DTU Library

A greedy construction heuristic for the liner service network design problem

Brouer, Berit Dangaard

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Brouer, B. D. (2010). *A greedy construction heuristic for the liner service network design problem*. Abstract from Seventh Triennial Symposium on Transportation Analysis, Tromsø, Norway.

A greedy construction heuristic for the Liner Service Network Design Problem

Berit Løfstedt
DTU Management Engineering
Technical University of Denmark
Email: blof@man.dtu.dk

3rd of November 2009

The Liner Service Network Design Problem (LSN-DP) is the problem of constructing a set of routes for a heterogeneous vessel fleet of a global liner shipping operator. Routes in the liner shipping context are non-simple, cyclic routes constructed for a specific vessel type. The problem is challenging due to the size of a global liner shipping operation and due to the hub-and-spoke network design, where a high percentage of the total cargo is transshipped. We present the first construction heuristic for large scale instances of the LSN-DP. The heuristic is able to find a solution for a real life case with 234 unique ports and 14000 demands in 33 seconds.

Literature overview: A MIP model of the LSN-DP consist of a highly unconstrained routing problem subject to a large degree of symmetry and a multicommodity flow problem dominating the constraint set and accountable for a large fraction of the cost. Previous work on liner service network design may be found in [1],[2], [3] and [4]. The models are distinct with regards to transshipments and the vessel fleet. In the early paper of [1] transshipments are not supported, whereas they are supported in [2], [3] and [4]. Transshipment costs are accounted for in the objective function of [2],[4] as opposed to [3]. The characteristics of the fleet differ as to whether it is heterogeneous for every vessel [1],[2] or consist of a heterogeneous fleet of homogeneous vessel classes [3],[4]. Non-linear capacity constraints are found in [1],[2] assuming that a vessel may complete its route an integral number of times during the planning horizon. Integrality is not imposed by [4]. The weekly frequency constraint is introduced by [3] assuming a number of homogeneous vessels assigned to each service to offer a weekly visit to each port en route with the capacity of the vessel class in question. Optimal results for smaller instances are presented by [2] and [4]. The approaches of [1],[2] and [3] have focused on solving the liner service network design problem with traditional decomposition and integer programming methods and fail to produce results for realistic network sizes of a global liner shipping operator anno 2009. This is addressed by [4] benchmarking a tabu search approach presenting results within 3-5% of the optimal solution for up to 7 ports. The multicommodity flow problem is solved in each iteration, which is reported by [4] to become computationally expensive already for the 7 port instance. A case study of 120 ports in [4] show that a heuristic approach may scale to large instances but no execution time is reported and the quality of the solution is hard to evaluate. It is reported to visit important ports infrequently. A global network connects several hundred ports worldwide and the corresponding forecasted cargo demand comprises a commodity set of 4 orders of magnitude. Methods based on relaxation of the proposed models or simply evaluating the objective function during a search is not computationally efficient for large scale problems.

Heuristic approach: A solution to the LSN-DP is a set of routes covering the ports serviced by the shipping operator and transporting the forecasted cargo demand. Viewed as a graph partitioning problem the solution is a set of strongly connected components with a high degree of interconnection. The construction heuristic is based on the Multiple Quadratic Knapsack Problem (MQKP) and relies on a graph of the current schedule, which is divided into a set of dense subgraphs related by demand, expected transshipment flow and geographical proximity. A solution found by the construction heuristic is expected to be feasible and realistic, but the quality of the solution cannot be guaranteed as the heuristic cannot account for the flow problem and the transshipment cost. In MQKP a set of mutually exclusive items $i \in V$ are placed in $\mathcal{R}$ knapsacks with different weight bounds C_r. The objective is to maximise the profit of the knapsacks defined by the profit matrix P.

$$maximize(MQKP) = \sum_{r\in\mathcal{R}} \sum_{i\in\mathcal{V}} \sum_{j\in\mathcal{V}} p_{ij} x_i^r x_j^r + \sum_{r\in\mathcal{R}} \sum_{j\in\mathcal{V}} p_j x_j^r \quad (1)$$

subject to:

$$\sum_{i\in\mathcal{V}} w_i x_i^r \leq C_r \quad \forall r \in \mathcal{R} \quad (2)$$

$$\sum_{r\in\mathcal{R}} x_i^r \leq 1 \quad \forall i \in \mathcal{V} \quad (3)$$

$$x_i^r \in \{0,1\} \quad \forall i \in \mathcal{V} \quad (4)$$

The variables x_i^r indicate whether item i is included in the r'th knapsack. The knapsack constraint (2) makes the total item weight obey the bound C_r and constraints (3) ensure that items are mutually exclusive to the knapsacks. When the MQKP is applied to the LSN-DP the knapsack items $i \in V$ are the accumulated port visits of each port $t \in T$ and the knapsacks $r \in R$ represent services, which are a specific vessel class visiting a sequence of ports. Let A be the set of vessel classes and let N_a denote the number of available vessels of class $a \in A$ in the fleet. Let C_a denote the capacity in TEU of a single vessel of class $a \in A$. The number of services/knapsacks is dependent on the expected rotation time of a service $\sigma(C_a)$. $\sigma(C_a)$ depends on vessel capacity as large vessels are typically assigned to cross regional services and small vessels are assigned to regional services. The number of knapsacks for the LSN-DP is hence $|R| = \sum_{a\in A}|R_a| = \sum_{a\in A}\lceil\frac{N_a}{\sigma(C_a)}\rceil$. The profit matrix $\mathcal{P}$ defines each entry $p_{ij} = f(l_{ij}, d_{ij}, h_{ij})$ where l_{ij} is the sailing distance in nautical miles and d_{ij} is the demand between ports $i, j \in V$. h_{ij} is the potential hub flow between port $i \in V$ and a hub port $j \in H \subset V$, where $H \subset V$ are ports with a small percentage of demand compared to the terminal capacity. A port $t \in T$ may be visited multiple times m_t by multiple services according to the capacity and schedule requirements of a port. Let M be a vector of size $|T|$ containing the number of weekly visits to each port $t \in T$. In the MQKP port $t \in T$ is duplicated m_t times for the knapsack items $i \in V$, $V = \{T \times M\}$ to represent the current schedule of ports. It is important to observe the weekly frequency constraint of the original problem in order to obtain a feasible solution to the LSN-DP using the construction heuristic. To ensure feasibility, each knapsack $r \in R$ is required to provide a Hamiltonian cycle of the items in knapsack r. The length of the cycle cannot exceed the mileage coverable by the vessels assigned to knapsack r. Edge variables y^r_{ij} and enumeration variables u^r_i are introduced in the MQKP to order the ports in each knapsack into a simple, cyclic route constrained by $\sigma(C_a)$. t^a_{ij} express the sailing time between ports i and j and t^a_i is the expected time spent in port i for vessel type a.

$$maximize(MQKP) = \sum_{r\in\mathcal{R}}\sum_{i\in\mathcal{V}}\sum_{j\in\mathcal{V}} p_{ij}x^r_i x^r_j + \sum_{r\in\mathcal{R}}\sum_{j\in\mathcal{V}} p_j x^r_j \tag{5}$$

$$\text{subject to:} \quad x^r_i x^r_j \geq y^r_{ij} \qquad \forall i \in \mathcal{V}, j \in \mathcal{V}, r \in \mathcal{R} \tag{6}$$

$$\sum_{j\in V} y^r_{ij} - \sum_{j\in V} y^r_{ji} = 0 \qquad \forall i \in \mathcal{V}, r \in \mathcal{R} \tag{7}$$

$$\sum_{j\in V} y^r_{ij} \leq 1 \qquad \forall i \in \mathcal{V}, r \in \mathcal{R} \tag{8}$$

$$u^r_i - u^r_j + y^r_{ij}\sum_{i\in V} x^r_i \leq \sum_{i\in V} x^r_i - 1 \qquad \forall i \in \mathcal{V}, j \in \mathcal{V}, r \in \mathcal{R} \tag{9}$$

$$\sum_{i\in V}\sum_{j\in V} y^r_{ij}(t_{ij} + t_i) \leq \sigma(C_a) \qquad \forall r \in \mathcal{R}_a, a \in \mathcal{A} \tag{10}$$

$$\sum_{r\in\mathcal{R}} x^r_i = 1 \qquad \forall i \in \mathcal{V} \tag{11}$$

$$x^r_i \in \{0, 1\} \qquad \forall i \in \mathcal{V}, r \in \mathcal{R} \tag{12}$$

$$y^r_{ij} \in \{0, 1\} \qquad \forall i \in \mathcal{V}, j \in \mathcal{V}, r \in \mathcal{R} \tag{13}$$

$$u^r_i \in \mathcal{Z}^+ \qquad \forall i \in \mathcal{V}, r \in \mathcal{R} \tag{14}$$

Constraints (6) ensure that an edge variable can only be activated if both endpoints of the arc are included in the knapsack. Constraints (7) ensure a cyclic route. Constraints (8) ensure that the cyclic route is simple and constraints (9) that the route is connected. Constraints (10) are the weekly frequency constraint ensuring that the simple, cyclic route has a voyage duration less than the expected rotation time.

The MQKP is solved using a greedy heuristic, where the knapsacks apply the football teaming principle taking turns at picking the best remaining item $max\ \Delta f(l_{ij}, d_{ij}, h_{ij}), i \in r, j \in \bar{V}$ where $\bar{V}$ are the unassigned items.

In a hub-and-spoke network design large vessels are deployed on deep sea services to achieve economies of scale[6], while smaller vessels are deployed between spoke and hub. The algorithm is multilayered to reflect the hub-and-spoke network design of major liner shipping operators. The function $f(l_{ij}, d_{ij}, h_{ij})$ is adapted to each layer of the network and the ports are correspondingly assigned to the layers according to their capacity requirements.

Computational results: The computational results are based on a real life case from Maersk Line with 234 unique ports and 14000 demands. The MQKP is able to find a solution in 33 seconds for the entire network with some ports unplaced. The solutions have been evaluated by optimization managers at Maersk Line regarding them as realistic with some modifications. Current work is on implementing layer specific seeding to improve the number of unplaced ports. We evaluate the actual flow and the network cost of the solution. We believe that meta heuristic approaches are needed to optimize liner service networks of global shipping operators and are working on specializing the Adaptive Large Neighbourhood Search [5] VRP framework towards the context of transshipments and cyclic routes. The first step is the construction heuristic for the LSN-DP presented here. The ALNS is to search for an improved solution according to a more sophisticated objective function and cargo allocation detection.

References

[1] K. Rana and R.G. Vickson, “Routing container Ships Using Lagrangian Relaxation and Decomposition”, *Transportation Science* 25, 201-214 (1991).

[2] L. B. Reinhardt and B. Kallehauge, “Network Design for Container Shipping Using Cutting Planes”,Conference on Maritime & Intermodal Logistics, Singapore, December 2007.

[3] R. Agarwal and O. Ergun,”Ship Scheduling and Network Design for Cargo routing in Liner Shipping”,*Transportation Science* 42, 175-196 (2008).

[4] J.F. Alvarez, “ Joint Routing and Deployment of a Fleet of Container Vessels”, *Maritime Economics and Logistics* 11, 186-208 (2009).

[5] S. Røpke and D. Pisinger, “A general heuristic for vehicle routing problems”, *Computers and Operations Research* 34, 2403-2435 (2007).

[6] I. Akio and K. Shintani and S.Papadimitriou, ”Multi-port vs. Hub-and-Spoke port calls by containerships” *Transportation Research Part E* 42 , 740-757 (2009).