Capacity-Oriented Marshaling and Shunting Yards Location Problem

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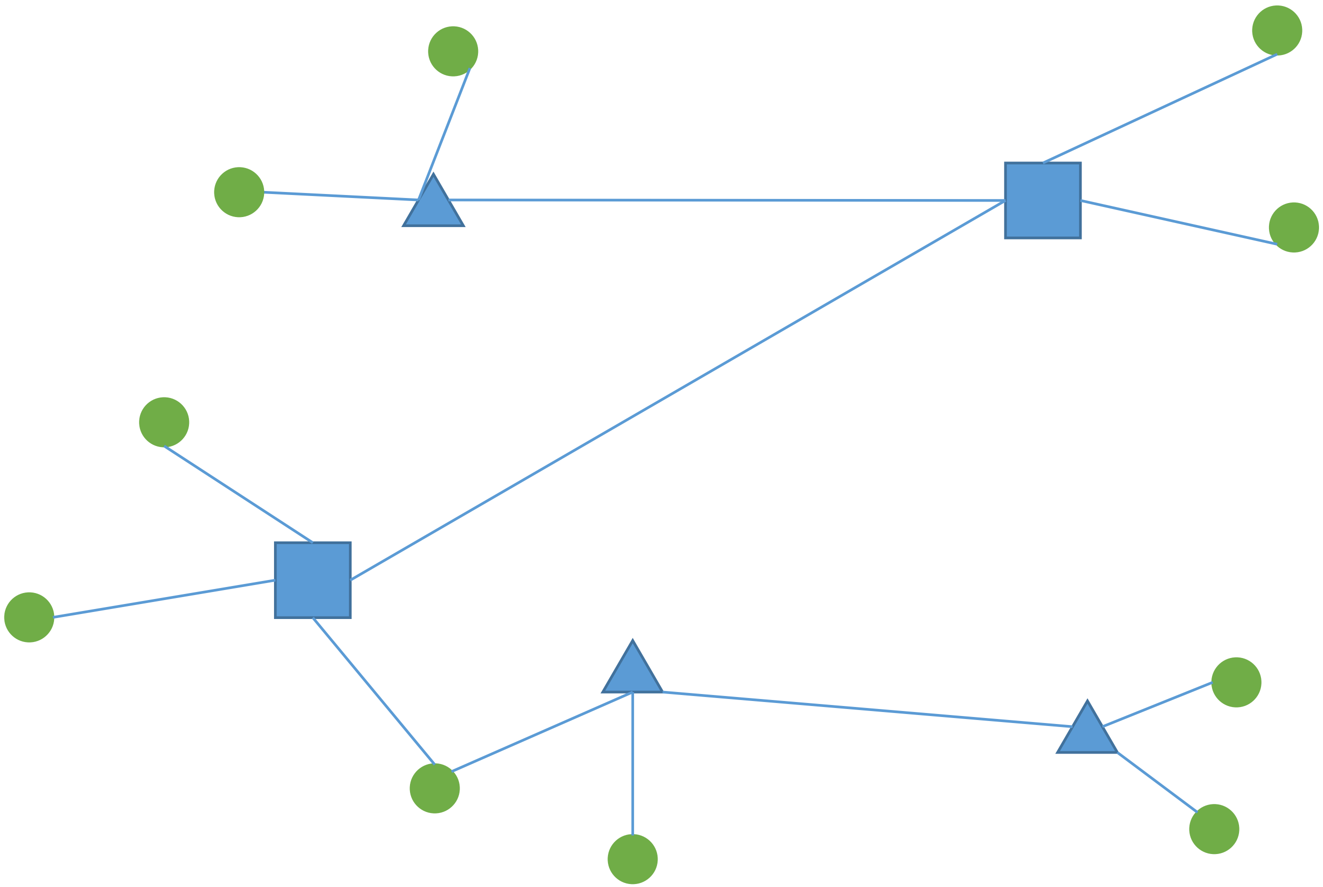
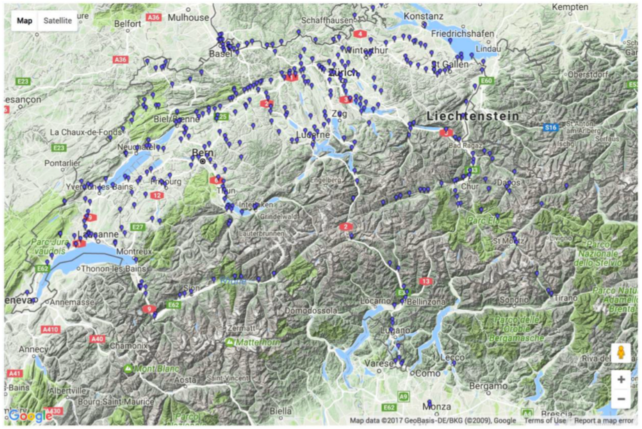
Marshaling and shunting yards

- 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



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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 HLP
- Network elements:
  - N – Set of stations, including potential marshaling and shunting yards
  - A – Set of direct links between the stations
  - K – Set of transported commodities each described with the origin, destination, weight and number of wagons

Problem definition *(cont.)*

- Constants:
  - d_{ij} – Shortest distance between nodes i and j
  - k_o – Origin of commodity k
  - k_d – Destination of commodity k
  - w^k – Weight of commodity k
  - P_W – Cost of transporting a weight unit of any commodity per distance unit
  - P_D – Cost of the locomotive and driver per distance unit
  - v^k – Number of wagons of commodity k
  - V_{max} – Maximum number of wagons in a train
  - S – Cost of shunting one wagon in a shunting yard
  - M – Cost of shunting one wagon in a marshaling yard

Problem definition *(cont.)*

- Transportation cost per distance unit:
  - Unbundled commodity:

$$c^k = w^k P_W + P_D \qquad \forall k \in K$$

  - Bundled commodity:

$$c_r^k = w^k P_W + \frac{v^k}{V_{max}} P_D \qquad \forall k \in K$$

Problem definition *(cont.)*

- Objective function:

$$\min \sum_{k \in K} \left(\sum_{i \in N} \sum_{j \in N} X_{ij}^{k} \left((d_{ik_o} + d_{jk_d}) c^k + d_{ij} c_r^k + (s_i S + m_i M + s_j S + m_j M) v^k \right) + (1 - z^k) d_{k_o k_d} c^k \right)$$

- Variables:
  - X_{ij}^{k} – Determines if commodity k is transported via hubs i and j
  - s_i – Determines if the node i is a shunting yard
  - m_i – Determines if the node i is a marshaling yard
  - z^k – Determines if the commodity k is transported bundled

Problem definition *(cont.)*

- Node type constraints:

$$r_i + s_i + m_i = 1, \qquad \forall i \in N$$

- Commodity shunting constraints:

$$\sum_{i \in N} \sum_{j \in N} X_{ij}^k = z^k, \qquad \forall k \in K$$

$$2X_{ij}^k \leq s_i + m_i + s_j + m_j, \qquad \forall k \in K, \forall i \in N, \forall j \in N$$

Problem definition *(cont.)*

- Node capacity constraints:

$$\sum_{k\in K}\sum_{j\in N} X_{ij}^{k} v^{k} + \sum_{k\in K}\sum_{j\in N} X_{ji}^{k} v^{k} = a_i, \qquad \forall i \in N$$

$$a_i \le r_i \mathcal{M} + s_i C_S + m_i C_M, \qquad \forall i \in N$$

Variables:

- a_i – Required capacity of the node i

Constants:

- $\mathcal{M}$ – Sufficiently large number
- C_S – Maximum capacity of a shunting yard
- C_M – Maximum capacity of a marshaling yard

Problem definition *(cont.)*

- Arc capacity constraints:

$$\sum_{k \in K} v^k \left(\sum_{i \in N} \sum_{j \in N} X_{ij}^k \left(b_{lm}^{k_o i} + b_{lm}^{k_d j} + b_{lm}^{ij} \right) + (1 - z^k) b_{lm}^{k_o k_d} \right) \leq u_{lm}, \forall (l, m) \in A$$

Constants:

- u_{lm} – Capacity of the arc (l, m)
- b_{lm}^{ij} – Determines if arc (l, m) belongs to the shortest path between i and j

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Problem definition *(cont.)*

- Maximum number of yards:

$$\sum_{i \in N} s_i \leq L_S \qquad \sum_{i \in N} m_i \leq L_M$$

- Integrality constraints:

$$X_{ij}^k \in \{0,1\}, \qquad \forall k \in K, \forall i \in N, \forall j \in N$$

$$z^k \in \{0,1\}, \qquad \forall k \in K$$

$$r_i \in \{0,1\}, \qquad \forall i \in N$$

$$s_i \in \{0,1\}, \qquad \forall i \in N$$

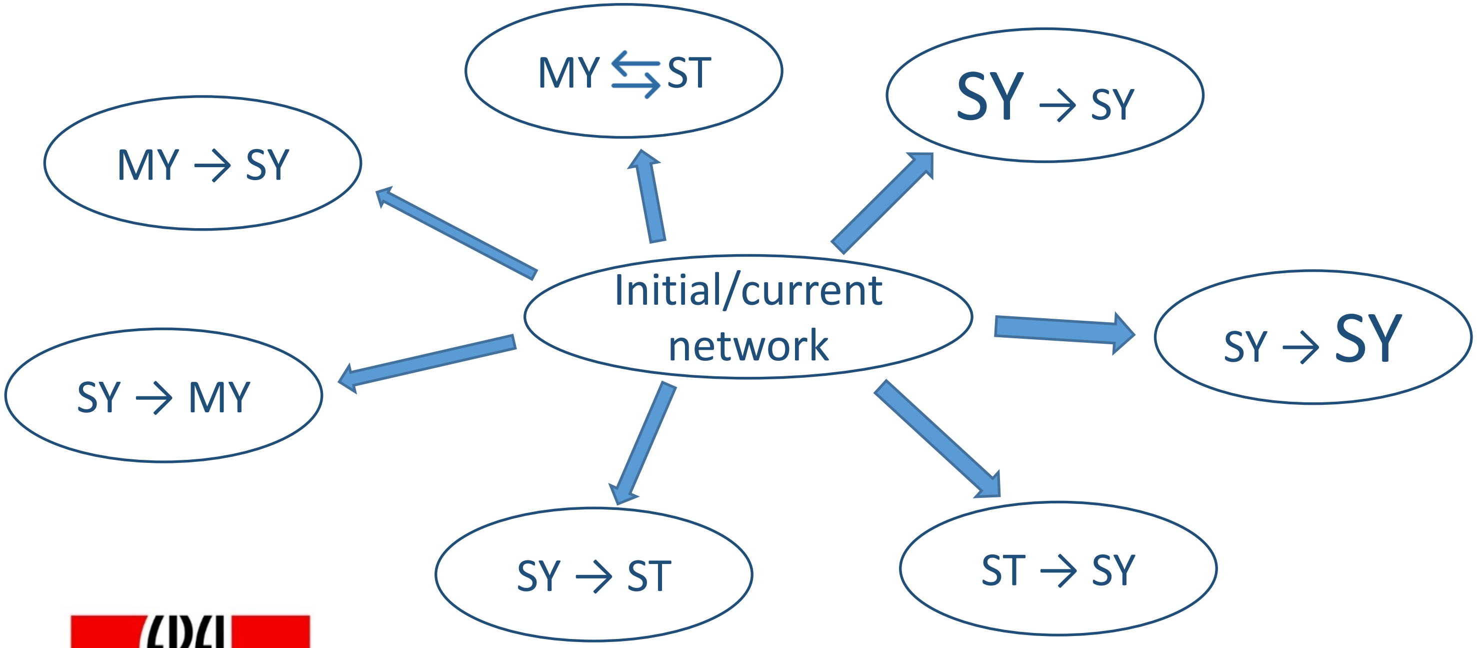
$$m_i \in \{0,1\}, \qquad \forall i \in N$$

Problem size

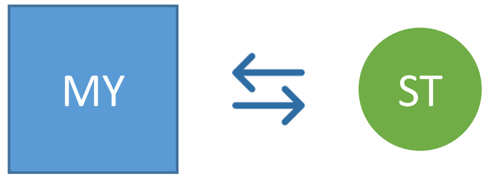
- Size of the SBB Cargo network:
  - Approx. 2100 stations
  - Approx. 2500 direct links
  - Over 65000 commodities

Heuristic algorithm

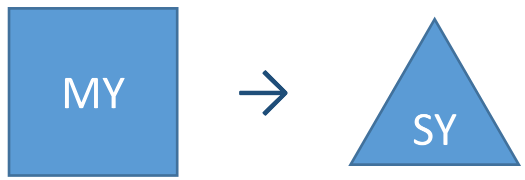
- Hub location:
  - Adaptive large neighborhood search
  - Variable neighborhood search



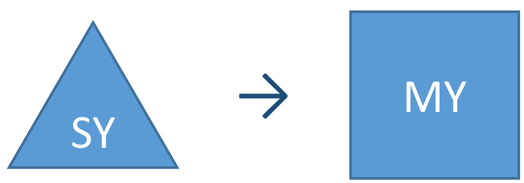
Heuristic algorithm - Neighborhoods



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

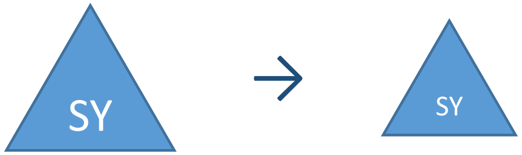


- Select the least used MY and convert it into SY

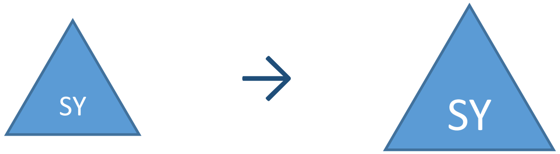


- Select SY with fully utilized, maximum capacity and convert it into MY

Heuristic algorithm - Neighborhoods

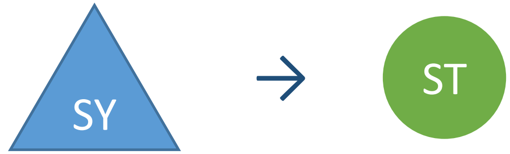


- Select SY with most unused capacity and decrease it

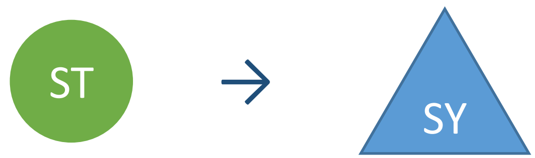


- Select SY with fully utilized, below-maximum capacity and increase it

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

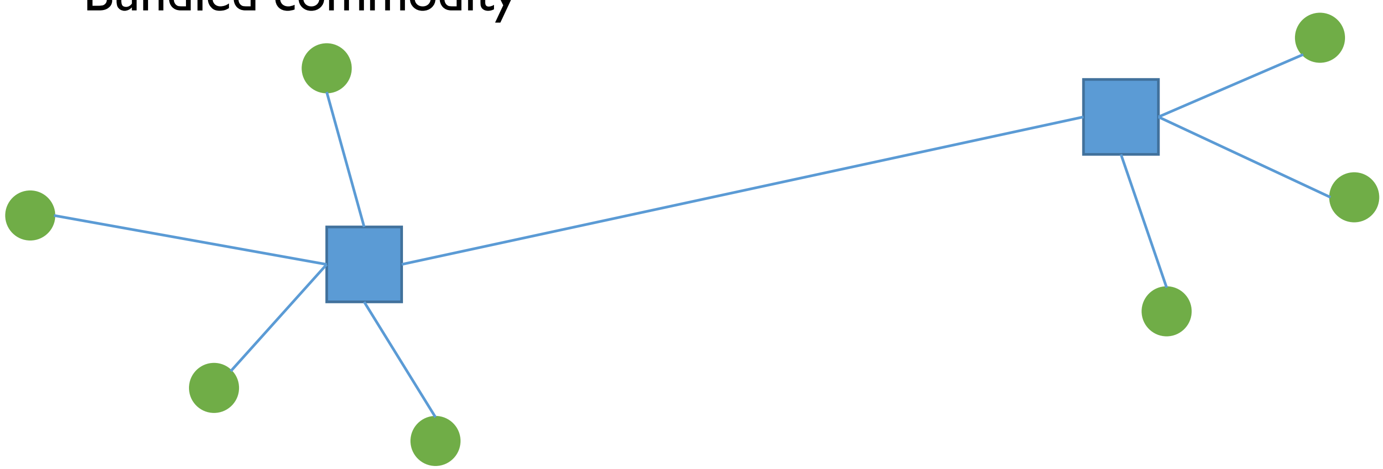
Path alternatives
1. Shortest path
2. Via marshaling yards
3. Via shunting yards

Path selection
Cheapest, available path

Heuristic algorithm - Path alternatives

- Direct (shortest) path
  - Unbundled commodity

- Via marshaling yards
  - Bundled commodity



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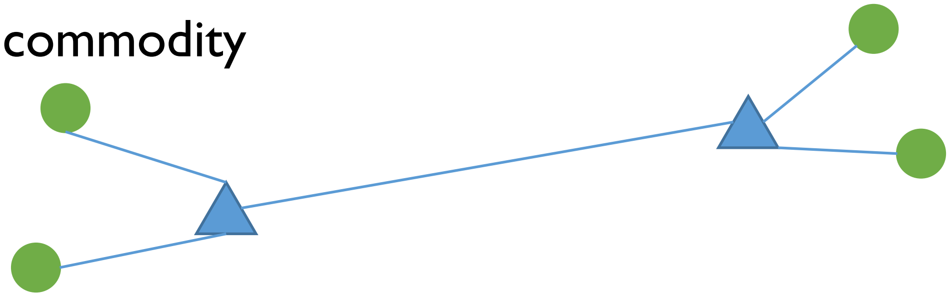
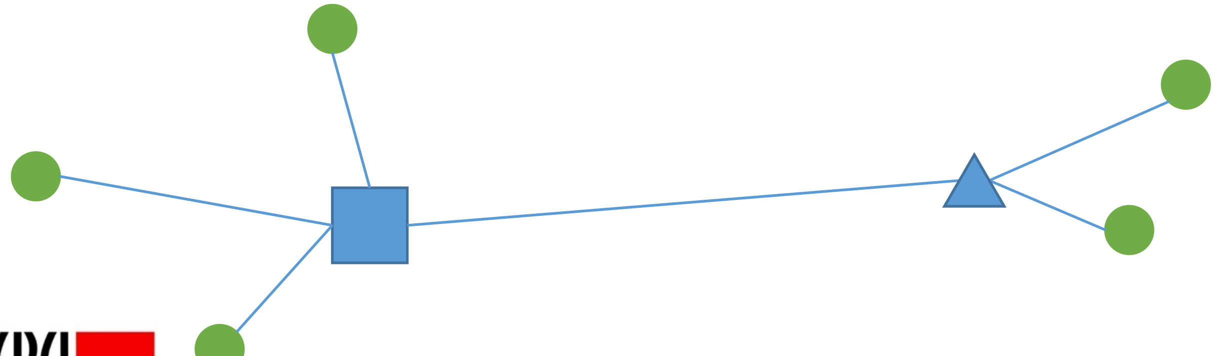
Heuristic algorithm - Path alternatives

- 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:

Strat.	New MY	Rem. MY	Mov. MY	Total MY	New SY	Rem. SY	Total SY	Cost reduct.
Orig. net.	-	-	-	2	-	-	50	-
S1	3	0	0	5	0	4	46	8.505%
S2	0	1	1	1	19	5	64	1.857%

- 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
- Solve the problem exactly on the subset of input data
  - To benchmark the heuristic result
- Implement visualization of the results
- Develop models based on MFP and MNDP
  - To compare results
  - If the current formulation cannot be solved exactly

Thank you!

Questions?

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