A Greedy Construction Heuristic for the Liner Shipping Network Design Problem

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A greedy construction heuristic for the Liner Service Network Design Problem

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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)

Methods based on integer and linear programming relaxations

LS-NDP as a multilayered Multiple Quadratic Knapsack Problem

The greedy construction heuristic

Critique of model and method

Future work
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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

- Cyclic
- Non-simple
- Inbound vs. outbound direction

Figure: Example of a single service
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>
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<td>[2]</td>
<td>Branch-&amp;-Cut</td>
<td>Yes</td>
<td>Yes, handling cost per container</td>
<td>6v, 20p</td>
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<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
Going global....

Challenges
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
Work in progress...

- Create a good model including bunker cost
- Build a local search framework (ALNS)
Create a good model including bunker cost
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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
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- Topic of this talk:
- First building block:
  1. Greedy construction heuristic
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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
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1. A set of routes
2. Place port calls on routes
Model simplifications

Rephrase the problem:
1. A set of routes
2. Place port calls on routes

Multiple Quadratic Knapsack Problem (MQKP)
Routes=Knapsacks
Port calls=items
Rephrase the problem:
1. A set of routes
2. Place port calls on routes

Avoid evaluating a large scale multicommodity flow problem

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

Profit function, $f$:
$$f(distance, demand, transhipment)$$
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<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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<tbody>
<tr>
<td>Feeder</td>
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<td>primary</td>
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<tr>
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<td>Hubs</td>
<td>Medium</td>
<td>primary</td>
<td>secondary</td>
<td>3-8</td>
</tr>
<tr>
<td>Super Main ports</td>
<td>Hubs</td>
<td>Long</td>
<td>primary</td>
<td>secondary</td>
<td>6-12</td>
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Table: Layer classification
## Layer characteristics

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**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></th>
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<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

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

subject to:

1. \( \sum_{r \in R} x_i^r = 1 \) \( \forall i \in V \) (Mutually exclusive)
2. \( x_i^r x_j^r \geq y_{ij}^r \) \( \forall i \in V, j \in V, r \in R \) (Activate edge variable)
3. \( \sum_{j \in V} y_{ij}^r - \sum_{j \in V} y_{ji}^r = 0 \) \( \forall i \in V, r \in R \) (Cyclic)
4. \( \sum_{j \in V} y_{ij}^r \leq 1 \) \( \forall i \in V, r \in R \) (Simple)
5. \( u_i^r - u_j^r + y_{ij}^r \sum_{i \in V} x_i^r \leq \sum_{i \in V} x_i^r - 1 \) \( \forall i \in V, j \in V, r \in R \) (Connected)
6. \( \sum_{i \in V} \sum_{j \in V} y_{ij}^r (t_{ij} + t_i) \leq \sigma(C_a) \) \( \forall r \in R, a \in A \) (Duration)

\( x_i^r \in \{0, 1\} \) \( \forall i \in V, r \in R \)

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

\( u_i^r \in \mathbb{Z}^+ \) \( \forall i \in V, r \in R \)

Quadratic objective function - heuristic solution method
The football teaming principle

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

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

**GreedyConstruction** *(instance)*
1. \( \text{layers} \leftarrow \text{FleetToLayers}(\text{instance}) \)
2. \( \text{ScheduleToItems}(\text{instance}, \text{layers}) \)
3. \( \text{profitIncrease} \leftarrow \text{TRUE} \)
4. \( \text{for each layer} \in \text{layers} \)
   5. \( \text{do MAKEKnapsacks()} \)
   6. \( \text{while}\ (V_{\text{layer}} \neq 0 \cup \text{profitIncrease}) \)
   7. \( \text{do profitIncrease} \leftarrow \text{FALSE} \)
   8. \( \text{for each } r \in R_{\text{layer}} \)
   9. \( \text{best} \leftarrow \text{NULL} \)
  10. \( \text{bestValue} \leftarrow 0 \)
  11. \( \text{for each } i \in V_{\text{layer}} \)
  12. \( \text{deltaValue} \leftarrow \sum_{j \in r} p_{ij} \)
  13. \( \text{if } (\text{deltaValue} > \text{bestValue}) \)
     14. \( \text{then} \)
     15. \( \text{bestValue} \leftarrow \text{deltaValue} \)
     16. \( \text{best} \leftarrow i \)
  17. \( \text{if } (\text{bestValue} > 0) \)
     18. \( \text{then} \)
  19. \( \text{profitIncrease} \leftarrow \text{TRUE} \)
  20. \( \text{UPDATEDemandMatrices}(\text{knapsack}, \text{best}) \)
  21. \( r \leftarrow \text{best} \)
  22. \( V_{\text{layer}} \leftarrow V_{\text{layer}} \setminus \text{best} \)
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
[K. Rana and R.G. Vickson]
“Routing container Ships Using Lagrangian Relaxation and Decomposition”
*Transportation Science* 25, 201-214 (1991)

[L. B. Reinhardt and B. Kallehauge]
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“A general heuristic for vehicle routing problems”,

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"Multi-port vs. Hub-and-Spoke port calls by containerships”
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"Large Neighborhood Search”

*Book Chapter*, http://www.diku.dk/hjemmesider/ansatte/sropke/Papers/lns.pdf