Adapting stopping patterns to improve robustness from the users' perspective

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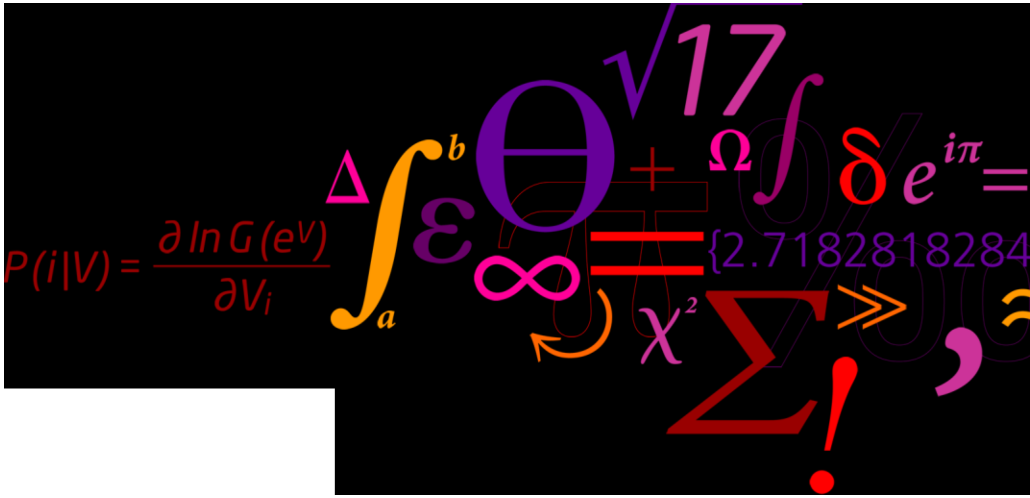

Outline

- Introduction & motivation
- Skip-stop optimisation
- Results
- Summary

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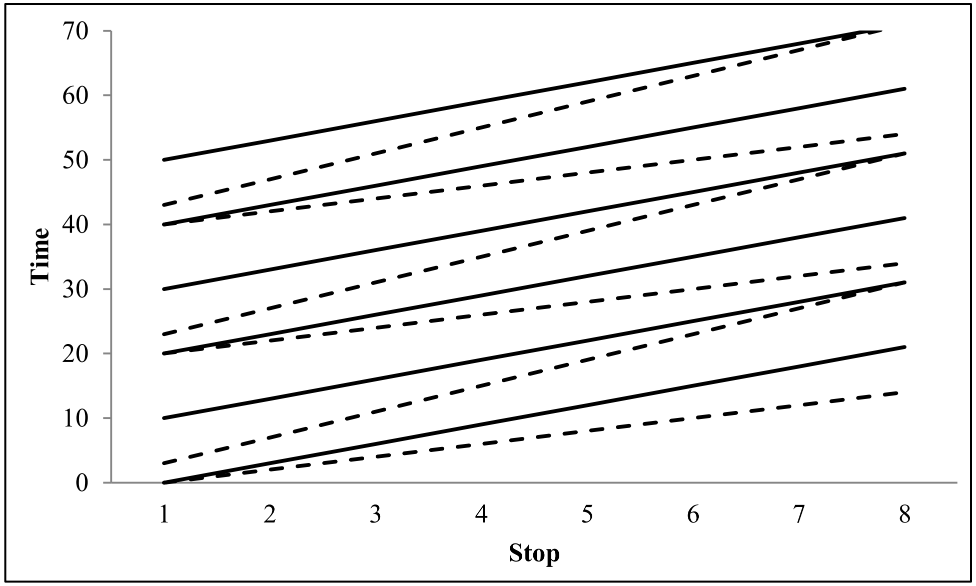
Introduction & Motivation

- Stopping patterns of railway lines have a large impact on travel time, but also on system-wide delays
- Applying skip-stop optimisation intelligently enables:
  - The benefits of skip-stop services (reduced travel time)
  - Reduced heterogeneity (i.e. operation less vulnerable to delays)
- Homogeneous (solid lines) vs. heterogeneous (dashed lines) operation



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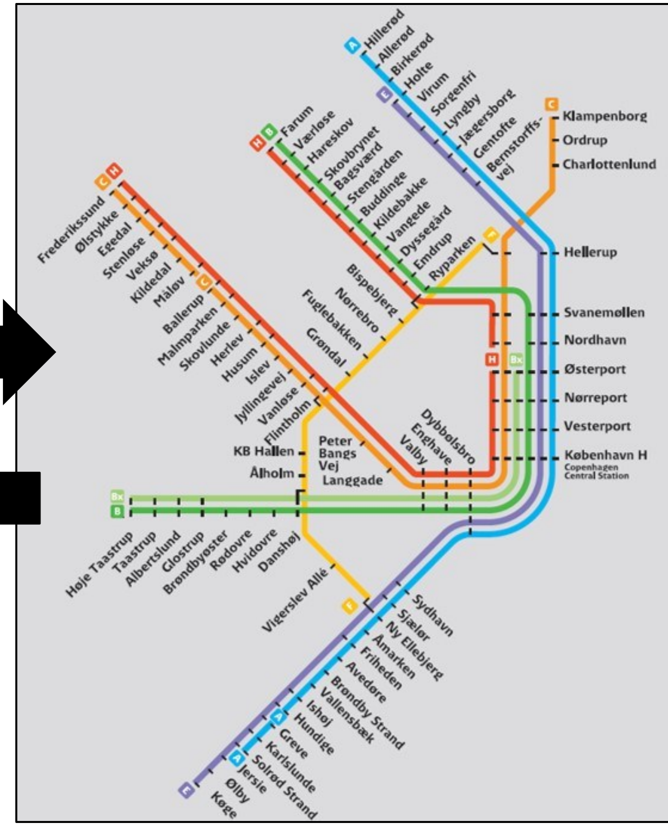
Skip-stop Optimisation

- Bi-level optimisation

Passengers' travel behaviour



Railway lines' stopping patterns

Mathematical Model (Upper level)

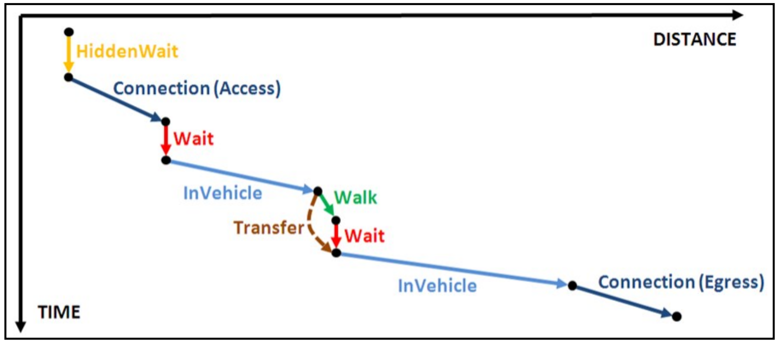
- Finding optimal stopping patterns.

Minimise
$$\sum_i \sum_j \sum_c TT_{ij} * d_{ijc} + \sum_s \sum_k \frac{1}{H_{s,k,k+1}}.$$

Subject to
$$H_{s,k,k+1} = ((b^{k+1,p} + t_s^{k+1,p}) - (b^{k,p} + t_s^{k,p})) * x^p, \forall k, p, s.$$
$$H_{s,k,k+1} \geq H, \forall s, k, k.$$
$$TT_{ij}^p = q_{ij}^p + M_1 * (1 - a_{ij}^p * x^p), \forall p, i, j.$$
$$TT_{ij} \geq TT_{ij}^p - M_2 * (1 - y_{ij}^p), \forall p, i, j.$$
$$\sum_p y_{ij}^p = 1, \forall i, j.$$
$$\sum_p x^p \leq TL.$$
$$y_{ij}^p \leq x^p, \forall p, i, j.$$
$$y_{ij}^p \in \{0,1\}, \forall p, i, j.$$
$$x^p \in \{0,1\}, \forall p.$$
$$t_s^{k,p} \geq 0, \forall k, p, s.$$
$$b^{k,p} \geq 0, \forall k, p.$$
$$TT_{ij} \geq 0, \forall i, j.$$
$$TT_{ij}^p \geq 0, \forall p, i, j.$$

Public assignment model (Lower level)

- Deriving passengers' travel behaviour.



- Utility-based approach.

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

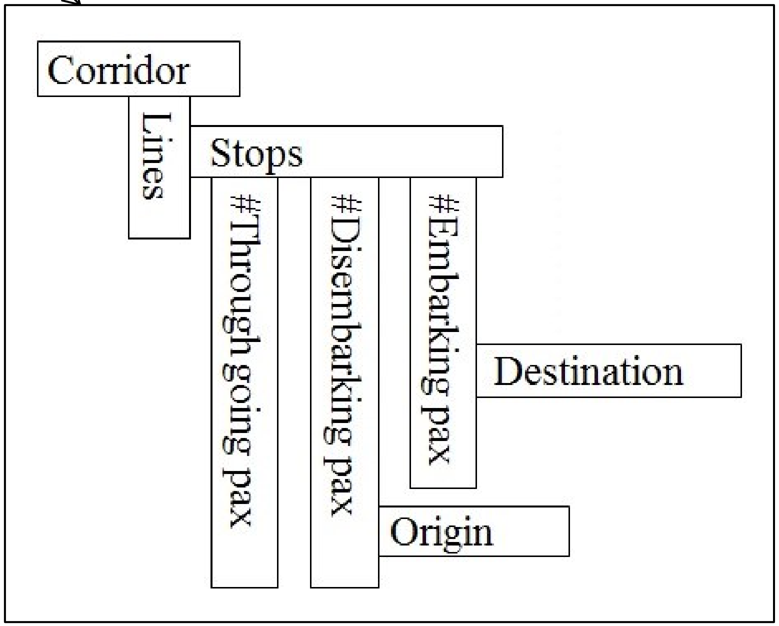
	WalkTime	*Waiting Time*	*Connector Time*	*WaitInZone Time*	*Change Penalty*	*Train InVehicleTime*
Commuter	0.633	0.633	0.75	0.28	8.8	0.45
Business	4.50	4.50	4.50	1.217	64	3.783
Leisure	0.467	0.467	0.33	0.117	4	0.15

Heuristic solution algorithm - Framework

1. Run public assignment.
2. Calculate optimisation potential for each skip-stop.
3. Calculate elaborate optimisation potential for the most promising skip-stops (2)
4. Impose skip-stops.
5. Prohibit skipping stops in the sub network for imposed skip-stops

Inner loop

6. If stopping criterion met, stop.
7. Otherwise, go to (1).



Heuristic solution algorithm – Elaborate optimisation potential

- When skipping a stop on a line, trips to/from the considered station within the corridor are separated in 3 types.

- Benefit: reduced in-vehicle time (2 min.)

- Trip 1 costs (Waiting time)

$$\frac{1}{2} * (new\_headway_{ijk} - headway_{ijk}) * (VoT_c * Passengers_{ijkc}), \forall i, j, k, c.$$

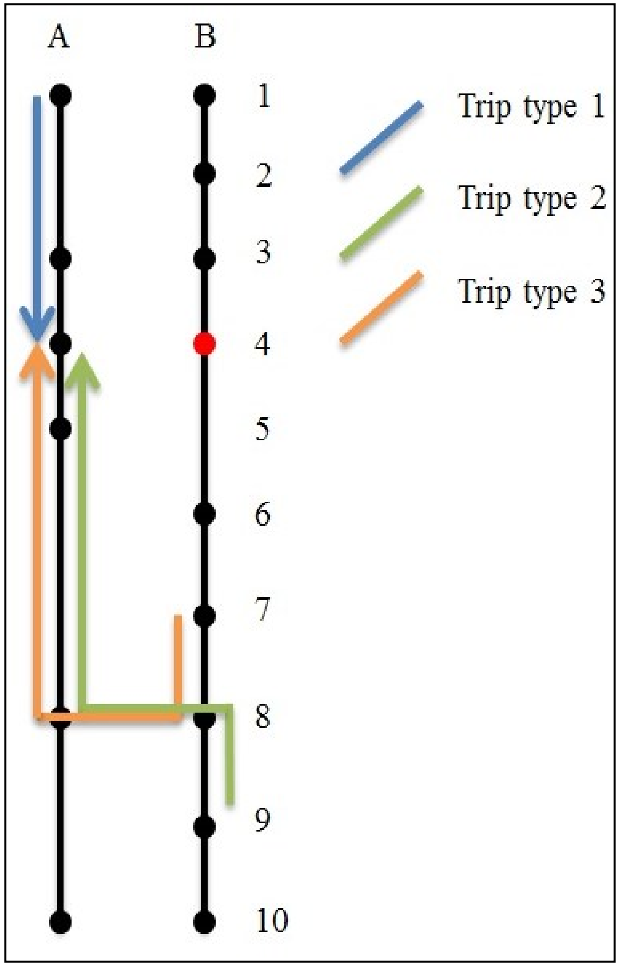
- Trip 2 costs (Waiting time + Transfer time)

$$(\frac{1}{2} * headway_{ijk} + headway_{jlk} + transferpenalty) * (VoT_c * Passengers_{ijkc}), \forall i, j, k, c.$$

- Type 3 trips are PROHIBITED!

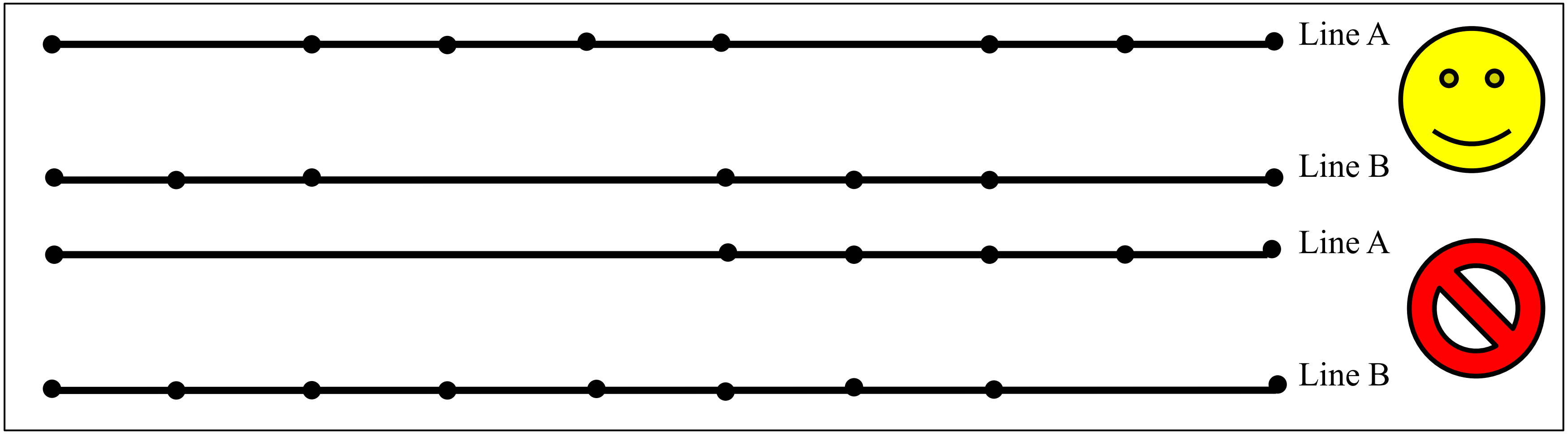
- Trips from outside the corridor (Waiting time)

$$\frac{1}{2} * (new\_headway_{jlk} - headway_{ijk}) * (VoT_c * Passengers_{ijkc}), \forall i, j, k, c.$$



Heuristic solution algorithm - Tackling overtaking and heterogeneity

- Limitation on the number of skipped stops between parallel lines when considering the stops sequentially.



- Conflicts between railway lines from different corridors can be handled by adapting depature times or adding buffer time.
- Reduced capacity utilisation as a result of more homogeneous operations.

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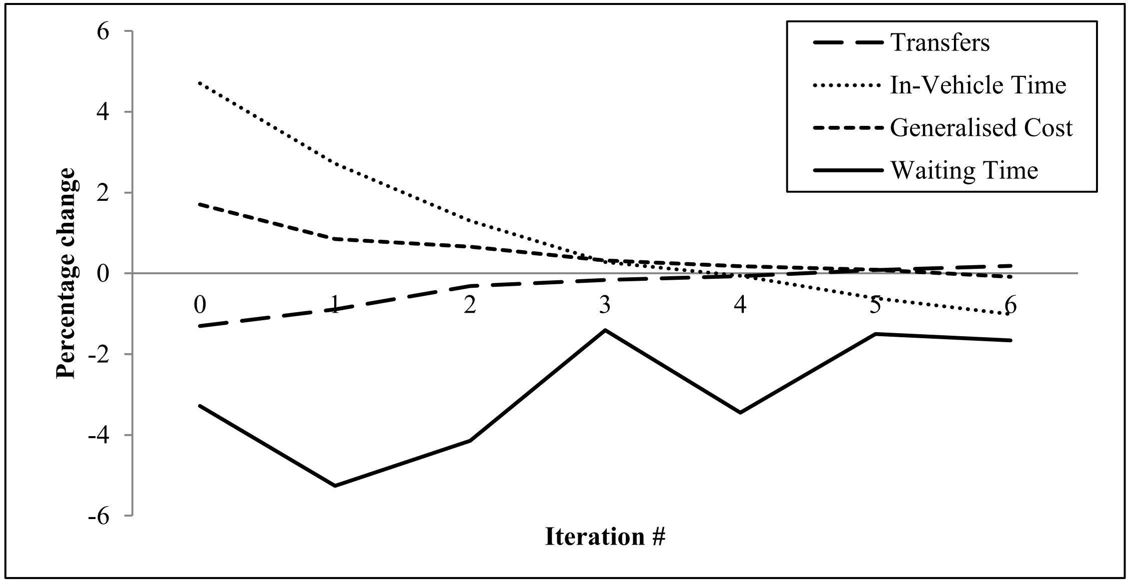
Results - Passengers’ travel cost

- Passengers are marginally better of compaired to the existing situation.

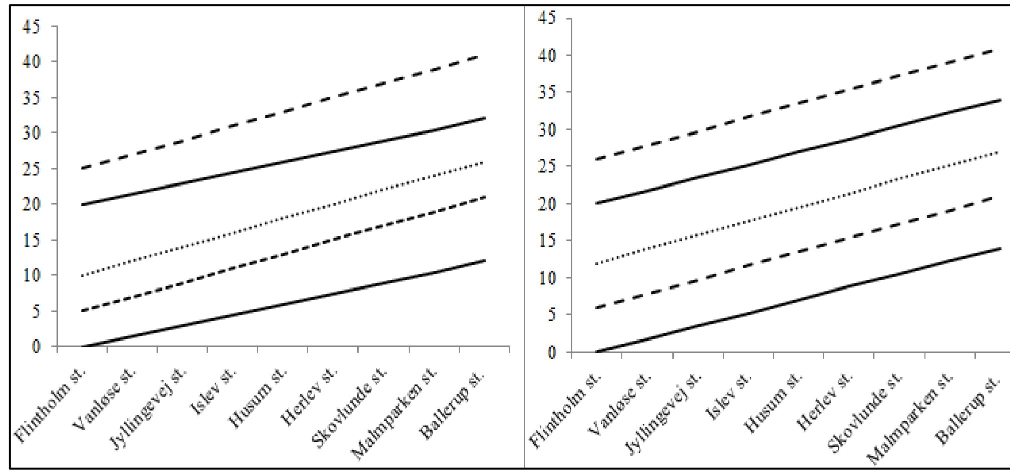


- The small reduction in Generalised travel cost is misleading

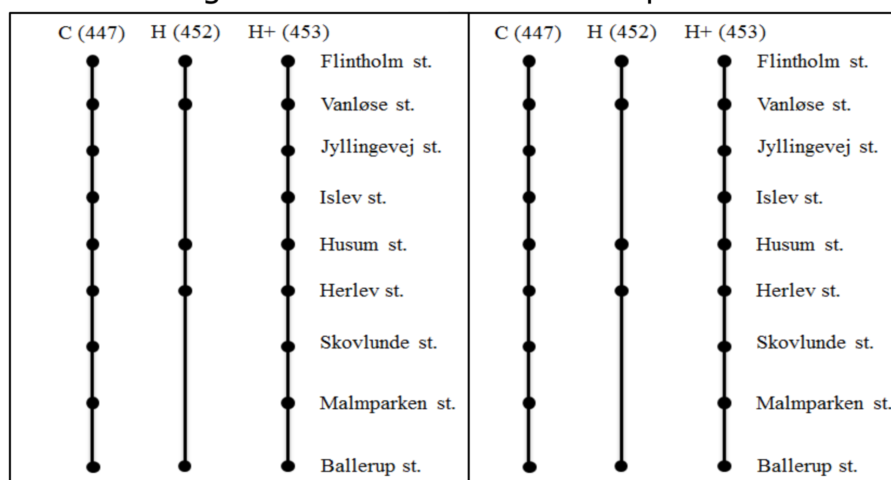
	Percentage change (Final solution)			
	Changes	In-Vehicle Time	Generalised Cost	Waiting Time
Relative to existing stoppping pattern	-0,18	1,01	0,09	1,66
Relative To All-stop Base	-1,51	5,46	1,76	-1,67

Results - Heterogeneity of railway operations

- Existing vs. optimised
  - Time-space diagrams
  - Line diagrams
- Optimised -> homogeneous
  - More buffer time
  - Delays are absorbed



Existing Optimised



Existing Optimised

Results - Heterogeneity (Continued)

- Number of skipped stops per line in each corridor.
  - Average
  - Standard deviation

Corridor No.	1		2		3		4		5	
Railway lines operating	4		3		3		2		4	
Stopping pattern	Exist.	Opt.	Exist.	Opt.	Exist.	Opt.	Exist.	Opt.	Exist.	Opt.
Average	4,25	4,75	1,00	1,33	1,33	1,33	2,50	1,00	2,50	2,25
Standard deviation	3,50	0,96	1,73	0,58	2,31	0,58	3,54	0,00	2,89	0,50

- *SSHR* (heterogeneity) values for each corridor.
- All-stop scenario serves as LB on SSHR.

Corridor No.	1	2	3	4	5
Existing	5	1.5	1.7	0.9	6
All-stop	2.4	1.35	1.35	0.6	2.4
Optimised	3.5 (-30%)	1.43 (-5%)	1.43 (-16%)	0.6 (-33%)	2.55 (-55%)

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

- Reduction equal to 1.01 % in in-vehicle time and 1.66 % in waiting time was obtained compared to existing network.

- Heterogeneity significantly improved in all corridors (5-55 %).

- Consequently, passengers get faster and more reliable from A to B.

Questions