How to make the most of on-board rail capacity?

Addressing the issue of uneven passenger loads

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Problem description

Crowding at stations and on-board vehicles

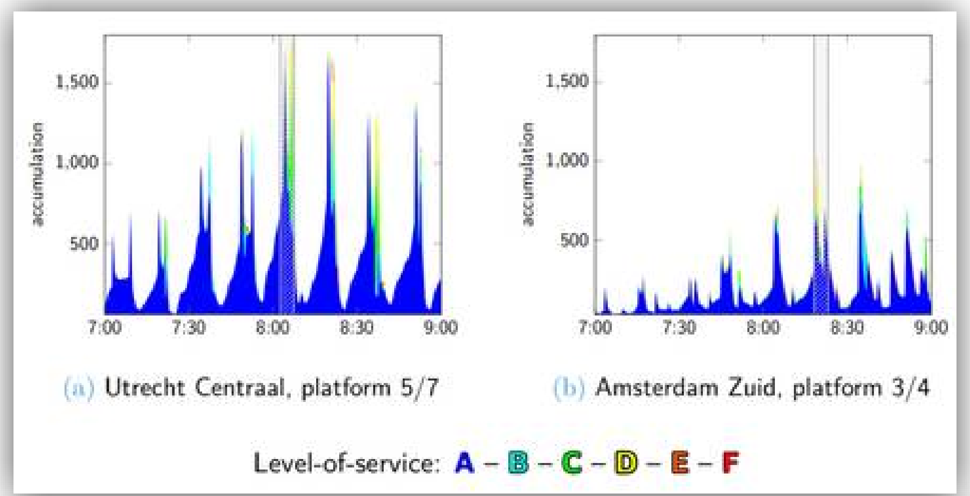
Largely a result of an uneven distribution of passengers

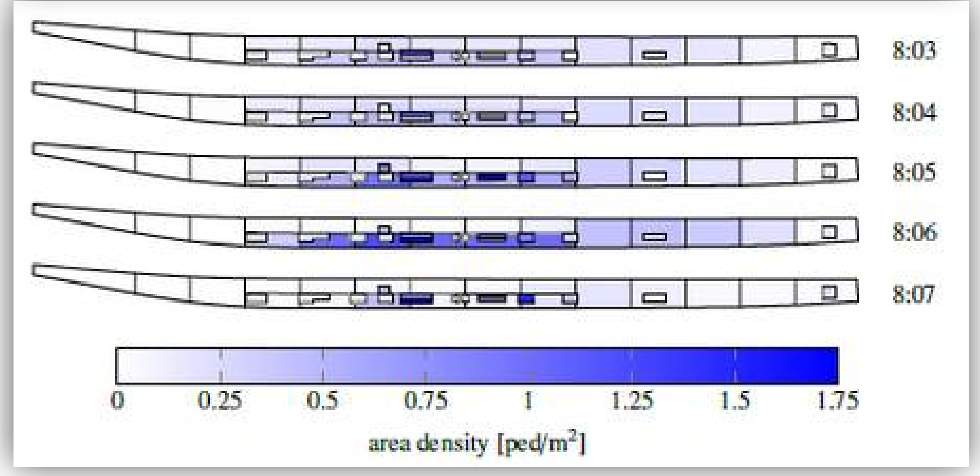
- Travel demand temporal distribution
- Travel demand spatial distribution
- Inter-vehicle arrival distribution
- Within-vehicle distribution

An inefficient utilisation of capacity, higher costs (for all parti

Example: Schiphol-Utrecht corridor

7-9 AM; 140 trains; 35-40k passengers





Research objectives

- Develop (and validate) a model to reproduce crowding distribution across individual train cars

- Assess the potential impact of provisioning crowding information concerning individual train cars

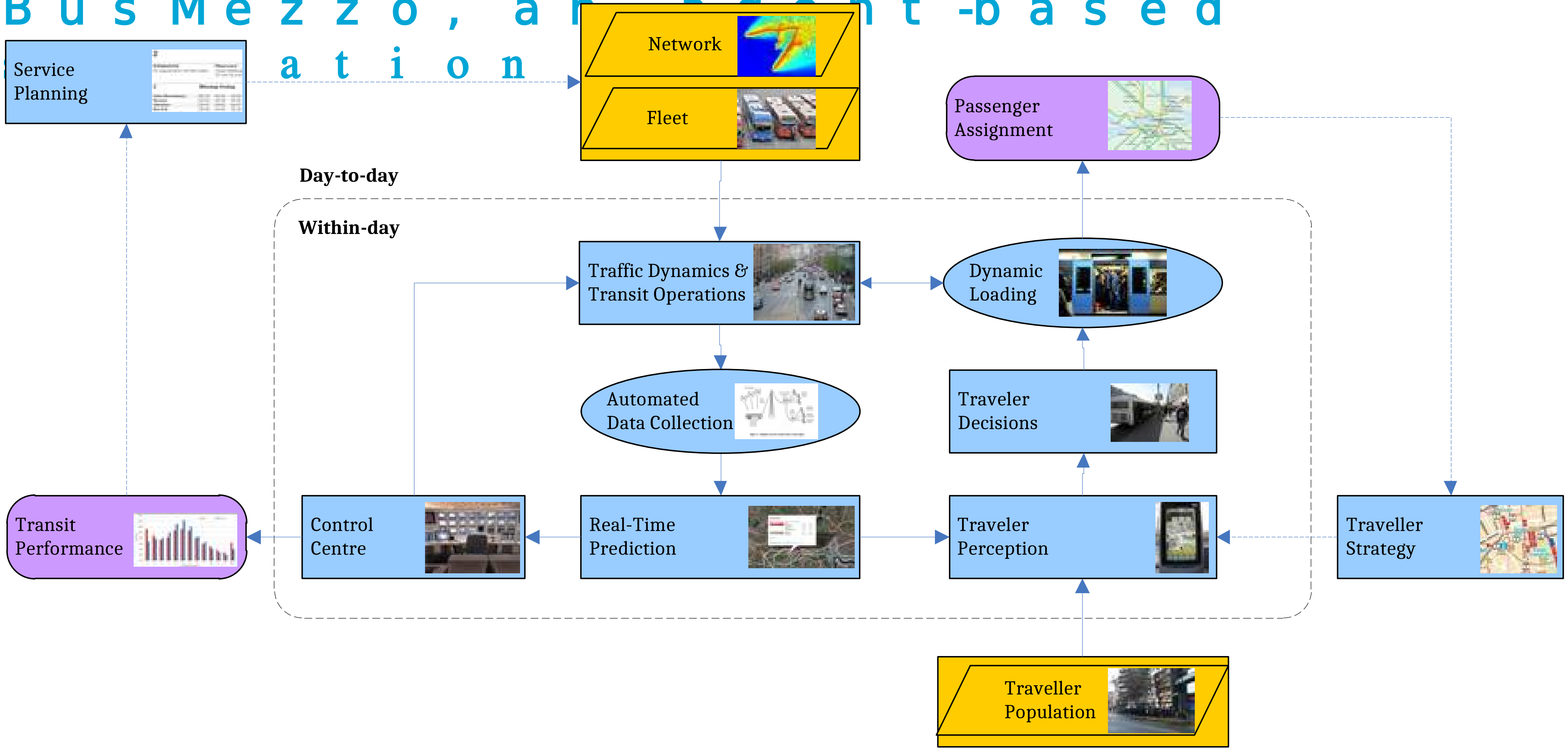
- Closing a station entrance can result with overall greater passenger comfort

- Having 50% of the passengers accessing real-time information result with greater overall time savings than if all passengers are granted access

Modelling approach

Dynamic Transit Operations and Assignment

BusMezzo, an agent-based simulation



Applications

Evaluating network alternatives	Reliability of timetable design	Real-time control strategies
Network robustness analysis	Transfer synchronization	Disruption management

terdam, The Hague, Stockholm, Haifa, Krakow

Modelling emerging collective dynamics

- Individual train-car specific path choice
  - Passenger arrival at/destined to different station entrances/exits
  - Platform + Car selection (introducing compartments)
  - Walking vs. in-vehicle time crowding

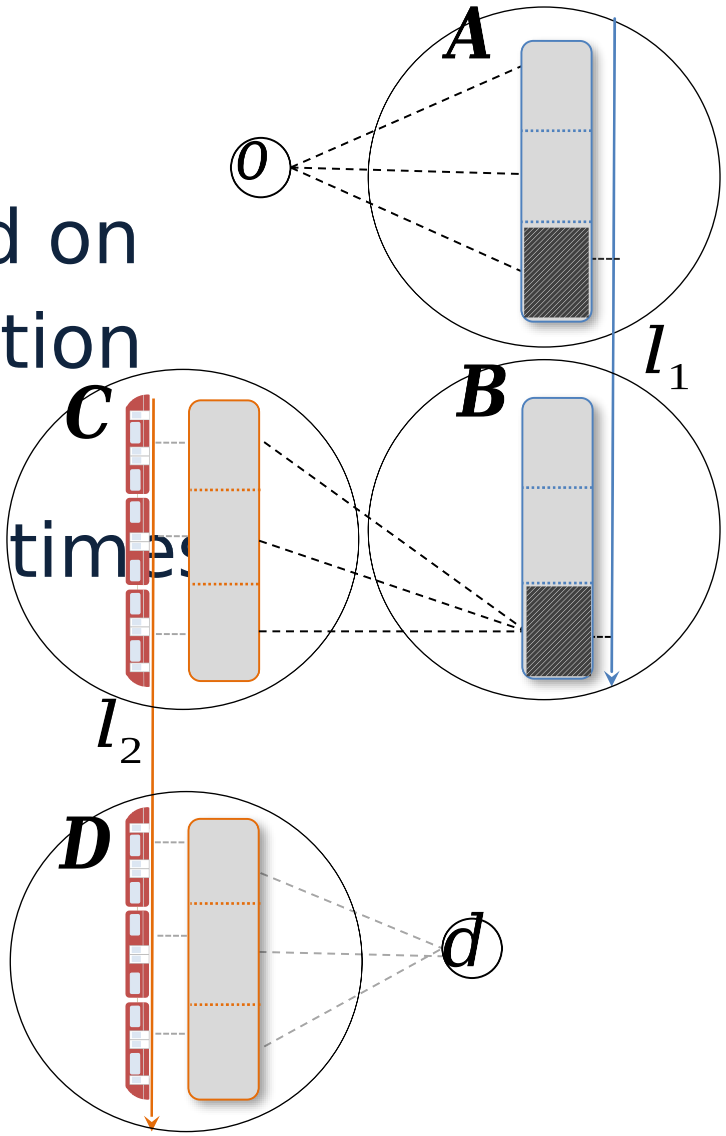
- Day-to-day experience and learning
  (iterative network loading)

- Real-time information generation and dissemination

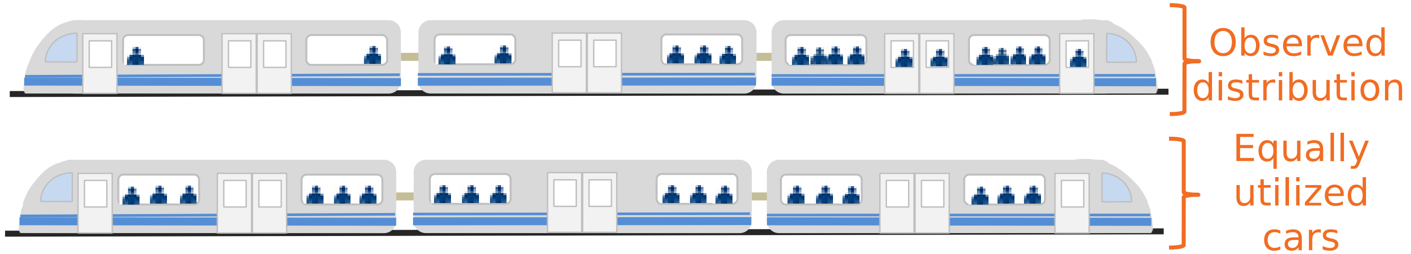
Individual car-specific path decision making

Platform section choice is based on
- Walking time to the platform section
- Expected future travel attributes
- Car-specific perceived in-vehicle times

Car choice is based on
- Selected platform section
- Car capacity constraints



Measuring crowding unevenness



$$G_{js} = \frac{1}{2|I| \sum_{i=1}^{I} q_{ijs}^{\text{onboard}}} \sum_{i=1}^{I} \sum_{i'=1}^{I} \left| q_{ijs}^{\text{onboard}} - q_{i'js}^{\text{onboard}} \right|$$

- A single metric to quantify passengers' distribution
- Measures how far the observed passenger distribution deviates from a totally even distribution

Passenger behavior

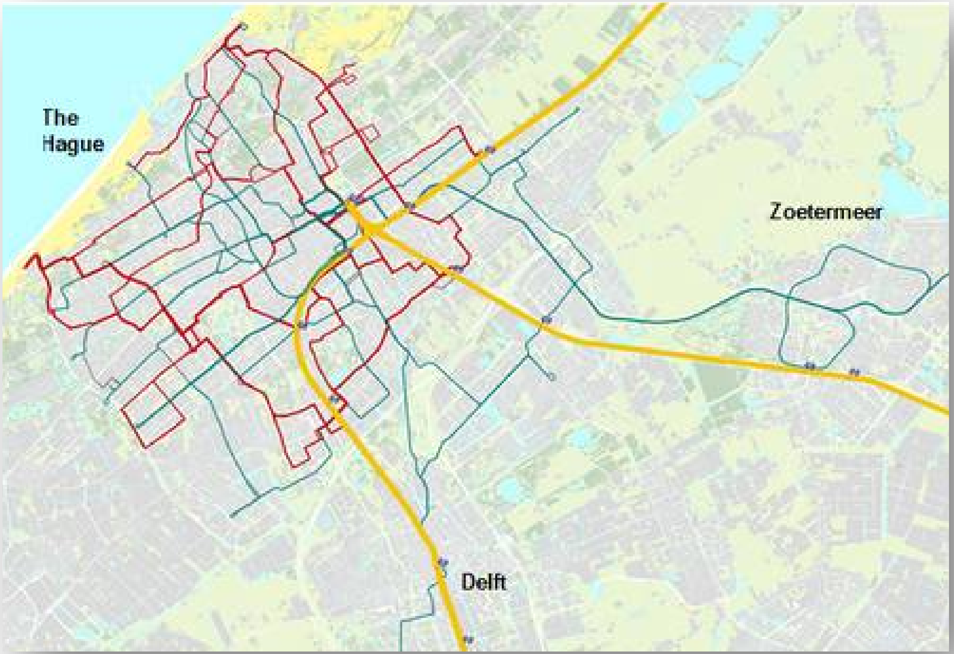
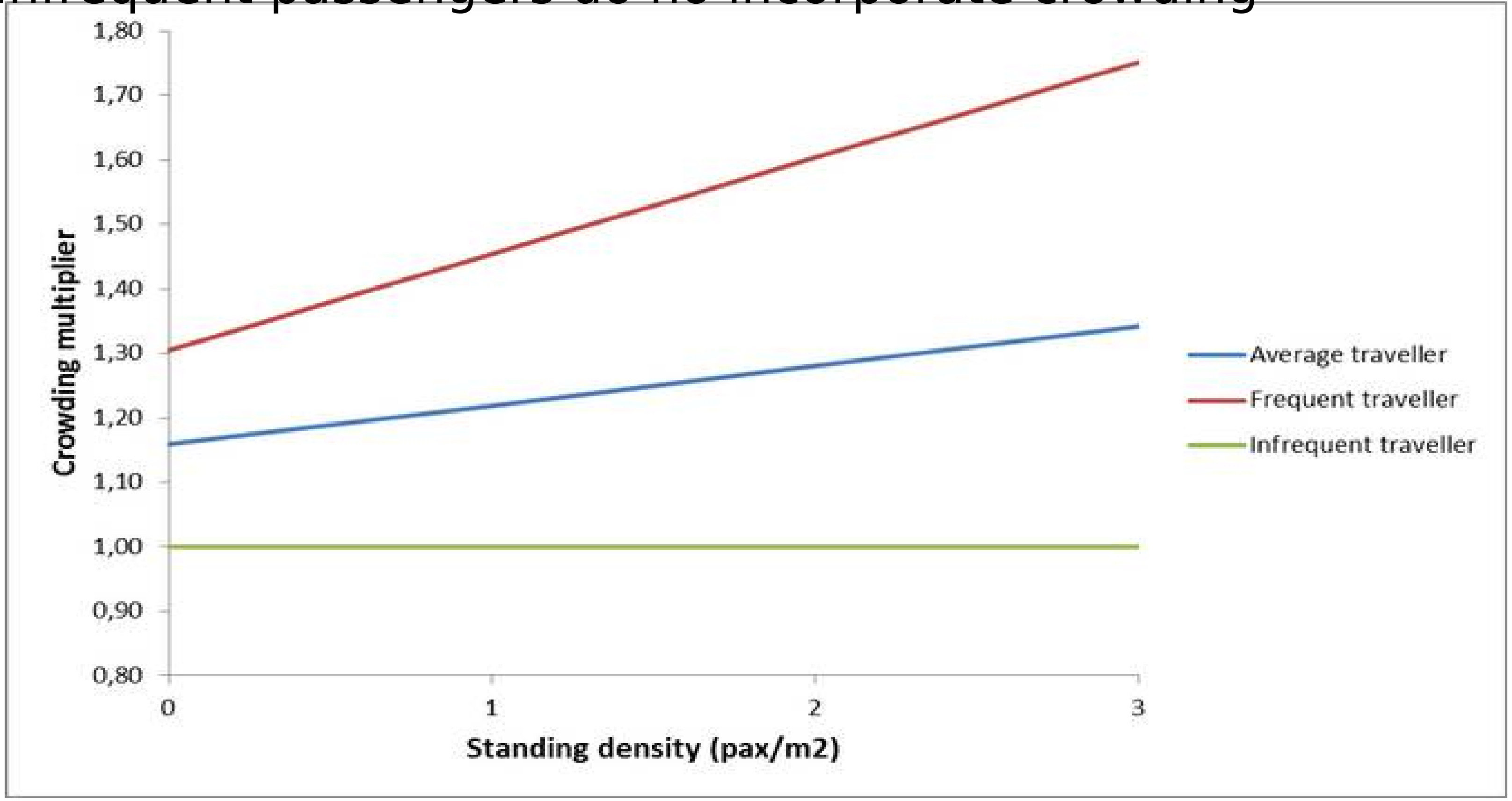


Table 4. Scaled estimation results

	Model 1 (no crowding, no segments)	Model 2 (crowding, no segments)	Model 3 (segments, no crowding)		Model 4 (segments, crowding)	
			Frequent	*Infrequent*	*Frequent*	*Infrequent*
in-vehicle time tram	0.6	0.6	0.6	0.6	0.6	0.6
in-vehicle time bus	1.0	1.0	1.0	1.0	1.0	1.0
waiting+transfer time	1.5	1.6	1.5	1.5	1.5	1.5
transfer penalty	3.8	4.8	2.8	5.4	5.2	5.2
seat occupancy	-	1.16	-	-	1.31	1.00
standing density	-	1.06	-	-	1.15	1.00

Crowding matters, but much lower than previous research has suggested

- All seats occupied: perceived in-vehicle time multiplier: 1.16
- Standing passengers: ivt-multiplier increases by 0.06 per
  - 1.31 for frequent travellers vs. 1.00 for infrequent travellers
- Infrequent passengers do no incorporate crowding



Perception of denied boarding systems

Coefficient	Name	Value (robust t-value)
β^{ivt}	in-vehicle time	-0.0739** (-8.61)
$\beta^{wtt,i}$	initial waiting time	-0.120** (-4.63)
$\beta^{wtt,d}$	waiting time after denied boarding	-0.201** (-5.13)
β^{tf}	transfer penalty	-0.627** (-5.21)
β^{lf}	load factor	0.389** (3.16)
β^{r}	log-path size factor	-2.46** (-12.9)

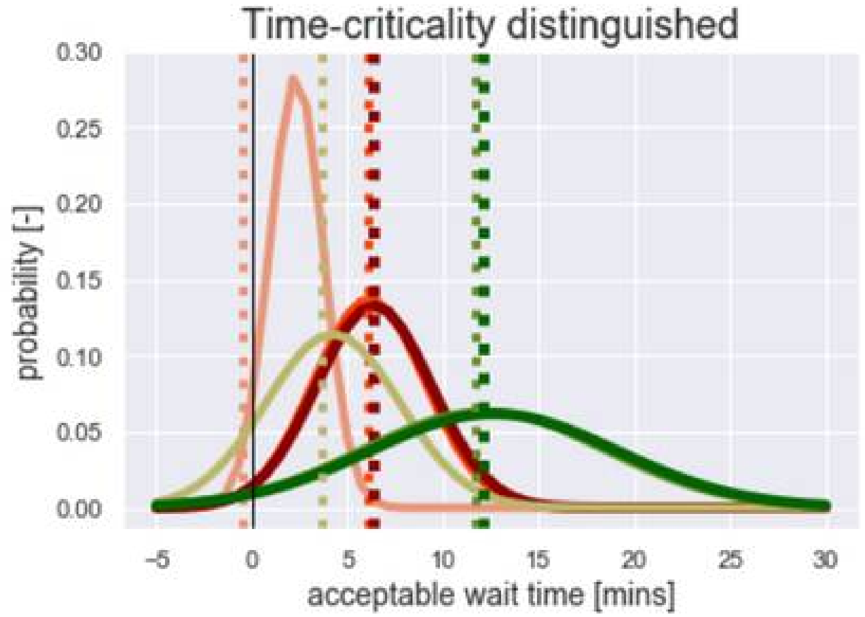
*robust t-values in parentheses. * $p<0.05$; ** $p<0.01$*

- One minute initial / denied boarding wait time is perceived as 1.62 / 2.72 minutes uncrowded on-board time, respectively
- Wait time after denied boarding is perceived 68% more negatively compared to initial wait time

Willingness to wait estim

- 380 respondents in Krakow
- Choice experiments

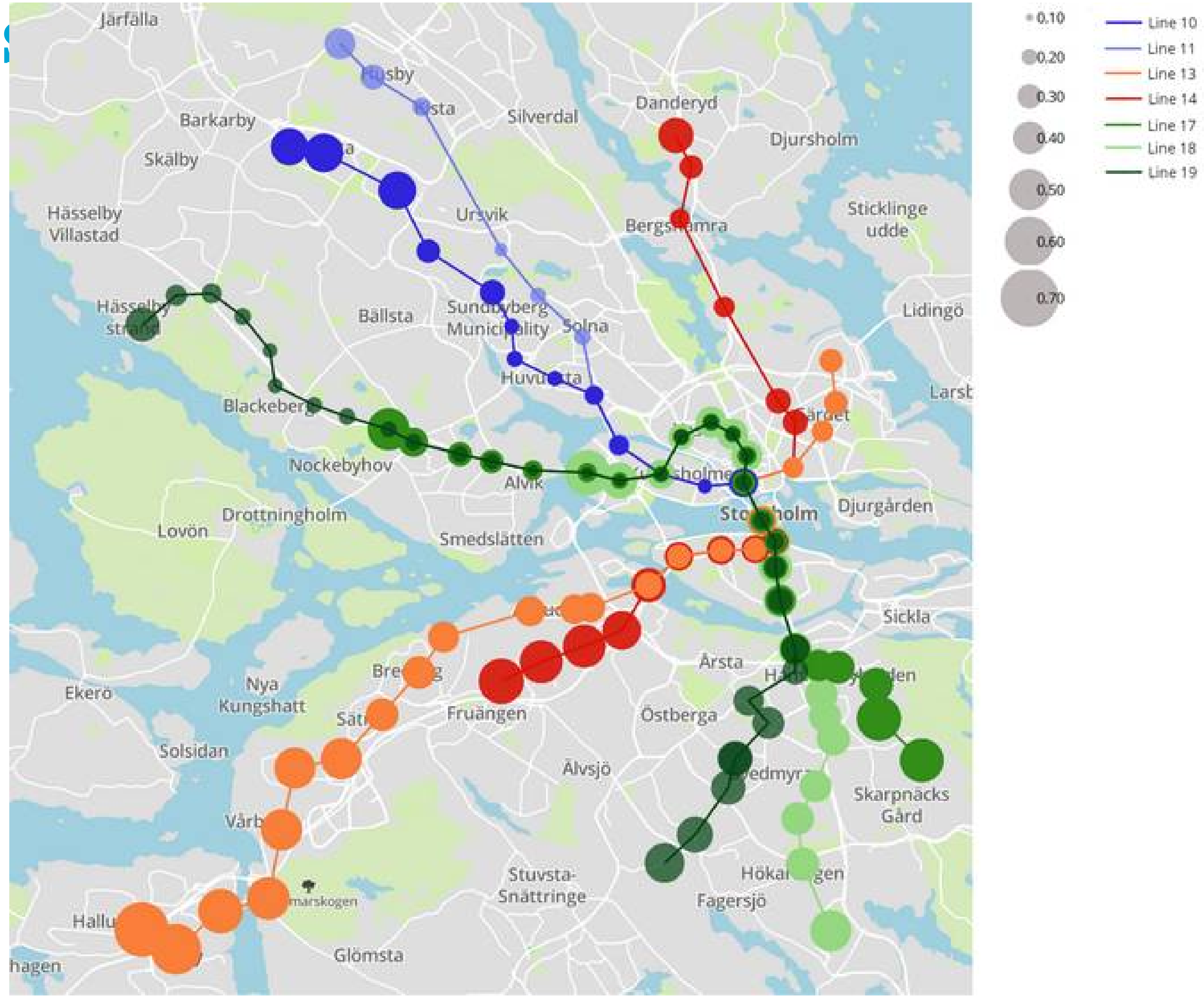
- Willingness to wait of
  - Typically 5-10 min
  - Up to 15-20 min in case of older travellers, non-time-critical trips, longer journeys and over-crowding



- Considerable heterogeneity

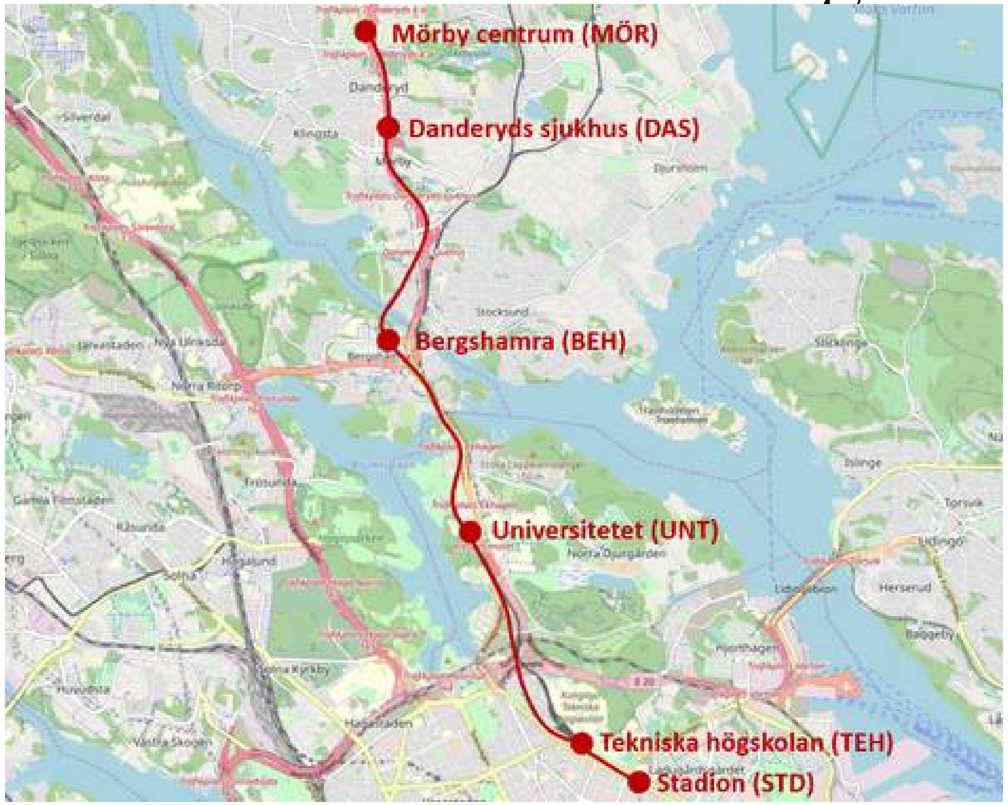
Application

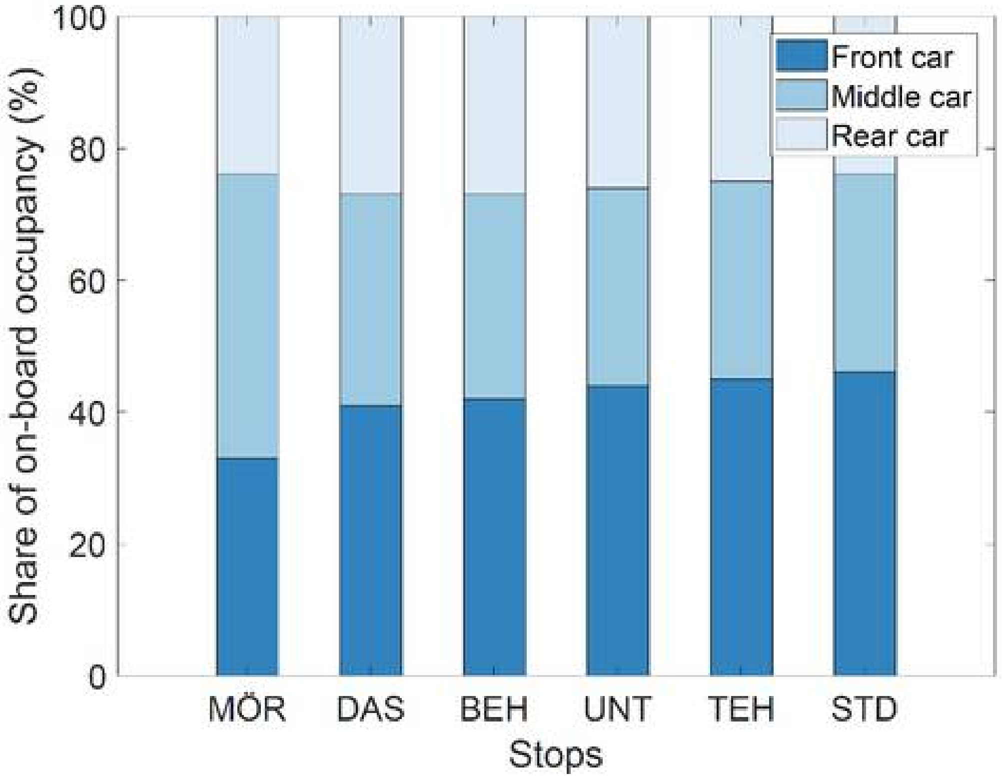
Example: Stockholm metro



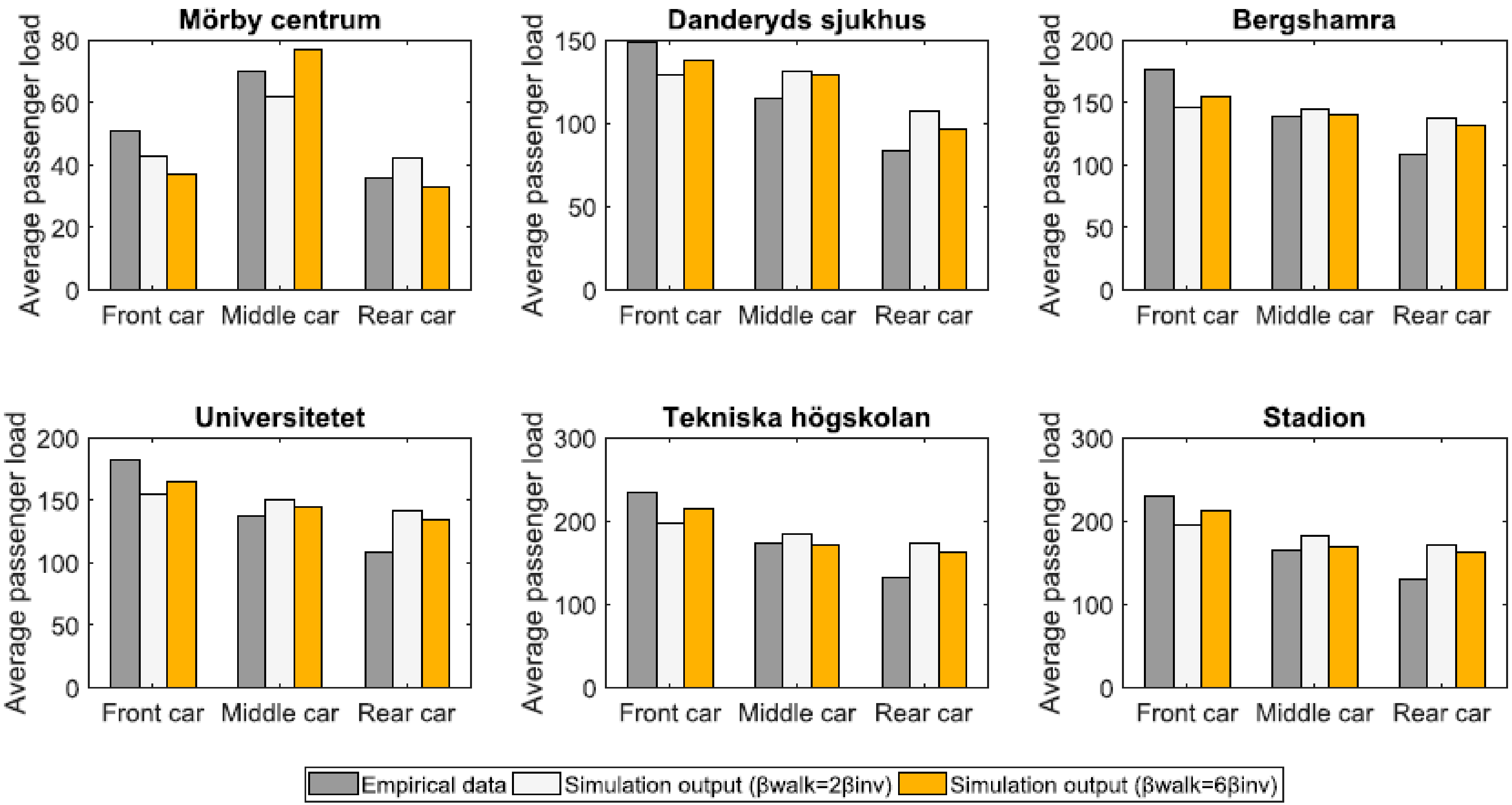
Application: Southbound part of the Red line

- Passengers are skewed towards the leading cars





Model validation



Scenarios design

- **Base scenario**: The studied area is simulated with the current average morning peak hour demand.

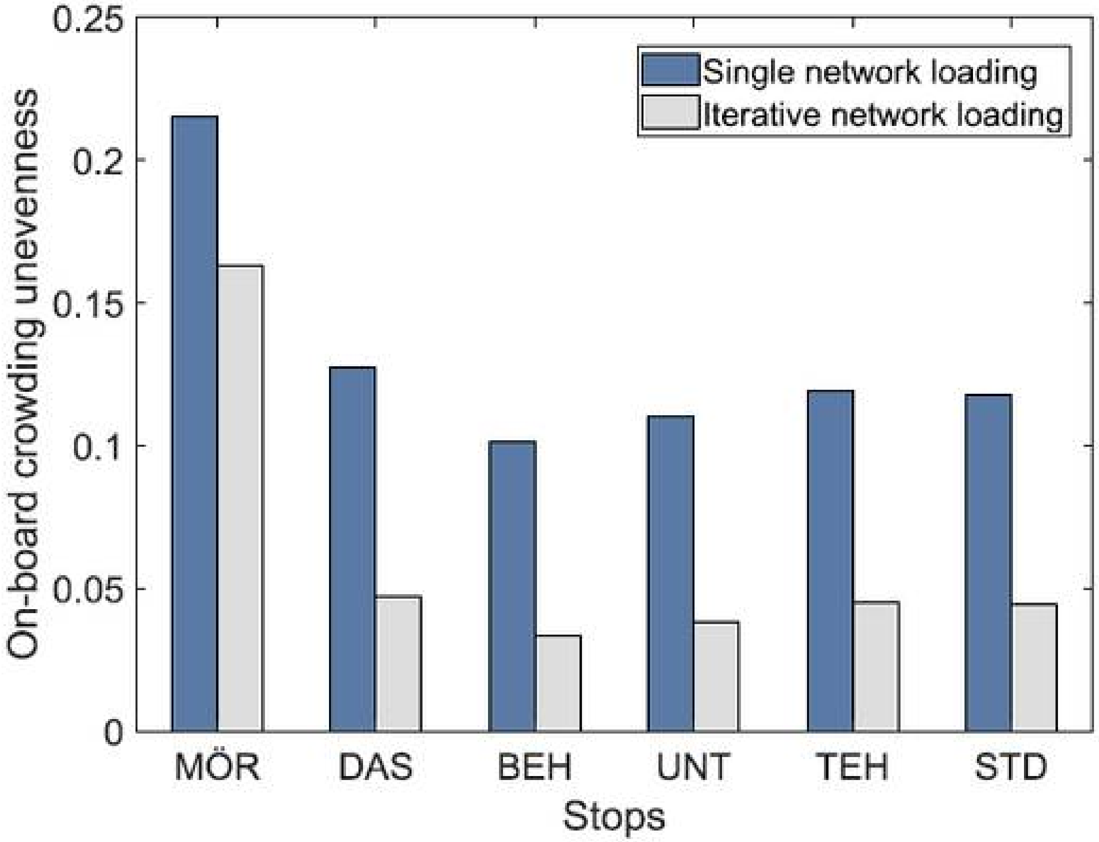
- **Increased demand scenario**: The studied area is simulated with increased demand by 50%.

- **Intervention scenario**: Closure of an entrance point at DAS.

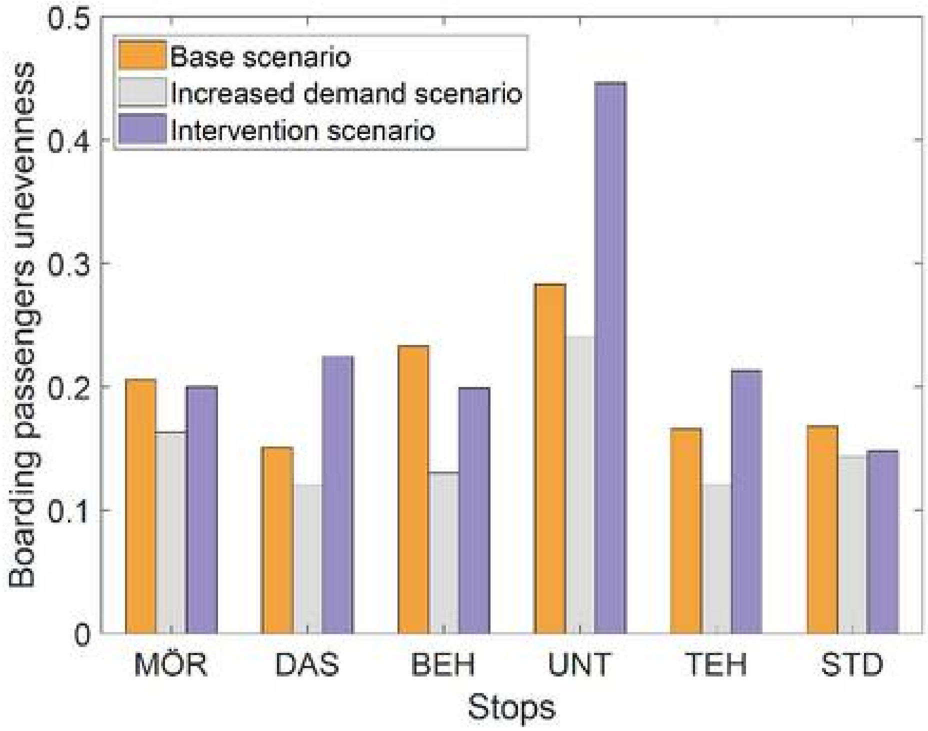
R o l e   o f   d a y -t o -

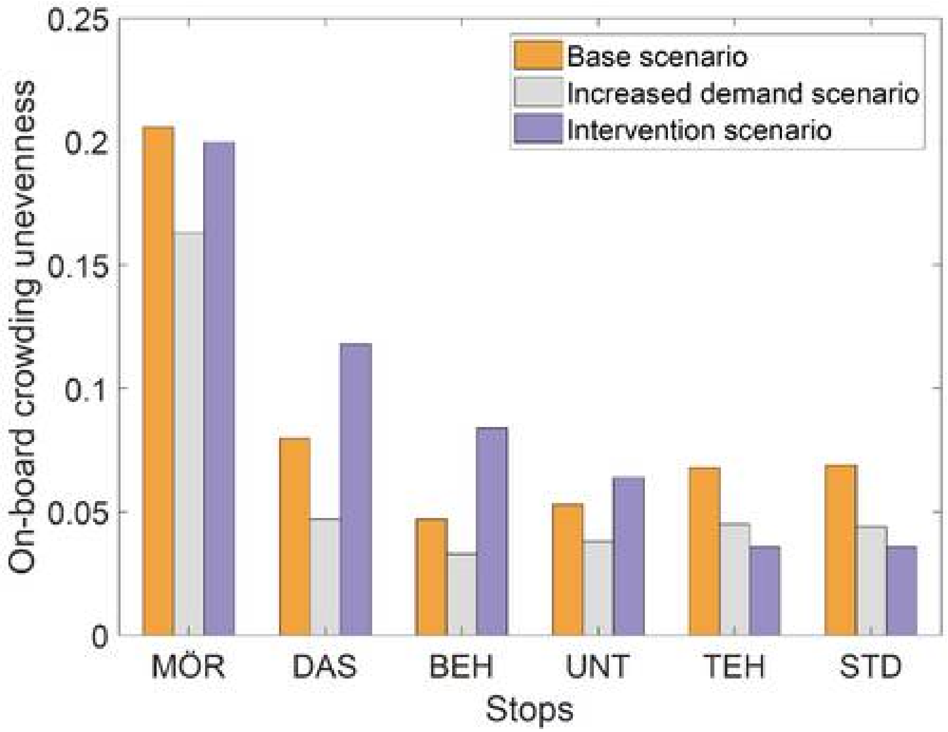
Experienced passengers alter their travel behavior aiming to minimize car-specific discomfort, leading to lower on-board crowding unevenness.

Increasingly so with increased demand.



Scenarios analysis



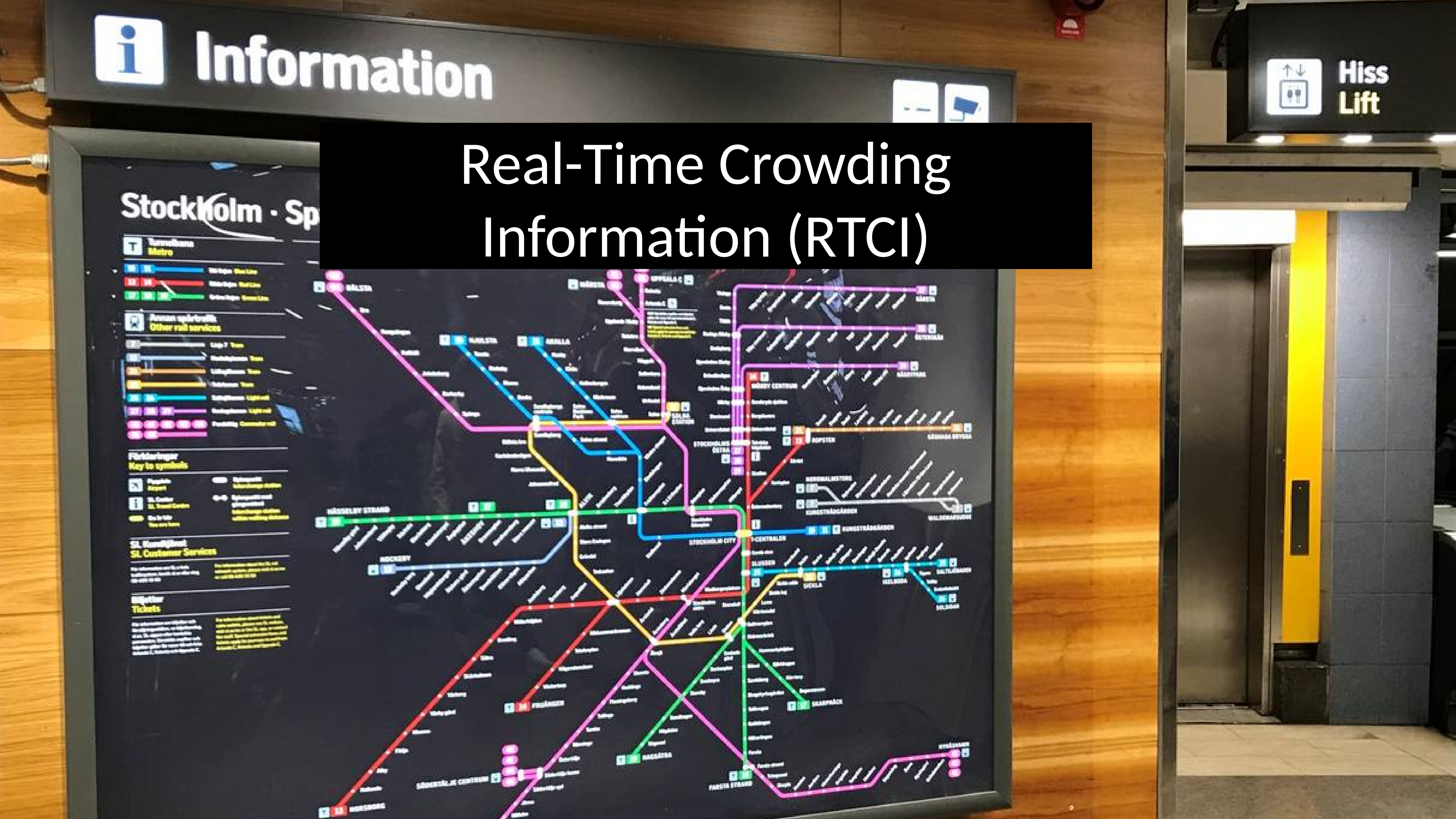


Closing an entrance at DAS ✉

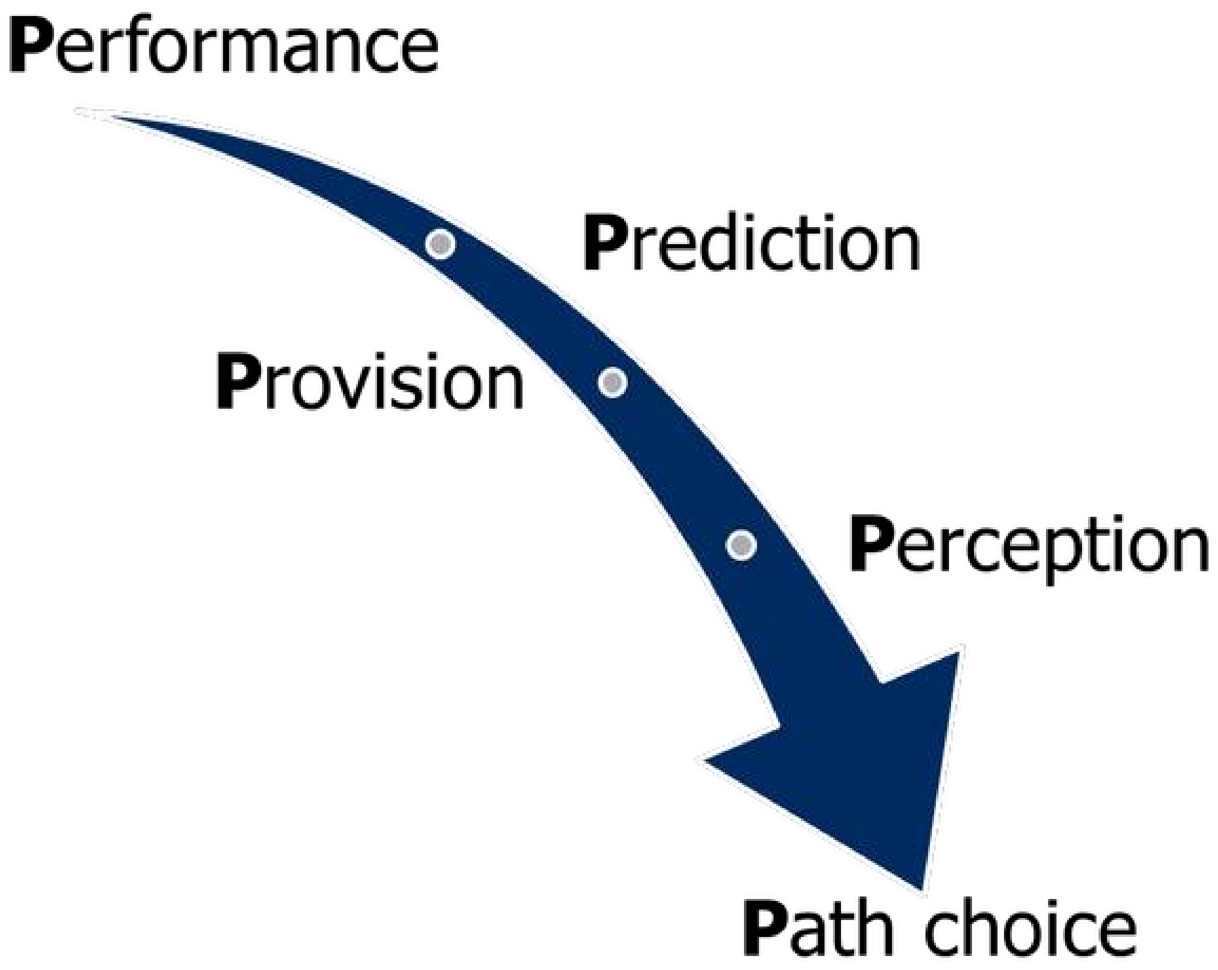
skewed boarding distribution at DAS ✉

a more even on-board distribution at downstream stations

Real-Time Crowding Information (RTCI)



Modelling impacts of information provision

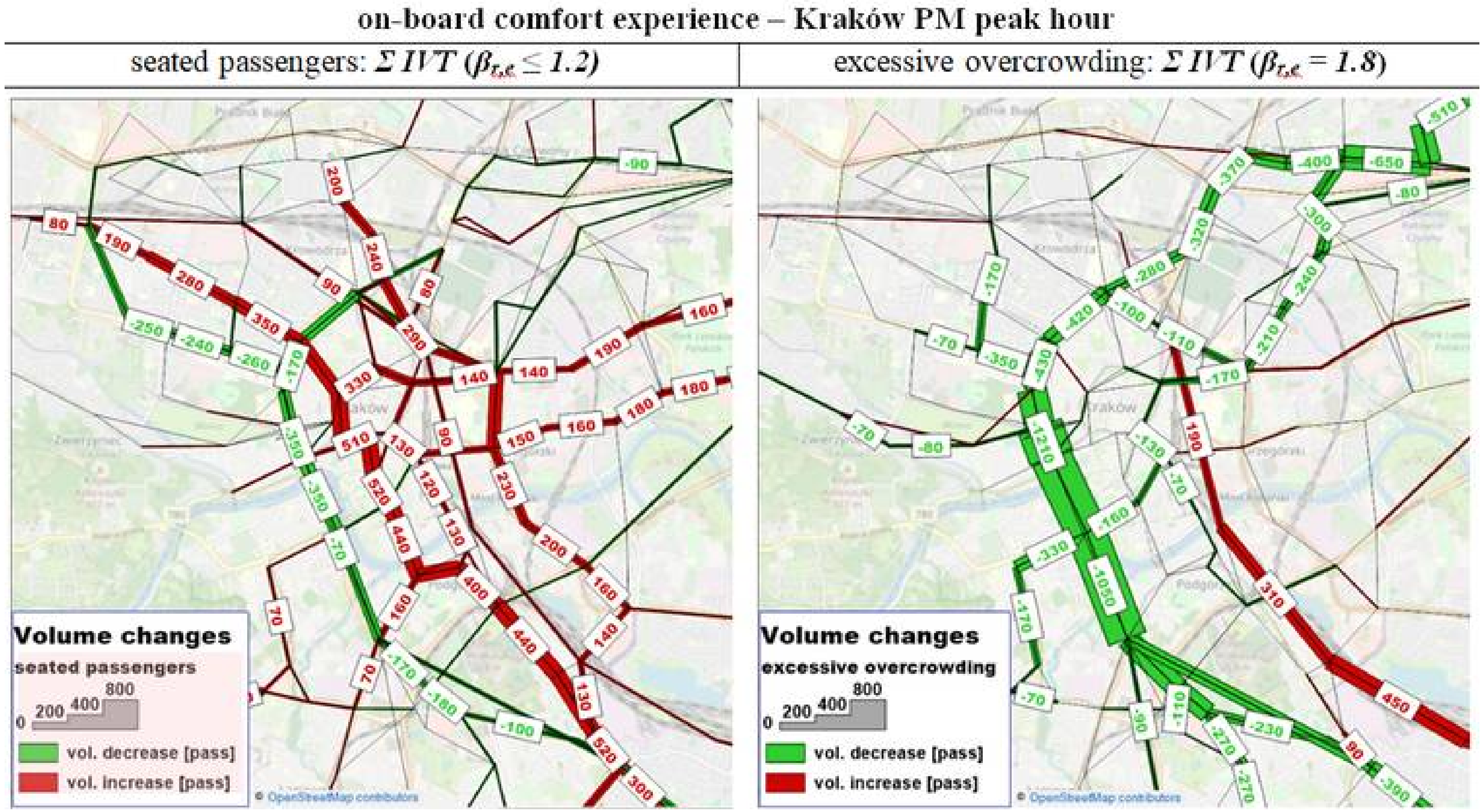


Modelling car-specific RTCI in BusMezzo

RTCI level	Car capacity utilization	Crowding factor
●○○○	<= 80% seated capacity	1.0
●●○○	>80% seated capacity | <= 100% seated capacity	1.3
●●●○	>100% seated capacity | <= 50% total capacity	1.5
●●●●	>50% total capacity	1.8

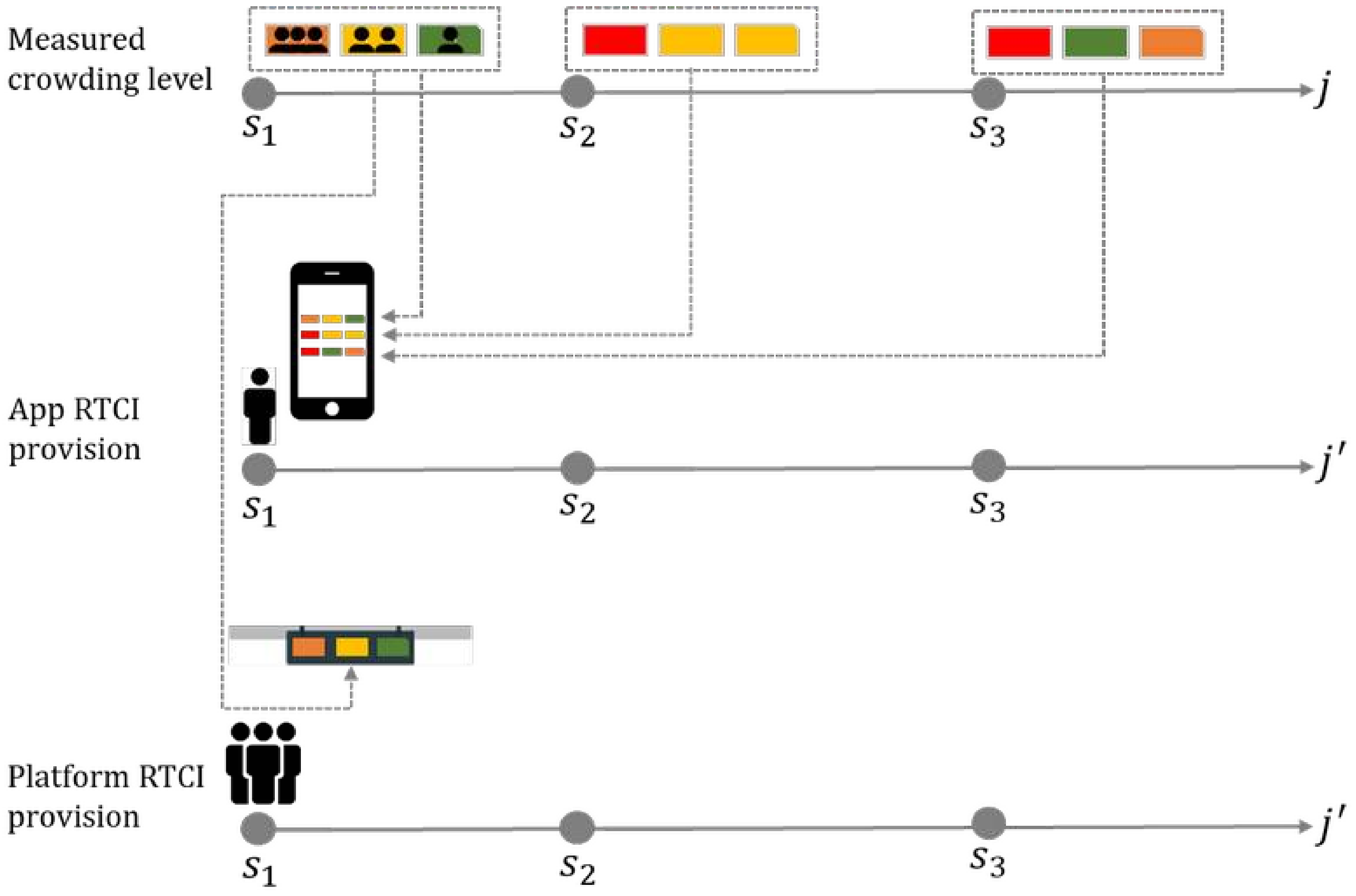
- Predict RTCI for each trip segment based on the measured car crowding level of the *most recent train run.*
- Each passenger utilizes the generated car-specific RTCI, as an *in-vehicle time multiplier* of a given trip segment, in the decision making process.

Already tested at the vehicle

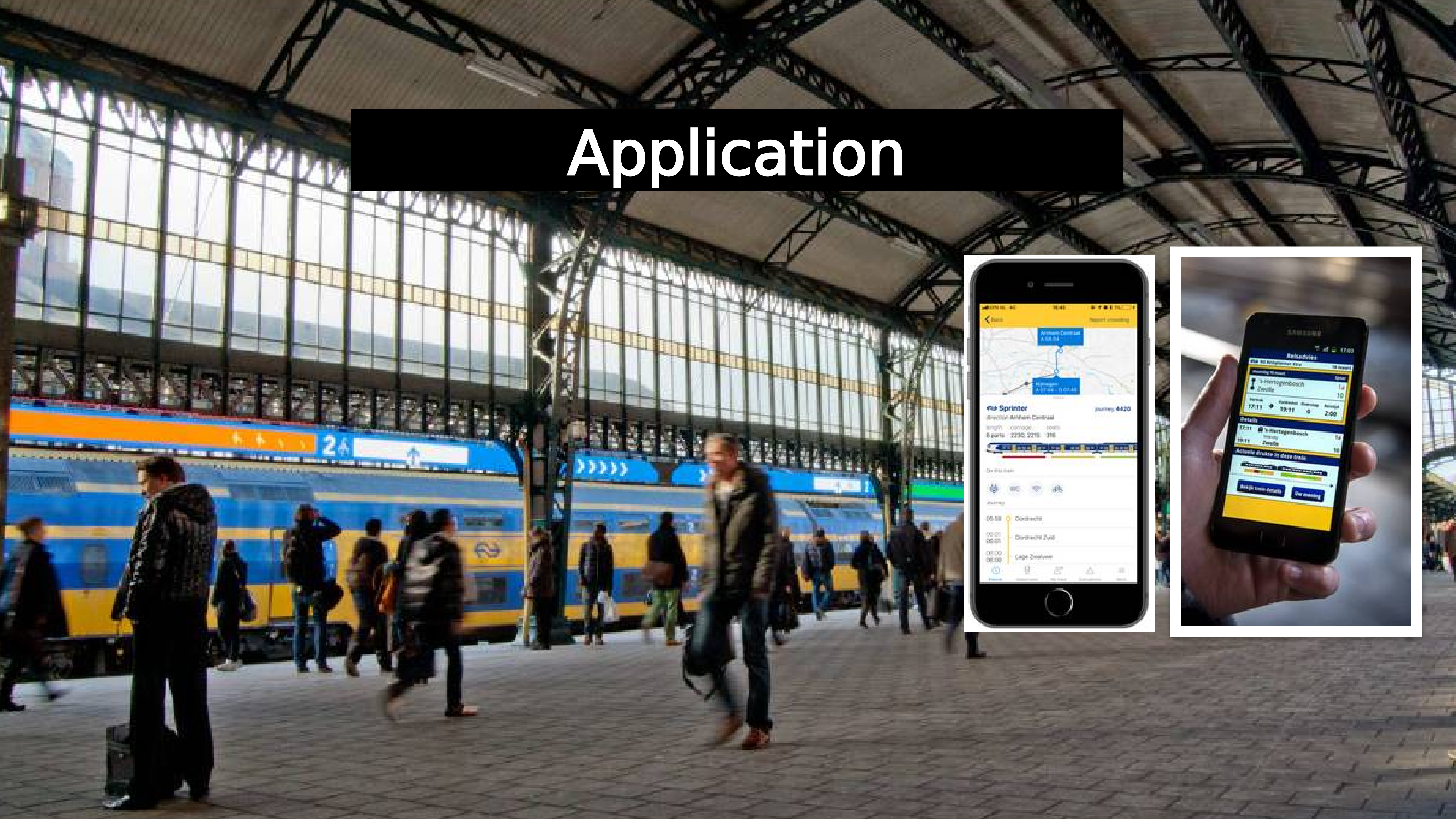


- share of the worst on-board overcrowding experience decreases by 27%
- waiting time due to denied boarding are reduces by 30%

RTCI provision schemes



Application

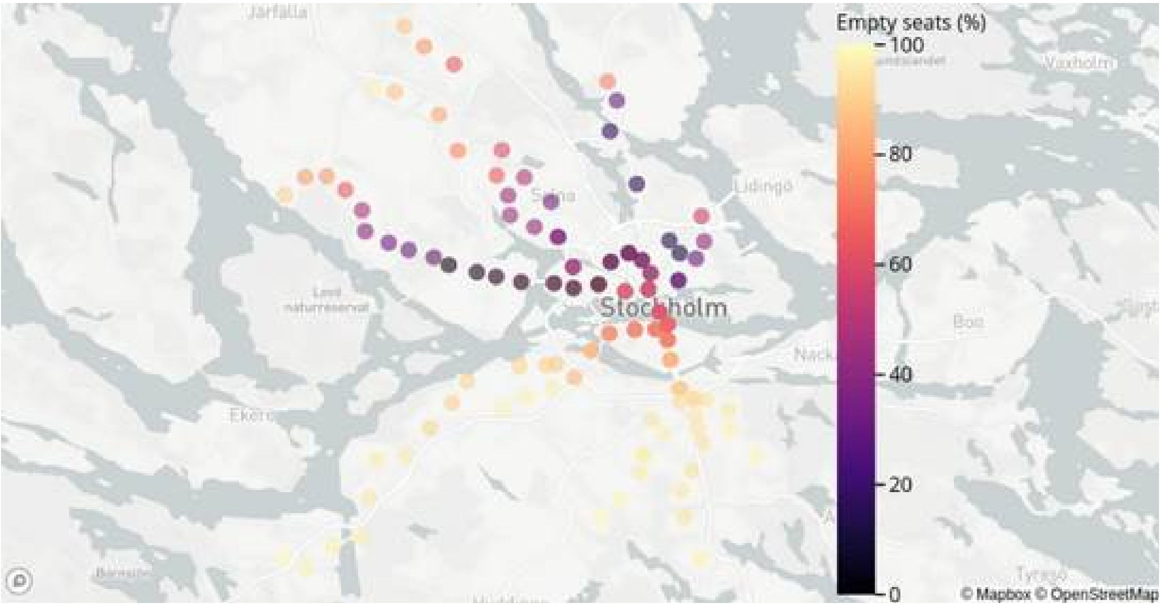


Case study application

- 1 million passengers daily
- 20% of the seats remain empty in the morning peak hour

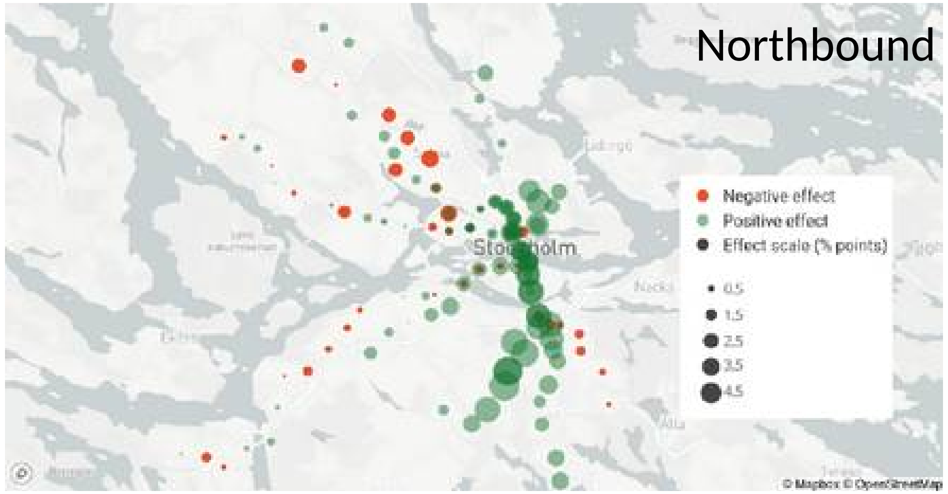
- Scenarios
  - App with varying penetr
  - 10 most heavily loaded
    stations with the larges
    unevenness of boardin
    passengers

Even when passenger load exceeds total seated capacity (378) for the train as a whole, there are still seats that remain unoccupied in individual cars.

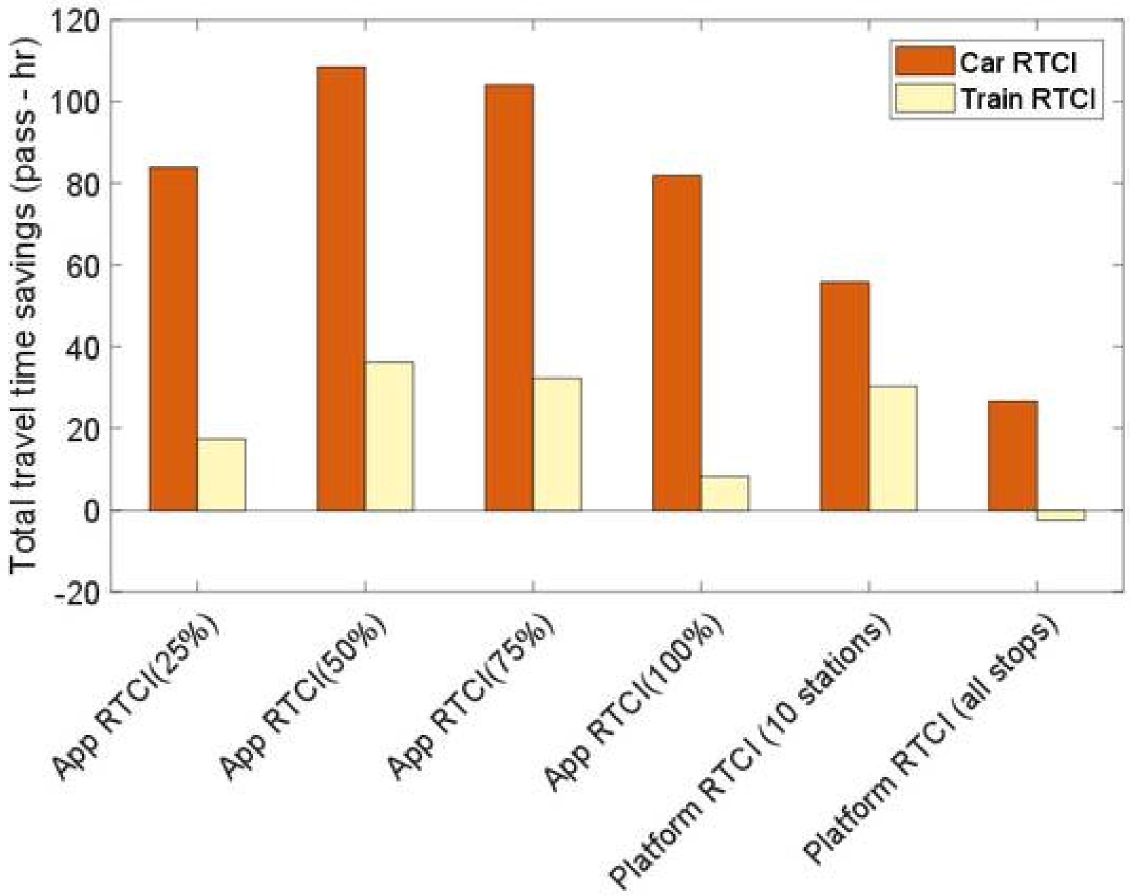


Effect of app-based RTCI on on-board crowding unevenness

- Positive effect on crowding unevenness on-board trains departing from the most heavily loaded stops (upstream of the center)
- Some ‘global’ route choice effects along crowded corridors



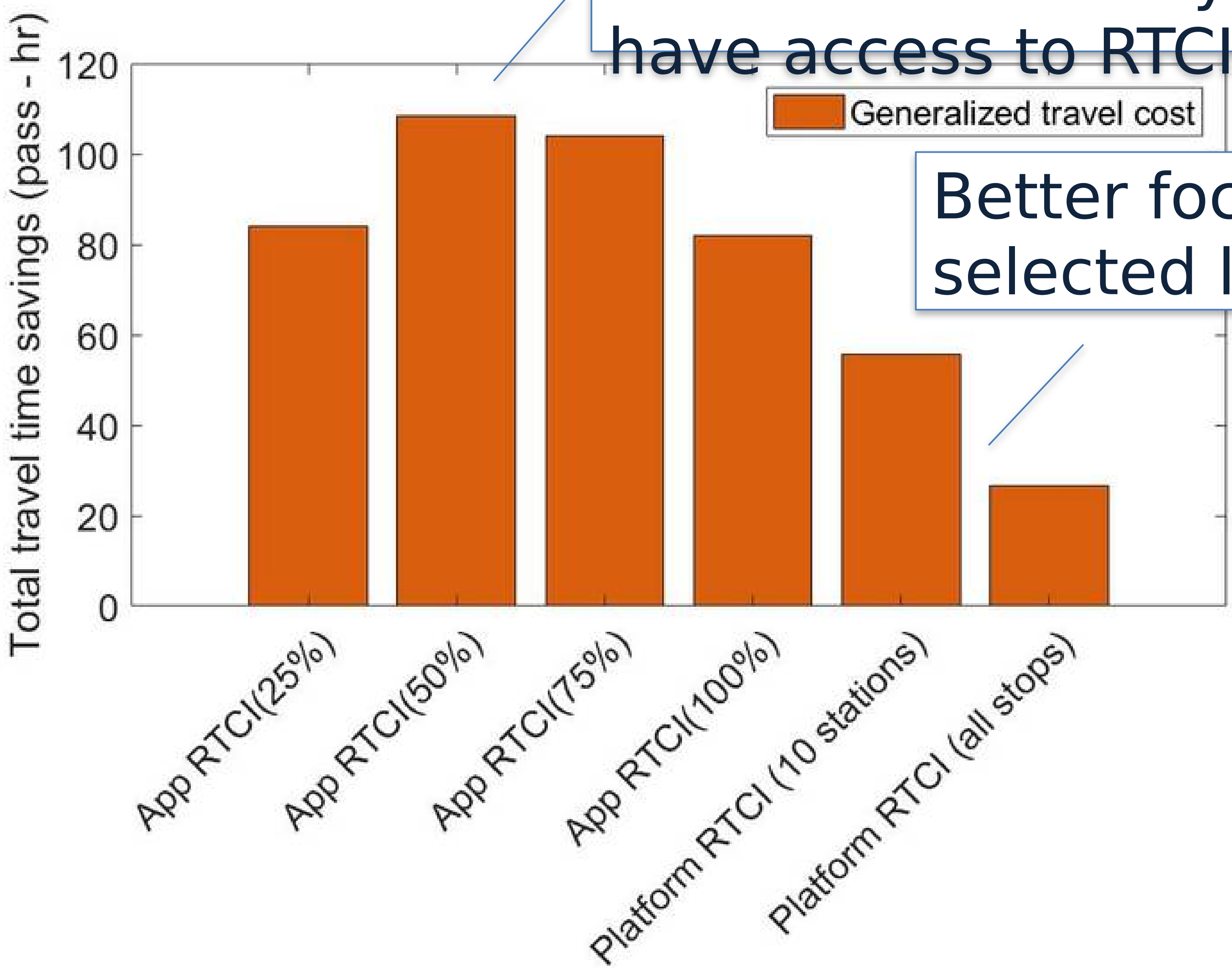
RTCI at train- vs. car-level



- Train-level assumes an even on-board crowding distribution
- Train-level information is less actionable

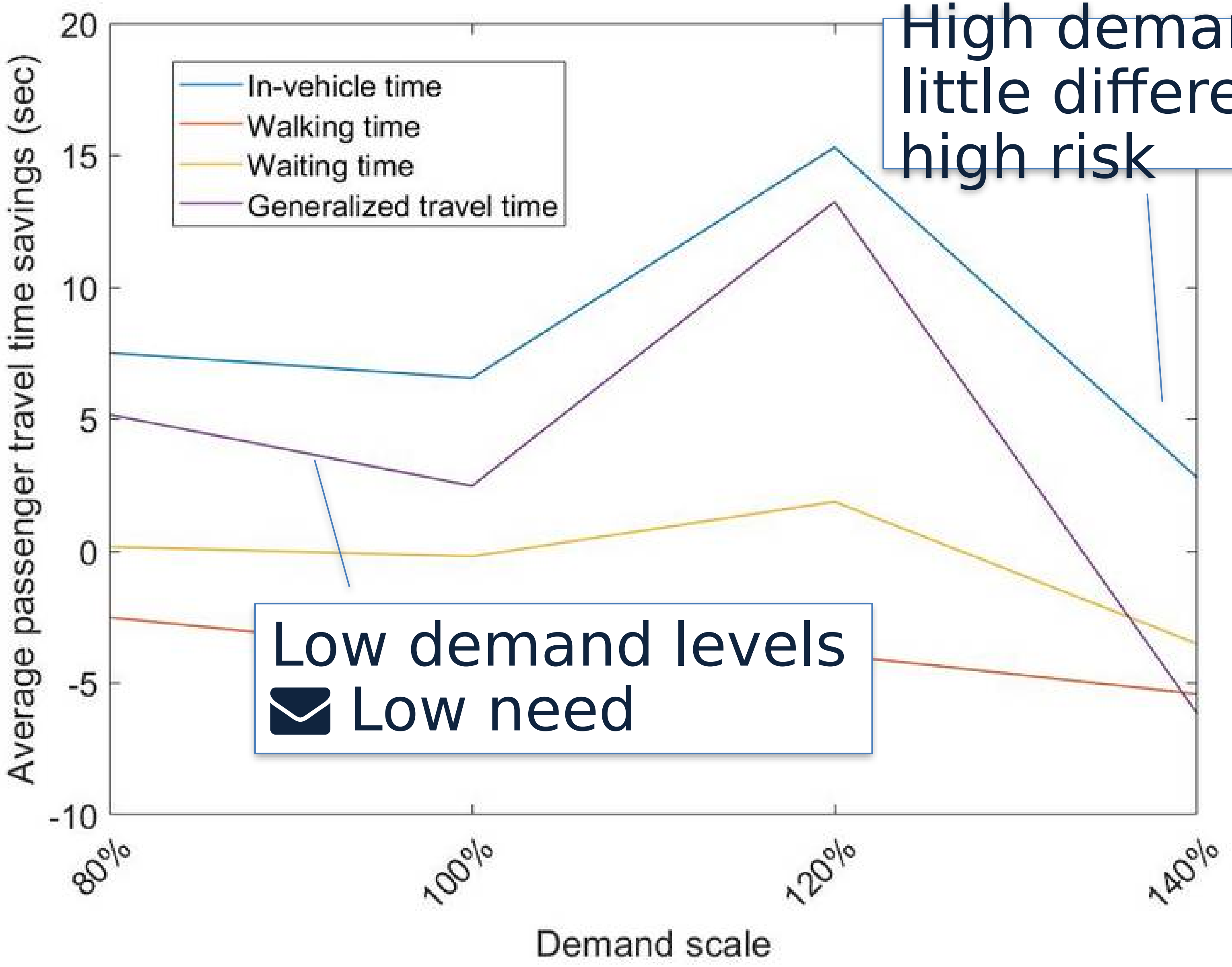
Effect of app-based RTCI on passeng generalize

Best collective outcome obtained when only 50% have access to RTCI



Better focus on selected locations

Sweet demand spot?



High demand levels little difference and high risk

Low demand levels Low need

Next steps

On-going and future work

- Using the simulation tool to devise service planning and control measures (e.g. skip-stop operations)
- Demand management tool (e.g. anti-bunching)
- Crowding perceptions during the pandemic

- Customized information

Relevant references: Data analysis

- Peftitsi S., Jenelius E. and Cats O. (2019). Determinants of Passengers’ Metro Car Choice Revealed through Automated Data Sources: A Stockholm Case Study. *Transportmetrica A*, 16 (3).
- Peftitsi S., Jenelius E. and Cats O. (2021). Evaluating Crowding in Individual Train Cars using a Dynamic Transit Assignment Model. *Transportmetrica B*, 9 (1), 693-711.
- Peftitsi S., Jenelius E. and Cats O. (2022). Modelling the Effect of Real-Time Crowding Information (RTCI) on Passenger Distribution in Trains. Transportation Research Part A, 166, 354-368.
- Hänseler F.S., van den Heuvel J., Cats O., Daamen W. and Hoogendoorn S. (2020). A Passenger-Pedestrian Model to Assess Platform and Train Usage from Automated Data. *Transportation Research Part A*, 132, 948-968.
- Drabicki A., Kucharski R., Cats O. and Szarata A. (2020). Modelling the Effects of Real-time Crowding Information in Urban Public Transport Systems

Relevant references: Behavioral

- Yap M., Cats O. and van Arem B. (2020). Crowding Valuation in Urban Tram and Bus Transportation based on Smart Card Data. *Transportmetrica A*, 16(1).
- Yap M. and Cats O. (2021). Taking the Path Less Travelled: Valuation of Denied Boarding in Crowded Public Transport Systems. *Transportation Research Part A*, 147, 1-13.
- Drabicki A., Cats O., Kucharski R., Fonzone A. and Szarata A. (2023). Should I Stay or Should I Board? Willingness to Wait with Real-time Crowding Information in Urban Public Transport. *Research in Transportation Business & Management*, in press.

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