Freight Railway Network Design Problem

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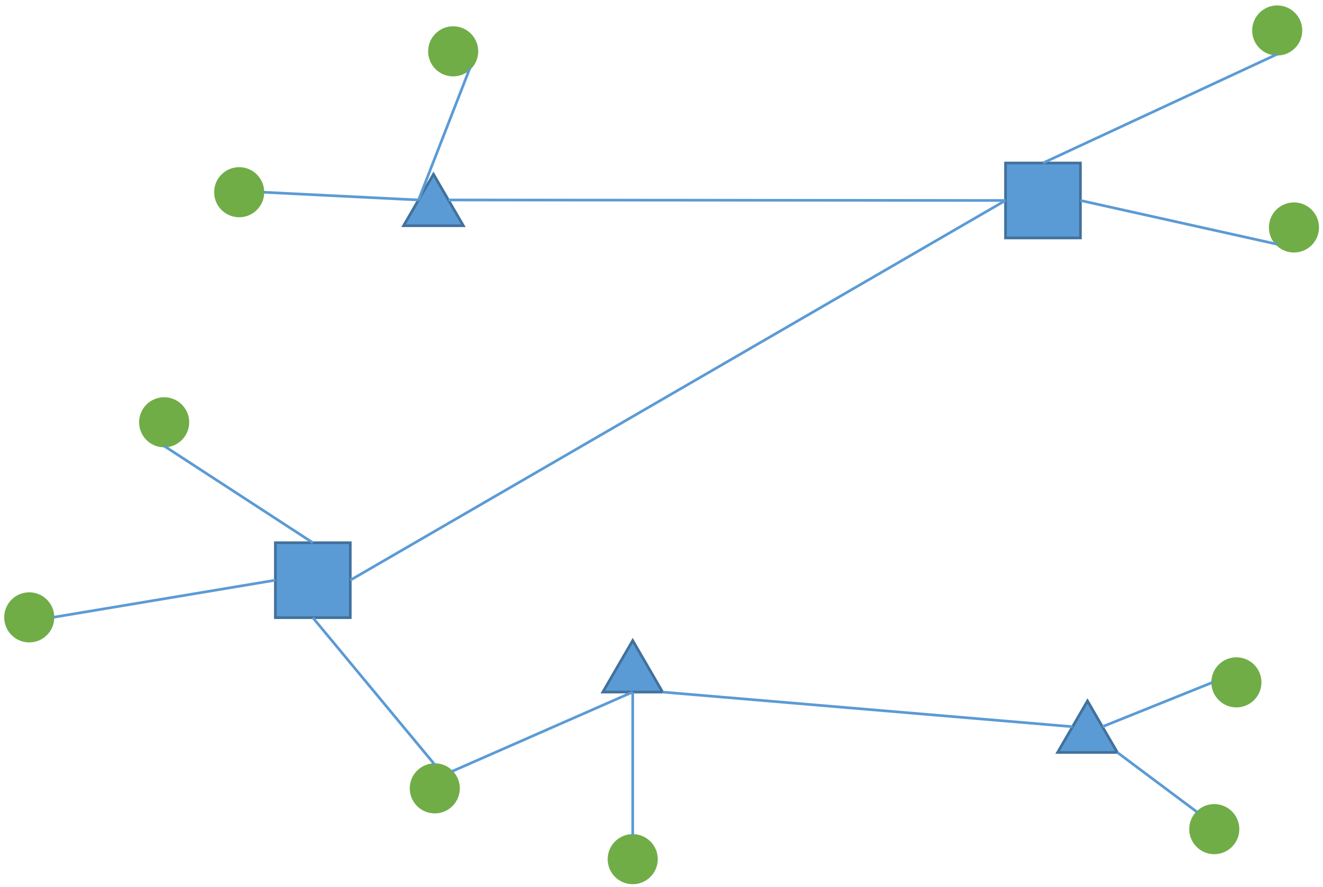
Outline

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



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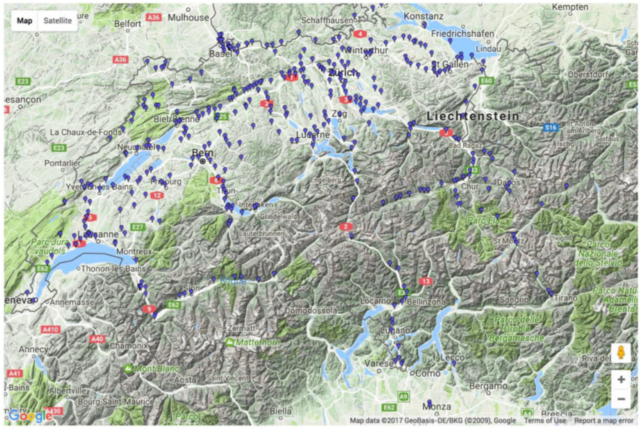
Problem setting

- 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

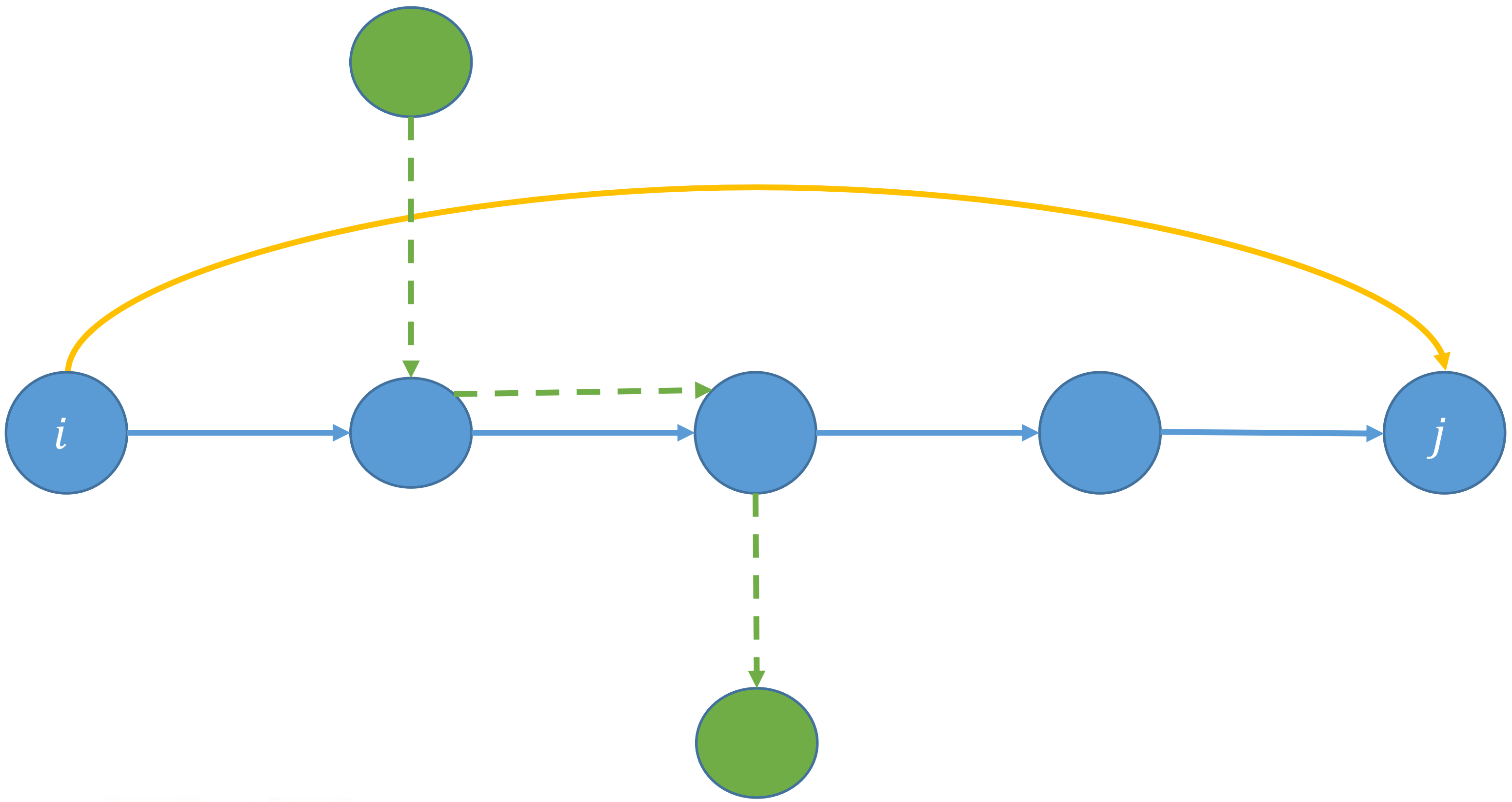
- Hub location problem (HLP)
  - Missing track capacities and hub operation costs
- Multicommodity flow problem (MFP)
  - Missing hub capacities and operation costs
- Multicommodity network design problem (MNDP)
  - Missing hub types and operation costs

Problem definition

- Extension of the 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

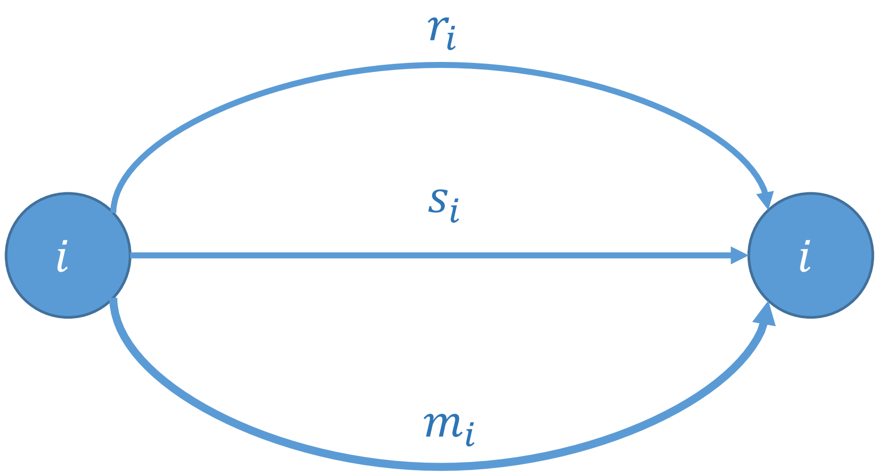
Problem definition *(cont.)*

- 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:

$$\min \sum_{k\in K} \sum_{(i,j)\in A\cup B} c_{ij}^{k} x_{ij}^{k} + \boxed{\sum_{k\in K} \sum_{i\in N} S v^{k} s_{i}^{k} + \sum_{k\in K} \sum_{i\in N} M v^{k} m_{i}^{k}}$$

- Constants:
  - c_{ij}^{k} – Cost of transporting commodity k via arc (i, j)
  - v^{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:

$$\sum_{k \in K} r_i^k \leq r_i \mathcal{M}_1, \qquad \forall i \in N$$

$$\sum_{k \in K} s_i^k \leq s_i \mathcal{M}_2, \qquad \forall i \in N$$

$$\sum_{k \in K} m_i^k \leq m_i \mathcal{M}_3, \qquad \forall i \in N$$

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

- 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:

$$2x_{ij}^k \leq s_i^k + m_i^k + s_j^k + m_j^k, \qquad \forall (i,j) \in B, \forall k \in K$$

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Problem definition *(cont.)*

- Inner arc capacity constraints:

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

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

- 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

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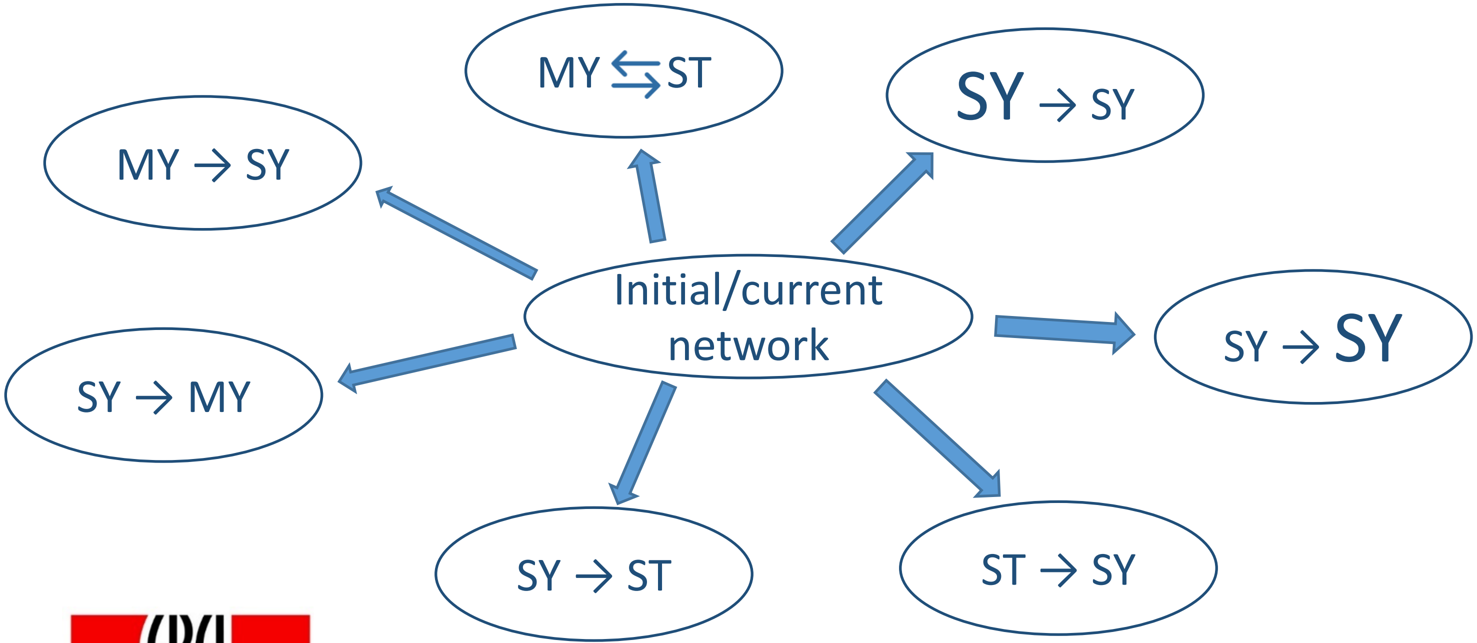
Input data

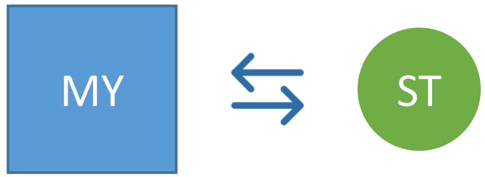
- Size of the SBB Cargo network:
  - Approx. 2100 stations
  - Approx. 2500 direct links
- Over 65000 commodities
  - Yearly demand, scaled to daily average

Heuristic algorithm

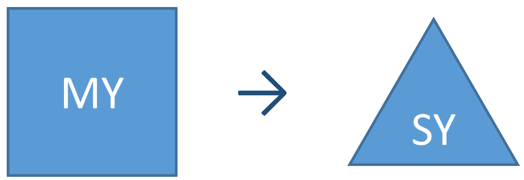
- Hub location:
    - Adaptive large neighborhood search
    - Variable neighborhood search



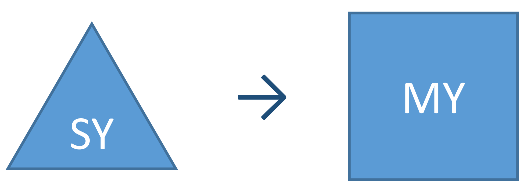
Heuristic algorithm - Neighborhoods



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

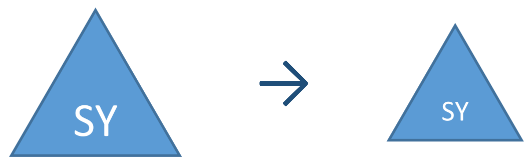


- Select the least used MY and convert it into SY

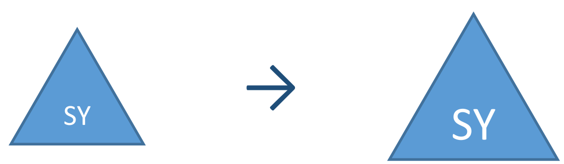


- Select SY with fully utilized, maximum capacity and convert it into MY

Heuristic algorithm - Neighborhoods

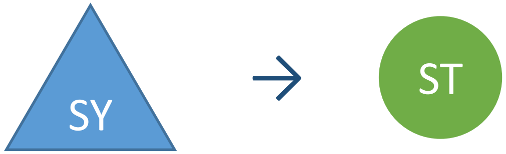


- Select SY with most unused capacity and decrease it

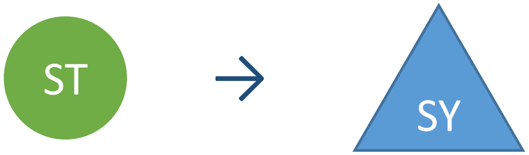


- Select SY with fully utilized, below-maximum capacity and increase it

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

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Heuristic algorithm

- Commodity routing:
  - Prioritized assignment algorithm

Select commodity by priority

Path alternatives

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

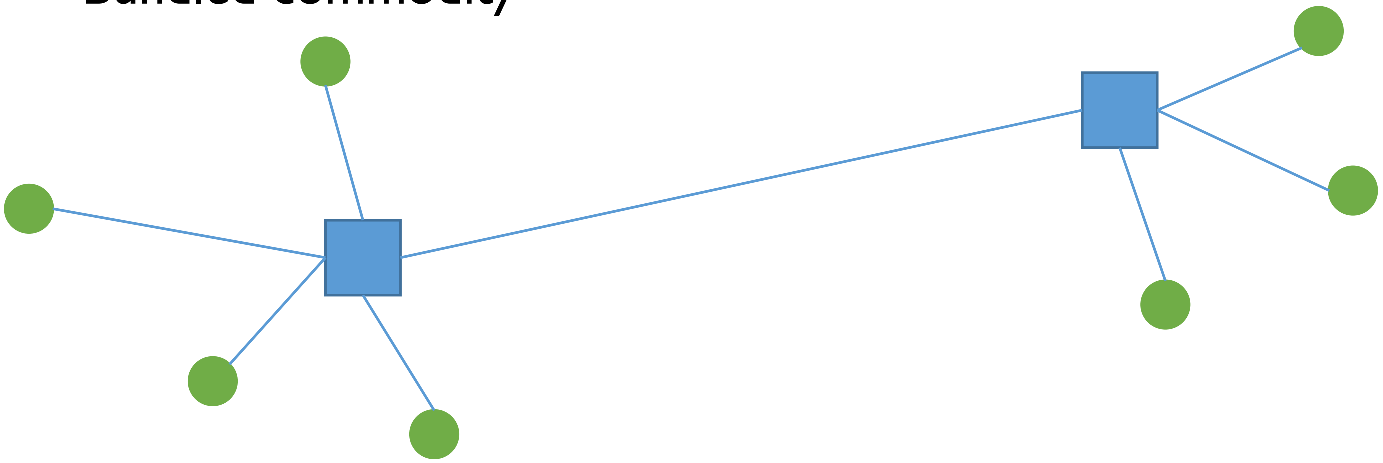
Path selection

Cheapest, available path

Heuristic algorithm - Path alternatives

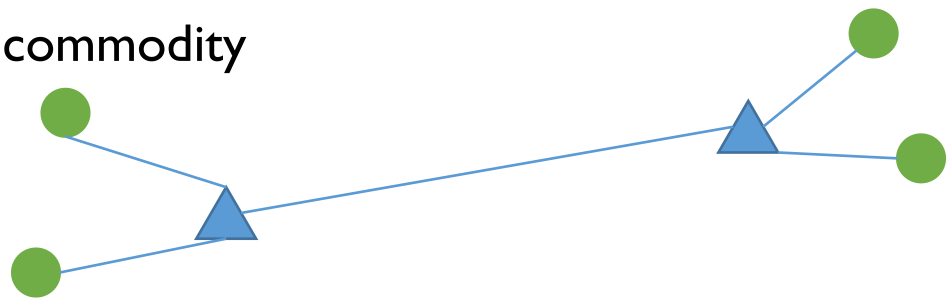
- Direct (shortest) path
  - Unbundled commodity

- Via marshaling yards
  - Bundled commodity

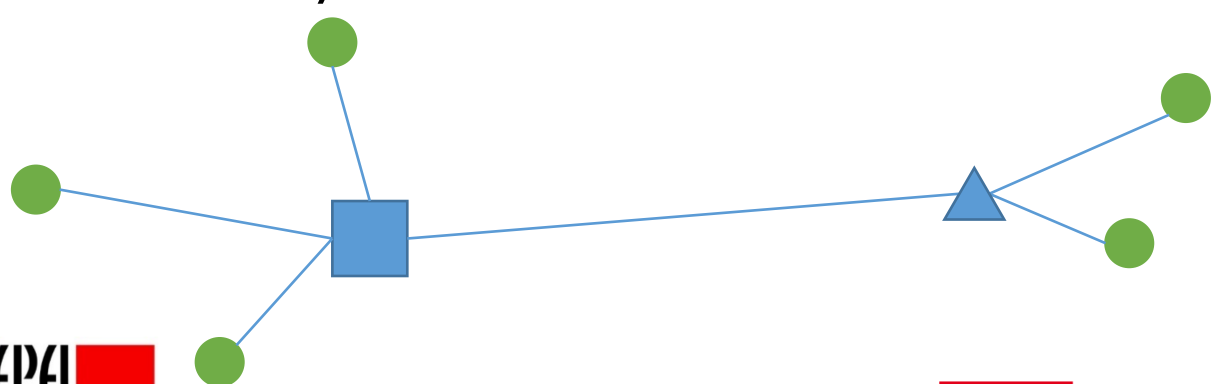


Heuristic algorithm - Path alternatives

- 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:

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
- 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?

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References

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