Freight Railway Network Design Problem

Nikola Obrenović, Virginie Lurkin, Michel Bierlaire
Transport and Mobility Laboratory TRANSP-OR
École Polytechnique Fédérale de Lausanne EPFL

Vincent J. Baeriswyl, Jasmin Bigdon
SBB Cargo AG, Olten, Switzerland

OR Days 2018, Bern, Switzerland
Outline

1. Problem introduction
2. Problem formulation
3. Heuristic algorithm
4. Preliminary results
5. Conclusions and future work
Marshaling and shunting yards

- Bundling different commodities with close origins and destinations
Problem setting

- Existing SBB Cargo network
  - 2 inner marshaling yards
  - 3 border marshaling yards
  - Approx. 70 shunting yards – 50 can be changed
- Determine optimal number and locations of the yards
Related problems

- Hub location problem (HLP)
  - Missing track capacities and hub operation costs
- Multicommodity flow problem (MFP)
  - Missing hub capacities and operation costs
- Multicommodity network design problem (MNDP)
  - Missing hub types and operation costs
Problem definition

- Extension of the arc-node formulation of the MFP
- Network elements:
  - $N$ – Set of stations, including potential marshaling and shunting yards
  - $A$ – Set of direct, existing links between the stations
  - $B$ – Set of added direct links between the yards
  - $K$ – Set of transported commodities each described with the origin, destination, weight and number of wagons
Problem definition (cont.)

- Additional arcs to model transport of bundled commodities
Problem definition (cont.)

- Inner node arcs to model different station types
  - Only one can be used
  - Shunting capacity as the inner arc capacity
Problem definition (cont.)

- **Objective function:**
  \[
  \min \sum_{k \in K} \sum_{(i,j) \in A \cup B} c_{ij}^k x_{ij}^k + \sum_{k \in K} \sum_{i \in N} S v_i^k s_i^k + \sum_{k \in K} \sum_{i \in N} M v_i^k m_i^k
  \]

- **Constants:**
  - \( c_{ij}^k \) – Cost of transporting commodity \( k \) via arc \((i,j)\)
  - \( v_i^k \) – Number of wagons of commodity \( k \)
  - \( S \) – Cost of shunting one wagon in a shunting yard
  - \( M \) - Cost of shunting one wagon in a marshaling yard

- **Variables:**
  - \( x_{ij}^k \) - Determines if commodity \( k \) is transported via arc \((i,j)\)
  - \( s_i^k \) - Determines if commodity \( k \) is shunted in the shunting yard \( i \)
  - \( m_i^k \) - Determines if commodity \( k \) is shunted in the marshaling yard \( i \)
Problem definition (cont.)

- **Node type constraints:**

\[
\sum_{k \in K} r_i^k \leq r_i M_1, \quad \forall i \in N
\]

\[
\sum_{k \in K} s_i^k \leq s_i M_2, \quad \forall i \in N
\]

\[
\sum_{k \in K} m_i^k \leq m_i M_3, \quad \forall i \in N
\]

\[r_i + s_i + m_i = 1, \quad \forall i \in N\]

- **Variables:**

  - \( r_i \) - Equals to 1 if \( i \) is a regular station, otherwise equals to 0
  
  - \( s_i \) - Equals to 1 if \( i \) is a shunting yard, otherwise equals to 0
  
  - \( m_i \) - Equals to 1 if \( i \) is a marshaling yard, otherwise equals to 0

- **Arc usage constraints:**

\[
2x_{i,j}^k \leq s_i^k + m_i^k + s_j^k + m_j^k, \quad \forall (i,j) \in B, \forall k \in K
\]
Problem definition (cont.)

- Inner arc capacity constraints:

\[
\sum_{k \in K} v^k (r_i^k + s_i^k + m_i^k) = d_i, \quad \forall i \in N
\]

\[
d_i \leq r_i M + s_i C_S + m_i C_M, \quad \forall i \in N
\]

- Constants:
  - \( C_S \) - Maximum capacity of a shunting yard
  - \( C_M \) - Maximum capacity of a marshaling yard

- Variables:
  - \( d_i \) - Required capacity of the node \( i \)
Input data

- Size of the SBB Cargo network:
  - Approx. 2100 stations
  - Approx. 2500 direct links
- Over 65000 commodities
  - Yearly demand, scaled to daily average
Heuristic algorithm

- Hub location:
  - Adaptive large neighborhood search
  - Variable neighborhood search
Heuristic algorithm - Neighborhoods

- Select the busiest station close to the MY and exchange their locations

- Select the least used MY and convert it into SY

- Select SY with fully utilized, maximum capacity and convert it into MY
Heuristic algorithm - Neighborhoods

- Select SY with most unused capacity and decrease it

- Select SY with fully utilized, below-maximum capacity and increase it
Heuristic algorithm - Neighborhoods

- Select underused SY with minimum capacity and convert it into a regular station

- Select frequently used regular station and convert it into a SY with minimum capacity
Heuristic algorithm

• Commodity routing:
  • Prioritized assignment algorithm

Select commodity by priority

Path alternatives
  1. Shortest path
  2. Via marshaling yards
  3. Via shunting yards

Path selection
  Cheapest, available path
Heuristic algorithm - Path alternatives

• Direct (shortest) path
  • Unbundled commodity

• Via marshaling yards
  • Bundled commodity
Heuristic algorithm - Path alternatives

- Via shunting yards
  - Bundled commodity

- Via one marshaling and one shunting yard
  - Bundled commodity
Heuristic algorithm – development details

• Developed algorithm is very flexible:
  • Easily extendable with additional neighborhood operators, i.e. network transformations
  • Easy definition of specific initial network states, e.g. all marshaling yards closed, several additional marshaling yards open, etc.
Preliminary results

- Network states with potential transportation cost reduction identified with two strategies (thus far):
  1. S1: Allowing opening of new marshaling yards
  2. S2: Disallowing opening of new marshaling yards
Preliminary results (cont.)

- Best resulting networks:

<table>
<thead>
<tr>
<th>Strat.</th>
<th>New MY</th>
<th>Rem. MY</th>
<th>Mov. MY</th>
<th>Total MY</th>
<th>New SY</th>
<th>Rem. SY</th>
<th>Total SY</th>
<th>Cost reduct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orig. net.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>S1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td>46</td>
<td>8.505%</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>19</td>
<td>5</td>
<td>64</td>
<td>1.857%</td>
</tr>
</tbody>
</table>

- Daily transportation cost in the original network: over 38 Million CHF
- Running time: approx. 9h
Results discussion

- Costs of transportation are dominant over yard operation costs
- Cost of yard maintenance is not taken into account
  - This cost contributes to reducing the number of yards and their size
  - Opening new yards will be less favored by the algorithm
  - Could be included in another case study
- New yards can be near the existing ones
  - E.g. in S1, new MY Territet is opened close to Lausanne MY
  - The objective function should penalize this situation
Conclusions

- Developed algorithm explores various network changes, their combinations and their influence to the transportation costs
  - Flexible, easily extendable algorithm
- The algorithm identified network changes resulting in **transportation cost reduction**
- The objective function should be extended with the real **costs of maintenance** of the marshaling and shunting yards
  - Relevant change in the algorithm result
Future work

• Include penalty for having two yards near each other
• Include trains in the model formulation and heuristic
• Solve the problem exactly on the subset of input data
  • To benchmark the heuristic result
Thank you!

Questions?

nikola.obrenovic@epfl.ch
References


