paper will discuss the use of mathematical programming to solve a liner container shipping problem. The purpose of the model is to propose a good (optimal) routing and scheduling strategy for a heterogeneous fleet of ships. Different interpretations of a “good” strategy will be discussed and compared.

The Liner Container Shipping Problem

Ignoring the operational decisions related to the acceptance and specific routing of individual freights, the liner container shipping (LCS) problem discussed is concerned with the overall design of the service network consisting of routing, scheduling and deployment decisions for a heterogeneous fleet of vessels available to a liner shipping provider (LSP). These decisions are often associated with strategic and tactical planning and typically occur on a time horizon of six months and more.

In contrast to e.g. tramp and industrial shipping which operate schedules in response to actual demand, liner shipping is based on a fixed schedule which is generally published up to six months into the future. This means that there are high requirements to the accuracy of demand forecasts and that the actual efficiency of the schedule is subject to a significant degree of uncertainty.

The major components of the LCS problem at the strategic and tactical planning level are

- Vessels (or vessel classes)
- Ports serviced by the LSP
- Demand (given by forecasts and expectations to future market share)

Although the owned vessel fleet will typically be assumed fixed on the tactical planning horizon, vessel charters and vessel sharing agreements may affect the actual fleet composition.

Each vessel is associated with a rotation which is set of ports visited in a closed tour. A rotation has a duration and is repeated each time the vessel has completed a cycle. A number of constraints may be imposed on individual rotations. This includes time windows for berthing at the individual ports, physical restrictions caused by harbors or canals, maximum duration and local or international regulatory restrictions. Additionally, there are capacity limitations on the individual vessels.

The set of ports serviced by a particular LSP can generally be assumed known in advance and will only include ports to which actual demand is associated. With respect to the overall demand pattern used to determine the network design, individual freights are aggregated into a number of commodities based on their origin-destination pairs.

1 Modeling and Solving the LCS Problem

The liner container shipping service network design problem is implemented as a MIP model. The basic model is an extension of the multicommodity capacitated network design (MCND) problem where the opening of an arc is associated with the deployment of a particular vessel between a specific pair of nodes (ports) (Ahuja et al.(1995) [1]). Furthermore, auxiliary variables have been introduced to allow for easy capture of transshipments of commodities between the different vessels. Finally, nodes are degree balanced with respect to the incoming and outgoing vessels thus forcing each vessel to perform a closed rotation (tour). Since the model is fundamentally a MCND problem with the primary differing feature being the presence of transshipment of commodities, it may be referred to as MCNDTS.

As in the MCND problem, it is the requirement that all commodities must be transported from their origin to their destination that drives the design of the network. This requirement may be justified by the fact that for many LSPs a large percentage of the total annual freight volume transported is determined by long term contractual commitments. However, as no consideration is given to the revenue gain achieved by the individual commodities, all flows are considered equally important which may not always be desirable.

A popular approach to solving this type of routing problem has been to rewrite the arc based model to a path-based formulation where each "path" corresponds to a rotation (tour) performed by a specific vessel. The advantage of employing the path based over the arc based formulation is that typically more complex rules can be maintained in the permitted rotations. Furthermore, using the path based formulation provides the schedulers of the LSP with a very high degree of control over the allowed rotations and thus also to some degree the final solution which is particularly useful when the model is used to evaluate various scenarios for the service network design. Although previous work (e.g. Sigurd et al. (2005) [5]) has shown the flexibility and feasibility of a column generation approach for a liner shipping scheduling problem, less constrained problems still pose significant computational challenges. In particular, MCND problems generally provide poor LP relaxation bounds which affects the branch-and-bound search. One approach adopted to tackle this problem is to use Lagrangian relaxation and Lagrangian based heuristics, Holmberg and Yuan (2000) [4].

In this work, the MCNDTS model is relaxed in a Lagrangian fashion to obtain a subproblem which is essentially decomposes into a number of minimum cost circulation problems (one for each vessel or vessel class) with resource constraints. These are recast as a series of shortest path problems with resource constraints that are solved by a dynamic programming algorithm. The Lagrangian dual problem is solved by means of the cutting-plane algorithm.

The Lagrangian based approach to the MCNDTS problem holds significant potential for more efficiently providing bounds that are better than those obtained through LP relaxation of the original problem. The performance of the solution approach is tested on a number of randomly generated test problems and bounds are compared with the LP bounds.

Perspectives

As it was briefly mentioned in the introduction, planners are basing their schedules on expectations to the future market and demand forecasts based on historical data. Obviously, this approach is associated with a considerable amount of uncertainty possibly making an otherwise good schedule inefficient. Furthermore, since container ships are generally operated around the clock, disruptions may cause delays that can propagate throughout the entire schedule. The effect can be amplified by the transshipment of freight causing other vessels to be affected by a delay. Thus, it is important that the service network design is robust to ensure that the effect of disruptions is pro-actively reduced. Capturing this aspect of the planning process remains for future work. However, it is clear that service reliability is one of the most important competitive parameters and it is only expected to increase in importance in the future. Thus, considerations to robustness must be an integral part of future research on liner container shipping.

References

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