

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

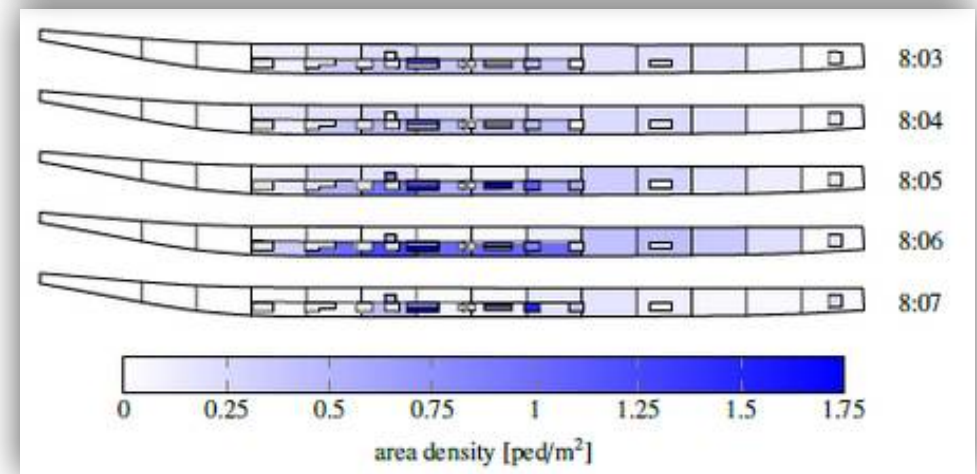
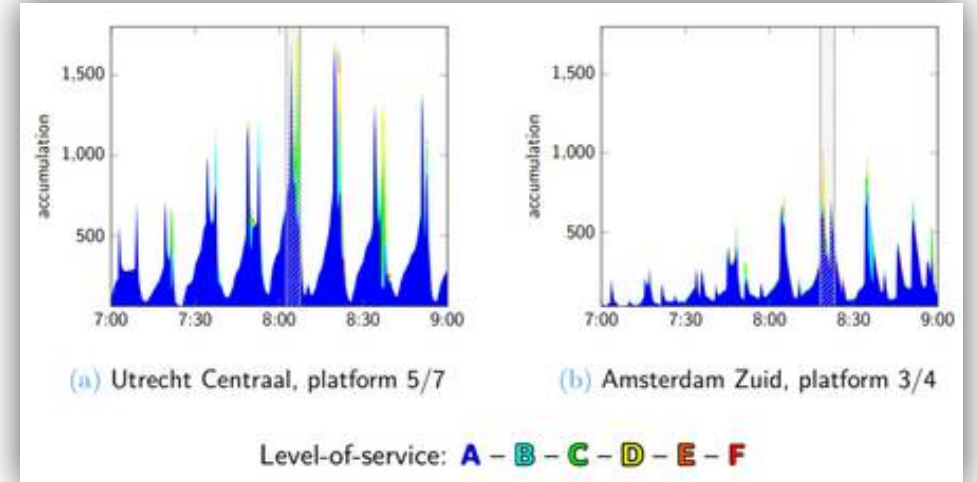
- Travel demand temporal distribution
- Travel demand spatial distribution
- Inter-vehicle arrival distribution
- Within-vehicle distribution



An inefficient utilisation of capacity, higher costs (for all parties)

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

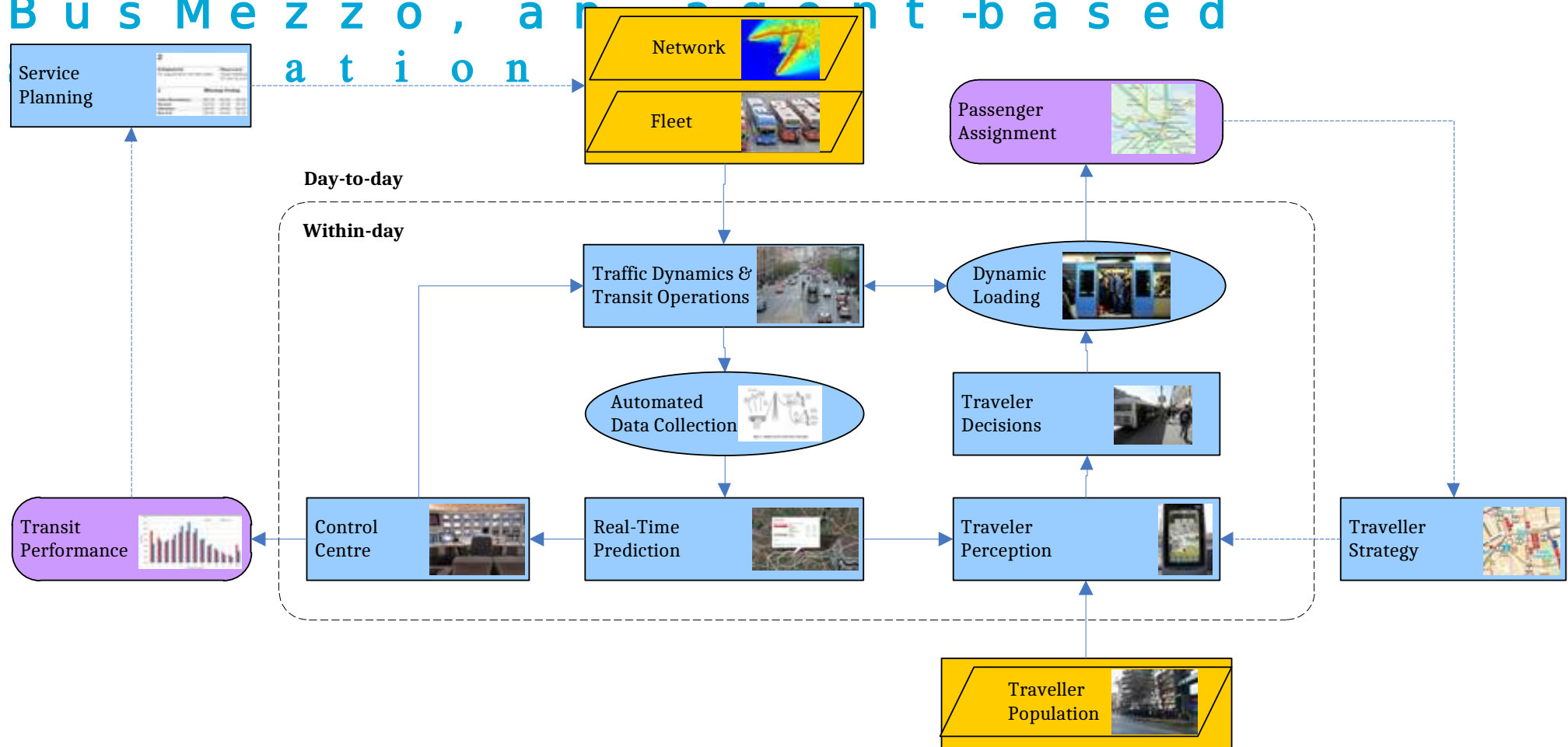
- Closing a station entrance can result with overall greater passenger comfort
- Having 50% of the passengers accessing real-time information result with greater overall time savings than if all passengers are granted access

Modelling approach




Dynamic Transit Operations and Assignment

Bus Mezzo, a representation-based



Applications

| Route | 0528 | 0544 | 0557 | 0614 | 0628 | 43 | 43 | 43 |
|----------------------|------|------|------|------|------|----|----|----|
| Green Salsbush Road | 0528 | 0553 | 0614 | 0628 | 0632 | 35 | 45 | 35 |
| ROYAL PARADE | 0543 | 0600 | 0624 | 0638 | 0639 | 38 | 48 | 38 |
| Green Approach Court | 0554 | 0612 | 0630 | 0645 | 0648 | 40 | 52 | 40 |
| ROYAL PARADE | 0552 | 0610 | 0642 | 0645 | 0655 | 58 | 59 | 52 |
| ROYAL PARADE | 0601 | 0620 | 0650 | 0704 | 0714 | 55 | 08 | 09 |
| ROYAL PARADE | 0605 | 0630 | 0700 | 0715 | 0725 | 11 | 15 | 18 |
| ROYAL PARADE (AA) | 0742 | 0807 | 0840 | 0901 | 0911 | 24 | 27 | 25 |
| Green Salsbush Road | 0742 | 0807 | 0840 | 0901 | 0911 | 27 | 34 | 27 |
| Green Approach Court | 0742 | 0807 | 0840 | 0901 | 0911 | 31 | 37 | 44 |
| Green Approach Court | 0742 | 0807 | 0840 | 0901 | 0911 | 31 | 37 | 44 |
| Green Approach Court | 0742 | 0807 | 0840 | 0901 | 0911 | 35 | 41 | 47 |
| Green Approach Court | 0742 | 0807 | 0840 | 0901 | 0911 | 35 | 41 | 47 |
| Green Approach Court | 0742 | 0807 | 0840 | 0901 | 0911 | 35 | 41 | 47 |



Evaluating network alternatives

Network robustness analysis

Reliability of timetable design

Transfer synchronization

Real-time control strategies

Disruption management

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

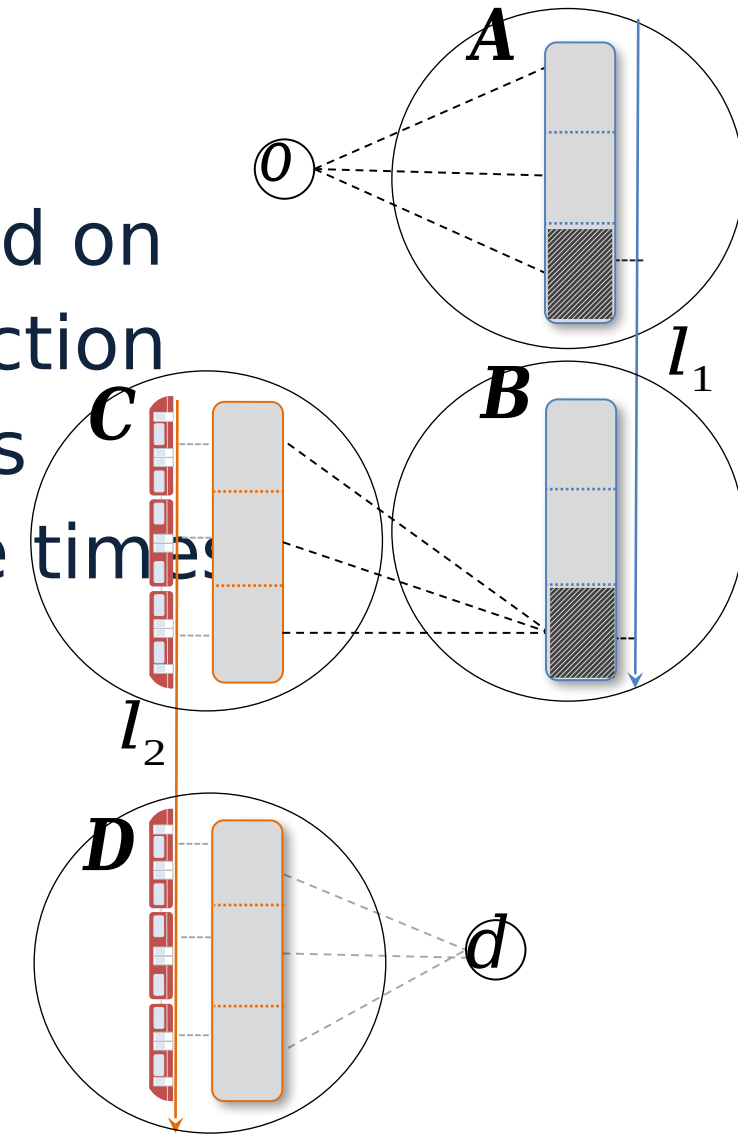
Individual car-specific path making

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



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

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

Passenger behavior

A high-angle, wide shot of a busy train platform at night. The platform is packed with a diverse crowd of people, many of whom are looking towards the camera or the train. A modern, silver-colored train is stopped at the platform, with its doors open. The train's interior lights are visible through the windows. In the background, there are signs for 'Passenger Center' and a digital display board showing train schedules. The overall atmosphere is one of a busy, well-lit transit hub.

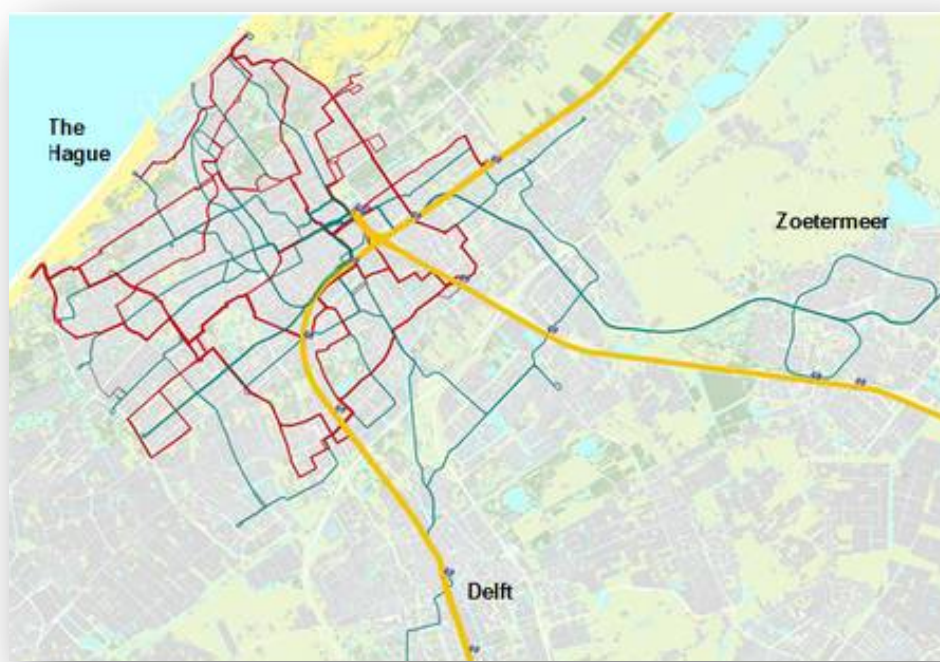
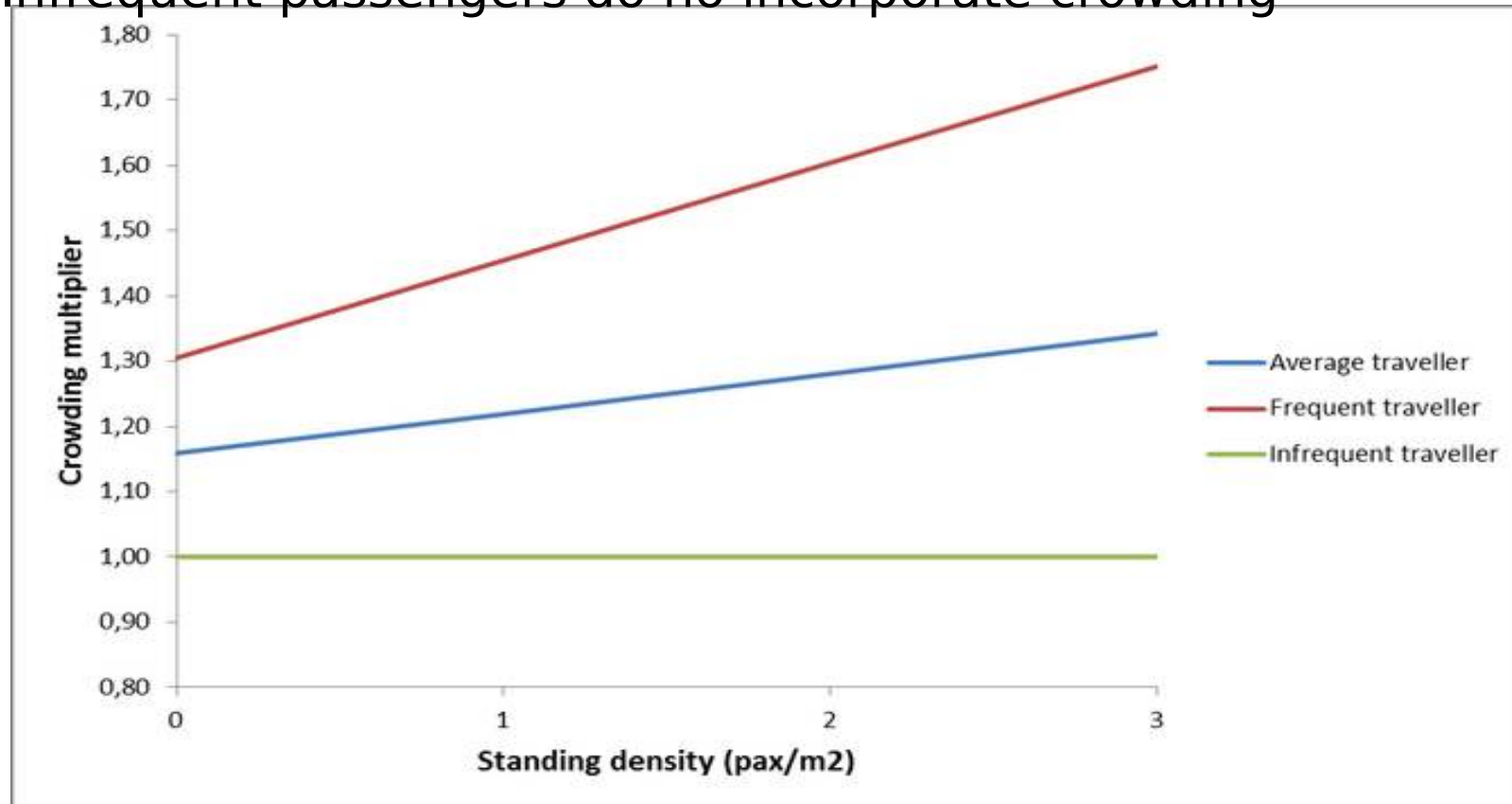


Table 4. Scaled estimation results

| | 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 not incorporate crowding



Perception of denied boarding

system

| 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 * $p < 0.05$; ** $p < 0.01$*



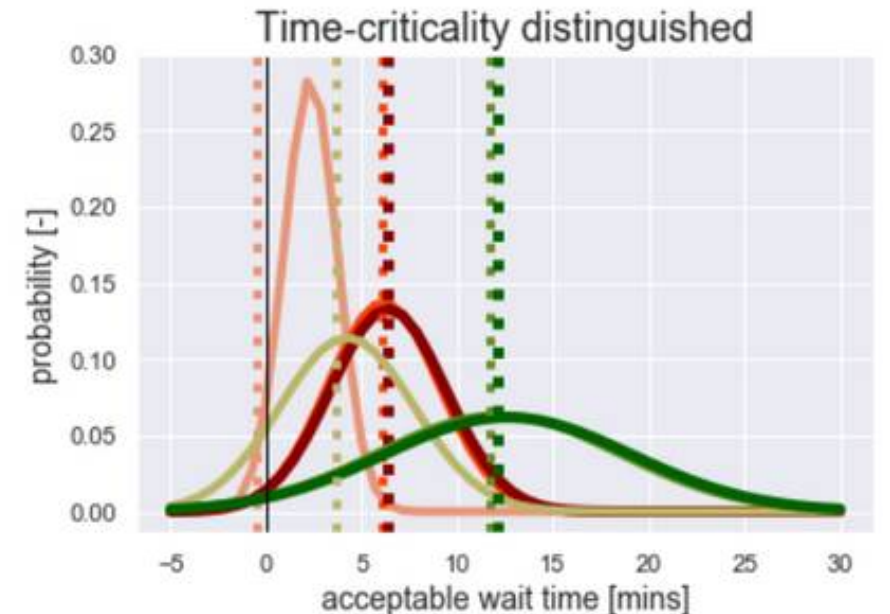
- One minute initial / denied boarding wait time is perceived as 1.62 / 2.72 minutes uncrowded on-board time, respectively
- Wait time after denied boarding is perceived 68% more negatively compared to initial wait time

Willingness to wait

- 380 respondents in Krakow
- Choice experiments

| | | |
|-------------------------|---------|---------------|
| Transit run 1-01 | ● ● ● ● | due |
| Transit run 2-01 | ● ● ● ● | 3 mins |
| Transit run 1-02 | ● ● ● ● | 5 mins |

- 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

Stockholm City

Way out Hiss Elevator Tunnelbana Metro Järnvägsst

Application

Utgång Way out



Trafikinformation Service Information

This panel displays a mobile application interface. On the left, a hand is shown holding a smartphone displaying a blue app screen. The main content area contains text in Swedish, including the heading 'Vad är det här?' (What is this?) and 'Vad kan jag göra?' (What can I do?). There are also some icons and a small map snippet.

Trafikinformation Service Information

This panel shows another view of the mobile application interface, featuring a grid of information cards or buttons. The text is in Swedish and appears to be providing service details or instructions. The layout is clean and organized, typical of a modern mobile app.

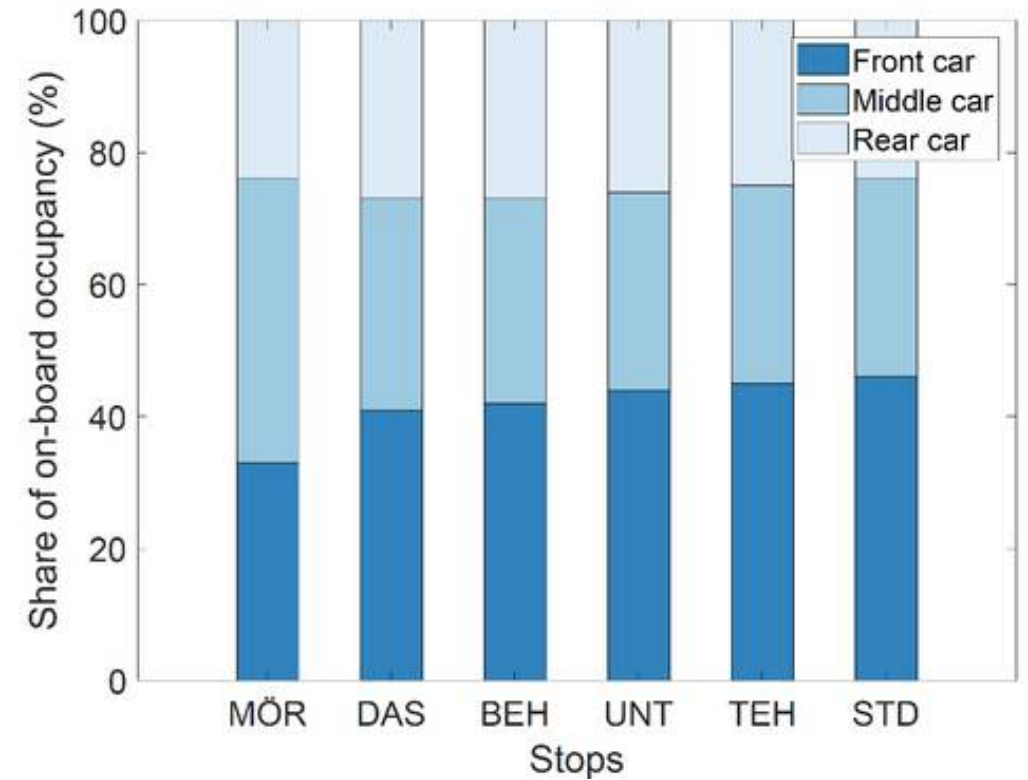


Example: Stockholm metro

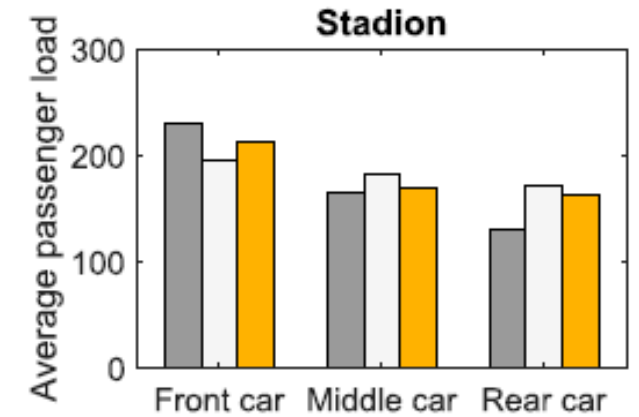
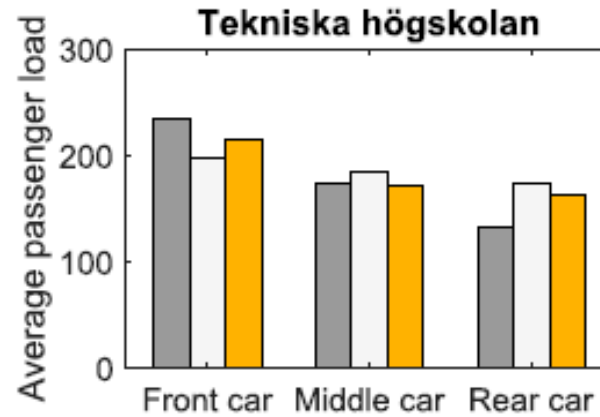
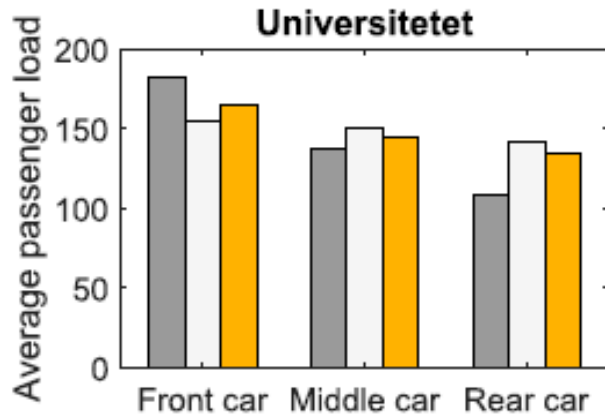
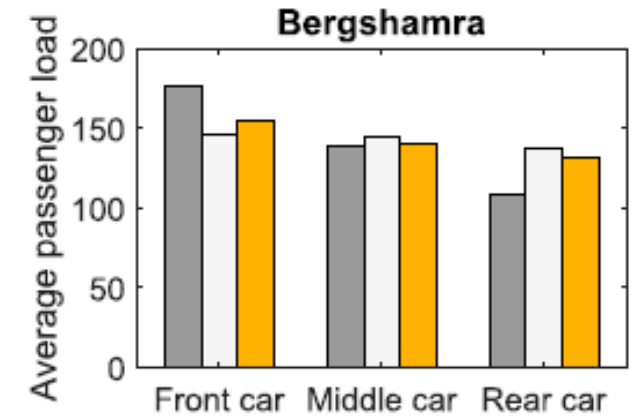
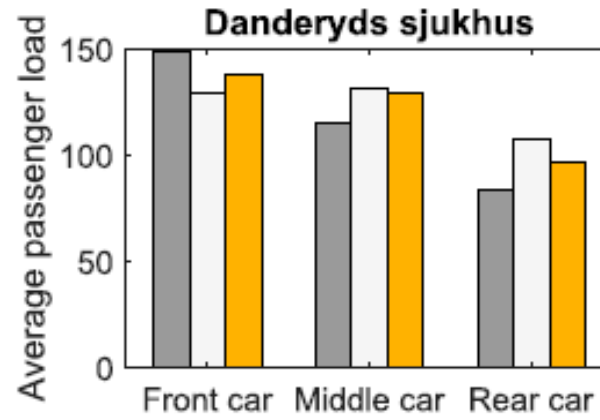
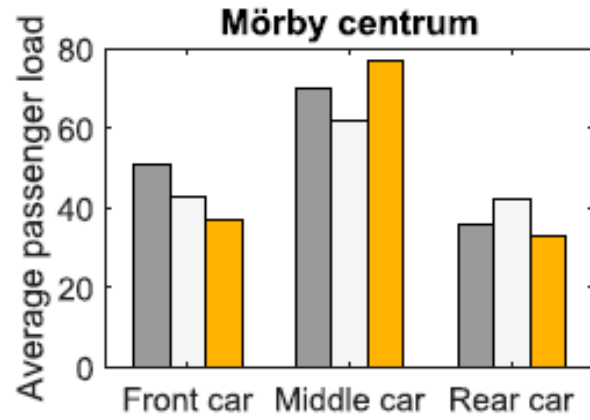


Application: Southbound part of the Red line

- Passengers are skewed towards the leading cars



Model validation



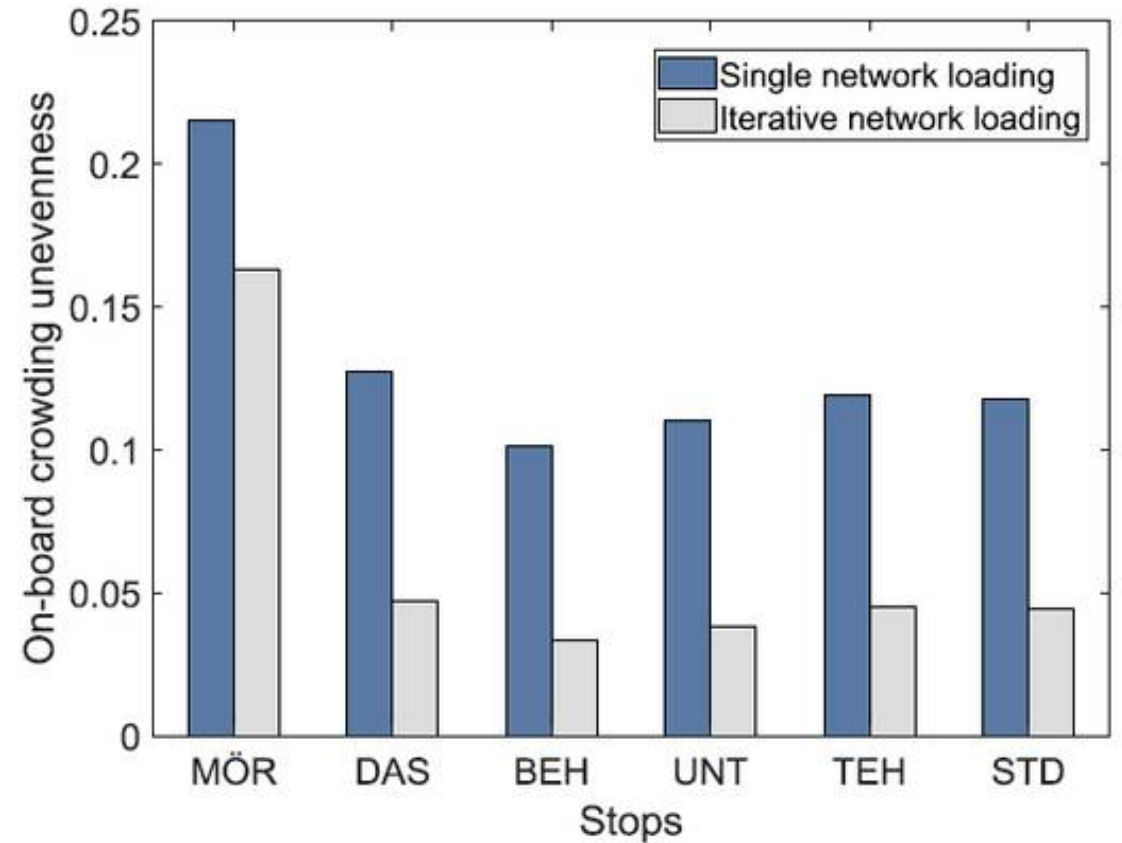
Empirical data
 Simulation output ($\beta_{walk}=2\beta_{inv}$)
 Simulation output ($\beta_{walk}=6\beta_{inv}$)

S c e n a r i o s d e s i g n

- **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.

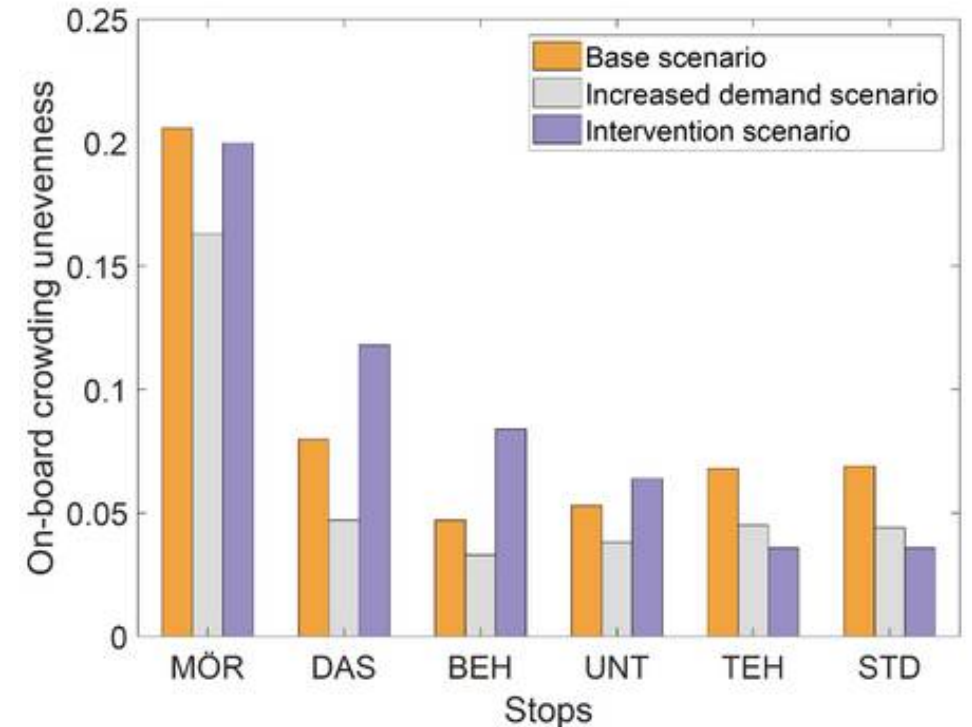
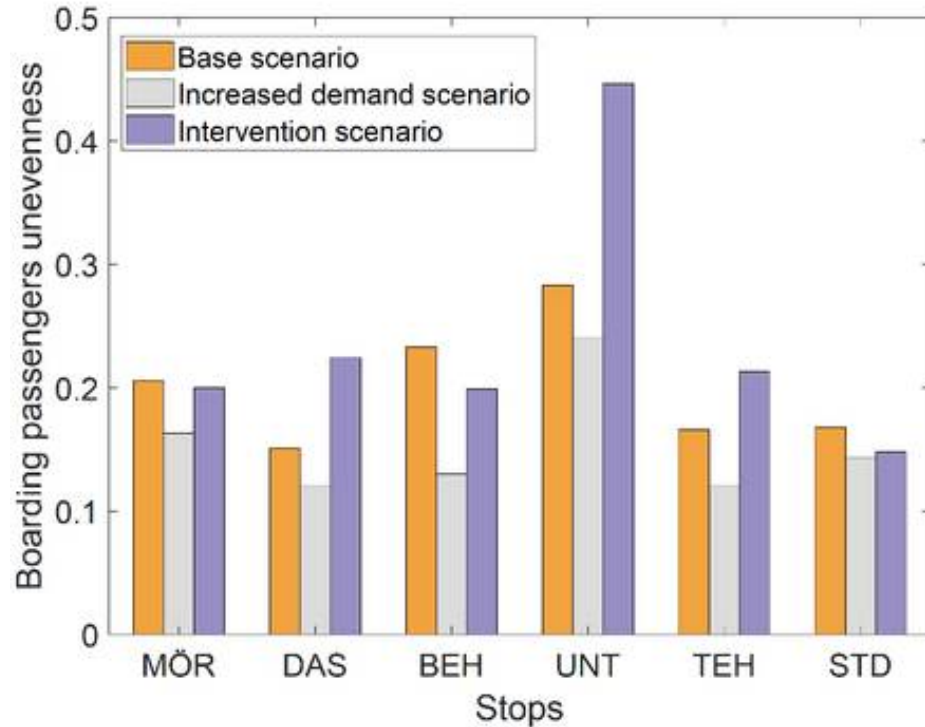
Role of day-to-

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



Information



Real-Time Crowding Information (RTCI)

Stockholm · Sp

Turevillans Metro

- Stockholm Blue Line
- Stockholm Red Line
- Stockholm Green Line

Andra spårstråk Other rail services

- Light Rail
- Commuter Train
- Light Rail
- Light Rail
- Light Rail
- Light Rail
- Light Rail

Förklaringar Key to symbols

- Station
- Transfer
- Barrier
- Barrier

SL Kundtjänst SL Customer Services

For information about SL, visit www.sl.se or call 08-400 4000.

Biljetter Tickets

For information on tickets, visit www.sl.se or call 08-400 4000.



Hiss
Lift



Modelling impacts of information p r o v i s i o n

Performance





Prediction

Provision

Perception

Path choice

Modelling car-specific RTCI in B u s M e z z o

| RTCI level | Car capacity utilization | Crowding factor |
|---|-----------------------------|-----------------|
|  | $\leq 80\%$ seated capacity | 1.0 |
|  | $>80\%$ seated capacity | 1.3 |
|  | $>100\%$ seated capacity | |
|  | $>50\%$ total capacity | 1.8 |

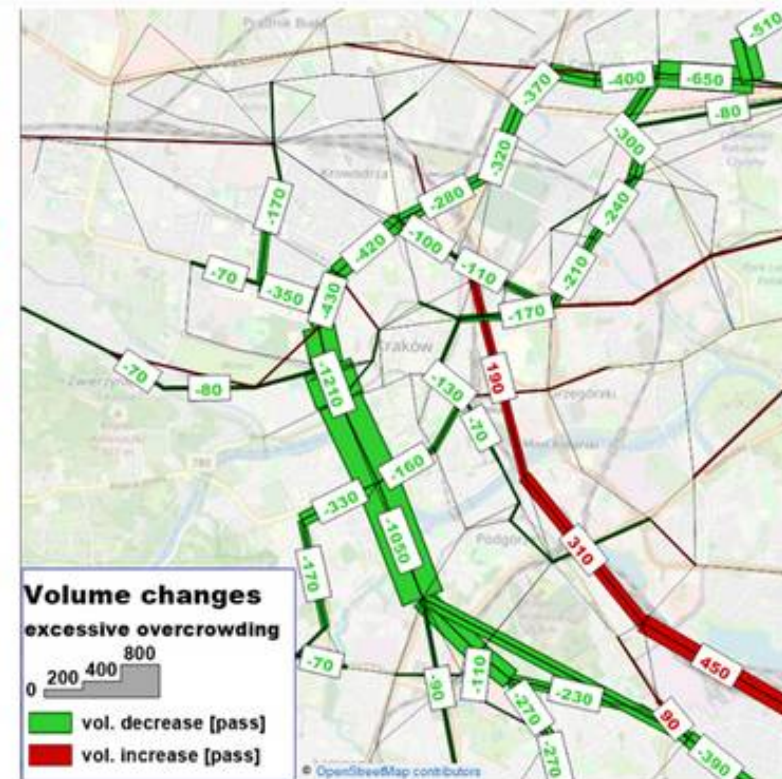
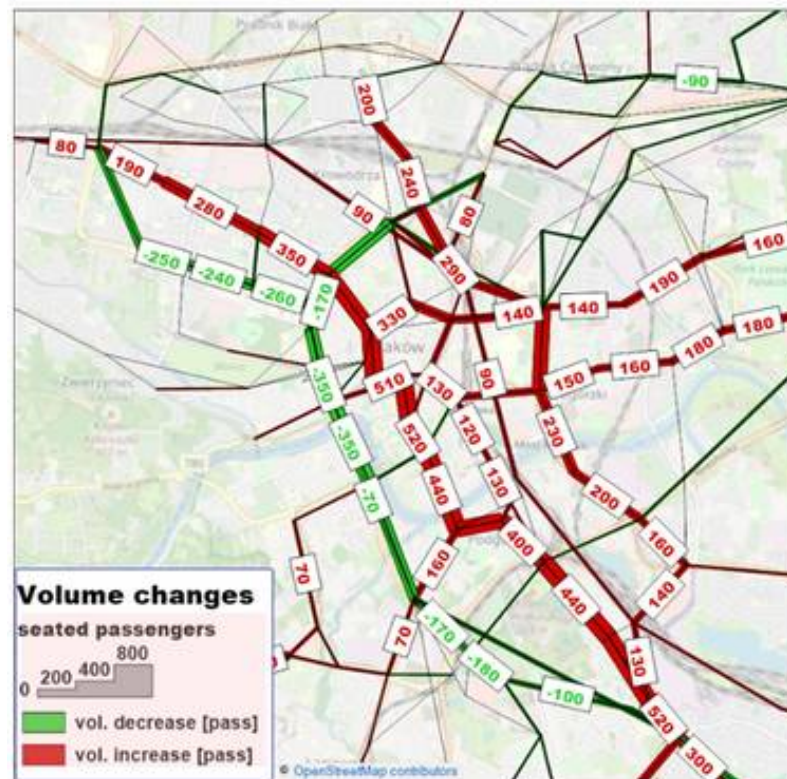
- Predict RTCI for each trip segment based on the measured car crowding level of the *most recent train run*.
- Each passenger utilizes the generated car-specific RTCI, as an *in-vehicle time multiplier* of a given trip segment, in the decision making process.

Already tested at the vehicle

on-board comfort experience – Kraków PM peak hour

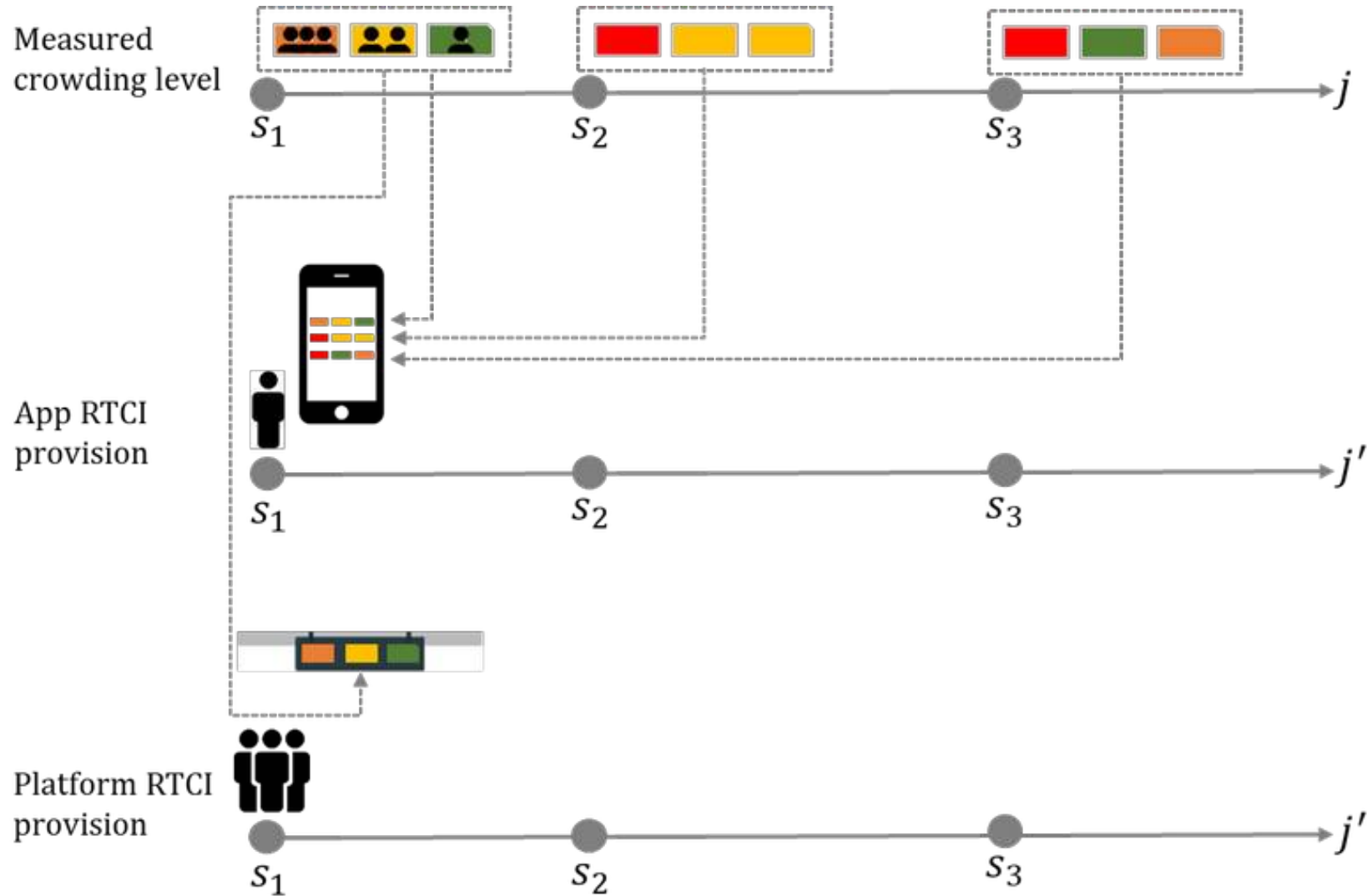
seated passengers: $\Sigma IVT (\beta_{r,\epsilon} \leq 1.2)$

excessive overcrowding: $\Sigma IVT (\beta_{r,\epsilon} = 1.8)$

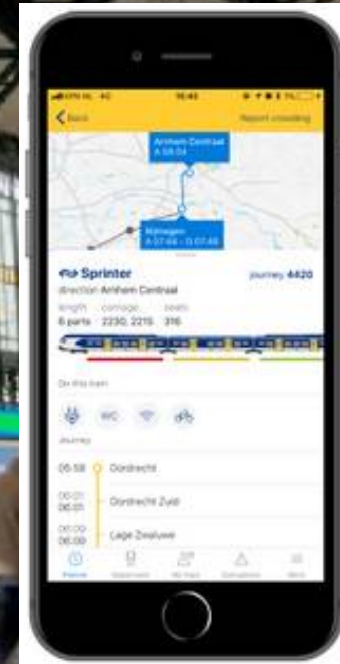


- share of the worst on-board overcrowding experience decreases by 27%
- waiting time due to denied boarding are reduces by 30%

RTCI provision schemes



Application

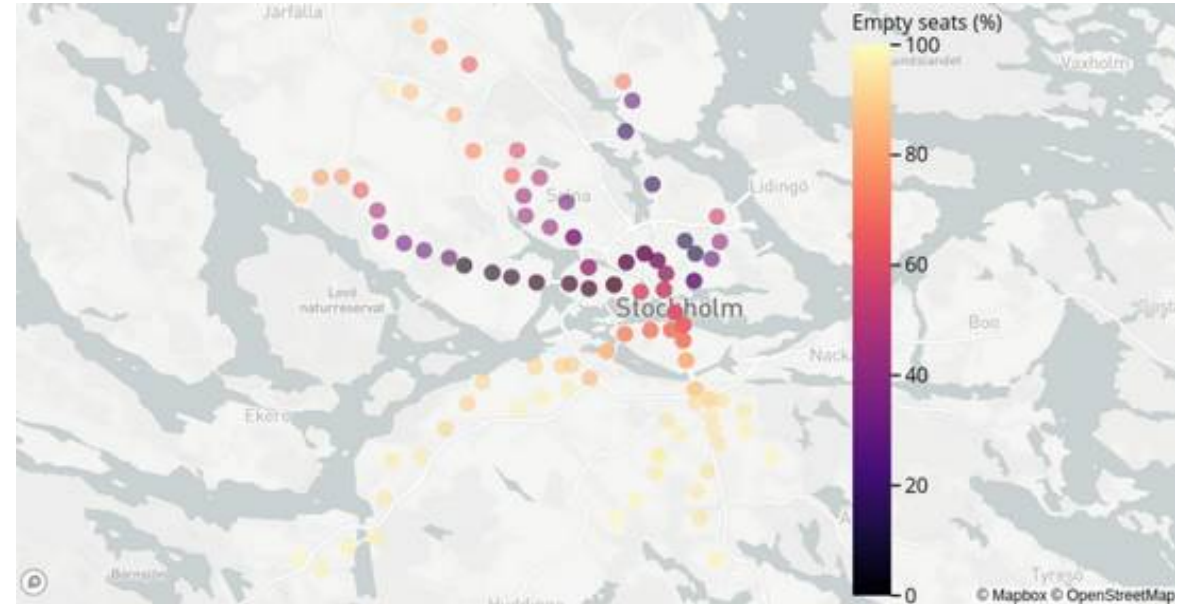


Case study application

- 1 million passengers daily
- 20% of the seats remain empty in the morning peak hour
- Scenarios
 - App with varying penetration
 - 10 most heavily loaded stations with the largest unevenness of boarding passengers



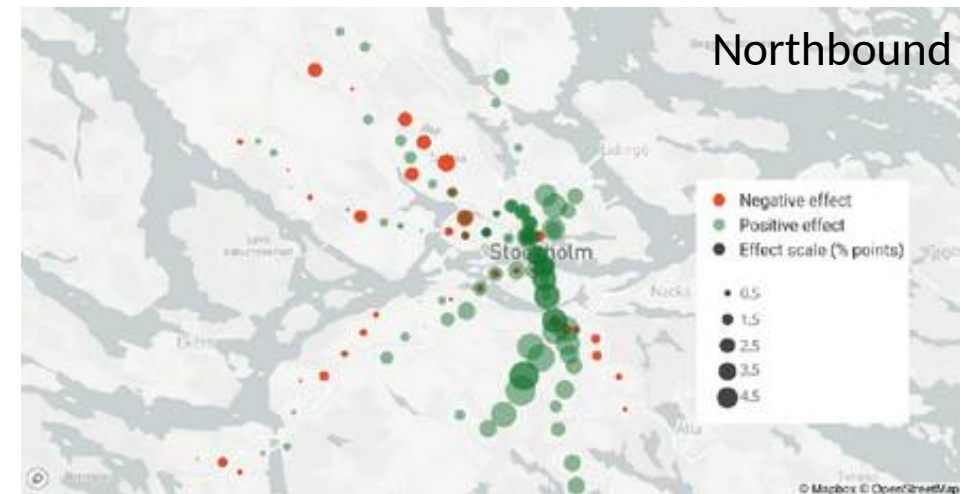
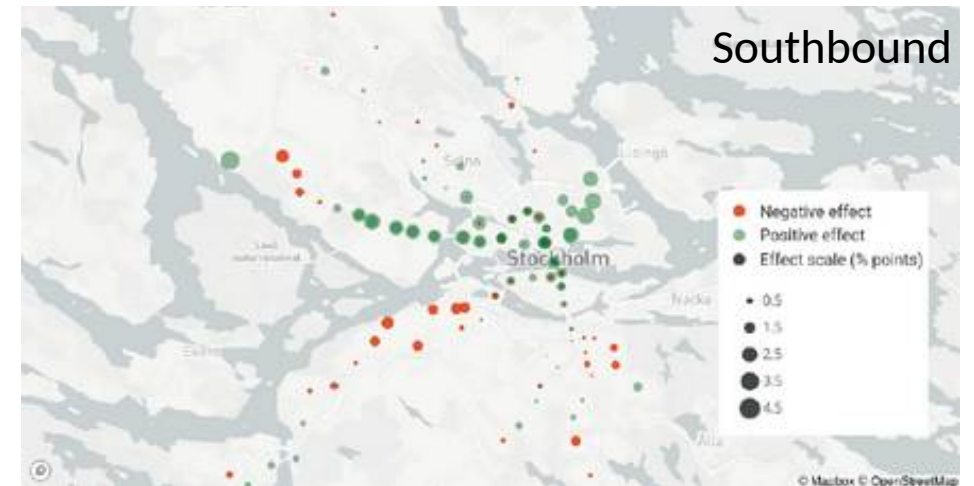
Even when passenger load exceeds total seated capacity (378) for the train as a whole, there are still seats that remain unoccupied in individual cars.



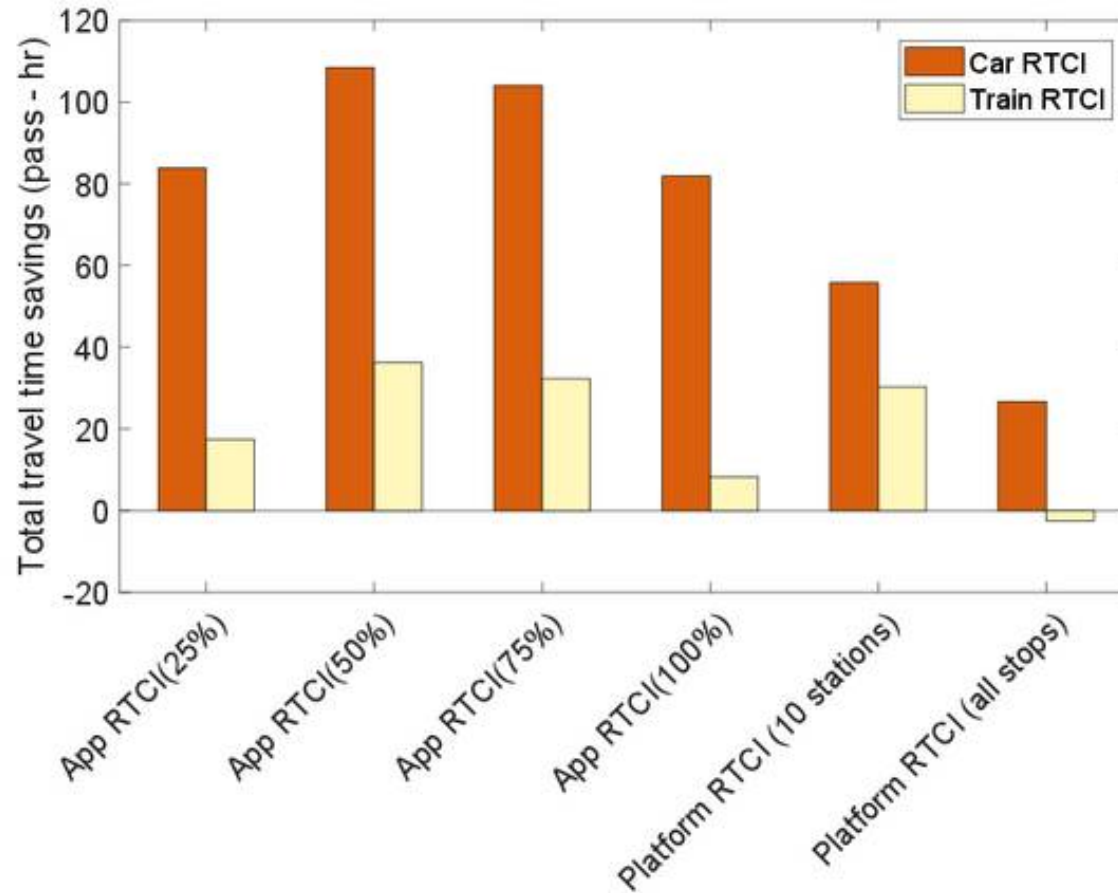
Effect of RTCI on on-board crowding unevenness

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

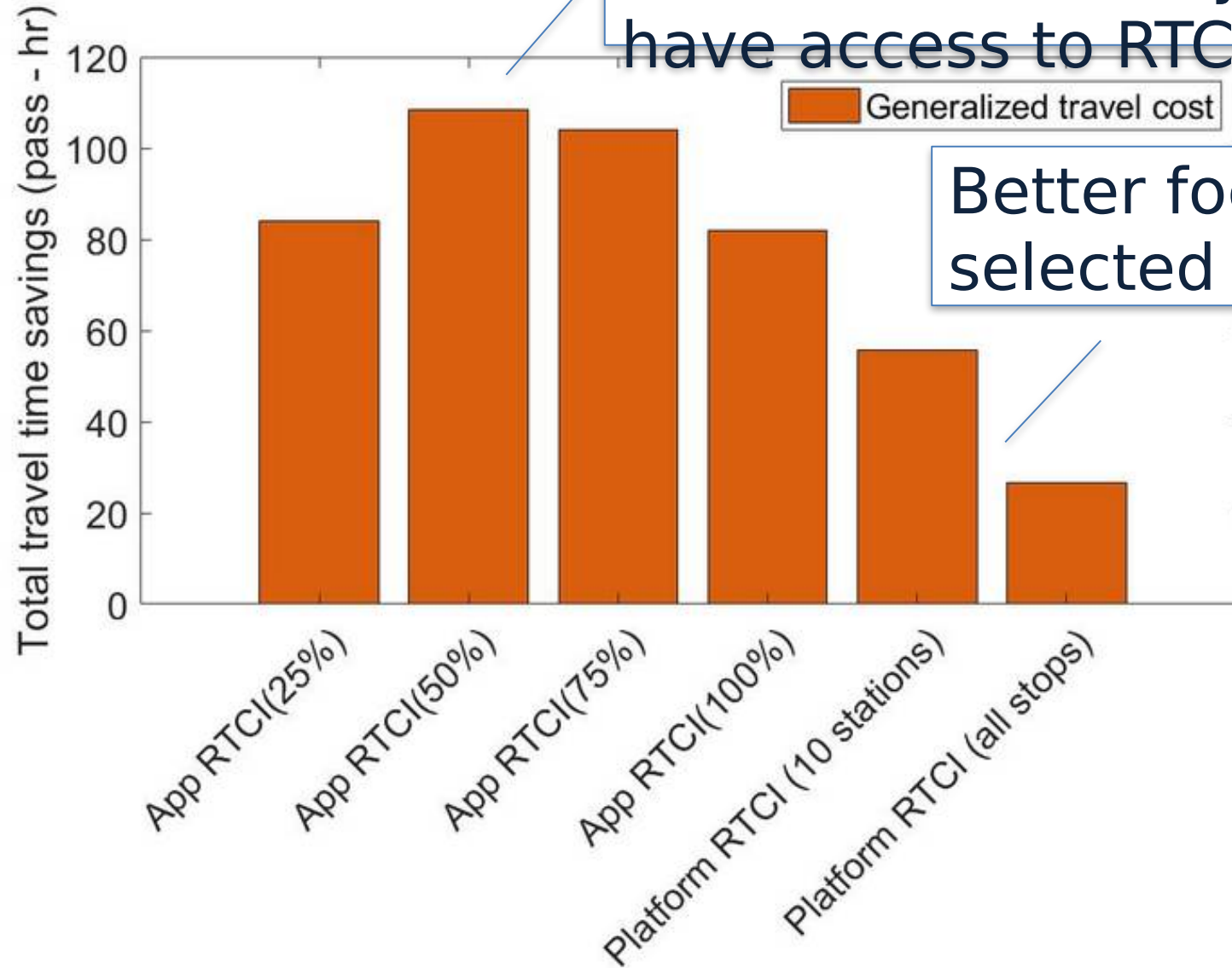


RTCI at train- vs. car-level

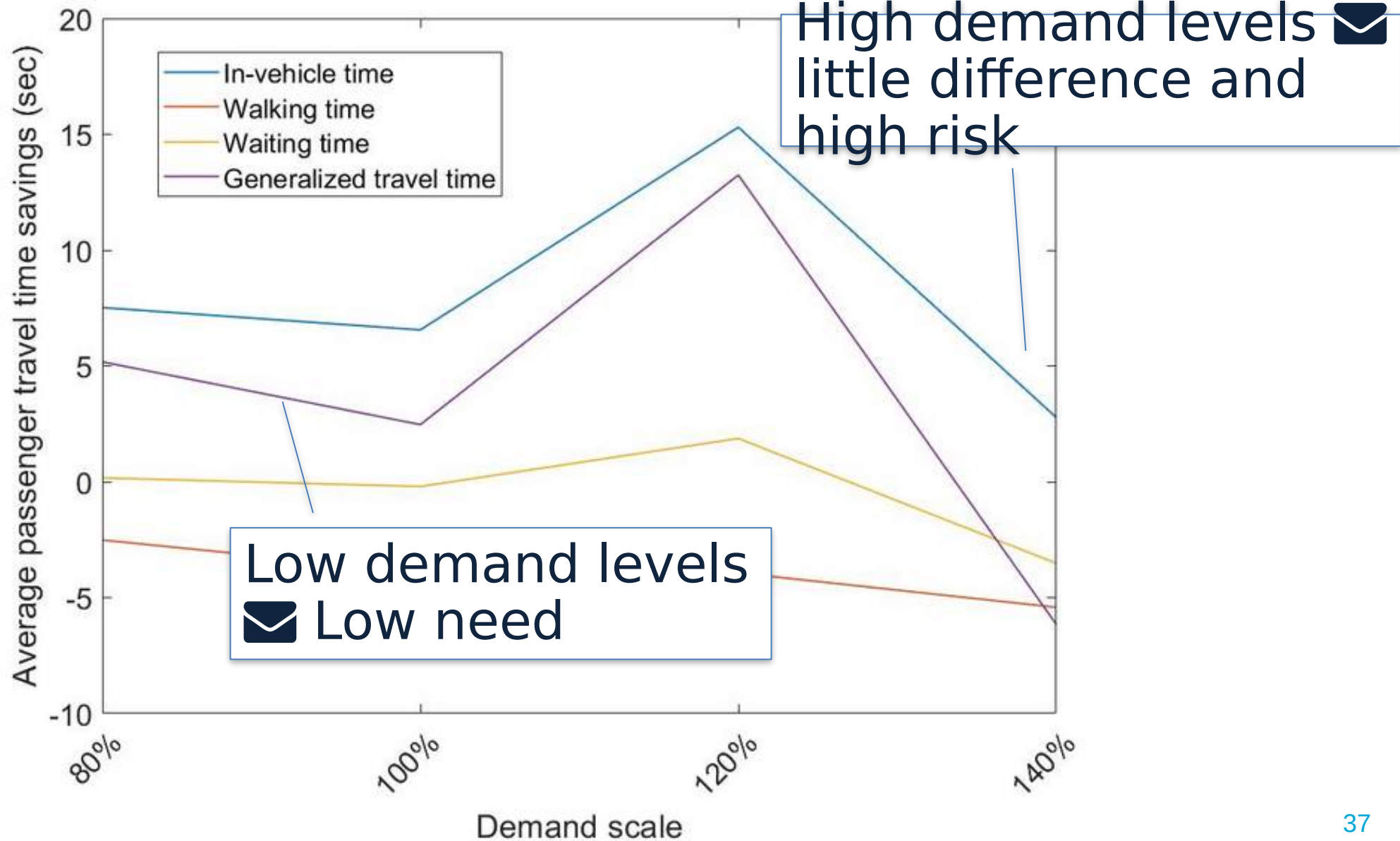


- Train-level assumes an even on-board crowding distribution
- Train-level information is less actionable

Effect of app-based RTCI on passenger generalization



Sweet demand spot?



A modern transit station with escalators and a large digital display. The scene is captured from an elevated perspective looking down at two escalators in the foreground. The floor is a mix of light-colored tiles and a darker, reddish-brown material. In the background, a large digital display shows a blue and white abstract pattern. A black banner with white text is overlaid on the image. Above the banner, a sign reads "Pendeltåg Commuter trains" with an upward arrow and icons for accessibility. The overall atmosphere is clean and contemporary.

Next steps

On-going and future work

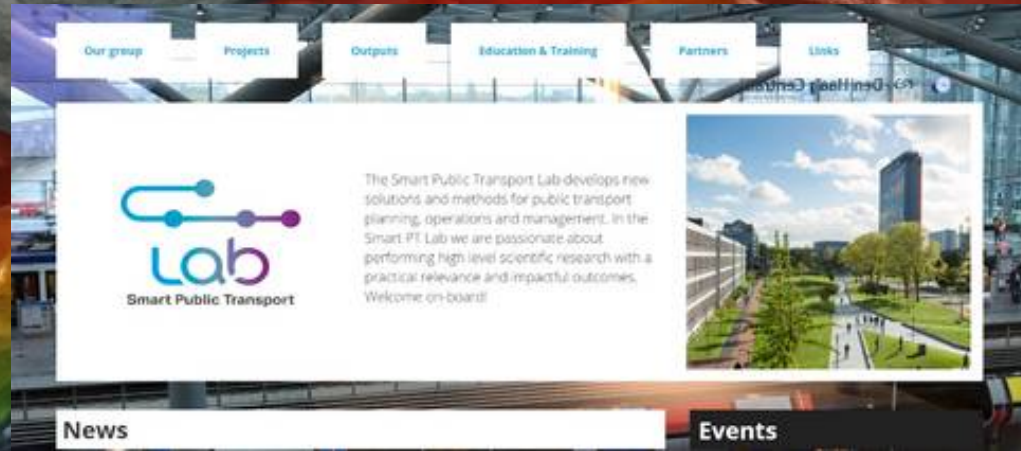
- Using the simulation tool to devise service planning and control measures (e.g. skip-stop operations)
- Demand management tool (e.g. anti-bunching)
- Crowding perceptions during the pandemic
- Customized information

Relevant references: Data analysis


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[Determinants of Passengers' Metro Car Choice Revealed through Automated Data Sources: A Stockholm Case Study](#)
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- Peftitsi S., Jenelius E. and Cats O. (2021).
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[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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