Improving Passenger-Oriented Line Planning Algorithm for High Frequent Railway Networks

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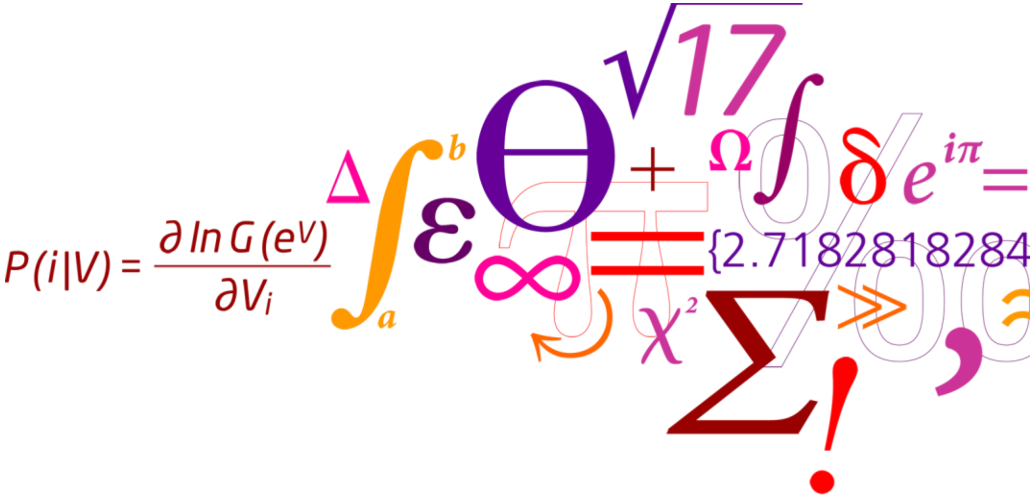

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Outline

- Introduction & motivation
- Methodology
- Results
- Conclusions

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Introduction

- Line planning at the tactical planning level

- Explicit passenger focus

- Formulated as a bi-level optimisation problem
  - Upper level: Determining railway line configuration
  - Lower level: Deriving passengers’ adapted route choice

Motivation

- Line plan configurations have a large impact on passengers' generalised travel cost.

- Urban sprawl (United Nations, 2014)
  - 2014: 54 percent in urban areas
  - 2050: 66 percent living in urban areas

- O/D demand will change – maybe disproportional

- Yearly timetable updates accompanied by yearly line plan updates

Objectives and contribution

- Objective
  - Optimise line plan configuration to minimise passengers’ travel cost.
  - Travel cost includes the number of transfers, the boarding waiting time and the transfer waiting time.

- Contribution
  - Explicit and detailed consideration of passengers’ route choice.
  - Line planning model applicable at the tactical planning level.
  - Maintains the timetable structure.
  - O/D-travel demand, mode choice and departure time choice is assumed unchanged, when changing the line plan configuration.

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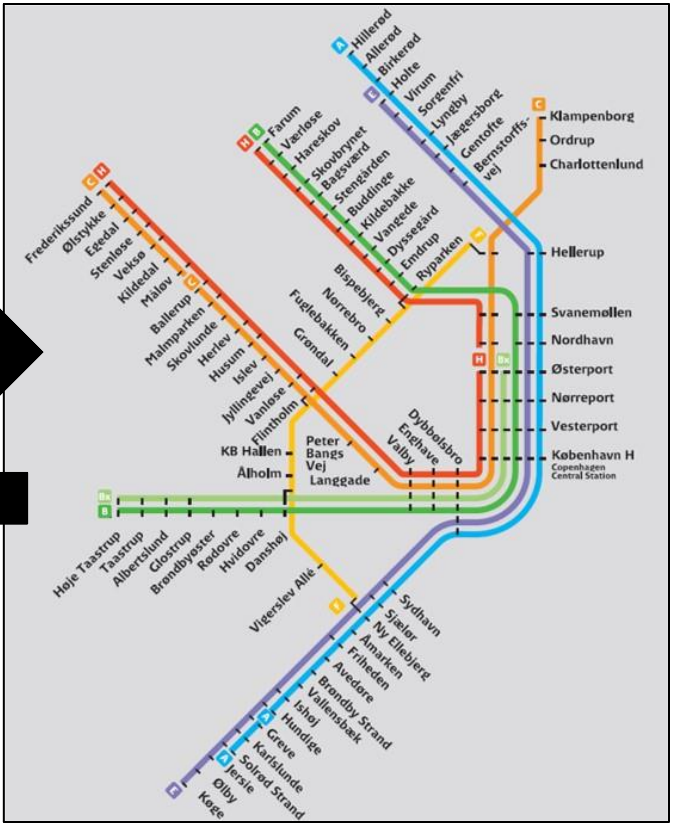
Line plan Optimisation

- Bi-level optimisation

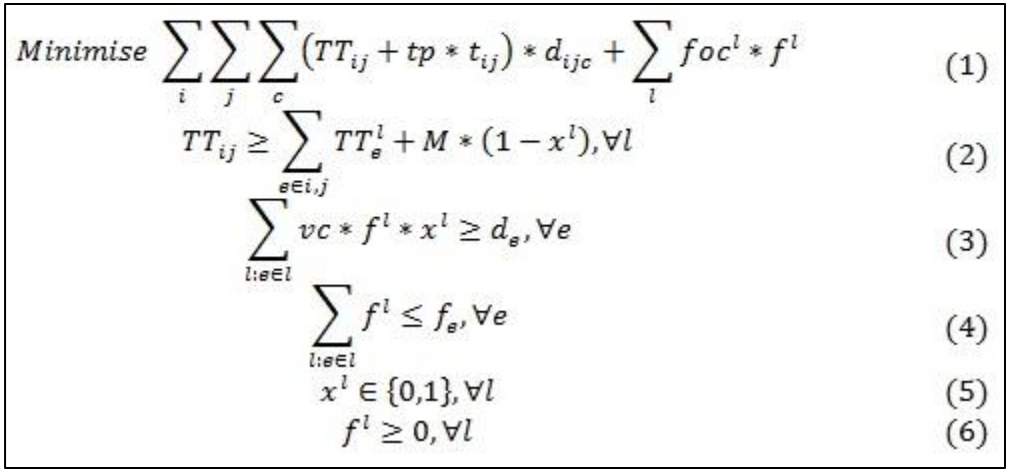
Passengers’ travel behaviour



Railway line plans

Mathematical Model (Upper level)

- Deriving the optimal line plan configuration.



$$\text{Minimise} \sum_{i}\sum_{j}\sum_{c}\left(TT_{ij} + tp * t_{ij}\right) * d_{ijc} + \sum_{l} foc^{l} * f^{l} \qquad (1)$$

$$TT_{ij} \geq \sum_{e \in i,j} TT_{e}^{l} + M * (1 - x^{l}), \forall l \qquad (2)$$

$$\sum_{l : e \in l} vc * f^{l} * x^{l} \geq d_{e}, \forall e \qquad (3)$$

$$\sum_{l : e \in l} f^{l} \leq f_{e}, \forall e \qquad (4)$$

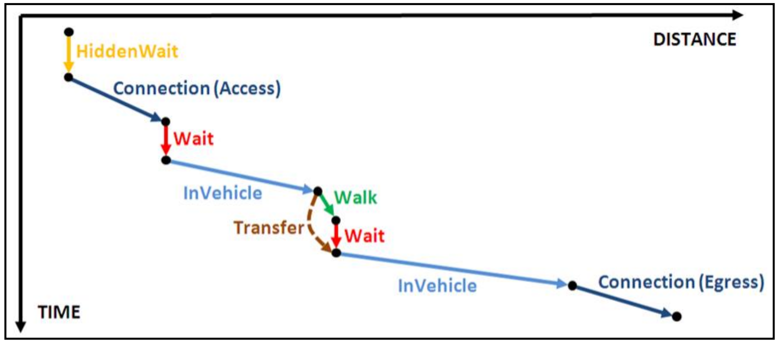
$$x^{l} \in \{0,1\}, \forall l \qquad (5)$$

$$f^{l} \geq 0, \forall l \qquad (6)$$

- (1) Minimise passengers' travel time and the frequency operating cost.
- (2) Setting travel time.
- (3) Accomodating demand on edges.
- (4) Limiting frequency on track segments (safety headway).
- (5) & (6) Domain setting (x_l: lines operated, f_l: frequency of line l).

Public assignment model (Lower level)

- Deriving passengers’ travel behaviour.



- Utility-based approach.

$$C_{ijc} = \beta_c * WaitingTime_{ij} + \beta_c * WaitInZoneTime_{ij} + \beta_c * WalkTime_{ij} + \beta_c * ConnectorTime_{ij} + \beta_c * NumberOfChanges_{ij} + \beta_c * TotalInVehicleTime_{ij}.$$

	WalkTime	*Waiting Time*	*Connector Time*	*WaitInZone Time*	*Change Penalty*	*Train InVehicleTime*
Commuter	0.633	0.633	0.75	0.28	8.8	0.45
Business	4.50	4.50	4.50	1.217	64	3.783
Leisure	0.467	0.467	0.33	0.117	4	0.15

Heuristic solution algorithm

- Passenger-oriented line planning problem is NP-hard (Schmidt & Schöbel, 2010).

- ***Stepwise approach of the bi-level Line planning problem***

    1. Run public assignment. (explained on previous slide)
    2. Calculate optimisation potential for change in line plan configuration.
    3. Based on (2), run tabu search algorithm and impose changes to line plan configuration.
    4. If stopping criterion is met, terminate.
    5. Otherwise, go to (1).

Optimisation potential

- Passenger-oriented optimisation potential includes:
  - #Transfers

$$\sum_{c} t_{ij} * d_{ijc} * \beta_{transfer,c}, \forall i\,, j$$

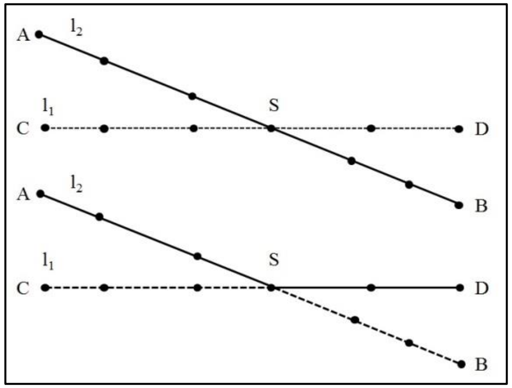
  - Boarding waiting time (availability/frequency)

$$\sum_{l:s\in l}\sum_{p}\sum_{s}\sum_{c}\left(\rho_{ij}^{p} * d_{ijc}\right) * (\delta_{p}^{s} * \tfrac{1}{2} * h_{l,s}) * \beta_{wait,c}, \forall i, j$$

  - Transfer waiting time

$$\sum_{l}\sum_{c} \tfrac{1}{2} * (h_{l(direct),bs} * y_{ij} + h_{l,bs} * (1 - y_{ij})) * d_{ijc}, \forall i = bs, j$$

Swap



Tabu Search algorithm

- Based on optimisation potential, select which lines to swap.
- Every line can only be swapped once.
- Tabu search algorithm applied to select which swaps to impose.

- Construction of initial solution
  - Select swaps [l_1,l_2,*s*] greedily based on their optimisation potential.
  - Derive the solution value *Solval* of the list of swaps to be imposed *Sol.*

- Improving heuristic (iterate over the following steps)
  - For each swap [l_1,l_2,*s*] in *Sol*, try swapping l_1 and l_2 with two different lines passing stop *s*.
  - Assess the impact on *SolVal*.
  - If the proposed swaps are imposed, label the opposite swaps as tabu (not allowed in *Sol*) for a predetermined number of iterations.
  - When #IterationMax is reached, terminate process and return *Sol*.

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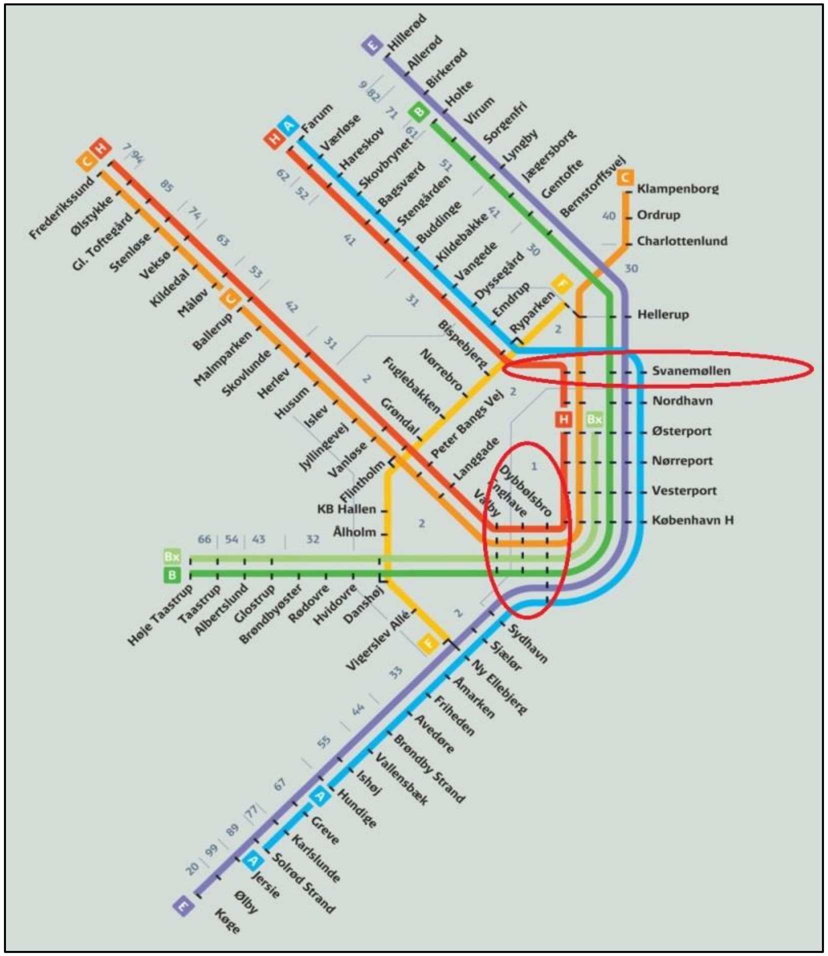
Test network – large scale application

- Suburban Railway network (Copenhagen, Denmark)
  - Morning peak hours (7am – 9am)
  - 61 different line variants
  - Line F (yellow) disregarded
  - Two ”swap stations”

- Route choice derived for entire transit network



Results

- Passengers are better of compared to the existing situation.

Benchmark							
Trains only			**Entire transit system**				
Trip type	*Changes*	*Waiting time*	*Changes*	*FirstWait*	*Waiting time*	*IVT*	*GenCost*
Commuters	12,229.3	34,557.7	75,589.5	10,038.6	183,175.2	3,438,482.6	3,368,389.2
Business	334.1	916.0	2369.9	1.4	5,512.8	102,650.0	756,221.3
Leisure	1,304.5	2,823.9	12,217.4	559.7	28,477.7	585,793.6	227,325.5
Total	13,867.8	38,297.5	90,176.8	10,599.8	217,165.6	4,126,926.2	4,351,936.0
Iteration Final							
Commuters	11,729.7	33,092.6	74,970.2	9,465.5	178,166.4	3,439,621.0	3,355,579.0
Business	322.5	872.6	2353.7	0.8	5,379.6	102,542.1	753,825.1
Leisure	1,285.1	2,845.5	12,200.8	508.9	28,222.3	586,228.1	227,466.5
Total	13,337.3	36,810.7	89,524.7	9,975.2	211,768.3	4,128,391.1	4,336,870.6
Percentage change							
Commuters	-4.09	-4.24	-0.82	-5.71	-2.73	0.03	-0.38
Business	-3.46	-4.73	-0.68	-43.20	-2.42	-0.11	-0.32
Leisure	-1.49	0.77	-0.14	-9.09	-0.90	0.07	0.06
Total	-3.83	-3.88	-0.72	-5.89	-2.49	0.04	-0.35

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Summary

- Optimisation tool developed, which has its strength both in the optimisation of the line plan configuration and in the accuracy of the results since passengers' adapted travel behaviour is considered explicitly.

- Line planning problem solved as a bi-level optimisation problem taking passengers' travel behaviour explicitly into account.

- Applicable to large-scale networks.

- Reduction equal to 3.83 % in railway passengers' number of changes and 3.88 % in transfer waiting time obtained compared to the values for the existing network.

- Transit passengers were on average slightly better off after the optimisation.

Questions

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