A Greedy Construction Heuristic for the Liner Shipping Network Design Problem

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Publication date:
2010

Document Version
Early version, also known as pre-print

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Citation (APA):
A greedy construction heuristic for the Liner Service Network Design Problem

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May 5, 2010
Outline

1. The Liner Service Network Design Problem (LS-NDP)
2. Methods based on integer and linear programming relaxations
3. LS-NDP as a multilayered Multiple Quadratic Knapsack Problem
4. The greedy construction heuristic
5. Critique of model and method
6. Future work
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The Liner Service Network Design Problem (LS-NDP)

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LS-NDP as a multilayered Multiple Quadratic Knapsack Problem

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The Liner shipping network design problem

Given a complete graph $G'$ between a set of ports $P$, a fleet divided into vessel classes $A$ and a set of commodities $K$ determine a minimum cost network $G = (V, E)$ consisting of disjoint non-simple cyclic vessel routes to transport the most profitable subset of the commodities.
Characteristics of a service

Figure: Example of a single service

- Cyclic
- Non-simple
- Inbound vs. outbound direction
Characteristics of a network

Figure: Network design

- Transhipment of cargo at transhipment hubs and main ports
- Capacity classes: feeder, panamax, super panamax
- Fixed schedule - mainly based on weekly port visits
Selection of previous work

Focus:
- Multiple routings (i.e. network design)
- Multiple hubs

Relevant literature:
- \#models = \#articles
- Main difference: transhipment

Figure: Transhipment of cargo
Previous work

<table>
<thead>
<tr>
<th>Article</th>
<th>Method</th>
<th>Optimal</th>
<th>Transhipment</th>
<th>vessels/ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>Lagrange, Benders</td>
<td>No</td>
<td>No</td>
<td>3v, 20p</td>
</tr>
<tr>
<td>[2]</td>
<td>Branch-&amp;-Cut</td>
<td>Yes</td>
<td>Yes, handling cost per container</td>
<td>6v, 20p</td>
</tr>
<tr>
<td>[3]</td>
<td>greedy, column generation, Benders</td>
<td>No</td>
<td>Yes, no cost</td>
<td>50v, 10p</td>
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<tr>
<td>[4]</td>
<td>tabu search, LP solver</td>
<td>No</td>
<td>Yes, individual cost per container</td>
<td>100v, 120p</td>
</tr>
</tbody>
</table>

**Table:** Overview of main articles with multiple route construction

- [1]: Rana & Vickson 1991
- [2]: Reinhardt & Kallehauge 2007
- [3]: Agarwal & Ergun 2008
- [4]: Alvarez 2009
Scaling to a global liner shipping network
200+ ports, 200+ vessels

Scalability Issues:

Symmetry: Cyclic Routing Vessel Specs

Large scale multicommodity flow problem
Motivation

Good solutions to the liner shipping network design problem

- Competitive network
- Low cost network
- Inclusion of dynamic non-linear bunker cost calculation
- No optimality guarantee

Figure: Fictitious example of non-linear bunker curve

Berit Løfstedt (DTU Management) LS-NDP May 5, 2010
Work in progress...

- Create a good model including bunker cost
- Build a local search framework (ALNS)
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Combining sets of:
1. Construction Heuristics
2. Destruction Heuristics
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Topic of this talk:
Create a good model including bunker cost
Build a local search framework (ALNS)
Combining sets of:
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Topic of this talk:
First building block:
1. Greedy construction heuristic
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Build a local search framework (ALNS)
Combining sets of:
   1 Construction Heuristics
   2 Destruction Heuristics

Topic of this talk:
First building block:
   1 Greedy construction heuristic
   2 Based on a simplified LS-NDP model with simplified cost structures
Model simplifications

Rephrase the problem:
Model simplifications

Rephrase the problem:

1. A set of routes
Model simplifications

Rephrase the problem:

1. A set of routes
2. Place port calls on routes
Model simplifications

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Multiple Quadratic Knapsack Problem (MQKP)
Routes=Knapsacks
Port calls=items
Model simplifications

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Avoid evaluating a large scale multicommodity flow problem

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Multiple Quadratic Knapsack Problem (MQKP)
Routes=Knapsacks
Port calls=items

Profit function, $f$:
$$f(distance, demand, transhipment)$$
### Layer characteristics

<table>
<thead>
<tr>
<th>Layer</th>
<th>Port types</th>
<th>Distances</th>
<th>Direct</th>
<th>Transport to Hub</th>
<th>Weeks</th>
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Table: Layer classification
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<td>Short</td>
<td>secondary</td>
<td>primary</td>
<td>1-3</td>
</tr>
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<tr>
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<td>Main ports Hubs</td>
<td>Medium</td>
<td>primary</td>
<td>secondary</td>
<td>3-8</td>
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<td></td>
<td>Hubs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super panamax</td>
<td>Main ports</td>
<td>Long</td>
<td>secondary</td>
<td>primary</td>
<td>6-12</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table:** Layer classification
Multilayered algorithm

Figure: Multi layered knapsack interpretation of the LS-NDP

- Three layers: feeder, panamax and super panamax
- Port items: Scheduled port visits
- Each layer may have multiple visits to a port
Solve an MQKP for each layer

<table>
<thead>
<tr>
<th>i</th>
<th>0</th>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>287</td>
<td>306</td>
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<td>1</td>
<td>-25</td>
<td>42</td>
<td>742</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>513</td>
<td>0</td>
</tr>
</tbody>
</table>

Table: Profit matrix

- $V_{layer}$: items (scheduled port calls with the capacity class of this layer)
- $R_{layer}$: knapsacks (Services)
- Services are assigned a standard number of vessels
- Number of vessels = Duration in weeks
Specialised MQKP - Mathematical model

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

subject to:

\sum_{r \in R} x_i^f = 1 \quad \forall i \in V \quad (\text{Mutually exclusive})

x_i^f x_j^f \geq y_{ij}^f \quad \forall i \in V, j \in V, r \in R \quad (\text{Activate edge variable})

\sum_{j \in V} y_{ij}^f - \sum_{j \in V} y_{ji}^f = 0 \quad \forall i \in V, r \in R \quad (\text{Cyclic})

\sum_{j \in V} y_{ij}^f \leq 1 \quad \forall i \in V, r \in R \quad (\text{Simple})

u_i^f - u_j^f + y_{ij}^f \sum_{i \in V} x_i^f \leq \sum_{i \in V} x_i^f - 1 \quad \forall i \in V, j \in V, r \in R \quad (\text{Connected})

\sum_{i \in V} \sum_{j \in V} y_{ij}^f (t_{ij} + t_i) \leq \sigma(C_a) \quad \forall r \in R_a, a \in A \quad (\text{Duration})

x_i^f \in \{0, 1\} \quad \forall i \in V, r \in R

y_{ij}^f \in \{0, 1\} \quad \forall i \in V, j \in V, r \in R

u_i^f \in \mathbb{Z}^+ \quad \forall i \in V, r \in R

Quadratic objective function - heuristic solution method
Greedy parallel insertion

The football teaming principle

The knapsacks take turn at choosing the most profitable item among the remaining items

- Principle: parallel insertion
- Motivation: Distribution of difficult items
Algorithm

GREEDYCONSTRUCTION (instance)

1. layers ← FLEETTOLAYERS(instance)
2. SCHEDULETOITEMS(instance, layers)
3. profitIncrease ← TRUE
4. for each layer ∈ layers
   do MAKEKNAPSACKS()
   while (V_layer ≠ ∅ ∪ profitIncrease)
     do profitIncrease ← FALSE
     for each r ∈ R_layer
     best ← NULL
     bestValue ← 0
     for each i ∈ V_layer
     deltaValue ← ∑j∈r pij
     if (deltaValue > bestValue)
       then
         bestValue ← deltaValue
         best ← i
     if (bestValue > 0)
       then
         profitIncrease ← TRUE
         UPDATEDEMANDMATRICES(knapsack, best)
         r ← best
     V_layer ← V_layer \ best
Results

- Solve an instance of 234 ports and roughly 14000 demands in 33 seconds
- Evaluated by Network specialists at Maersk Line
  1. The routings are overall realistic
  2. Emphasis on direct transportation
  3. Transhipment facilities are weak
  4. Good basis for a local search

Conclusion:
Good construction heuristic as initial solution for further local search
Critique of the approach

- Not based on the true objective i.e. the MCF problem
- Little interaction between layers
- Only tested on a single instance of the Maerskline network
- No transhipment cost, bunker cost or vessel deployment cost
- **Note:** Integration in ALNS will provide evaluation of true cost
Future work for MQKP heuristic

- Interaction between layers
- More realistic goal function
  1. Solve uncapacitated MCF
  2. Evaluate the transit times and the potential throughput
- Test on real life data (Benchmark suite in progress)
- Compare results to the network cost of the initial schedule
Future work for ALNS framework

- Fast delta evaluation of multi commodity flow problem
- Destruction/ construction heuristics
- Benchmark suite for Liner shipping
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