

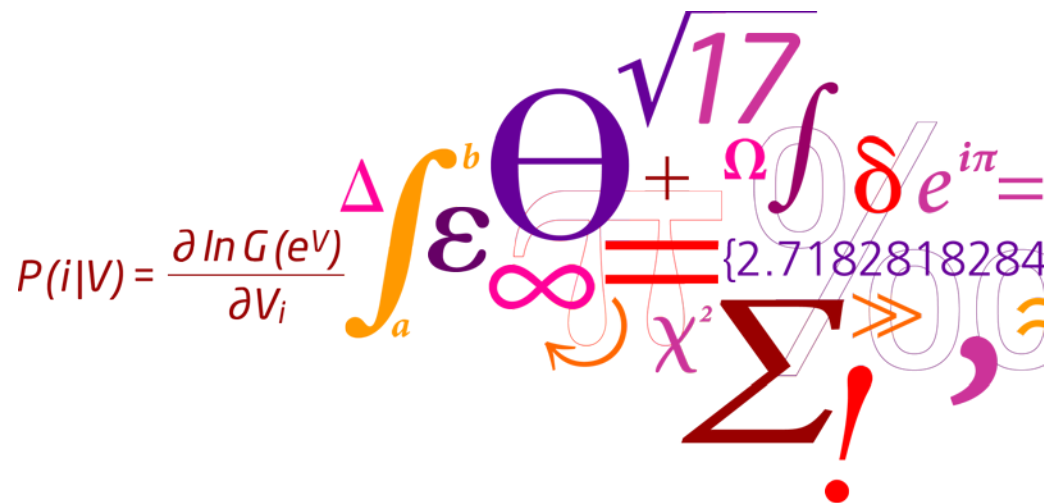
Improving Passenger-Oriented Line Planning Algorithm for High Frequent Railway Networks

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$$P(i|V) = \frac{\partial \ln G(e^V)}{\partial V_i}$$

$$\int_a^b \varepsilon \Theta + \Omega \int \delta e^{i\pi} = \{2.7182818284\}$$

$$\chi^2 \sum !$$

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 (zone-to-zone level) – 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.

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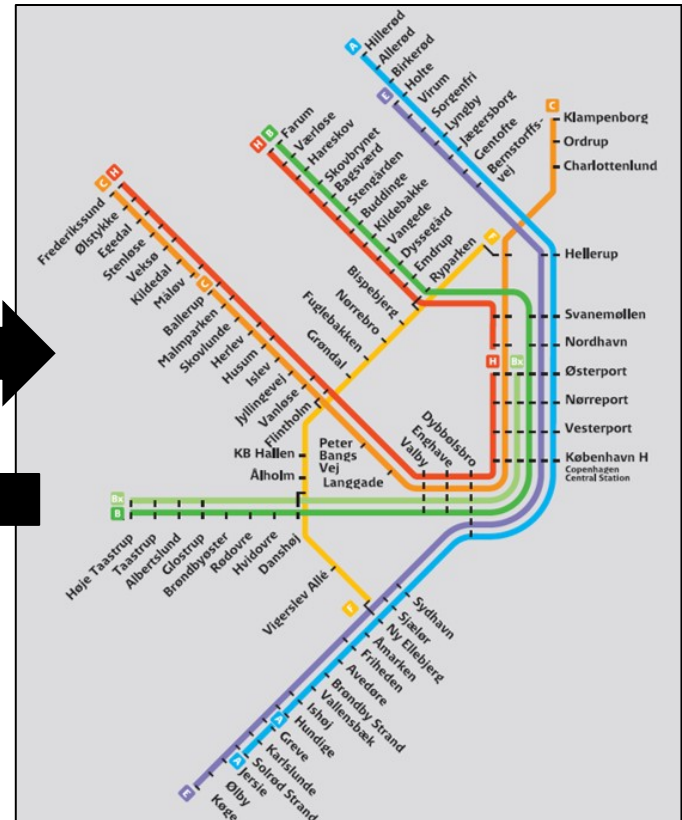
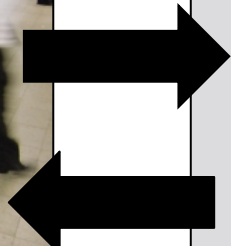
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Line plan Optimisation

- Bi-level optimisation



Passengers' travel behaviour



Railway line plans

Mathematical Model (Upper level)

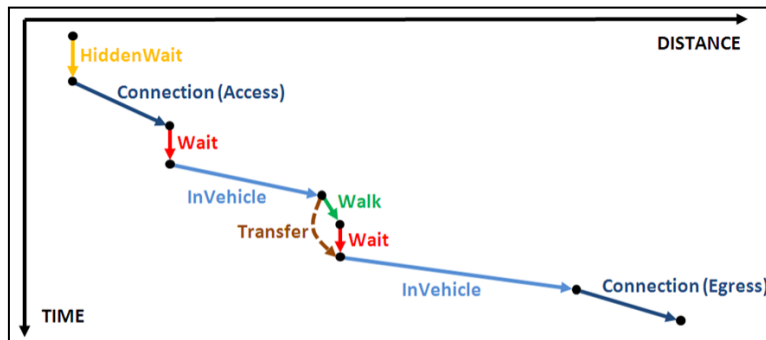
- Deriving the optimal line plan configuration.

$$\begin{aligned} \text{Minimise } & \sum_i \sum_j \sum_c (TT_{ij} + tp * t_{ij}) * d_{ijc} + \sum_l f_{oc}^l * f^l & (1) \\ TT_{ij} & \geq \sum_{e \in E_{i,j}} TT_e^l + M * (1 - x^l), \forall l & (2) \\ \sum_{l: e \in l} & vc * f^l * x^l \geq d_e, \forall e & (3) \\ \sum_{l: e \in l} & f^l \leq f_e, \forall e & (4) \\ x^l & \in \{0,1\}, \forall l & (5) \\ f^l & \geq 0, \forall l & (6) \end{aligned}$$

- (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.

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

	<i>WalkTime</i>	<i>Waiting Time</i>	<i>Connector Time</i>	<i>WaitInZone Time</i>	<i>Change Penalty</i>	<i>Train InVehicleTime</i>
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

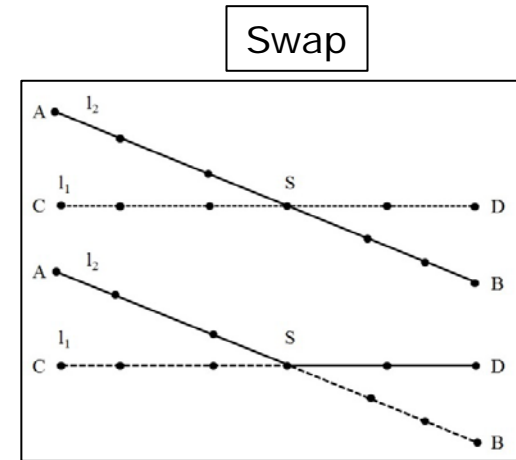
$$\sum_c t_{ij} * d_{ijc} * \beta_{transfer,c}, \forall i, j$$

– Boarding waiting time (availability/frequency)

$$\sum_{l:s \in l} \sum_p \sum_s \sum_c (\rho_{ij}^p * d_{ijc}) * (\delta_p^s * \frac{1}{2} * h_{l,s}) * \beta_{wait,c}, \forall i, j$$

– Transfer waiting time

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



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 off compared to the existing situation.

Benchmark							
Trains only			Entire transit system				
Trip type	Changes	Waiting time	Changes	FirstWait	Waiting time	IVT	GenCost
<i>Commuters</i>	12,229.3	34,557.7	75,589.5	10,038.6	183,175.2	3,438,482.6	3,368,389.2
<i>Business</i>	334.1	916.0	2369.9	1.4	5,512.8	102,650.0	756,221.3
<i>Leisure</i>	1,304.5	2,823.9	12,217.4	559.7	28,477.7	585,793.6	227,325.5
<i>Total</i>	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							
<i>Commuters</i>	11,729.7	33,092.6	74,970.2	9,465.5	178,166.4	3,439,621.0	3,355,579.0
<i>Business</i>	322.5	872.6	2353.7	0.8	5,379.6	102,542.1	753,825.1
<i>Leisure</i>	1,285.1	2,845.5	12,200.8	508.9	28,222.3	586,228.1	227,466.5
<i>Total</i>	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							
<i>Commuters</i>	-4.09	-4.24	-0.82	-5.71	-2.73	0.03	-0.38
<i>Business</i>	-3.46	-4.73	-0.68	-43.20	-2.42	-0.11	-0.32
<i>Leisure</i>	-1.49	0.77	-0.14	-9.09	-0.90	0.07	0.06
<i>Total</i>	-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



References

- Borndörfer, R., Grötschel, M., & Pfetsch, M. E. (2007). A column-generation approach to line planning in public transport. *Transportation Science*, 41(1), 123-132
- Bussieck, M. R., Lindner, T., & Lübbecke, M. E. (2004). A fast algorithm for near cost optimal line plans. *Mathematical Methods of Operations Research*, 59 (2), 205-220.
- Cancela, H., Mauttone, A., & Urquhart, M. E. (2015). Mathematical programming formulations for transit network design. *Transportation Research Part B: Methodological*, 77, 17-37.
- Ceder, A. (2007). *Public transit planning and operation: theory, modeling and practice*. Elsevier, Butterworth-Heinemann.
- Fu, H., Nie, L., Meng, L., Sperry, B. R., & He, Z. (2015). A hierarchical line planning approach for a large-scale high speed rail network: The China case. *Transportation Research Part A: Policy and Practice*, 75, 61-83.
- Goossens, J. W., Van Hoesel, S., & Kroon, L. (2004). A branch-and-cut approach for solving railway line-planning problems. *Transportation Science*, 38(3), 379-393.
- Goosens, J. W., van Hoesel, S., & Kroon, L. (2006). On solving multi-type railway line planning problems. *European Journal of Operational Research*, 168(2), 403-424.
- Guihaire, V., & Hao, J. K. (2008). Transit network design and scheduling: A global review. *Transportation Research Part A: Policy and Practice*, 42(10), 1251-1273.
- Kepaptsoglou, K., & Karlaftis, M. (2009). Transit route network design problem: review. *Journal of transportation engineering*, 135(8), 491-505.
- Lee, Y. J., & Vuchic, V. R. (2005). Transit network design with variable demand. *Journal of Transportation Engineering*, 131(1), 1-10.
- Meng, L. and Zhou, X. (2011). Robust single-track train dispatching model under a dynamic and stochastic environment: a scenario-based rolling horizon solution approach. *Transportation Research Part B: Methodological*, 45 (7), 1080–1102.
- Nachtigall, K., & Jeros, K. (2008). Simultaneous network line planning and traffic assignment. In *OASICs-Open Access Series in Informatics (Vol. 9)*. Schloss Dagstuhl-Leibniz-Zentrum für Informatik.
- Szeto, W. Y., & Jiang, Y. (2014) Transit route and frequency design: Bi-level modeling and hybrid artificial bee colony algorithm approach. *Transportation Research Part B: Methodological*, 67, 235-263.
- Schmidt, M., & Schöbel, A. (2010). The Complexity of Integrating Routing Decisions in Public Transportation Models. In *Proceedings OASICs*, 2757.
- Schöbel, A., & Scholl, S. (2005). Line planning with minimal transfers. In *5th Workshop on Algorithmic methods and Models for Optimization of Railways (No. 06901)*.
- Schöbel, A. (2012). Line planning in public transportation: models and methods. *OR spectrum*, 34(3), 491-510.
- United Nations. Department of Economic and Social Affairs. Population Division. (2014). *World urbanization prospects: The 2014 revision*. UN.
- Wan, Q. K., & Lo, H. K. (2003). A mixed integer formulation for multiple-route transit network design. *Journal of Mathematical Modelling and Algorithms*, 2(4), 299-308.
- Wang, L., Jia, L. M., Qin, Y., Xu, J., & Mo, W. T. (2011). A two-layer optimization model for high-speed railway line planning. *Journal of Zhejiang University SCIENCE A*, 12(12), 902-912.
- Zhao, F., Ubaka, L. & Gan, A. (2005). Transit network optimization: minimizing transfers and maximizing service coverage with an integrated simulated annealing and tabu search method. *Transportation Research Record: Journal of the Transportation Research Board*, 1923(1), 180-188.
- Zhao, F. & Zeng, X. (2008). Optimization of transit route network, vehicle headways and timetables for large-scale transit networks. *European Journal of Operational Research*, 186(2), 841-855.