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 Service Network Design Problem (LS-NDP)

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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
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>
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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>
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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
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
Create a good model including bunker cost
Build a local search framework (ALNS)
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
Create a good model including bunker cost
Build a local search framework (ALNS)
Combining sets of:
1. Construction 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:
1 Construction Heuristics
2 Destruction Heuristics

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

1. A set of routes
2. Place port calls on routes
3. Avoid evaluating a large scale multicommodity flow problem

Multiple Quadratic Knapsack Problem (MQKP)

Routes = Knapsacks
Port calls = items
Profit function, \( f \):

\[ f(\text{distance}, \text{demand}, \text{transhipment}) \]
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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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<tbody>
<tr>
<td>Feeder Spokes</td>
<td>Short secondary primary</td>
<td>1-3</td>
<td></td>
<td></td>
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<tr>
<td>Main ports Hubs</td>
<td>Panamax</td>
<td>Medium primary secondary</td>
<td>3-8</td>
<td></td>
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<tr>
<td>Super Main ports Panamax Hubs</td>
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</tr>
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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>
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<tr>
<th></th>
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<th>2</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

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

subject to:

\[ \sum_{r \in R} x^r_i = 1 \quad \forall i \in V \quad \text{(Mutually exclusive)} \]

\[ x^r_i x^r_j \geq y^r_{ij} \quad \forall i \in V, j \in V, r \in R \quad \text{(Activate edge variable)} \]

\[ \sum_{j \in V} y^r_{ij} - \sum_{j \in V} y^r_{ji} = 0 \quad \forall i \in V, r \in R \quad \text{(Cyclic)} \]

\[ \sum_{j \in V} y^r_{ij} \leq 1 \quad \forall i \in V, r \in R \quad \text{(Simple)} \]

\[ u^r_i - u^r_j + y^r_{ij} \sum_{i \in V} x^r_i \leq \sum_{i \in V} x^r_i - 1 \quad \forall i \in V, j \in V, r \in R \quad \text{(Connected)} \]

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

\[ x^r_i \in \{0, 1\} \quad \forall i \in V, r \in R \]

\[ y^r_{ij} \in \{0, 1\} \quad \forall i \in V, j \in V, r \in R \]

\[ u^r_i \in \mathbb{Z}^+ \quad \forall i \in V, r \in R \]

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. $\text{layers} \leftarrow \text{FLEETTOLAYERS}(*\text{instance}*)$
2. $\text{SCHEDULETOITEMS}(*\text{instance}, \text{layers}*)$
3. $\text{profitIncrease} \leftarrow \text{TRUE}$
4. for each $\text{layer} \in \text{layers}$
   
   do $\text{MAKEKNAPSACKS}()$

   while ($V_{\text{layer}} \neq \emptyset \cup \text{profitIncrease}$ )

   do $\text{profitIncrease} \leftarrow \text{FALSE}$

   for each $r \in R_{\text{layer}}$

   $\text{best} \leftarrow \text{NULL}$

   $\text{bestValue} \leftarrow 0$

   for each $i \in V_{\text{layer}}$

   $\text{deltaValue} \leftarrow \sum_{j \in r} p_{ij}$

   if ($\text{deltaValue} > \text{bestValue}$)

     then $\text{bestValue} \leftarrow \text{deltaValue}$

     $\text{best} \leftarrow i$

   if ($\text{bestValue} > 0$)

     then $\text{profitIncrease} \leftarrow \text{TRUE}$

   $\text{UPDATEDEMANDMATRICES(} \text{knapsack, best} \text{)}$

   $r \leftarrow \text{best}$

20. $V_{\text{layer}} \leftarrow V_{\text{layer}} \setminus \text{best}$
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
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