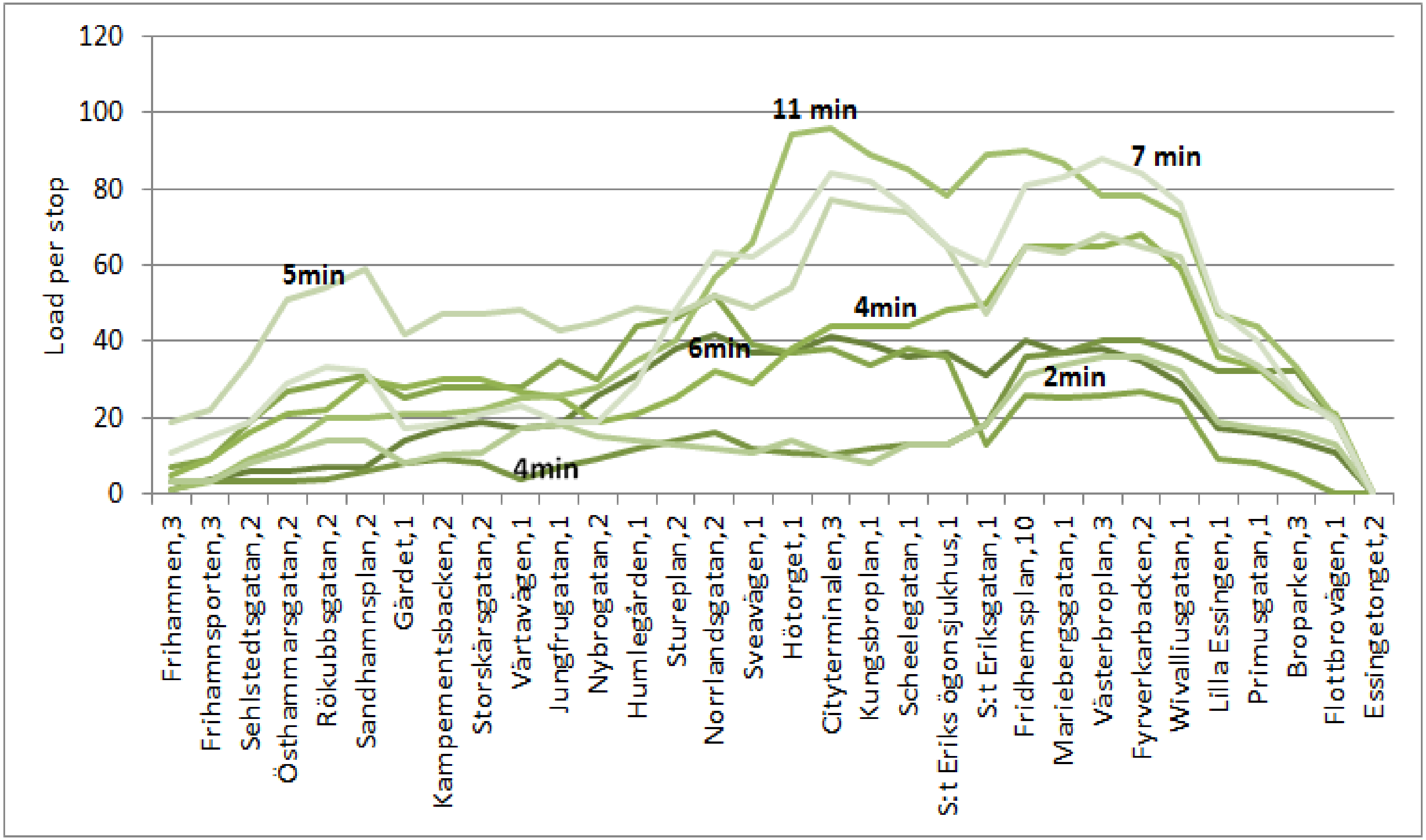
An Empirical Evaluation of Measures to Improve Bus Service Reliability

Performance Metrics and a Case Study in Stockholm

Masoud Fadaei Oshyani and Oded Cats
KTH, Sweden / TU Delft, The Netherlands

Service unreliability: A vicious cycle

Line 1, Stockholm



How can we improve regularity without compromisning speed?

Urban mobility strategy

Objective B2

Rapid transit traffic in the inner city* will have an average speed (including stops) of 20 km per hour by 2030.

What results will be achieved by fulfilling the objective?	Those who choose to travel by public transport on the city's roads and streets will acquire attractive and reliable journey times. This will make public transport more attractive, increase freedom of choice and reserve the roads for essential car journeys and commercial traffic.
How does this fulfil the vision?	Measured worldwide, Stockholm will be the city whose inhabitants use public transport the most. With an increasing number of people using public transport on the city's streets, it is necessary to prioritise and improve their access if this vision is to be achieved..
What is required to fulfil the objective?	The strategy for how buses and trams that belong to the rapid transit network in the city will be permitted to drive at higher speeds will be produced in a rapid transit network strategy. Dedicated lanes and signal priority are a prerequisite. This involves taking space away from vehicular traffic and parked cars, and that the rapid transit network is prioritised by traffic signals, which reduces accessibility for other road users in certain places. This also requires an optimal distance between stops and good opportunities for fast boarding and alighting.
What will happen if we do not do this?	If public transport cannot offer attractive journey times, more people will choose to travel by car. More cars in the same amount of space will lead to increased congestion and less reliable journey times.
Who is responsible?	The Traffic and Waste Management Committee is responsible for designing the traffic environment in a manner that supports fast and reliable rapid transit traffic. The City Development Committee and the City Planning Committee share the responsibility for this also functioning in new street environments. The Stockholm County Council in its role of public transport authority also carries a major share of the responsibility for bus and tram traffic meeting the target speed.
What is the situation today?	In 2010, the average speed for rapid transit buses in the inner city, including stops, was 14 kph.

Bus preferential measures

- Running time
  - Right of way
  - Street layout
  - Demand management

- Crossing time
  - Priority in time
  - Priority in space

- Dwell time
  - Stop layout
  - Fare validation
  - [stop consolidation]

Reliability

A series of field experiments

RETT2

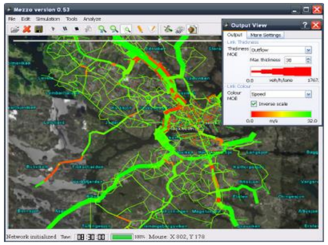
- Experiment – L1
- Focus on regularity, decentalization

RETT3

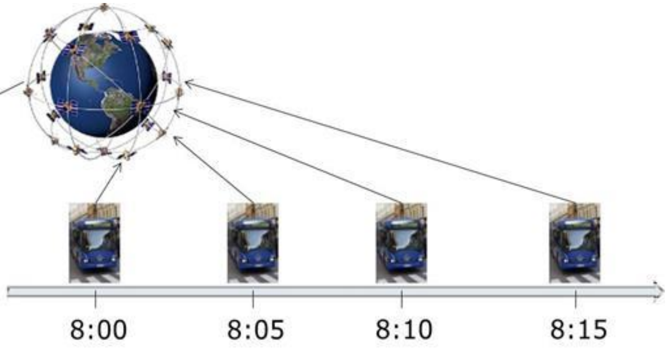
- Experiment – L1; L3
- Clean-operations, control center actions
- Led to its incorporation in the tendering process

RETT4

- Experiment – L4
- Additional measures – boarding, priority
- Support full-scale implementation



Adaptive headway-control strategy

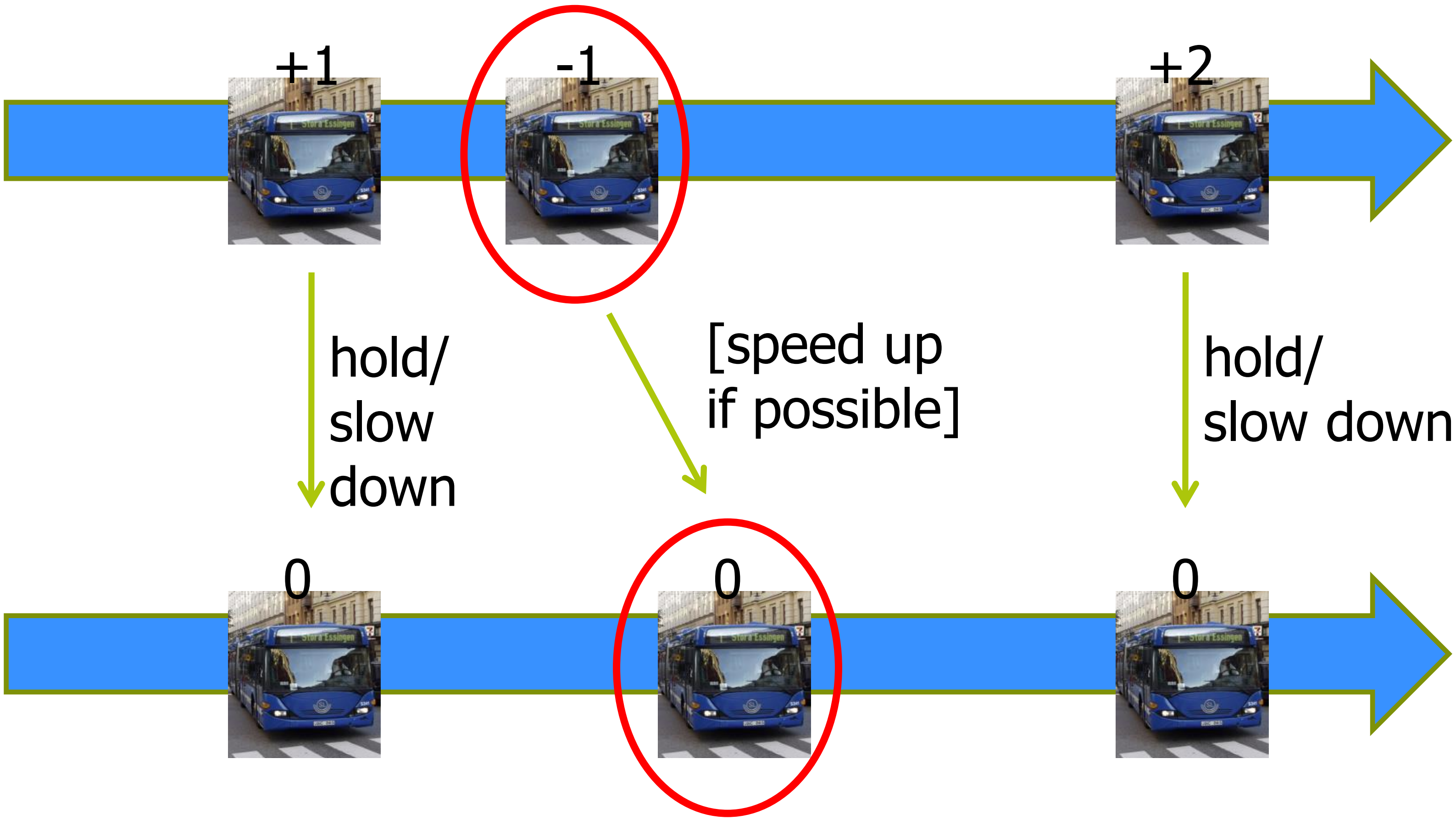


- Various strategies were evaluated using BusMezzo

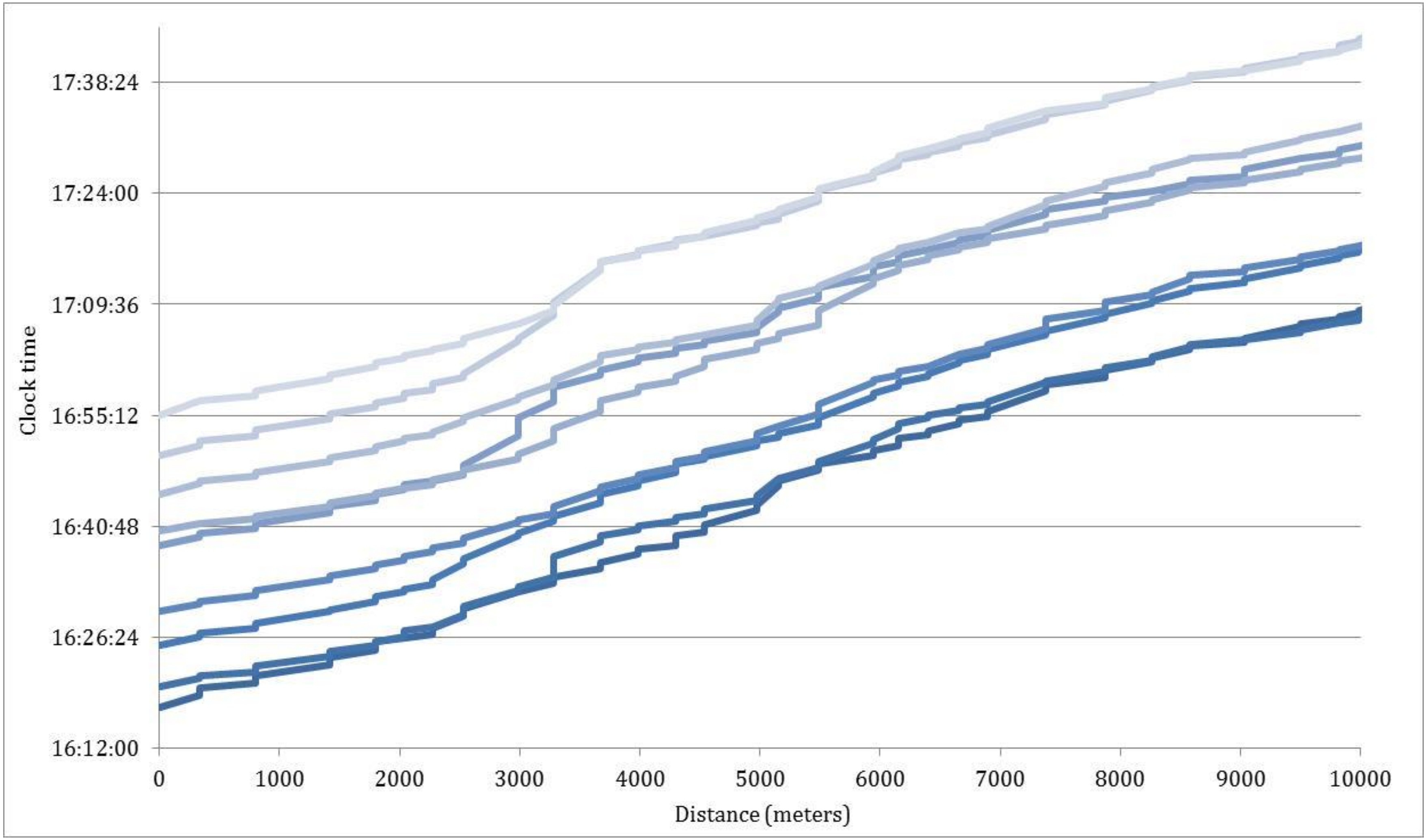
- The most promising strategy
  - Try to remain in the middle with respect to the preceding and successive buses
  - Adjust your speed if possible
  - Disregard the timetable

$$ET_{s,l}^{k} = \max\left(\min\left(AT_{s,l}^{k-1} + \frac{AT_{m,l}^{k+1} + SRT_{m,s} - AT_{s,l}^{k-1}}{2}, AT_{s,l}^{k-1} + \alpha \mathrm{h}_{\mathrm{s,l}}^{\mathrm{k}}\right), AT_{s,l}^{k} + DT_{s,l}^{k}\right) \quad \forall s \in S_{l}^{k}$$

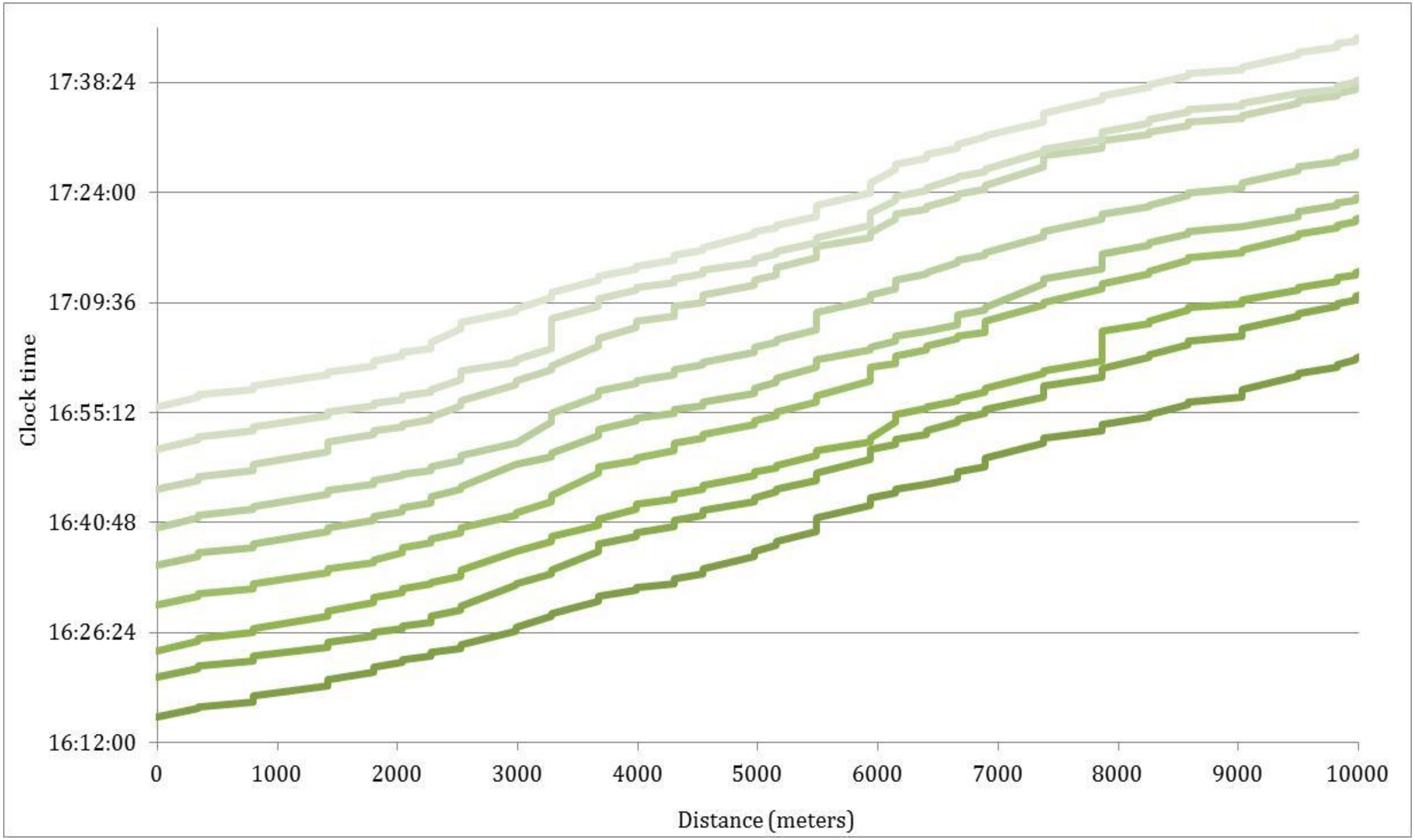
Decentralized headway control



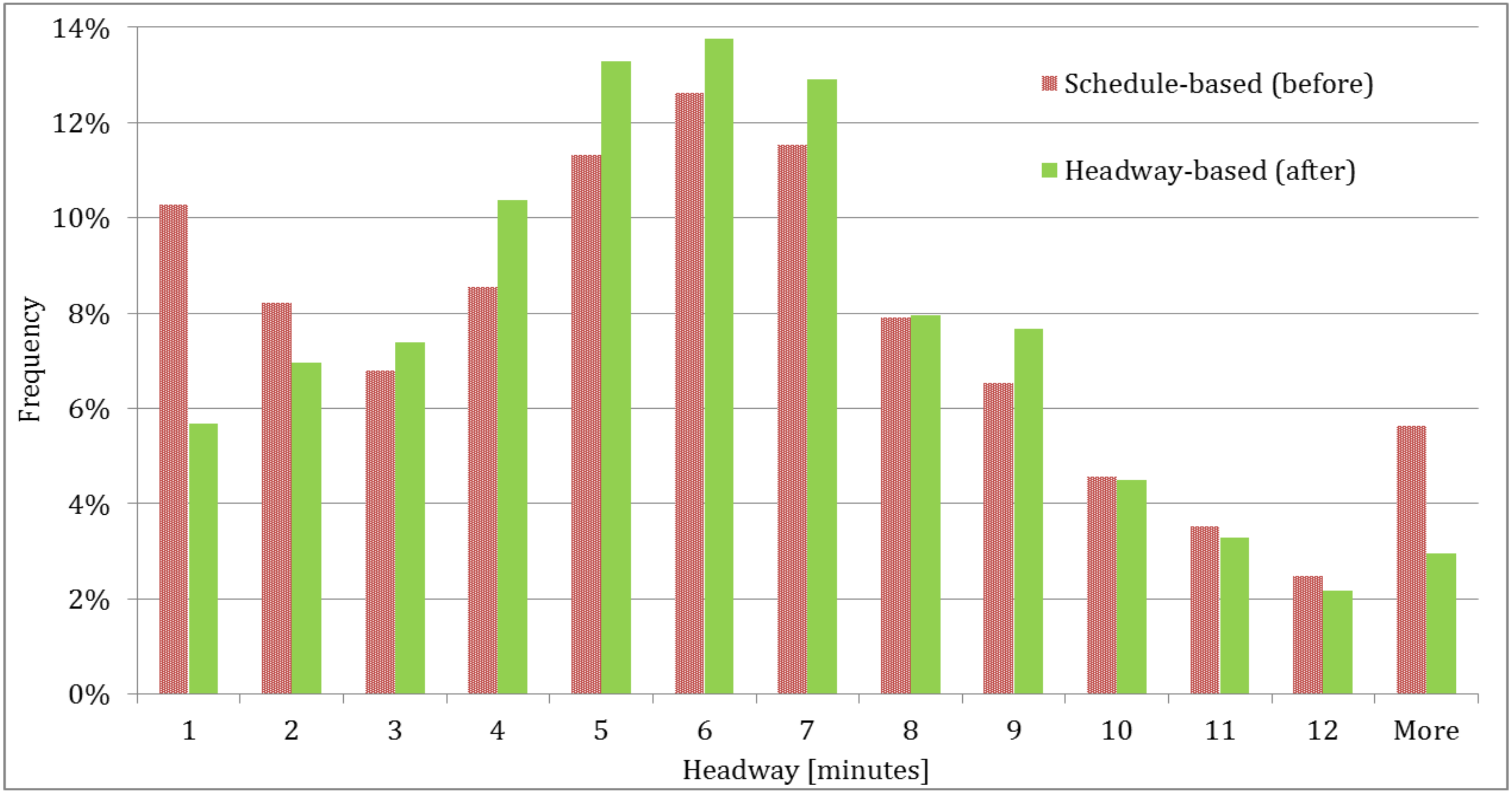
Before (RETT3) – buses form platoons



After (RETT3) – control implementation

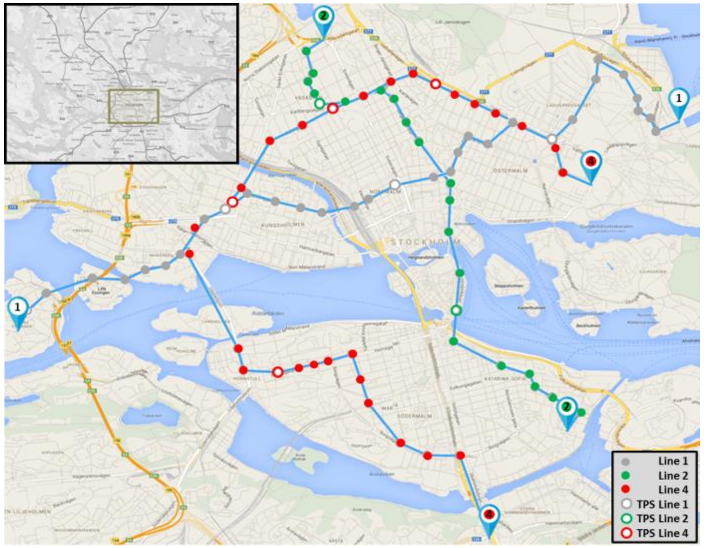


Also at the aggregate level – Headway distribution



Line 4 Stockholm
Fact sheet

- Route: 31 stops along 12km, cross-radial inner-city line
- Commercial speed: 12.56 km/hr
- Frequency: 4-6 minutes all day long
- Vehicle: Articulated buses
- Demand: 65,000 passengers per day



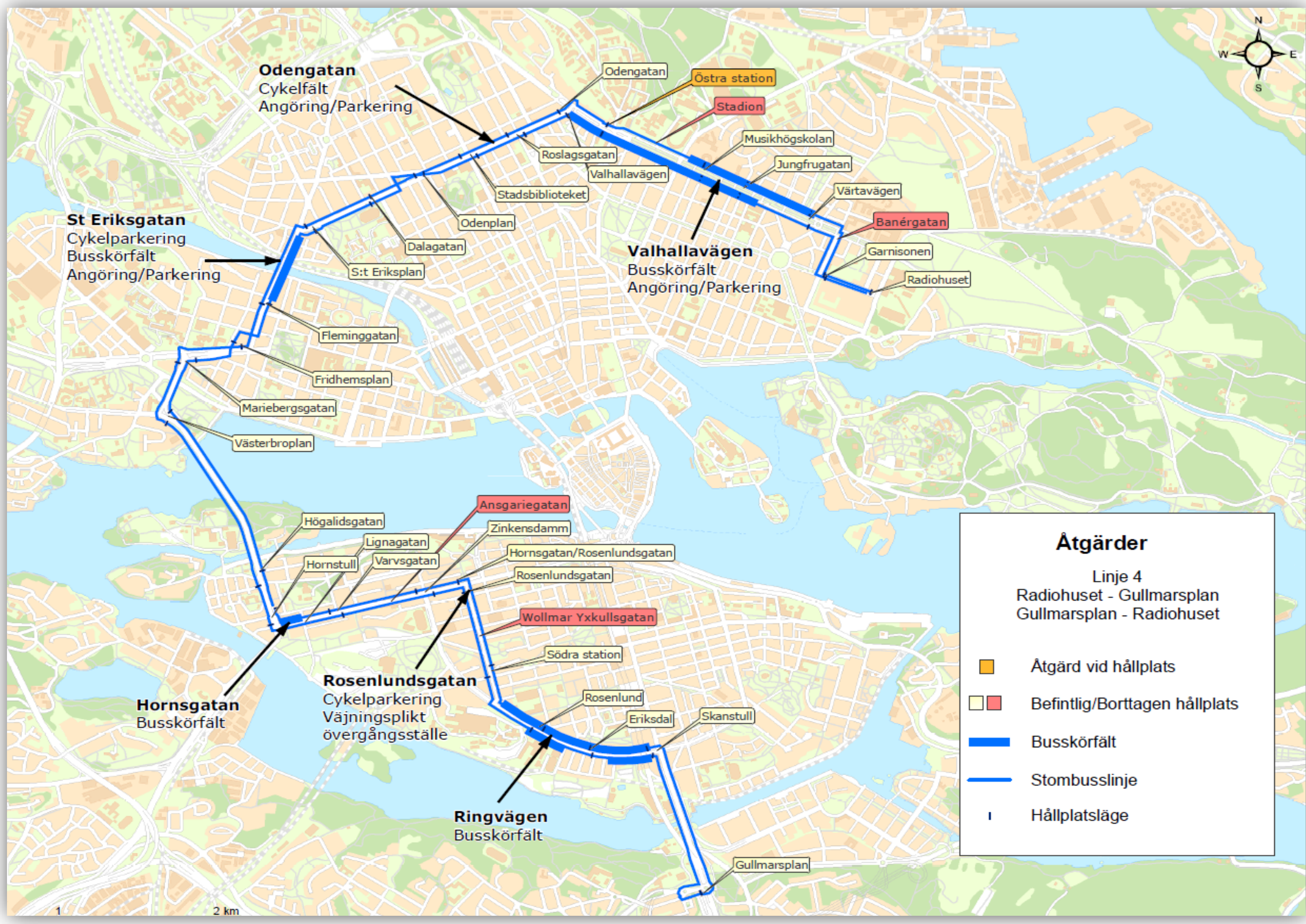
Line 4 Stockholm
Field experiment details

- Measures
  - ✓ Introducing bus lanes on some line sections
  - ✓ Cancelling 4 stops
  - ✓ Running based on regularity
  - ✓ Improving transit signal priority
  - ✓ Allowing restricted boarding from the third door
  - ✓ Street layout changes

- Period: 17-03-2014 – 19-06-2014
  - AVL (100%) and APC (15%) data
  - Compare with same period in 2013

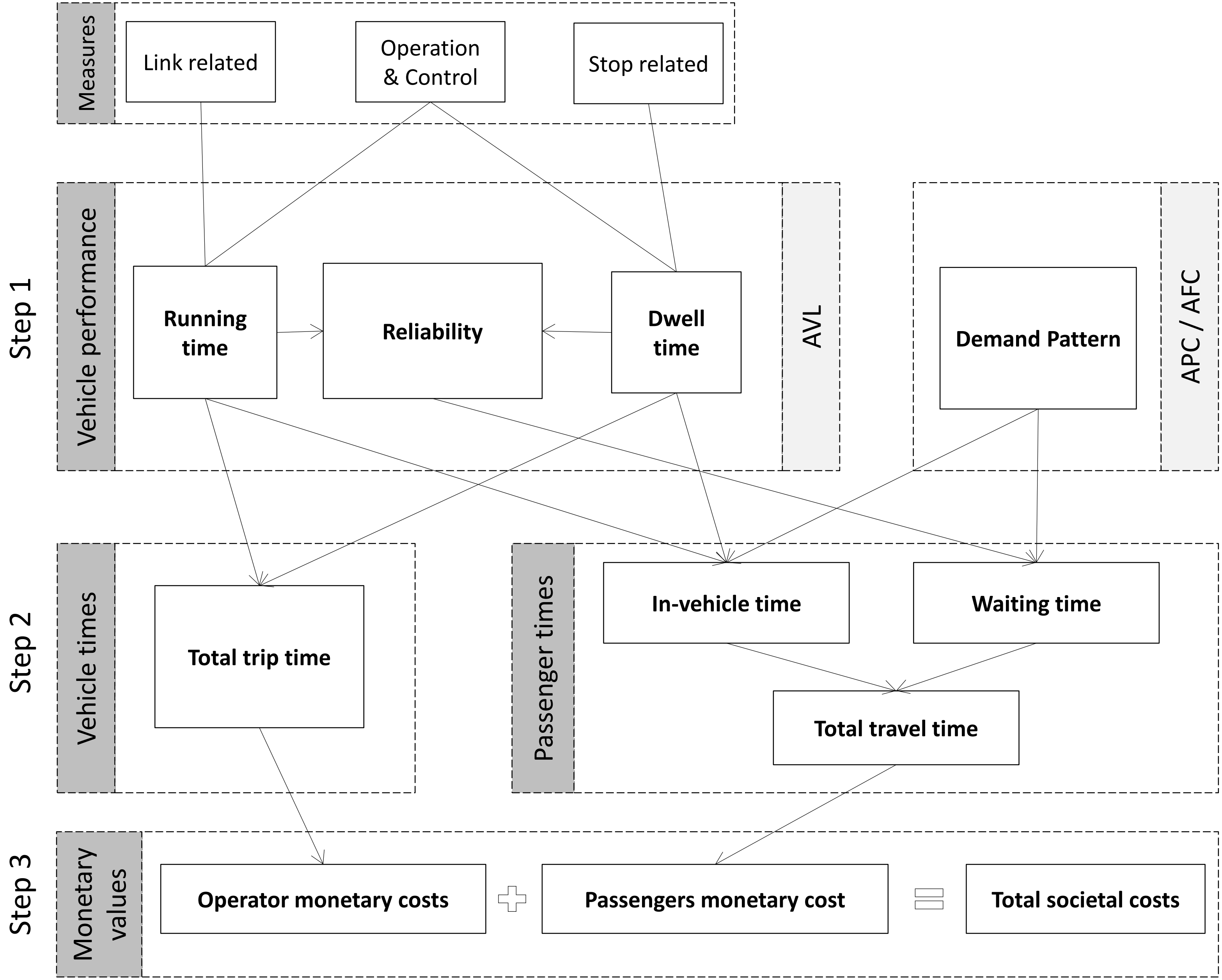

Gullmarsplan
Lewéns
CRAFT


Gullmarsplan



Odengatan
Cykelfält
Angöring/Parkering
St Eriksgatan
Cykelparkering
Busskörfält
Angöring/Parkering
Valhallavägen
Busskörfält
Angöring/Parkering
Hornsgatan
Busskörfält
Rosenlundsgatan
Cykelparkering
Väjningsplikt
övergångsställe
Ringvägen
Busskörfält
Odengatan
Östra station
Stadion
Musikhögskolan
Jungfrugatan
Värtavägen
Banérgatan
Garnisonen
Radiohuset
Roslagsgatan
Valhallavägen
Stadsbiblioteket
Odenplan
Dalagatan
S:t Eriksplan
Fleminggatan
Fridhemsplan
Mariebergsgatan
Västerbroplan
Högalidsgatan
Lignagatan
Hornstull
Varvsgatan
Ansgariegatan
Zinkensdamm
Hornsgatan/Rosenlundsgatan
Rosenlundsgatan
Wollmar Yxkullsgatan
Södra station
Rosenlund
Eriksdal
Skanstull
Gullmarsplan
Åtgärder
Linje 4
Radiohuset - Gullmarsplan
Gullmarsplan - Radiohuset
Åtgärd vid hållplats
Befintlig/Borttagen hållplats
Busskörfält
Stombusslinje
Hållplatsläge
N
W
E
S
2 km

Evaluation framework



Passenger travel time metrics

- Average passenger waiting time

$$\frac{1}{\sum_{k\in K}\sum_{i=1}^{|S|-1} b_{k,s_i}}\sum_{k\in K}\sum_{i=1}^{|S|-1} b_{k,s_i}\cdot\frac{h^{o}_{k,s_i}}{2}$$

- Average passenger in-vehicle time

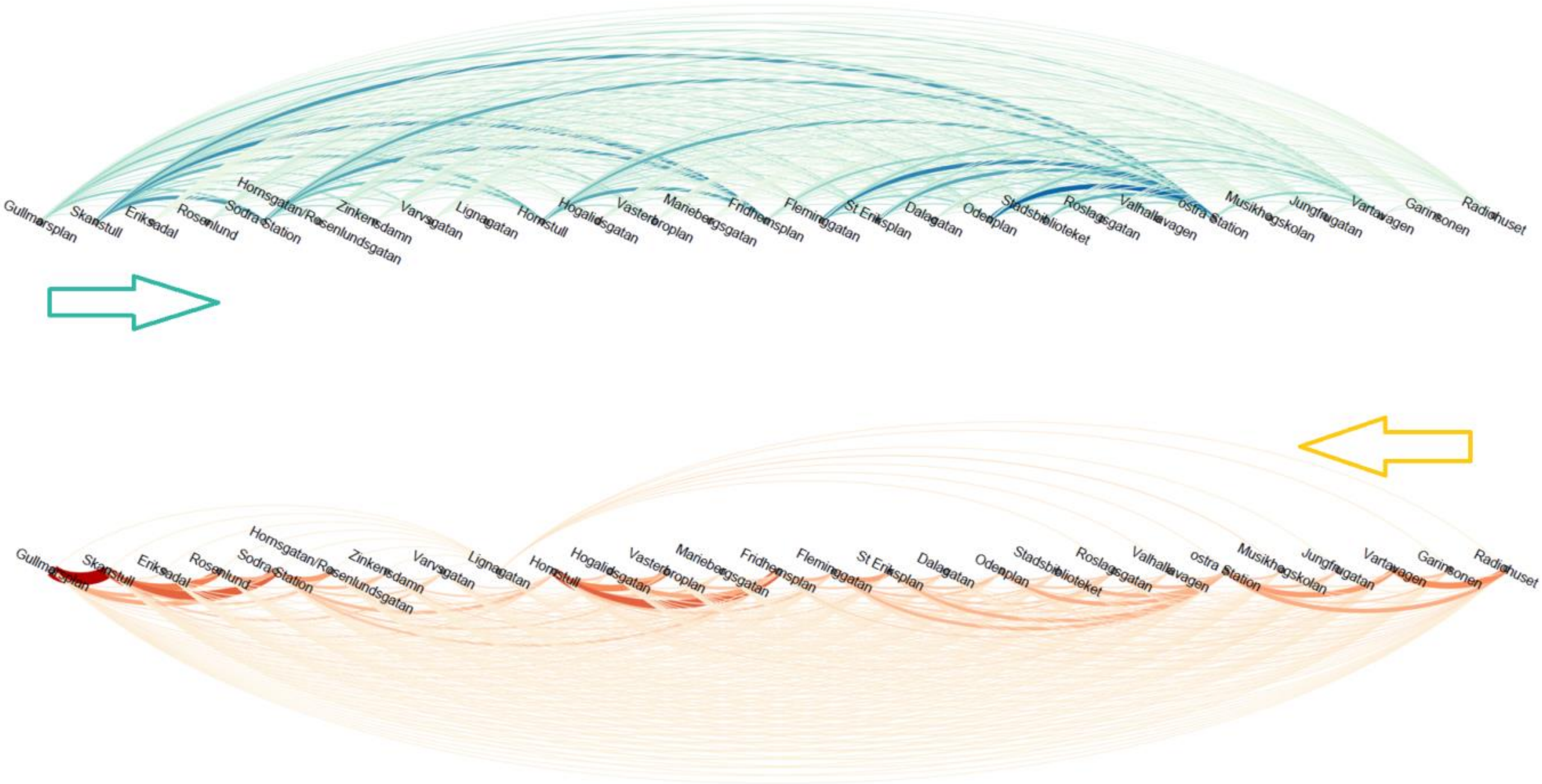
$$\frac{1}{\sum_{k\in K}\sum_{i=1}^{|S|-1} l_{k,s_i}}\sum_{k\in K}\sum_{m=1}^{|S|-1} l_{k,s_m} * \left[t^{dwell}_{k,s_m} + t^{running}_{k,s_m}\right]$$

- Average generalized passenger in-vehicle time

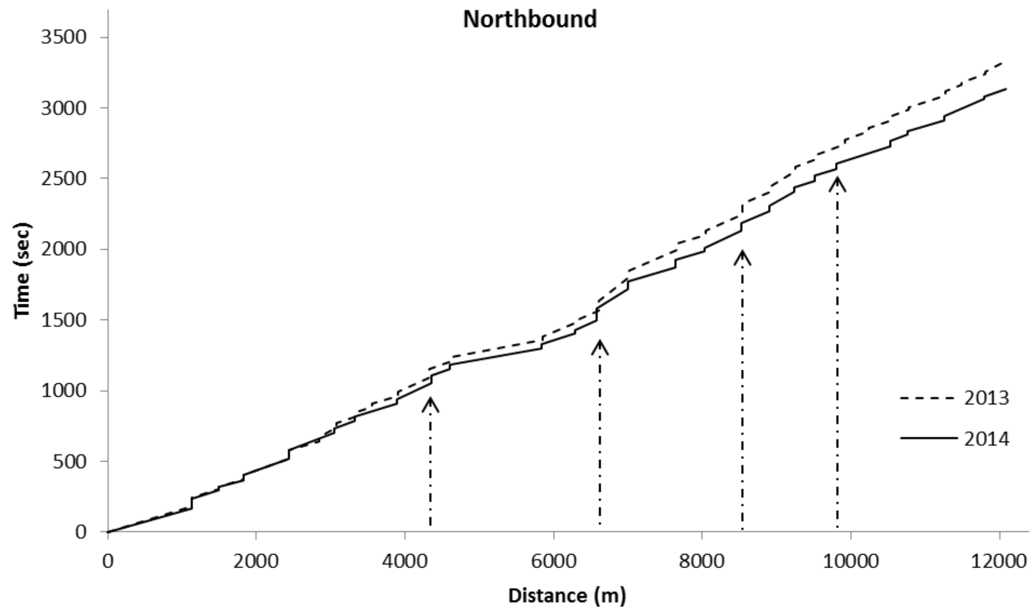
$$\frac{1}{\sum_{k\in K}\sum_{i=1}^{|S|-1} l_{k,s_i}}\sum_{k\in K}\sum_{i=1}^{|S|-1} PIVT_{k,s_i}$$

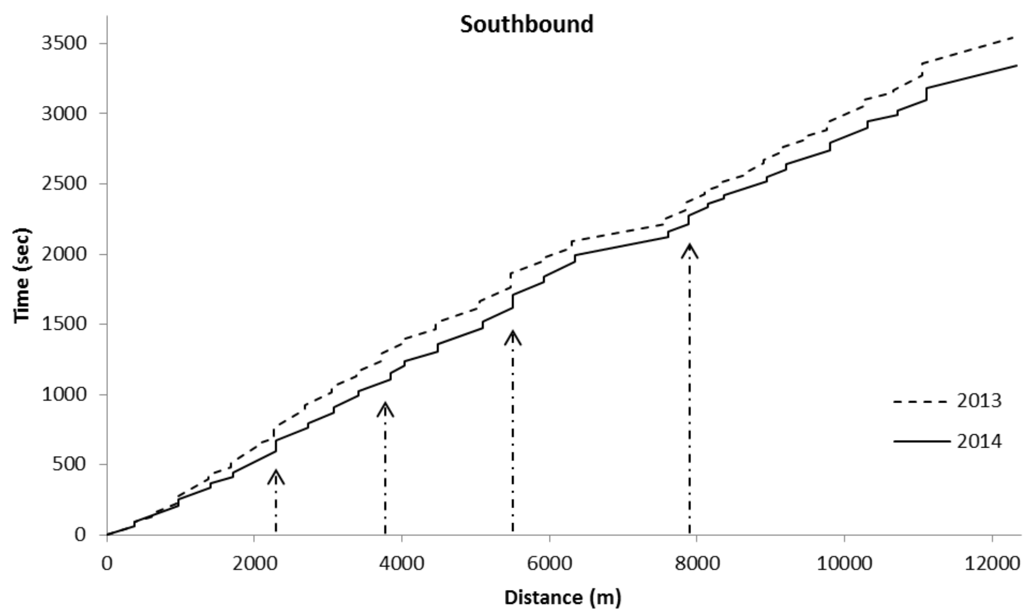
$$\left[\min\left(\gamma_{k,s_i},1\right) * v^{seat}_{k} * \beta^{sitting}_{k,s_i} + \max\left(0,\left(\gamma_{k,s_i}-1\right)\right)\left(l_{k,s_i} - v^{seat}_{k}\right) * \beta^{standing}_{k,s_i}\right]\cdot\left[t^{dwell}_{k,s_i} + t^{running}_{k,s_i}\right]$$

Estimating OD matrix from APC
15:00-18:00, 2014



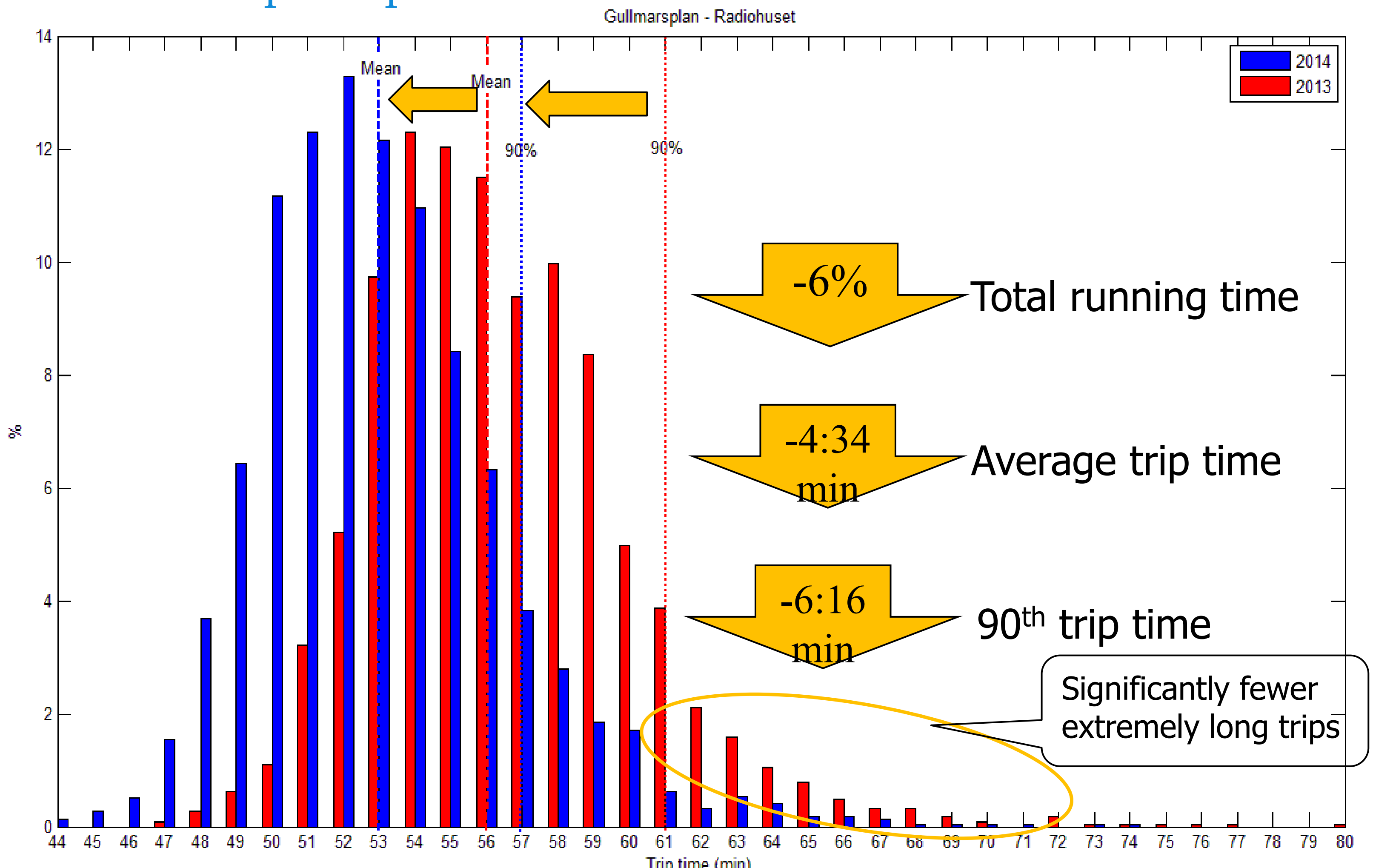
Vehicle trajectories





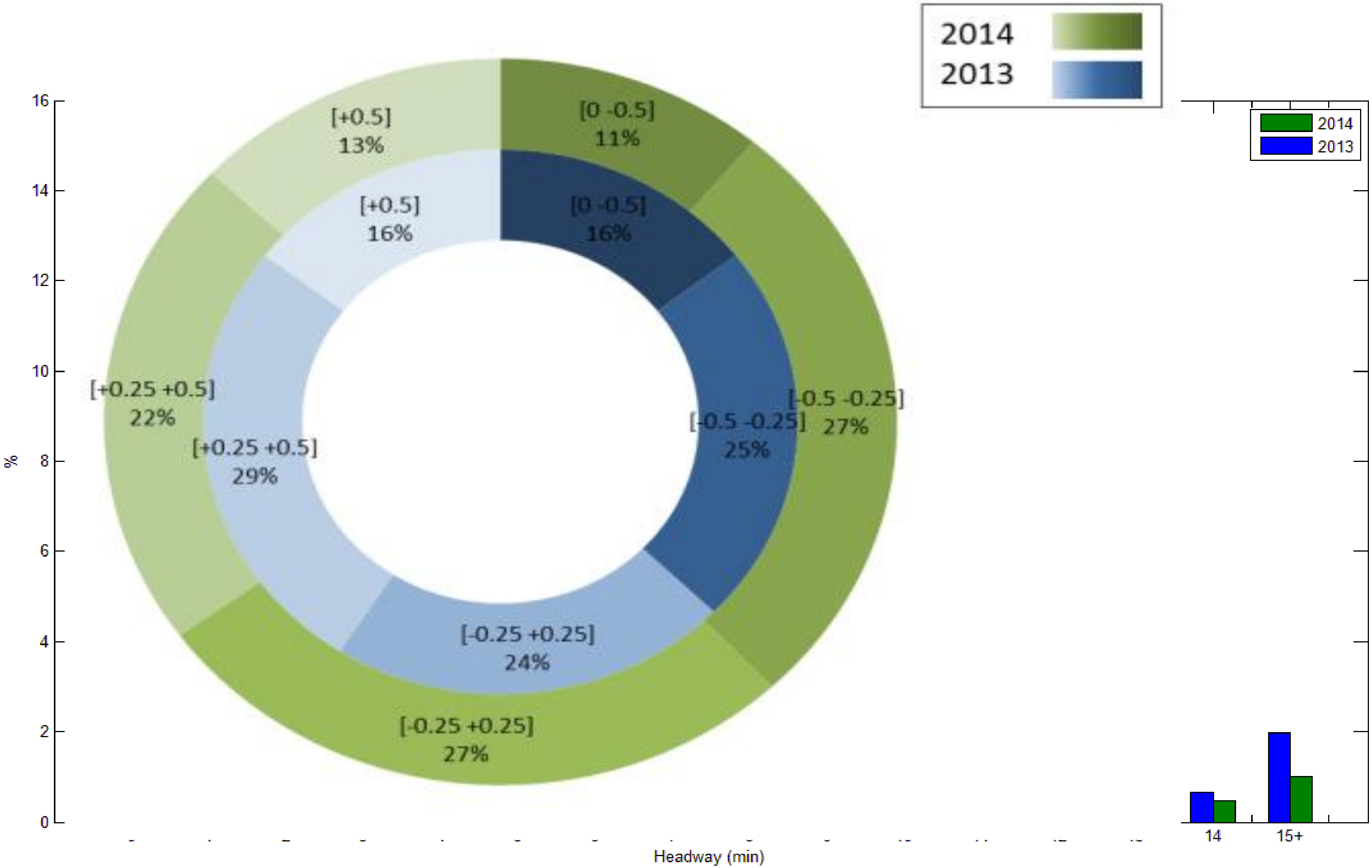
More reliable fleet operations

Afternoon peak period

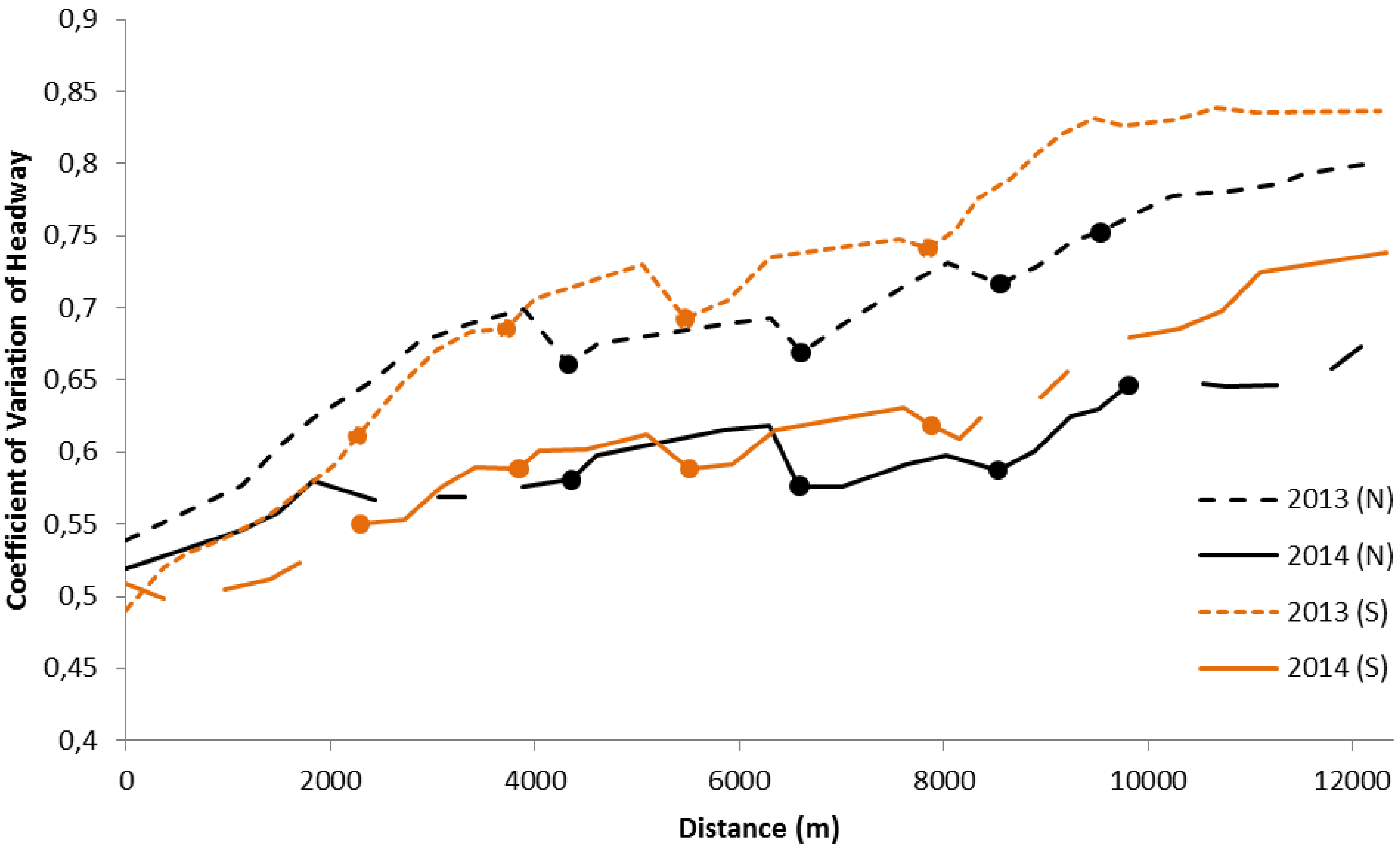


Can run 26 instead of 28 buses and attain the same frequency

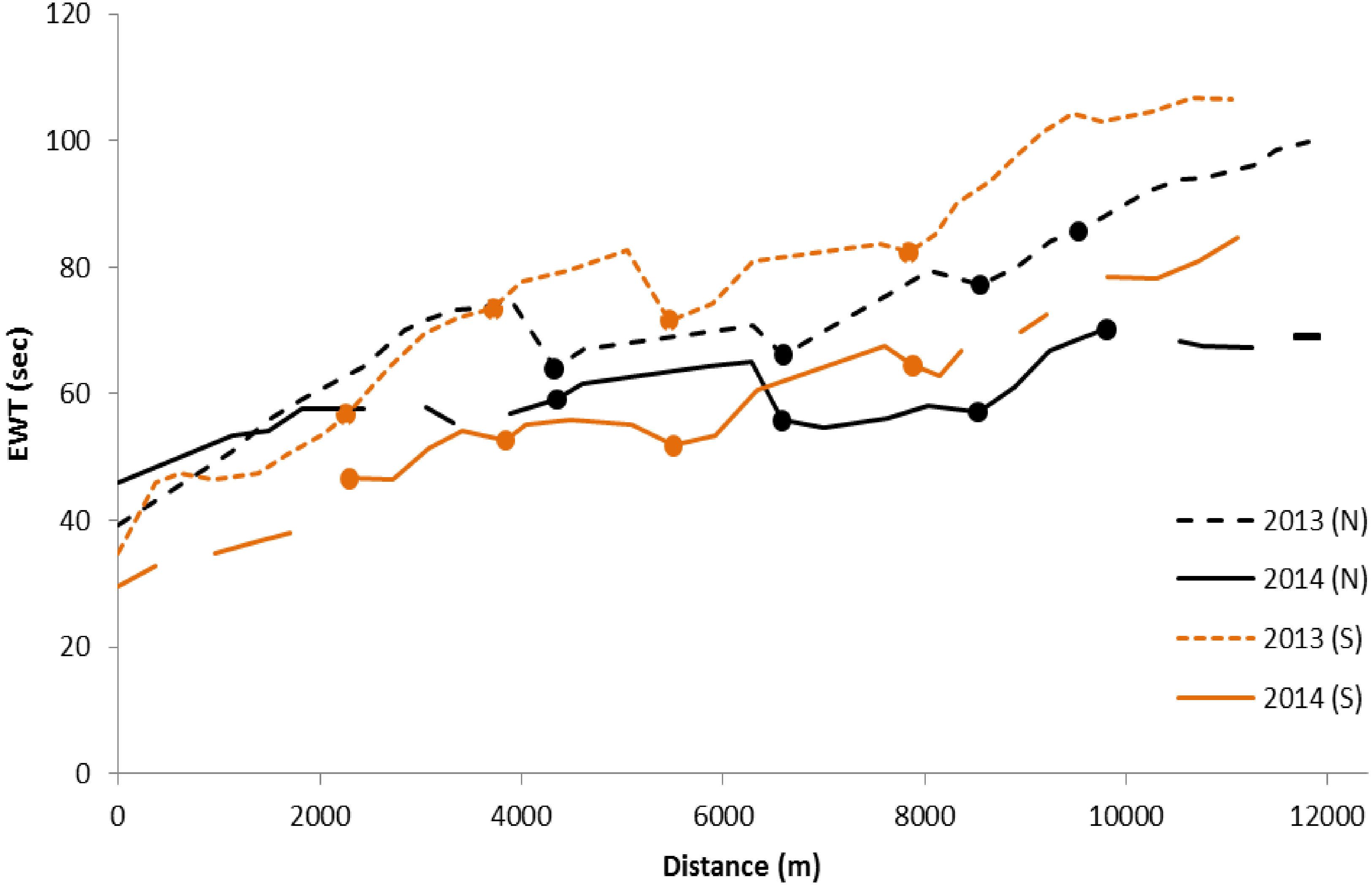
More regular service



Headway regularity evolution along the routes

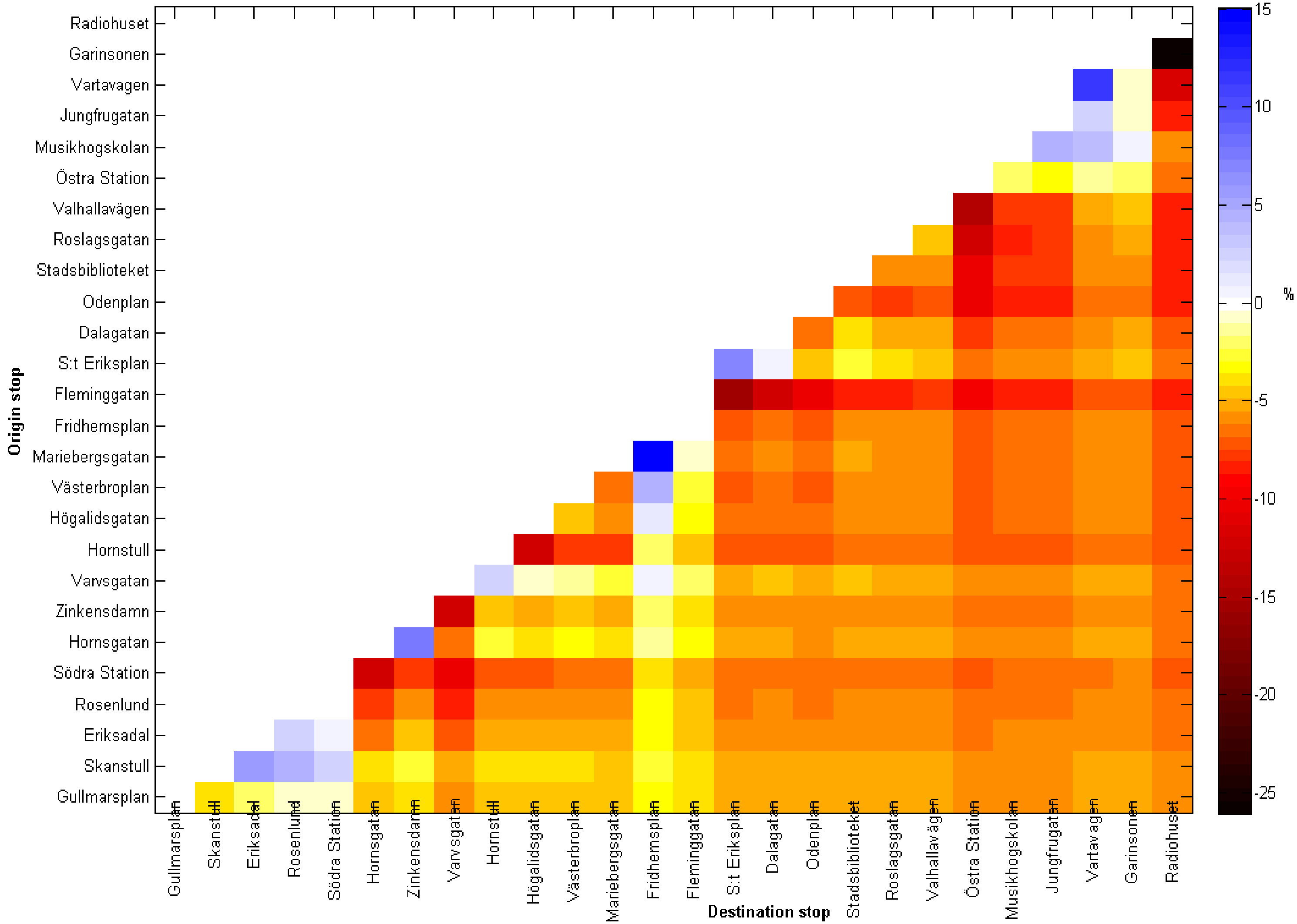


…and excessive waiting time follows suit



On-board passenger time effects

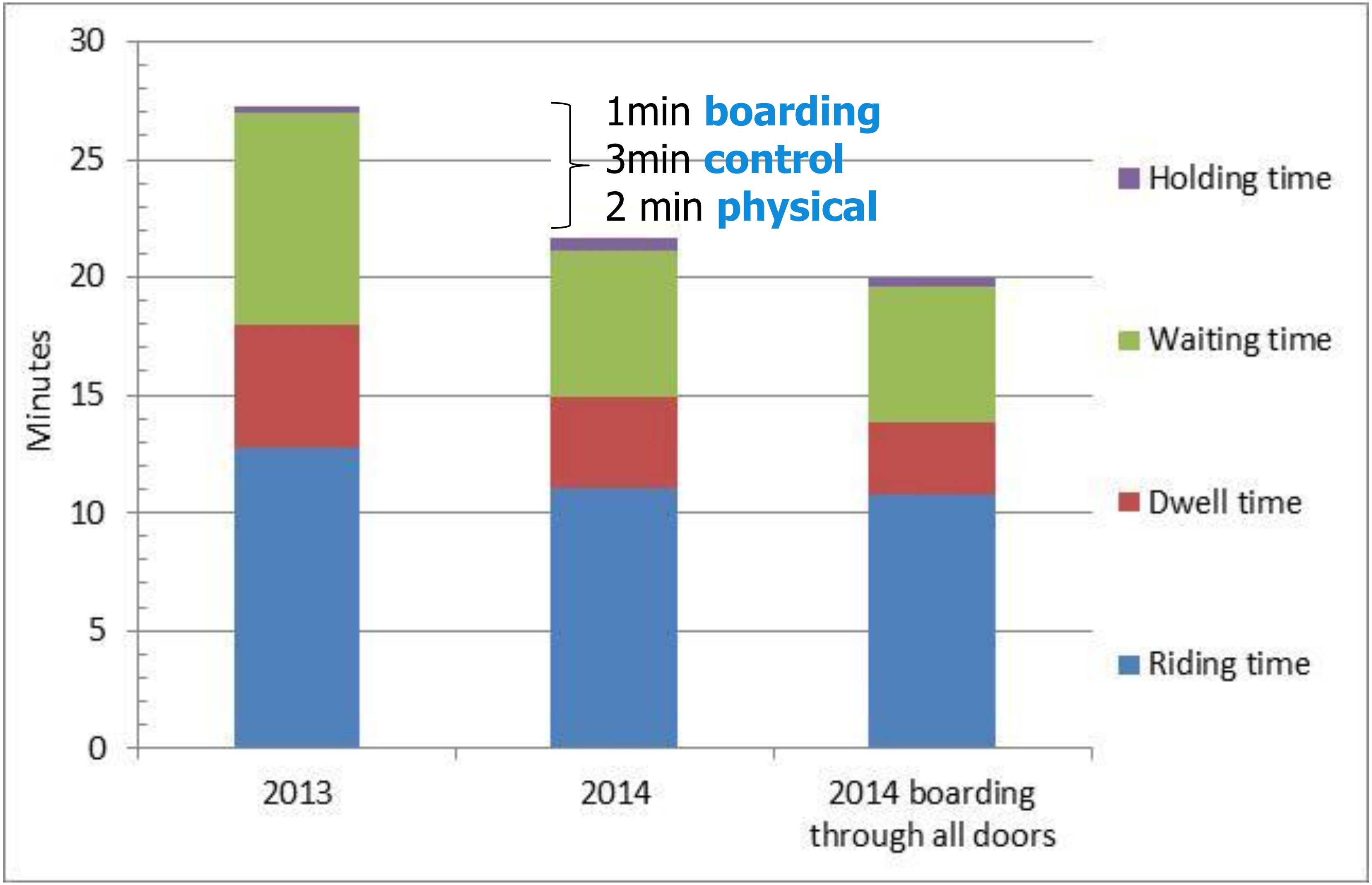
Afternoon peak period



Travel time savings

- Excessive waiting time -25%
- In-vehicle time -10%
- Total travel time (1172->1056 sec) -10%
- Time savings amount to 2.8 SEK per boarding pass
- Annual savings of **43.5 million SEK** for weekdays 7am-7pm (underestimation of congestion effects)

Insights from a simulation analysis



Conclusion

- Systematic evaluation of the impact of bus improvement measures
  - both passenger and operator perspectives
- Supports decision making and design
  - comparison of different implementations and their effectiveness
  - provide a sound basis for motivating investments in such measures
- Simulation study to
  - isolate the effects of individual measures
  - estimate crowding variation
  - assess the potential benefits of truly allowing boarding from all doors
- Induced demand (reliability, metro)/ removed demand (accessibility)
- Bus operator decided to continue with headway-based control and operations; Need to apply new incentive schemes


Thank you! Questions?
o.cats@tudelft.nl
odedcats.weblog.tudelft.nl