Line planning optimization at DSB

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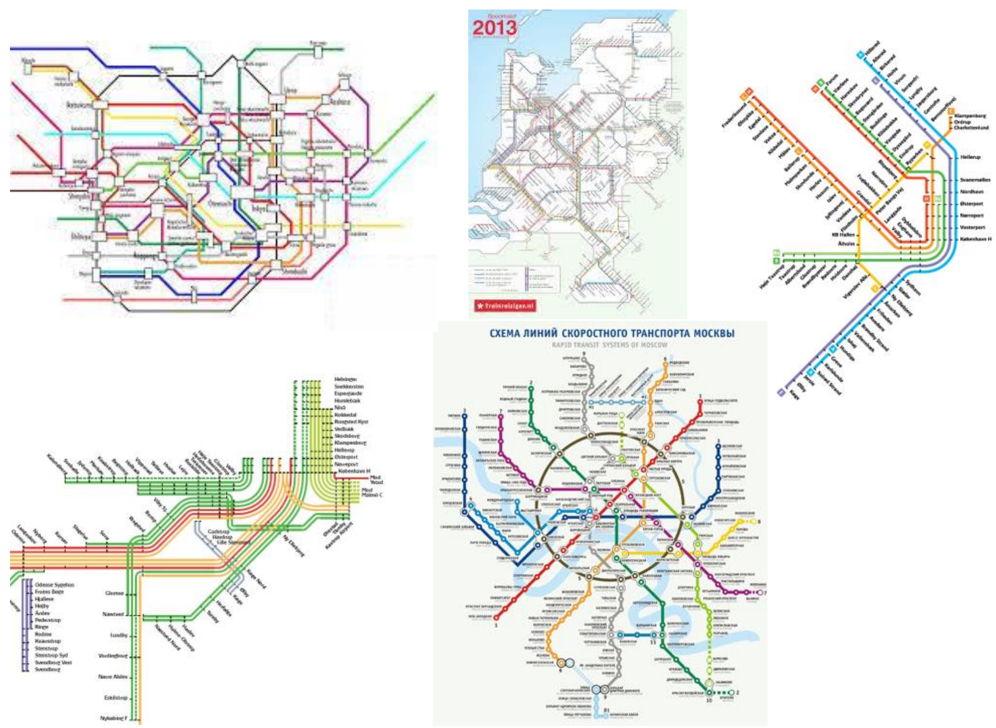
Line planning – an important step in railway strategic planning

DSB

- Infrastructure design
- **→ Lines and frequencies**
- Timetable
- Rolling stock schedules
- Crew schedules

A set of train lines (**line concept**):

- Paths between two terminal stations
- Symmetric stopping pattern in both directions
- Periodic: fixed frequency within a time period



DSB line planning problem

Feasibility constraints:

- Contract between DSB and Ministry of Transport:
  - Frequency of trains per network segment (lower bounds)
  - Number of stops per station
  - Direct connections between chosen cities
- Passenger demand is satisfied:
  - Line frequency
  - Rolling stock composition capacity
- Operational requirements:
  - Frequency of trains per network segment (upper bounds)
  - Limited number of line terminations at some end stations
  - Some line combinations are not feasible
  - Limits to the rolling stock assigned to the plan

Objectives:
- What is optimal?

- Minimize operational costs:
  - Train driving minutes (driver costs)
  - Rolling stock kilometer costs (every carriage in operation)
  - The unit cost of using one train carriage in the plan
- Maximize plan's attractiveness from the passenger's point of view:
  - Frequency of the line (as often as possible)
  - Train capacity (as many seats as possible)
  - Short driving time (on a train)
  - Short travel time, including time for switching lines
  - As few line switches as possible
- Find solutions with specific properties:
  - Lines with specific properties
  - Train driving minutes of lines with specific properties

Conflicting objectives!

Line planning problem formulations

DSB

Passenger-oriented models:

- Direct travellers approach
- Total travel time
- Number of lien changes

Given an operational budget

Cost-oriented models:

- Minimize operational costs

Given a minimum level of quality for passengers

J. W. Goossens, S. van Hoesel, and L. Kroon, "On solving multi-type railway line planning problems", EJOR, 2006.

Modelling decision variables

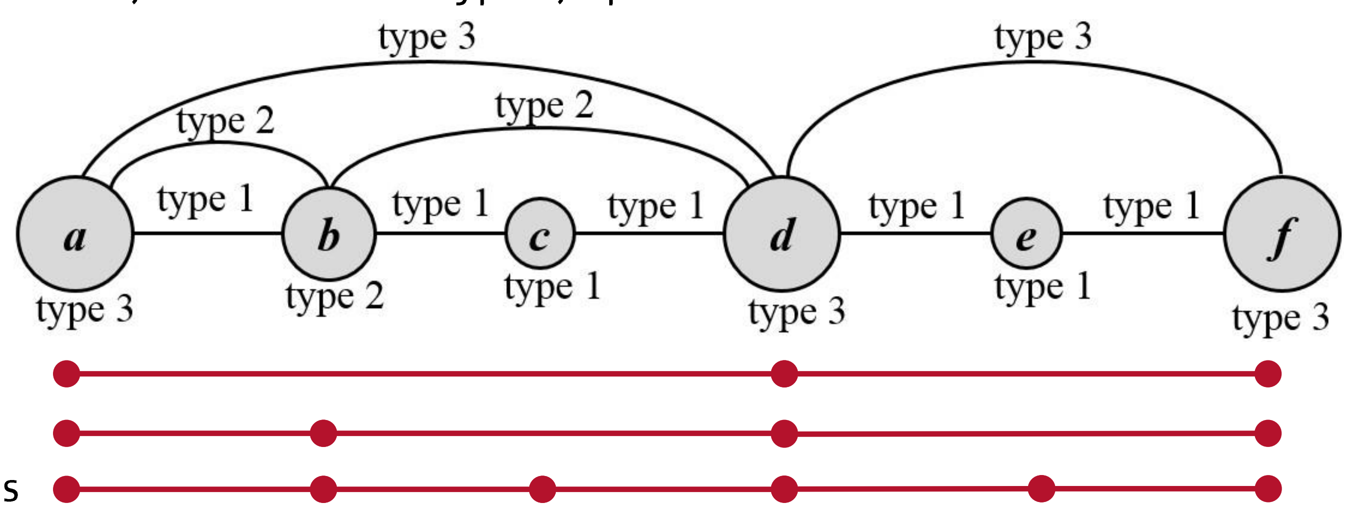
Goossens, van Hoesel & Kroon 2006

→ A binary variable for each combination of:

- Line (route and stopping pattern)
- Frequency
- Rolling stock composition assigned to the line

} *seat capacity* of the line

→ Line patterns are generated on a type graph:



Fast lines

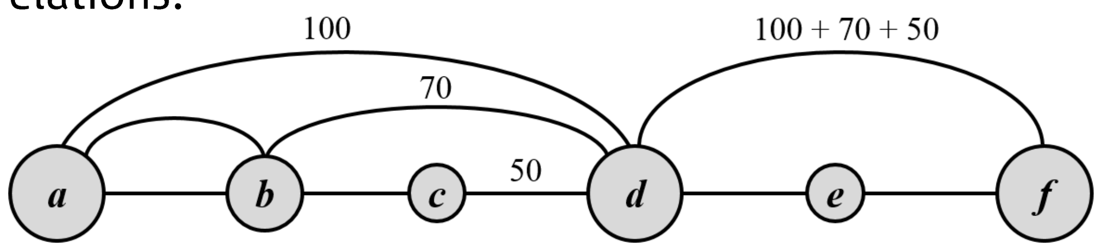
IC lines

Regional lines

Passenger demand and line seat capacity

Goossens, van Hoesel & Kroon 2006

- Given an OD-matrix of passenger relations and assuming that passenger prefer shortest driving time routes, we estimate the *preferred* traffic load on each arc of the type graph:
  - Example with 3 passenger relations:
    - Pax($a \rightarrow f$) = 100
    - Pax($b \rightarrow f$) = 70
    - Pax($c \rightarrow f$) = 50



- Not all passengers will have their preferred travelling route in the optimal line planning solution: we only ensure that the *total seat capacity* for each network segment is big enough to cover the *total traffic load* on covering arcs.
  - Example: for network segment (c, d):
    - line capacity (c, d) ≥ 50
    - line capacity (c, d), (b, d) ≥ 50+70
    - line capacity (c, d), (a, d) ≥ 50+100
    - line capacity (c, d), (b, d), (a, d) ≥ 50+70+100

The model allows different line stopping patterns in one optimization

Extra constraints

- Upper and lower bounds on the frequency on each network segment
- Upper and lower bounds on the number of stops at each station
- Upper bound on the number of carriages of each fleet type in the plan
- Upper bound on line terminations at certain end stations
- Lines with specific characteristic are not allowed to exist together in the plan

Modelling the cost function

Operational costs:

- Line driving distance and time:
  - Train km and minute cost
- Assigned rolling stock composition:
  - Carriage km and minute cost
- Minimum number of trains needed for the line within the time period:

  $$\left\lceil \frac{\text{line circulation time} \times \text{frequency}}{\text{time period length}} \right\rceil$$

  - Train unit cost

Passenger attractiveness:

- Line frequency:
  - High frequency is more attractive
- Assigned rolling stock composition:
  - More seats are more attractive
- Passenger demand along the route:
  - Lines with higher traffic load along route are more preferable

Conflicting objectives with weights in objective function

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Scenario analysis or multi-criteria optimization

Strengths and weeknesses of the model

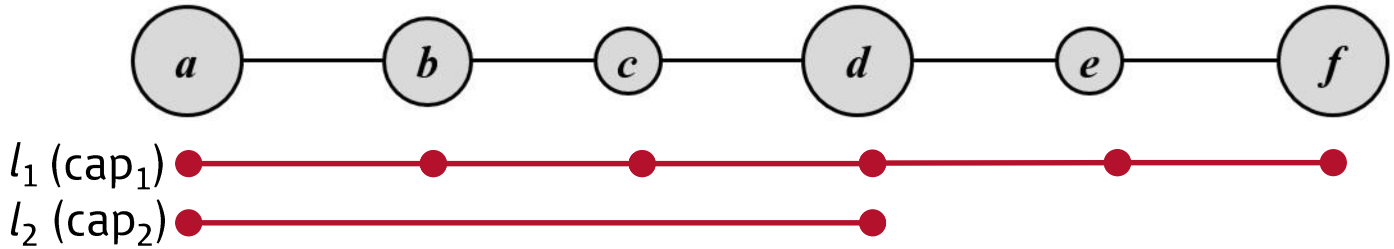
Strengths:

- Easy to model all operational *costs* on decision variables
- Easy to add extra *operational* and *contractual* constraints to the model
- Possible to express some of the *passenger-attractiveness* parameters on decision variables
- Good model *formulation* – solvable to optimality for realistic problem instances

Weeknesses:

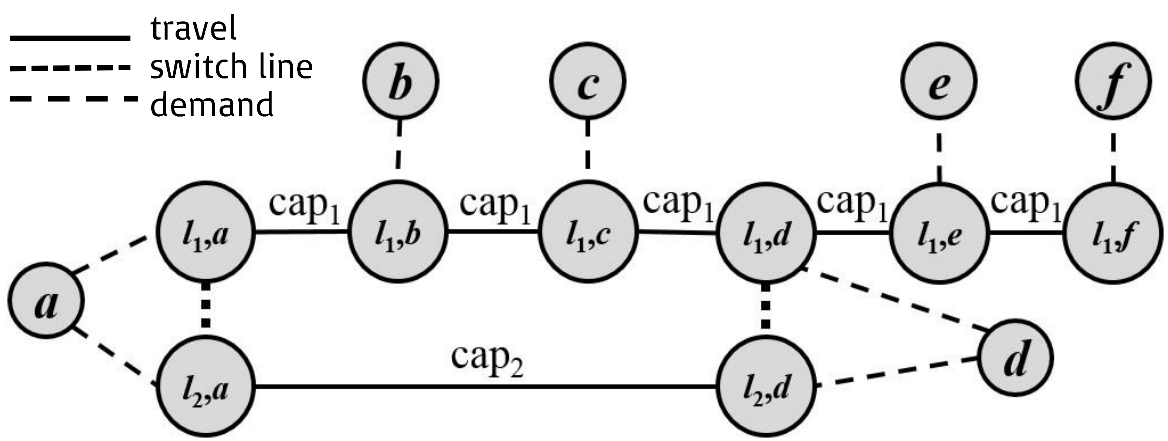
- Requires *a priori* line pool generation
- Rolling stock composition assignment assumed unchanged during the whole round-trip of a line, causing *over-estimation* of rolling stock
- Not possible to minimize passenger travel time *including* line switches

Evaluating passenger perspective



Optimal line planning solution

Change-and-go graph (*Schöbel & Scholl 2005*)



Capacitated multi-commodity network flow problem

Case study in October 2014: DSB S-tog, line planning S16

DSB

DSB S-tog network: fast and slow lines

Challenges for line planning on S-bane 2016

- Signalling Programme: S-bane to be equipped with CBTC signalling system.
- Phase 2 north of Svanemøllen and Ryparken stations: estimated finish beginning of 2016.
- The challenge:
  - Not all train drivers were planned to be licensed for CBTC at the beginning of 2016.
  - Only licensed drivers are allowed to drive under both signalling systems
  - Wish to have as few driver duties with driving on both signalling systems!

First line planning objective for S16

- Problem: Not all train drivers are planned to be licensed for CBTC.
- Objective: Minimize train minutes of lines running across two signalling systems.

DSB S-tog S14

Trains across: 55
Train minutes across: 7.132

First objective S16

Trains across: 44
Train minutes across: 4.755

Second line planning objective for S16

- New information: All drivers at Hillerød and Køge depots will be licensed. Therefore the two segments are to be covered by the same lines.
- Objective: minimize train minutes of lines connecting unwanted segments.

DSB S-tog S14

Trains on unwanted lines: 43
Train minutes on unwanted lines : 5.936

Second objective S16

Trains on unwanted lines: 5
Train minutes on unwanted lines : 500

Third (and final!) line planning objective for S16

- New wish: S16 is to be similar to S15, at the same time respecting the above!
- Objective: minimize train minutes of lines that: 1) do not exist in S15 and 2) connect unwanted segments.

DSB S-tog S15

Trains on unwanted lines: 14
Train minutes on unwanted lines : 1.892
Train minutes as in S15: 100%

Third objective S16

Trains on unwanted lines: 5
Train minutes on unwanted lines : 500
Train minutes as in S15: 83%

S16 story – update July 2015

- Signalling Programme is delayed
- All drivers will be licensed when Phase 2 is implemented
- DSB S-tog continues with S15 line plan until the next big challenge occurs

The lessons learned

- The implemented line planning optimization tool is useful for strategic planning:
  - Flexible objective function
  - Evaluating manual solutions
- We are interested in more passenger perspective optimization:
  - PhD project at DTU Management (Simon Bull)
- We are interested in a more sophisticated automatic line pool generation
- Adressing the over-estimation of the rolling stock capacity
- All aspects of planning are inter-connected:
  - Investigate integrated approaches!

Thank you