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

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Problem definition

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

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

Figure: Network design
Selection of previous work

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

Relevant literature:
- $\#\text{models} = \#\text{articles}$
- 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>
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<tbody>
<tr>
<td>[1]</td>
<td>Lagrange, Benders</td>
<td>No</td>
<td>No</td>
<td>3v, 20p</td>
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<td>[2]</td>
<td>Branch-&amp;-Cut</td>
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<td>Yes, handling cost per container</td>
<td>6v, 20p</td>
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<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>
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</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
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
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Topic of this talk:
First building block:
1. Greedy construction heuristic
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
Work in progress...

- Create a good model including bunker cost
- 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

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

Avoid evaluating a large scale multicommodity flow problem

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

Avoid evaluating a large scale multic commodity flow problem

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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<tr>
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<td>Short secondary primary</td>
<td>1-3</td>
<td></td>
<td></td>
<td></td>
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<td>Main ports Hubs</td>
<td>Panamax Medium primary secondary</td>
<td>3-8</td>
<td></td>
<td></td>
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<tr>
<td>Super Main ports Hubs</td>
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**Table:** Layer classification
Multilayered algorithm

Three layers: feeder, panamax and super panamax
Port items: Scheduled port visits
Each layer may have multiple visits to a port

Figure: Multi layered knapsack interpretation of the LS-NDP
Solve an MQKP for each layer

Table: Profit matrix

<table>
<thead>
<tr>
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<th>1</th>
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</thead>
<tbody>
<tr>
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<td>287</td>
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<tr>
<td>1</td>
<td>-25</td>
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<tr>
<td>2</td>
<td>14</td>
<td>513</td>
<td>0</td>
</tr>
</tbody>
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- $V_{layer}$: 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
maximize(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: \sum_{r \in R} x_i^r = 1 \quad \forall i \in V \quad \text{(Mutually exclusive)}
\]
\[x_i^r x_j^r \geq y_{ij}^r \quad \forall i \in V, j \in V, r \in R \quad \text{(Activate edge variable)}
\]
\[\sum_{j \in V} y_{ij}^r - \sum_{j \in V} y_{ji}^r = 0 \quad \forall i \in V, r \in R \quad \text{(Cyclic)}
\]
\[\sum_{j \in V} y_{ij}^r \leq 1 \quad \forall i \in V, r \in R \quad \text{(Simple)}
\]
\[u_i^r - u_j^r + y_{ij}^r \sum_{i \in V} x_i^r \leq \sum_{i \in V} x_i^r - 1 \quad \forall i \in V, j \in V, r \in R \quad \text{(Connected)}
\]
\[\sum_{i \in V} \sum_{j \in V} y_{ij}^r (t_{ij} + t_i) \leq \sigma(C_a) \quad \forall r \in R, a \in A \quad \text{(Duration)}
\]
\[x_i^r \in \{0, 1\} \quad \forall i \in V, r \in R
\]
\[y_{ij}^r \in \{0, 1\} \quad \forall i \in V, j \in V, r \in R
\]
\[u_i^r \in \mathbb{Z}^+ \quad \forall i \in V, r \in R
\]

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
GreedyConstruction (instance)

1. \textit{layers} $\leftarrow$ FLEETTOLAYERS\textit{(instance)}
2. SCHEDULETOITEMS\textit{(instance, layers)}
3. profitIncrease $\leftarrow$ TRUE
4. for each \textit{layer} $\in$ \textit{layers} do
5. \hspace{1em} MAKEKNAPSACKS()
6. \hspace{1em} while ($V_{\text{layer}} \neq \emptyset \cup \text{profitIncrease}$) do
7. \hspace{2em} profitIncrease $\leftarrow$ FALSE
8. \hspace{2em} for each \textit{r} $\in R_{\text{layer}}$
9. \hspace{3em} \textit{best} $\leftarrow$ NULL
10. \hspace{3em} bestValue $\leftarrow$ 0
11. \hspace{2em} for each \textit{i} $\in V_{\text{layer}}$
12. \hspace{3em} deltaValue $\leftarrow$ $\sum_{j \in r} p_{ij}$
13. \hspace{3em} if (deltaValue $>$ bestValue)
14. \hspace{4em} bestValue $\leftarrow$ deltaValue
15. \hspace{4em} best $\leftarrow$ \text{i}
16. \hspace{2em} if (bestValue $>$ 0)
17. \hspace{3em} then
18. \hspace{4em} profitIncrease $\leftarrow$ TRUE
19. \hspace{4em} UPDATEDEMANDMATRICES\textit{(knapsack, best)}
20. \hspace{3em} \textit{r} $\leftarrow$ best
21. \hspace{2em} \textit{V}_{\text{layer}}$ $\leftarrow$ \textit{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
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