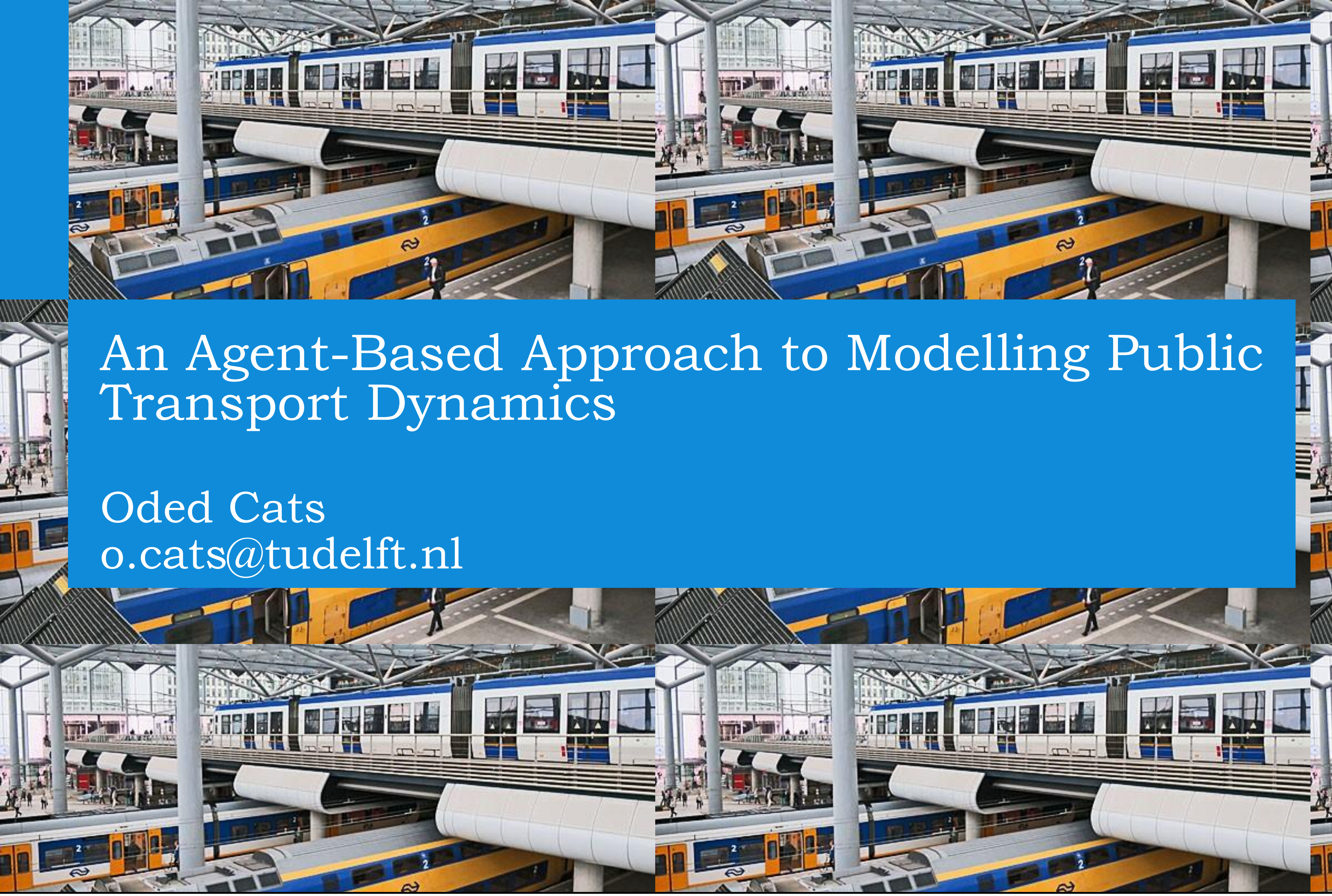

An Agent-Based Approach to Modelling Public Transport Dynamics

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Outline

Concepts

1. PT assignment principles
2. Modelling PT dynamics
3. Agent-based simulation model

Applications

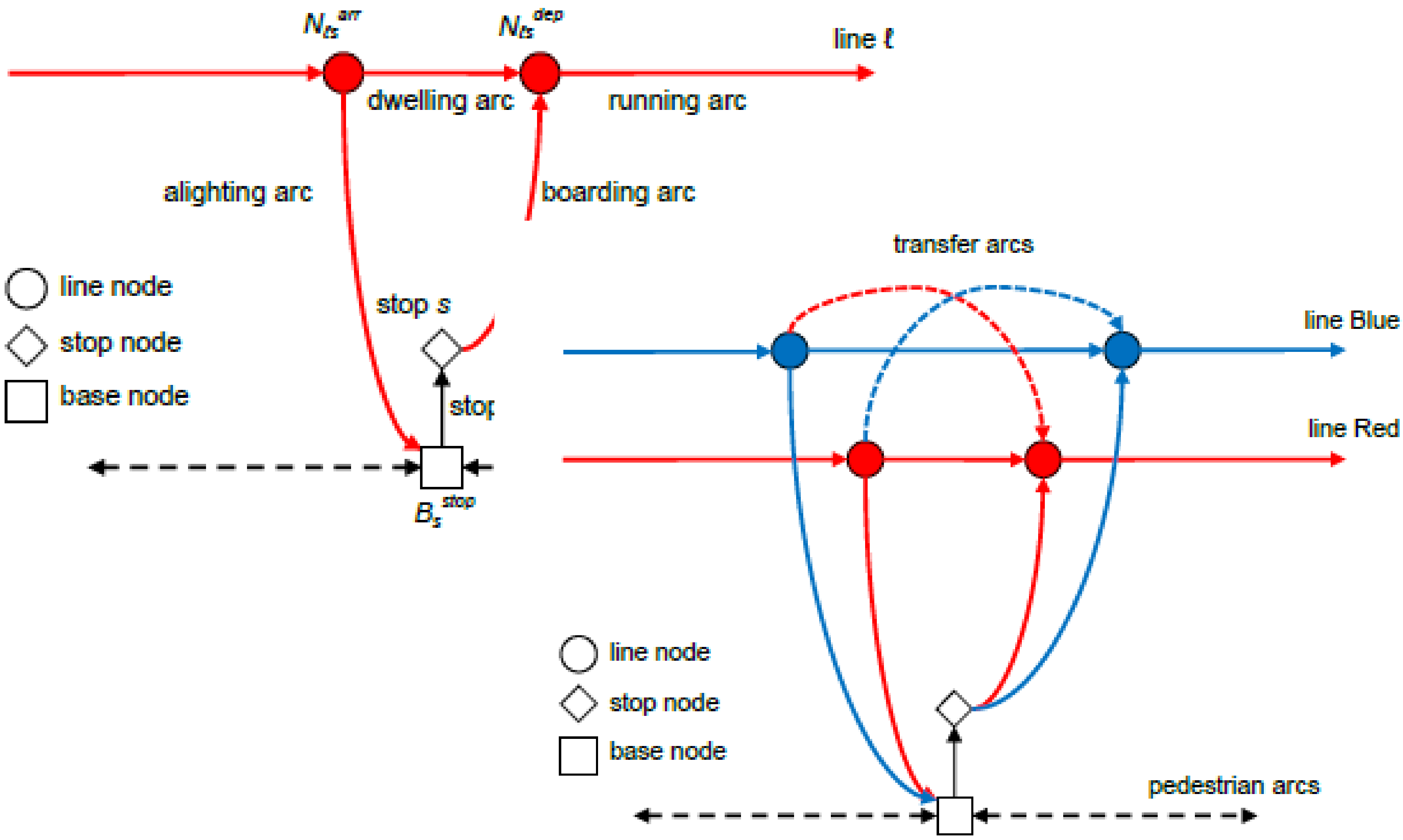
1. Congestion
2. Real-time travel information
3. Service disruptions
4. Control and operational strategies

PTA principles and approaches

Frequency-based: Assignment principles

- PT network is represented in terms of segments of lines
- Demand is assigned based on service frequencies
- Adopting concepts and solution methods from car traffic assignment

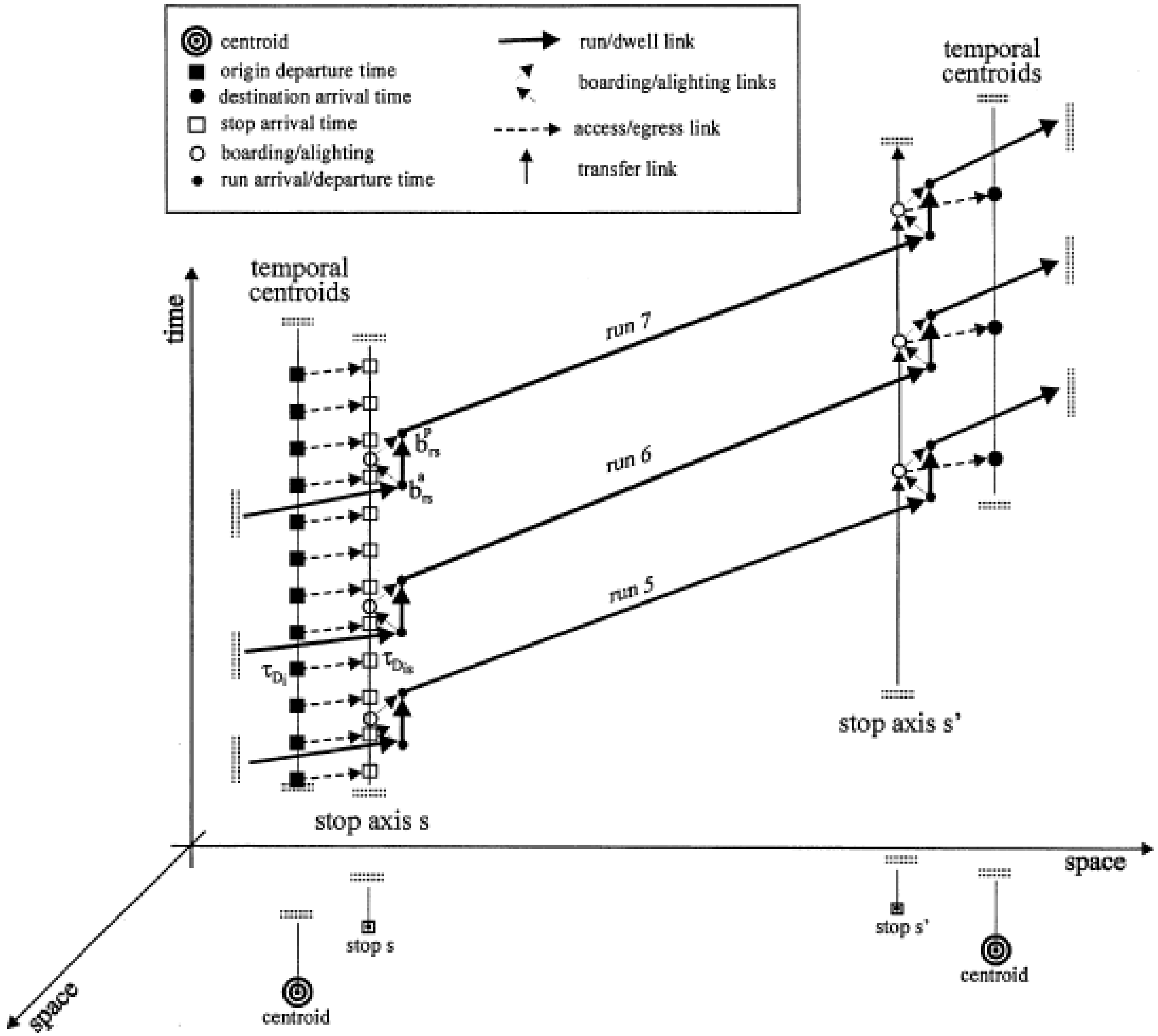
Frequency-based: Network representation



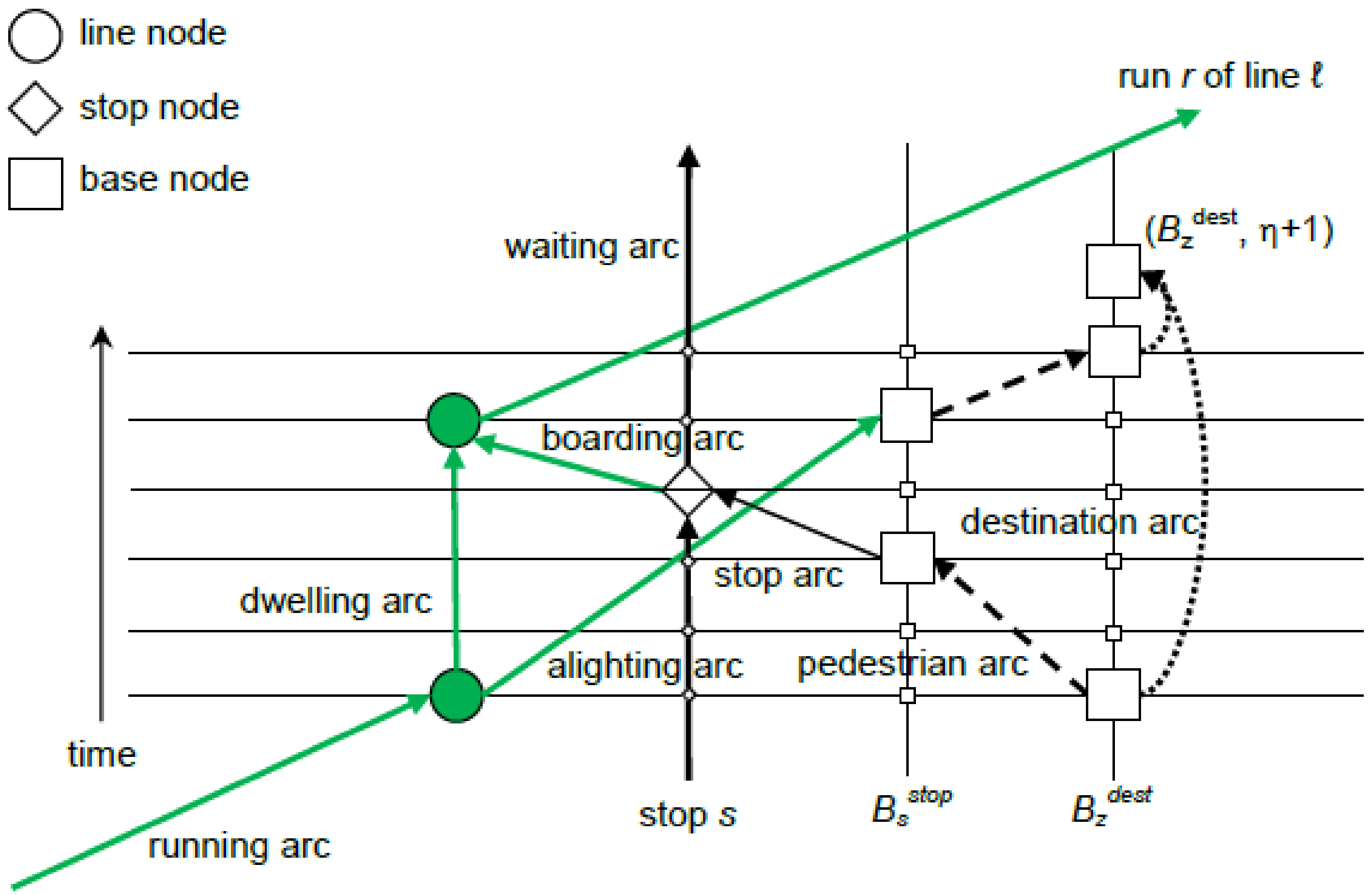
Schedule-based: Assignment principles

- PT network is represented in terms of individual vehicle trips/runs following a timetable
- Demand is assigned to specific trips, takes into account time-dependent characteristics
- The concept of accumulative shortest path is not valid anymore

Schedule-based: Network representation



Schedule-based: Stop topology



Traditional assumptions

- Travel times is equal on all lines riding the same arc (FB)
- Passengers arrive randomly at stops
- No capacity constraints
- Perfect reliability (regularity – FB; punctuality – SB)
- Passengers board the first arriving vehicle
- Perfect infomration
- Homogenous travellers' population

Flow-dependent in-vehicle time

Flow-capacity ratio multiplier

- Already in the original presentation of optimal strategies
- on-board crowding
- Link travel time as a non-linear function of passenger flows
- Iterative network loading to obtain equilibrium
- BPR crowding function

$$\gamma_{\ell s}\left(q_a\right)=1+\alpha_\ell^{run}\cdot\left(\frac{q_a}{f_{\ell s}\cdot\kappa_\ell^{veh}}\right)^{\beta_\ell^{run}}, \quad a=\left(N_{\ell s}^{dep}, N_{\ell s^{+\ell}}^{arr}\right)\in A^{run}$$

- $q_a / (f_{\ell s} \cdot \kappa_\ell^{veh})$ is the saturation rate of the vehicle on the line segment;
- α_ℓ^{run} and β_ℓ^{run} are the BPR coefficient and exponent for running congestion.

Flow-dependent travel time

Effective frequency

- Assigning weights to waiting times
- Reliability effects and risk of denied boarding
- An infinite penalty when capacity is exceeded
- Reducing the nominal frequency by the BPR term

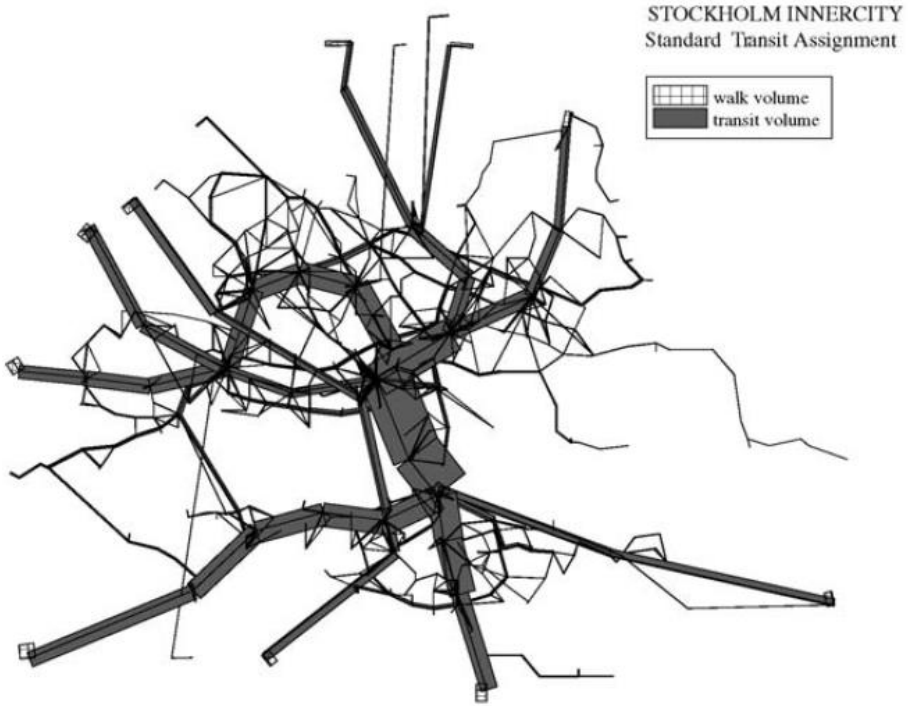
$$f_{\ell s}^{eff}\left(q_a\right) = \frac{f_{\ell s}}{1+\alpha_{\ell}^{wait}\cdot\left(\dfrac{q_a}{f_{\ell s}\cdot\kappa_{\ell}^{veh}}\right)^{\beta_{\ell}^{wait}}}, \quad a = \left(N_{\ell s}^{dep}, N_{\ell s^{+\ell}}^{arr}\right)\in A^{run}$$

$$t_{\ell s}^{wait}\left(q_a\right) = \frac{0.5}{f_{\ell s}^{eff}\left(q_a\right)}\cdot\left(1+\sigma_{\ell s}\right)$$

Does not guarantee that capacity is not exceeded!

Average VOC ratio drops from 4.77 to 1.5
Number of over-saturated line segments drops from 45 to 10

Cpeda et al. (2006)

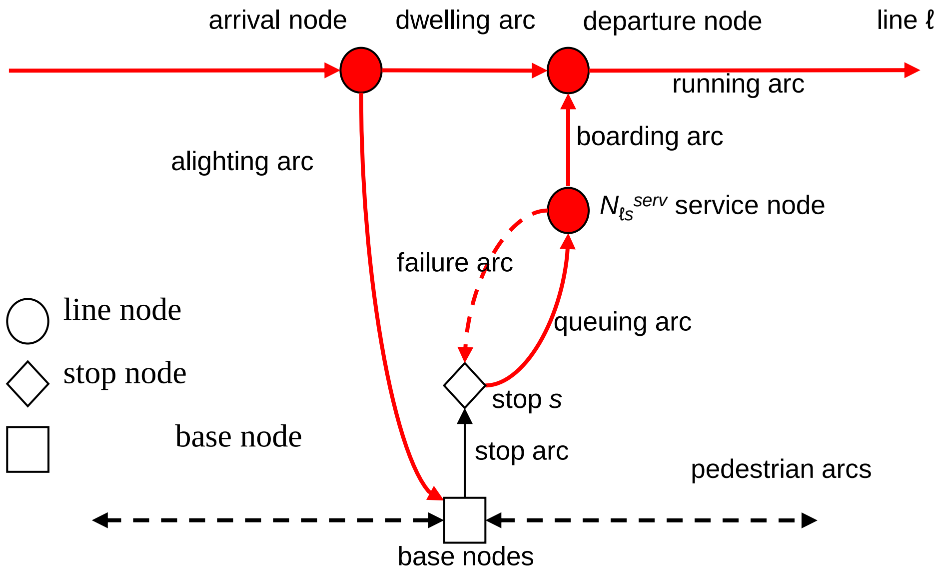


Failure-to-board probability

- FB: a quasi-dynamic model where *the share of passengers that exceeds the residual capacity* on the respective time period is transmitted to the next period

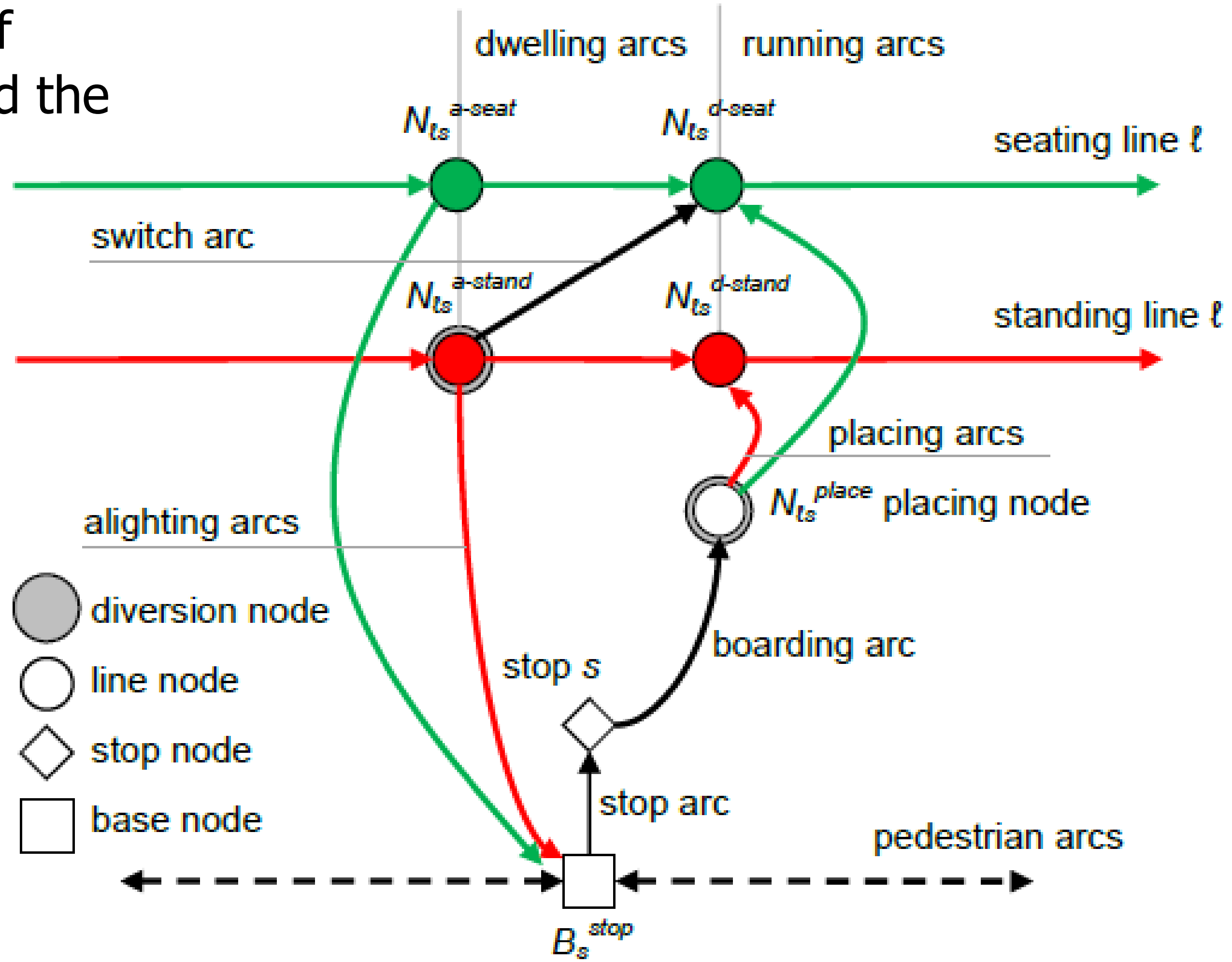
- SB: guarantees that capacity constraints are *satisfied at the individual vehicle level* by introducing new arcs between successive vehicle trips

- Queuing (FIFO, mingling)



Seating and priorities

- satisfy the set of priority rules and the seat capacity constraint



Main trends in developments of PT assignment models (Liu et al 2010)

- Consistently lagged behind developments in traffic modeling
- Expected and emerging developments
  - **Multi-agent** simulation models
  - **Dynamic** loading process
  - **Adaptive** user decisions
  - **Supply uncertainties**

2.

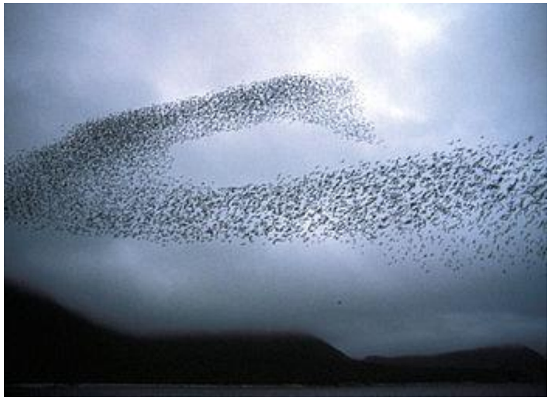
Agent-based approach to PTA

Prominent research questions

- How does the **system perform** under various conditions?
- How can APTS be deployed most **effectively** to improve serive operations?
- How to **mitigate** and manage service **disruptions**?
- How could service providers and users become more **adaptive** by taking advantage of the abundance of real-time data?
- What is the **impact** of APTS measures?

Agent-based TAM

- Represents individual vehicles and travellers
- Emerging solution based on agents interaction with each other throughout the simulation
- En-route decisions
- Day-to-day learning as proxy to equilbrium conditions
- Integration with traffic simulation models

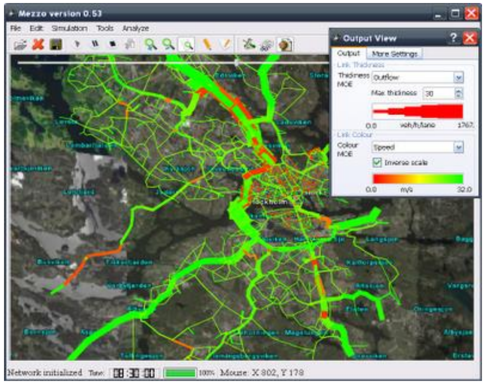


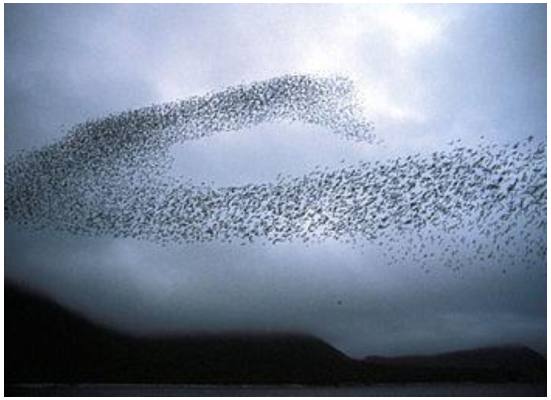
Implementation: BusMezzo
Transit Assignment and Operations Simulation Model

- A framework for analyzing transit performance under various operational conditions and APTS

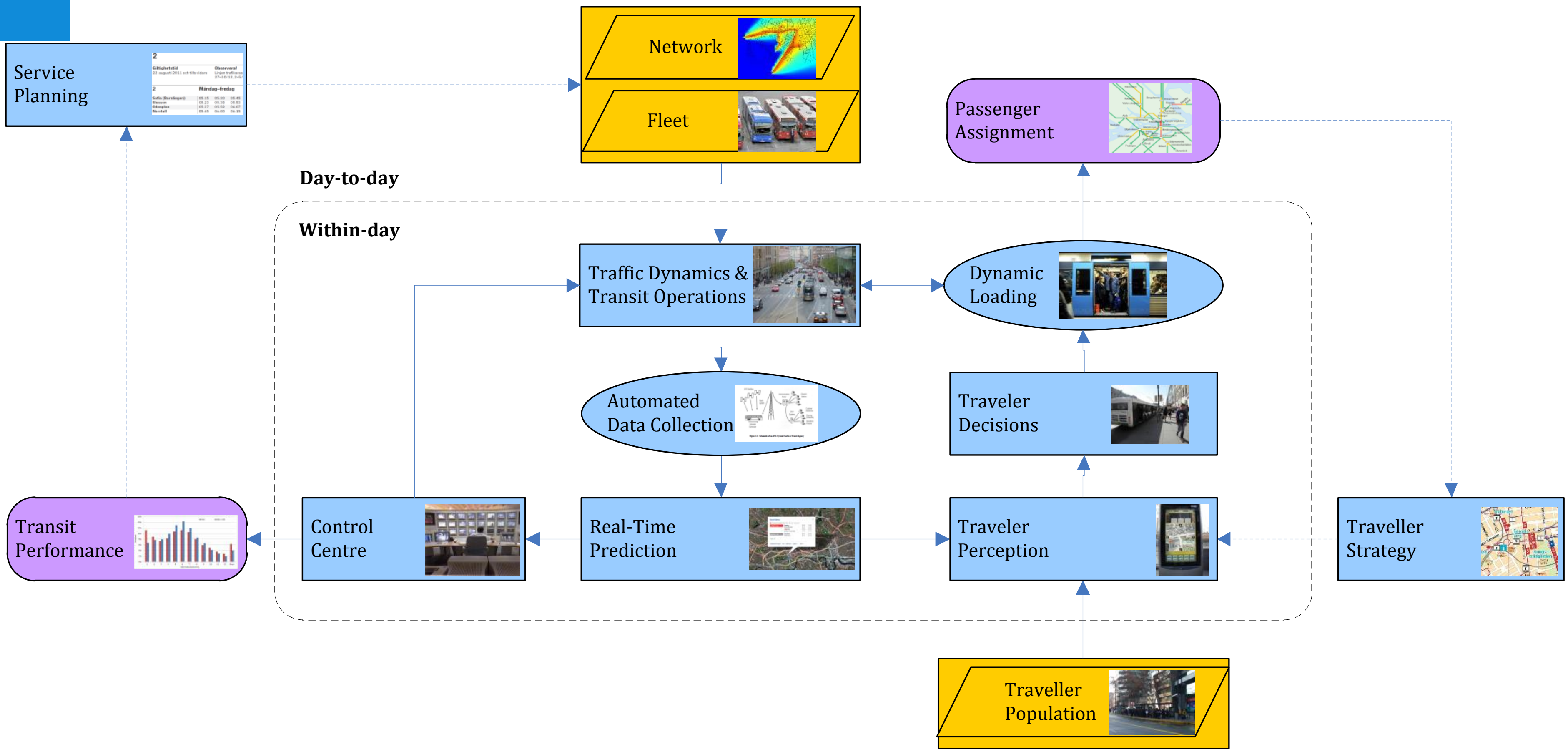
- **BusMezzo**: integrated into Mezzo, a mesoscopic traffic simulation model

- Agent-based
- Operations-oriented
- Sources of uncertainty
- Adaptive decision making
- System level analysis





A modelling framework for Analyzing Public Transport Operations



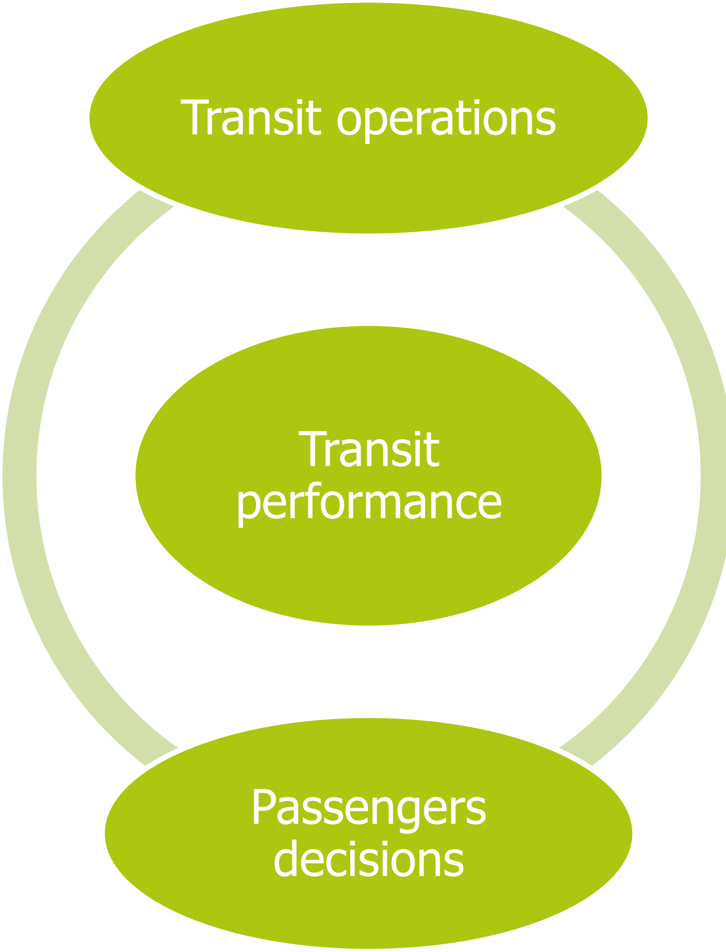
Network representation

- *Transit vehicle trajectory*
  - Ride
  - Queue
  - Dwell
  - Recover
- *Traveller trajectory*
  - Walk
  - Wait
  - On-board

Public Transport Dynamics

Joint car and PT; mode-specifics
Dwell times
Fleet; vehicle scheduling
Crowding and capacity

Operations planning
Control and management strategies
Adaptive route choice
Real-time information



Demand representation

- $\lambda_{od}(t,\tau)$ – Poisson arrival process
- Non-compensatory rule-based choice-set generation process

- En-route decisions
  - Assess the attributes of each avilable *path*

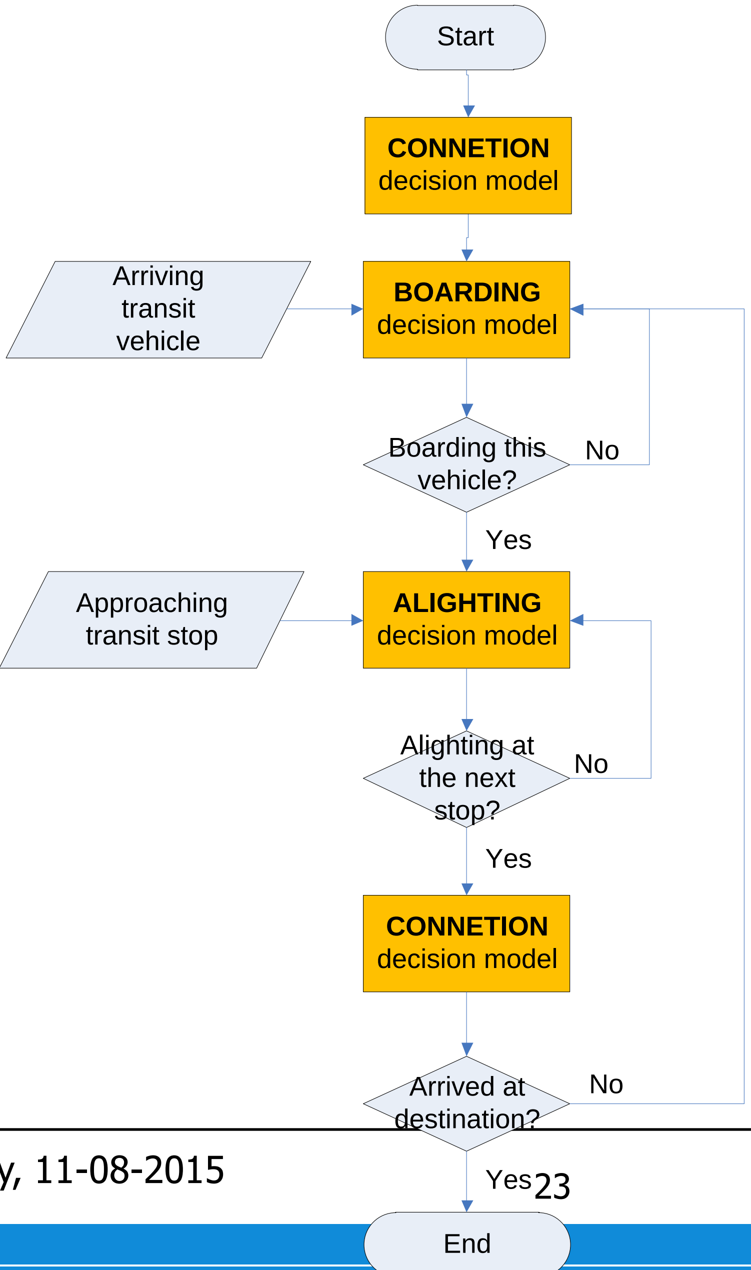
$$v_{i,n} = \beta_{i,n} X_{i,n}$$

  - Calculate the *joint utility* of the bundled paths

$$v_{I,n} = ln \sum_{i \in I} e^{v_{i,n}}$$

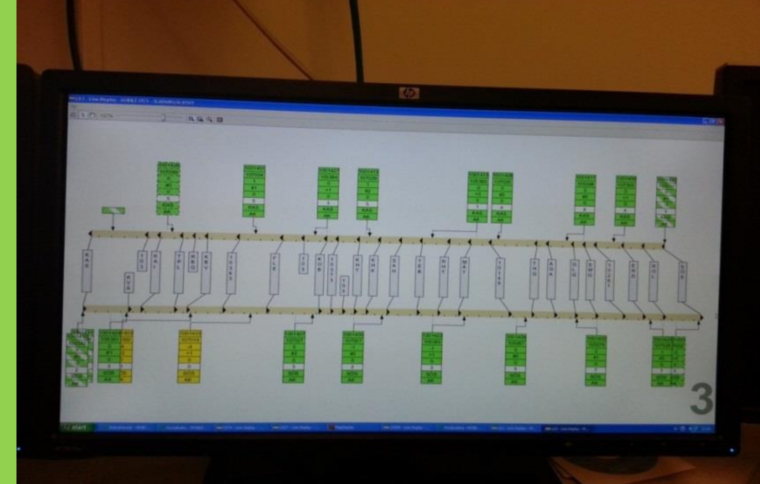
- Path: outcome of successive decisions

- Preserve passenger integrity from one day to the other



Applications

Reliability and Control



Real-time Information

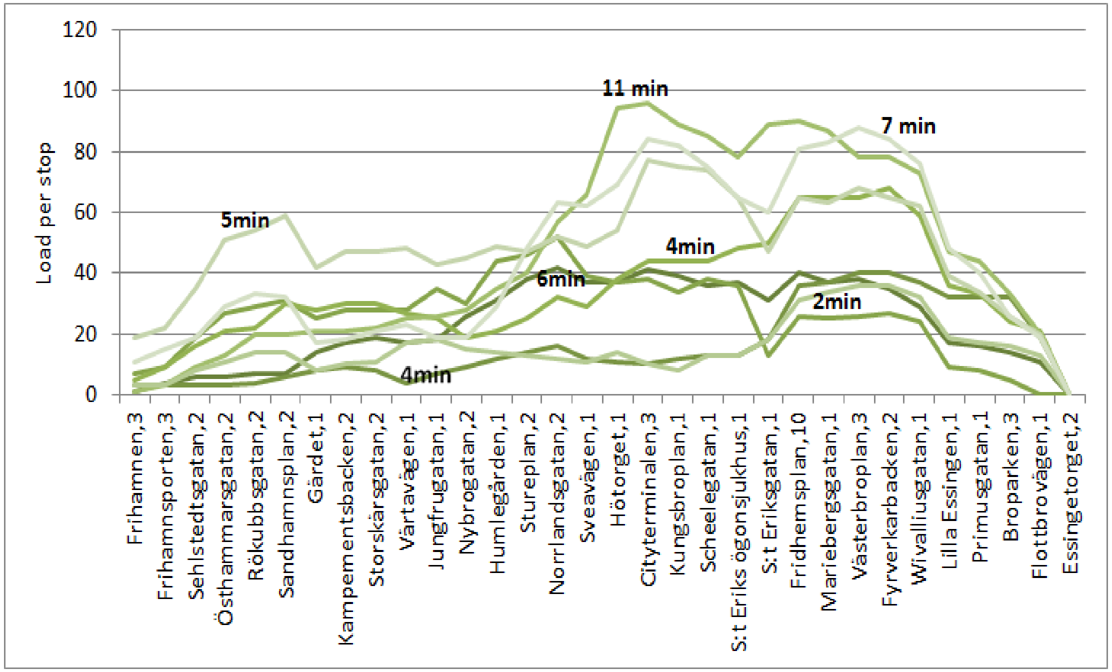
Network Resilience

Congestion

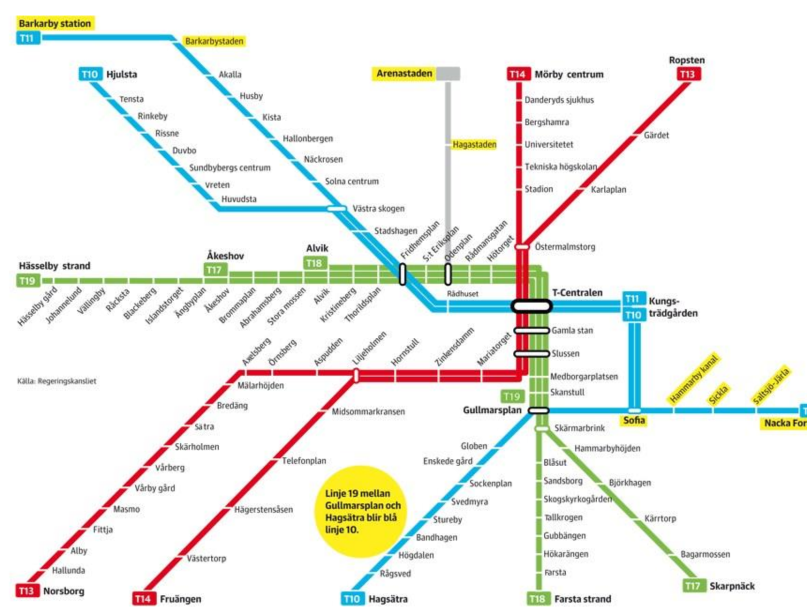
Application: Increased capacity

The dynamics of reliability & congestion

- Route choice
- Service reliability
- Demand variation



How can the value of reduced congestion be quantified?

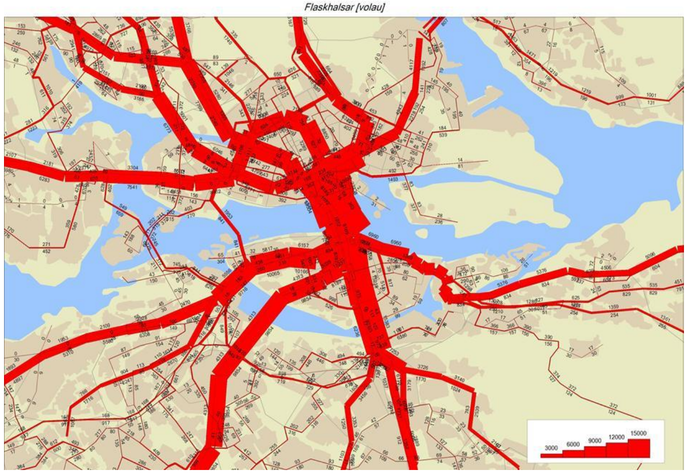


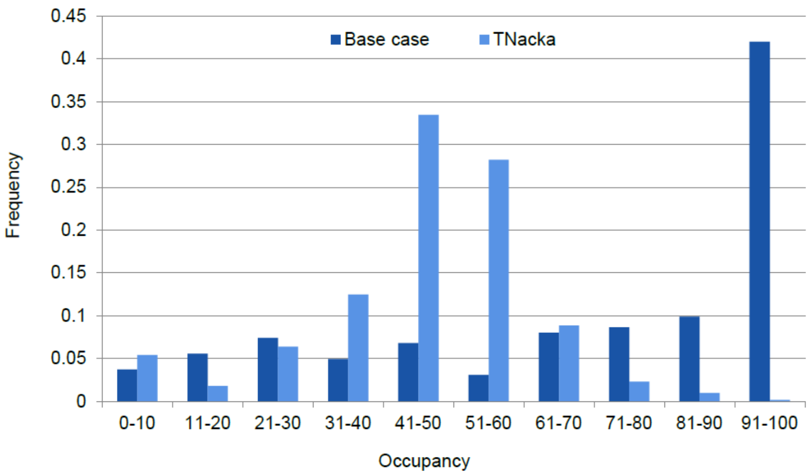
Evaluation of congestion effects

On-board crowding → Increased preceived in-vehicle time

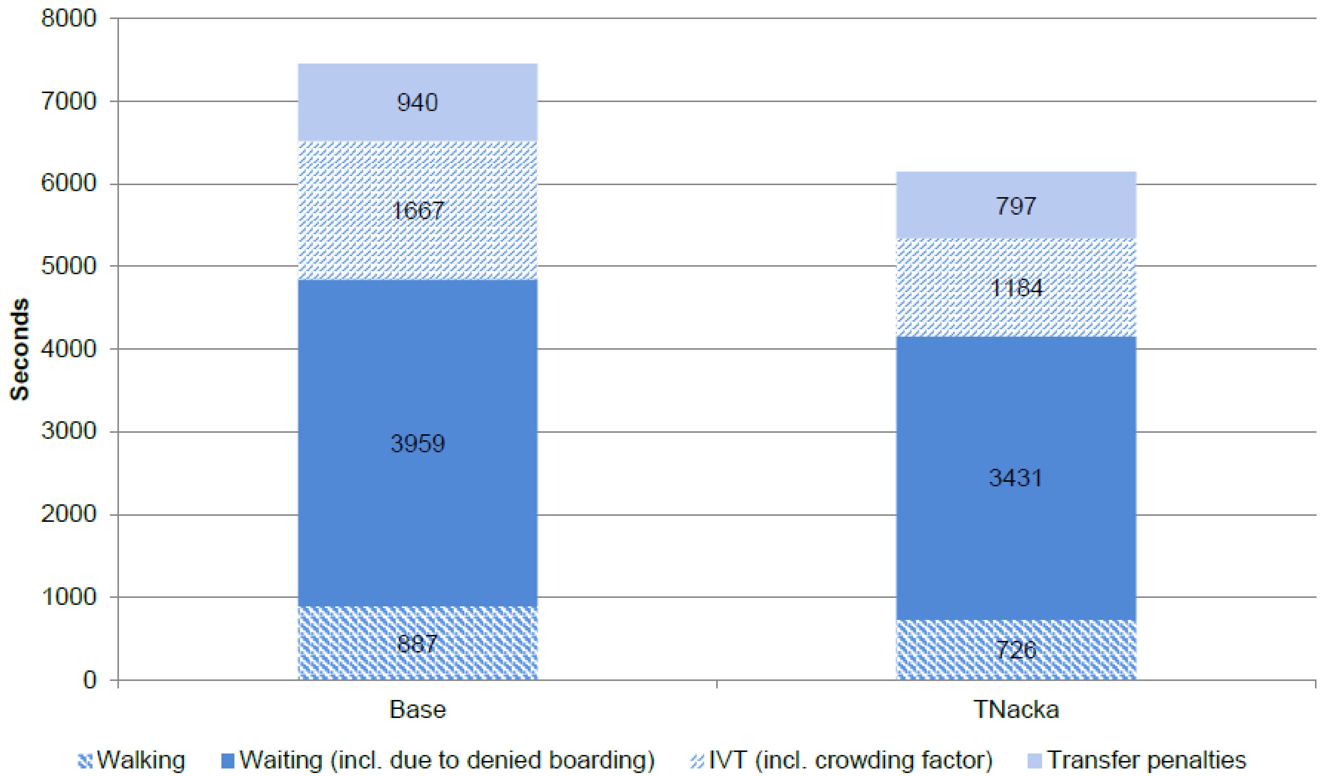
Denied boarding → Increased waiting time

Reduced service relaibility → Increased total travel time





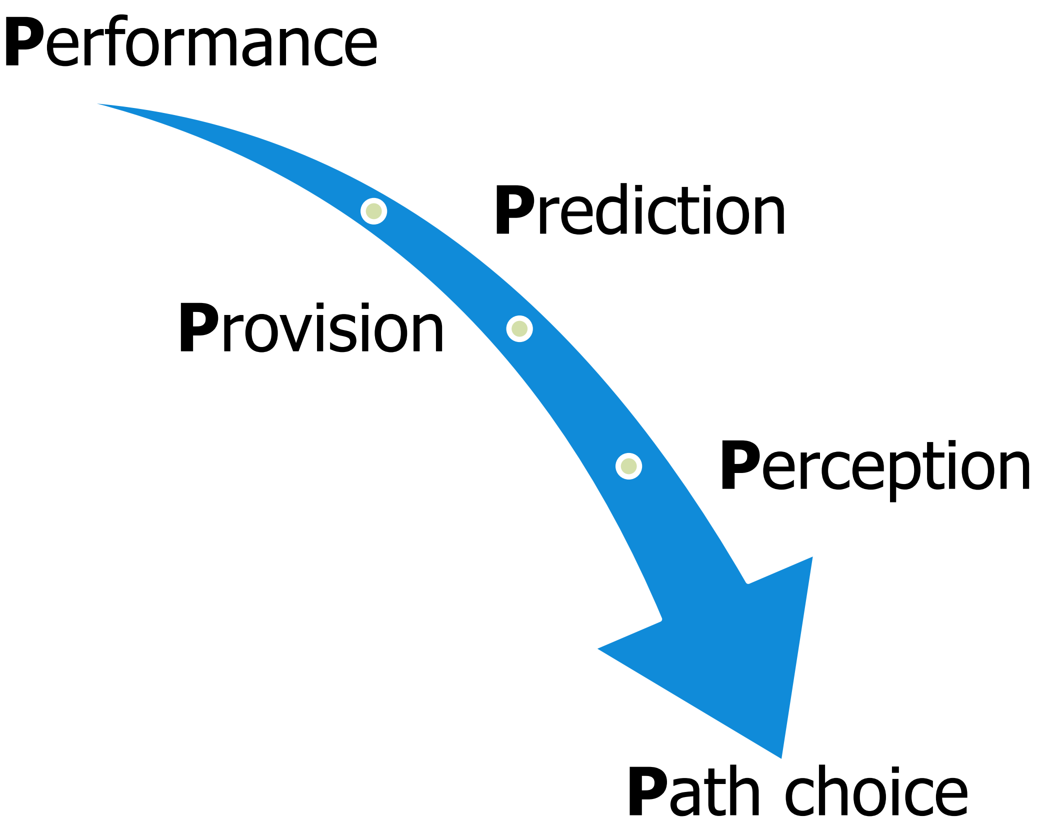
Appraisal of Increased Capacity



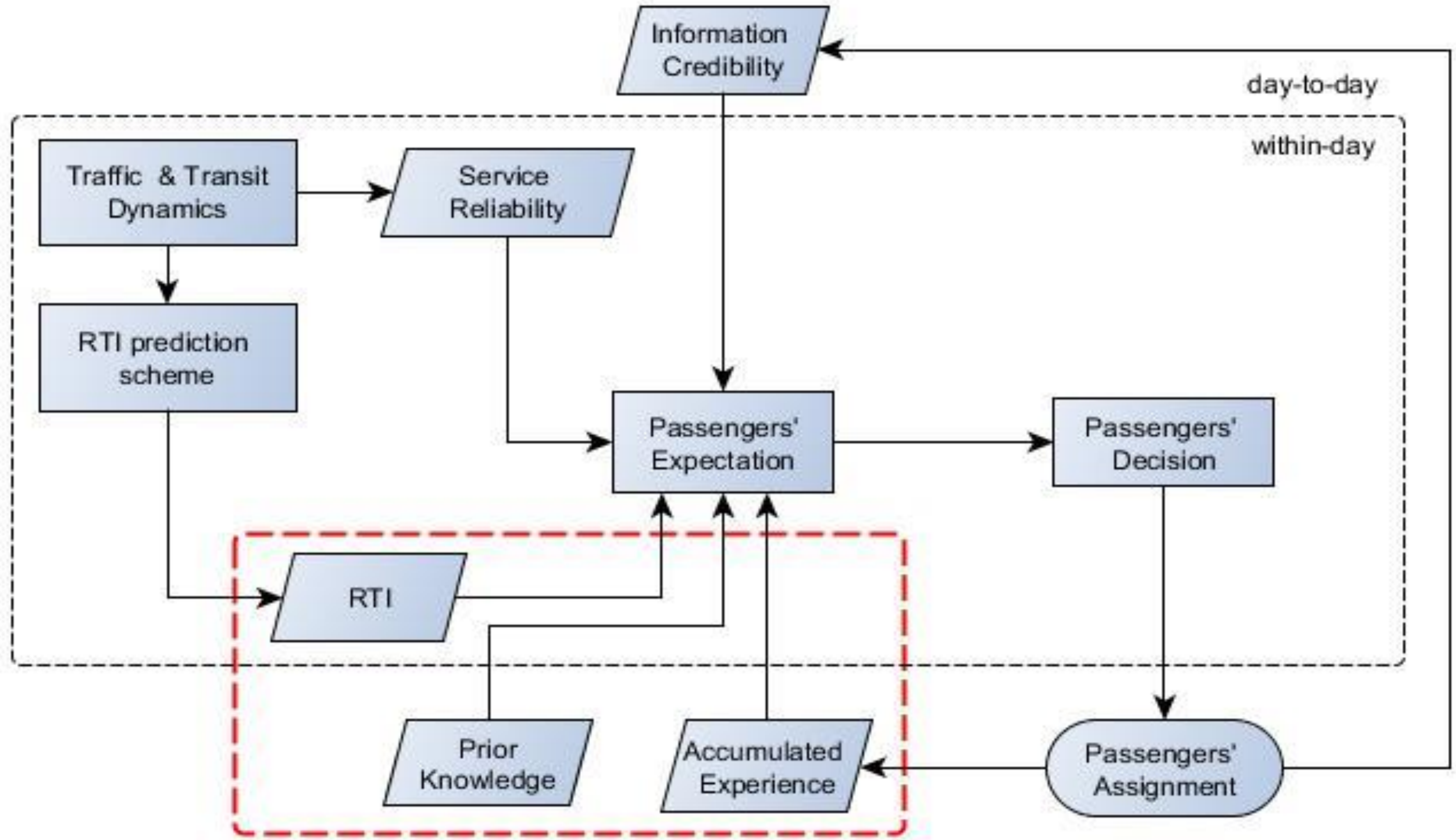
- Crowding factor in static/dynamic model: +3%/+60%
- Value of increased capacity: underestimated in static models
- Overestimation in BusMezzo: currently incorporate crowding in the route choice model

Real-time Travel Information: Predicting, disseminating, rerouting

Modelling Impacts of Information

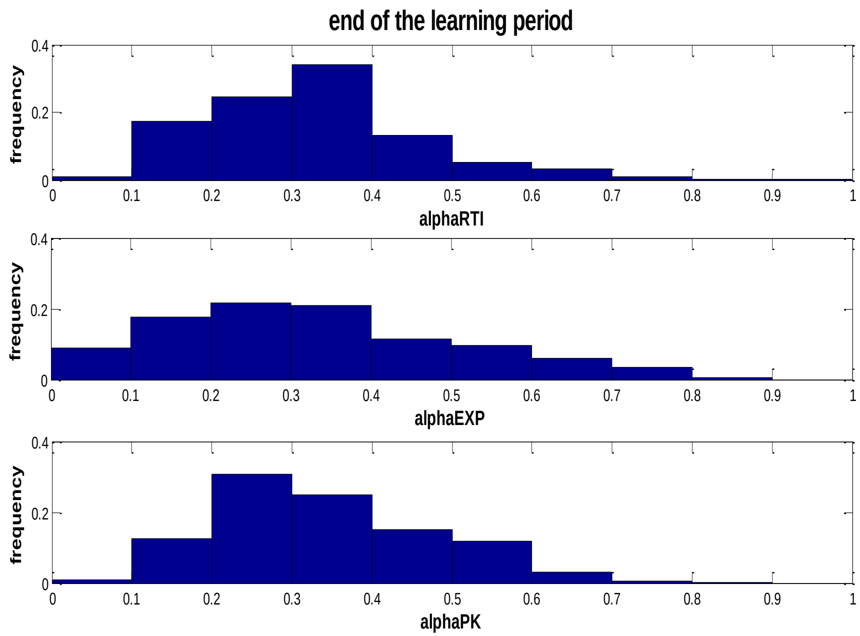


Passengers' Response to Service Reliability and Travel Information

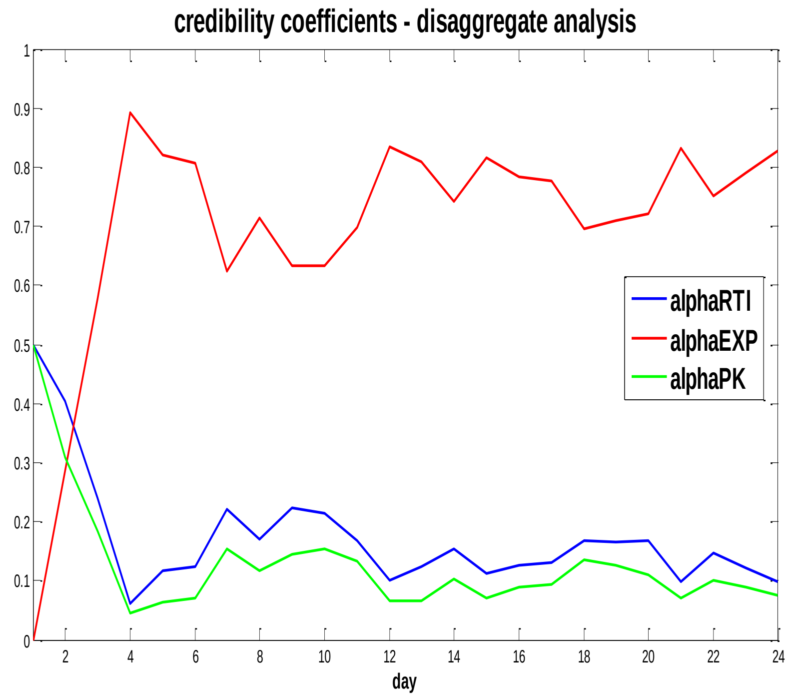


Day-to-Day Learning of Service and Information Reliability

Final distribution of credibility coeff.

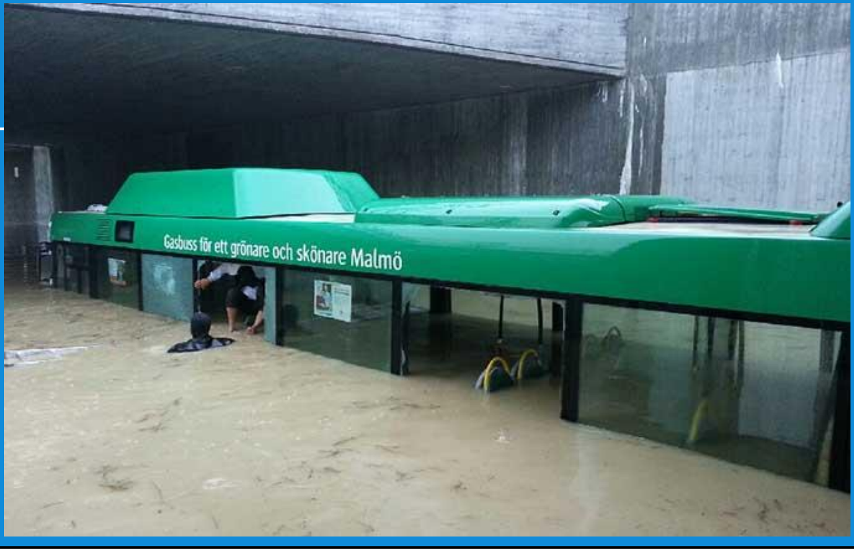


Example: evolution of credbility coeff.

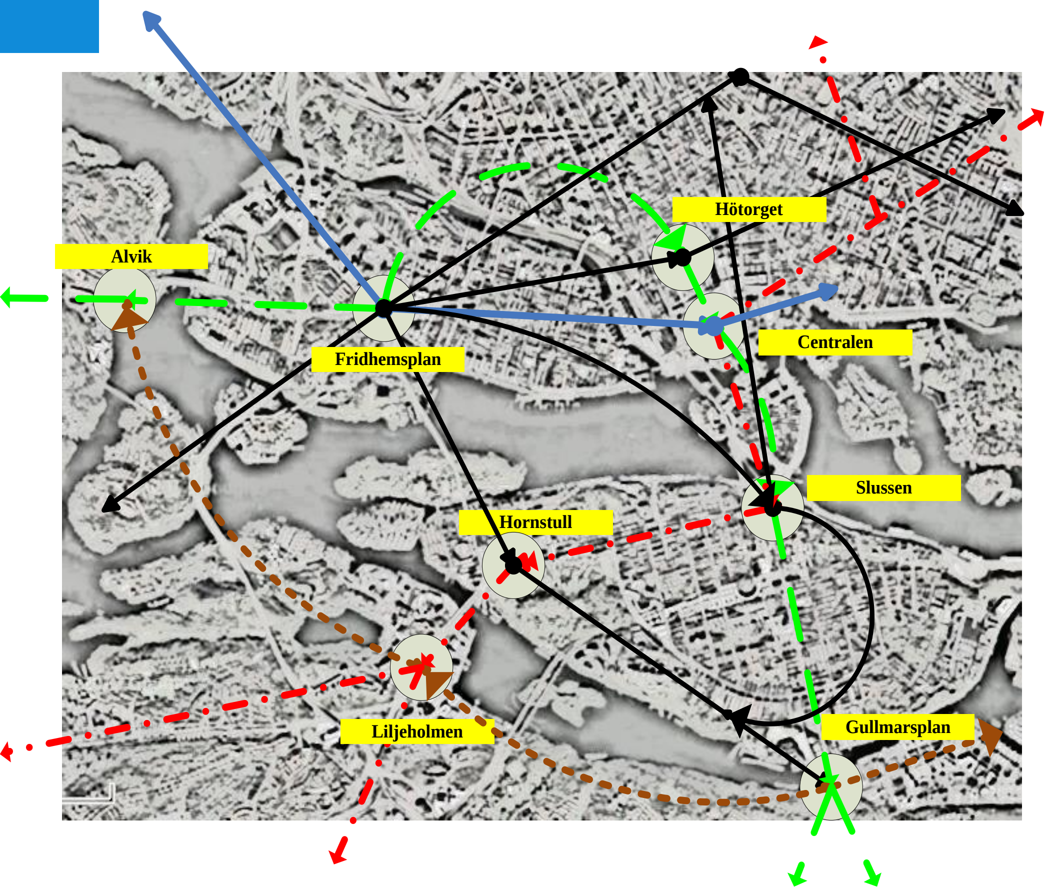


$$\alpha_{j,n}^{\lambda}(d+1) = (1-\kappa_n^a) * \alpha_{j,n}^{\lambda}(d) + \kappa_n^a * \left(\left(\left|\frac{t_{j,n}^{e(\lambda)}(d)}{t_{j,n}^{a}(d)} - 1\right| + 1\right)\right)^{\nu}$$

Disruptions: impact and implications for strategic planning and operational management



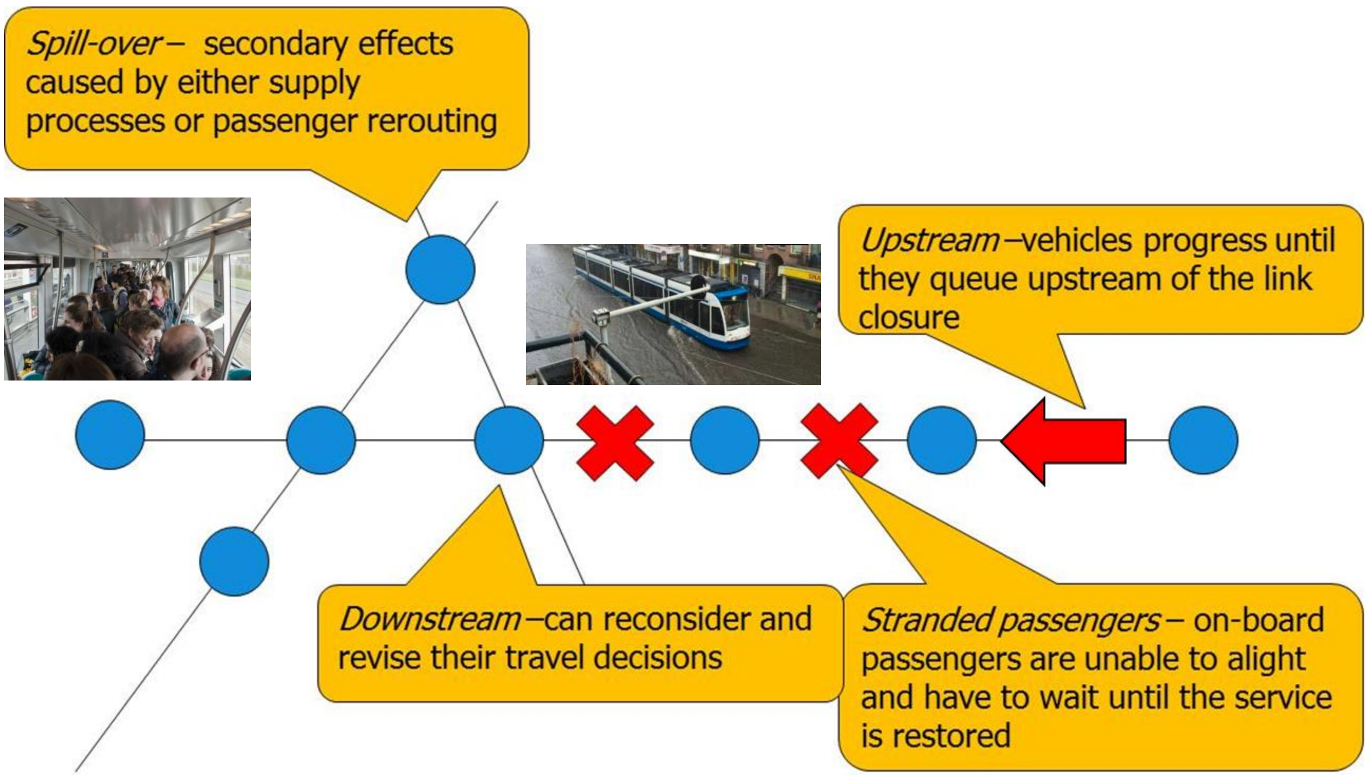
What is the Weakest Link?



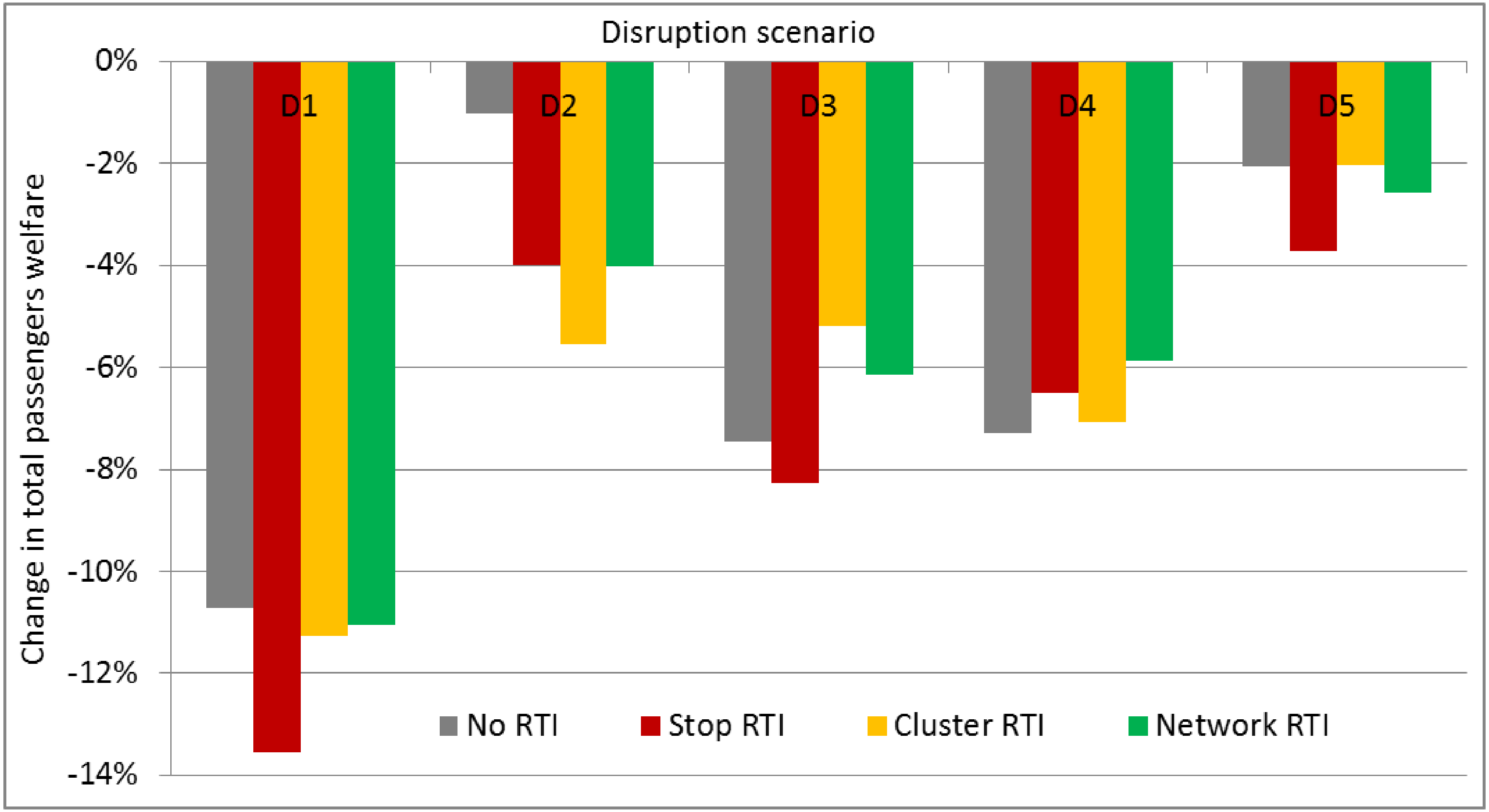
- *Main determinants of network **robustness**?*
- *Potential benefits of real-time **information** dissemination?*
- *How incorporate vulnerability into network **planning** decisions?*
- Requires **non-equilbrium assignment**

Capturing disruption dynamics

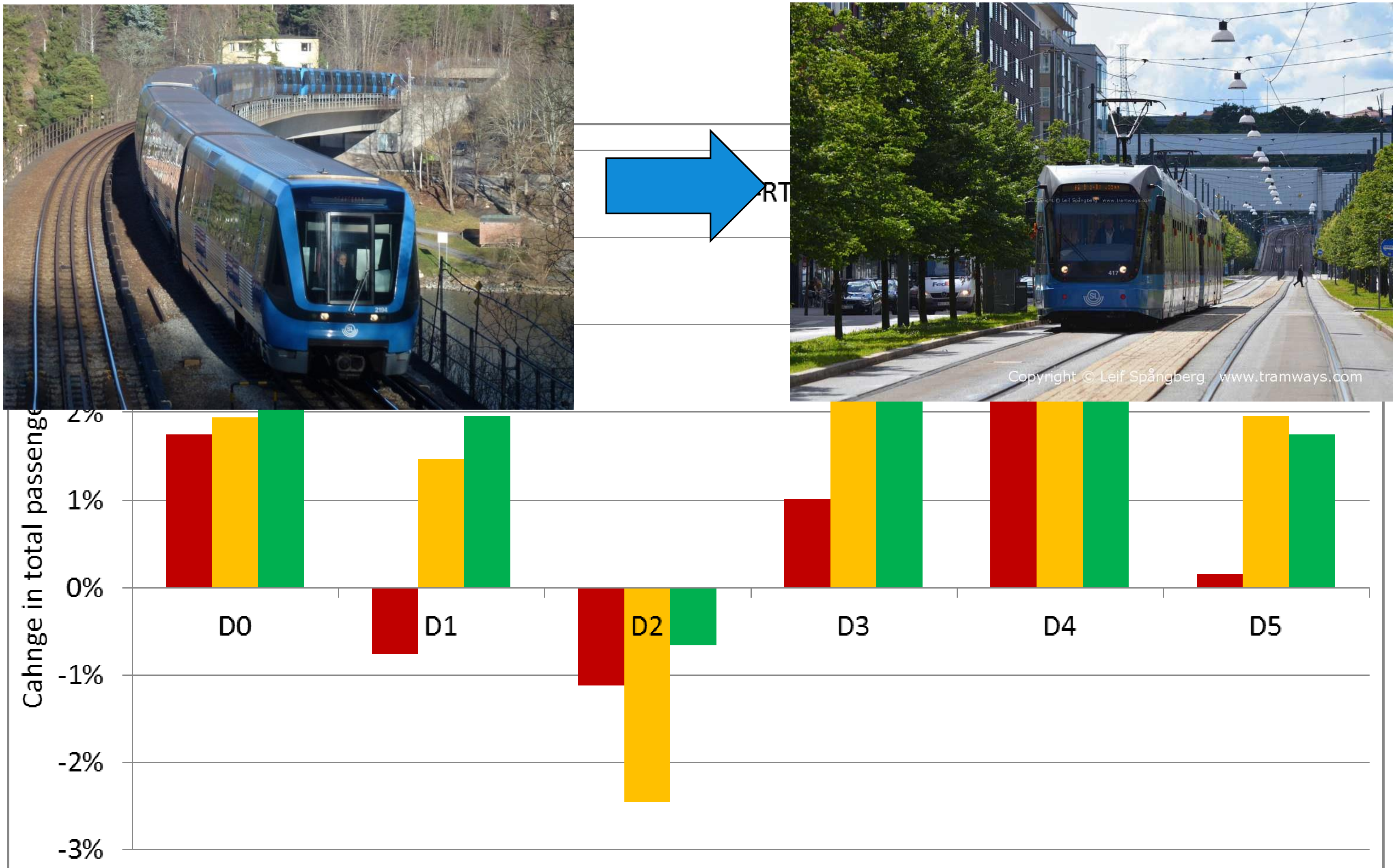
- Static model: underestimation of disruption effects
- En-route decisions, imperfect information
- Both passengers and operators can respond to disruptions



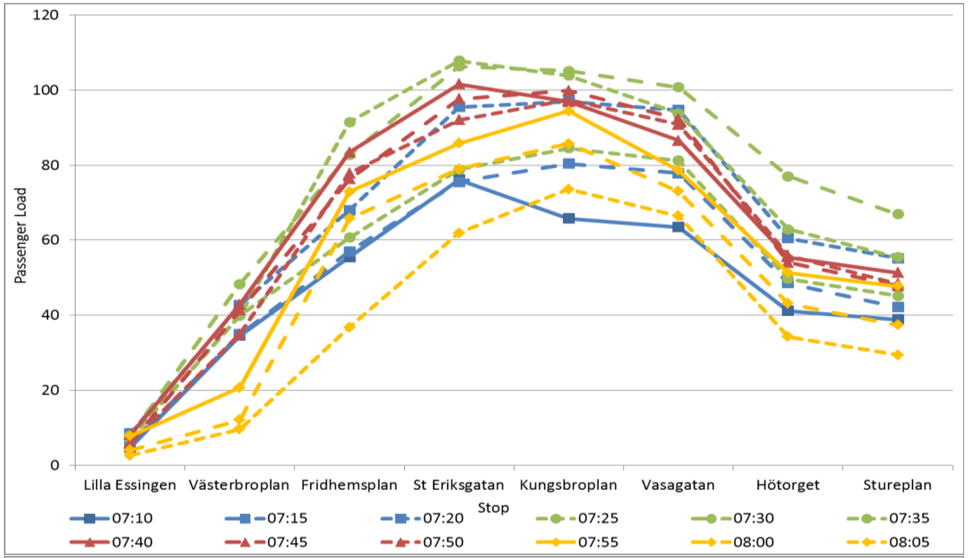
Criticality: Relative welfare loss

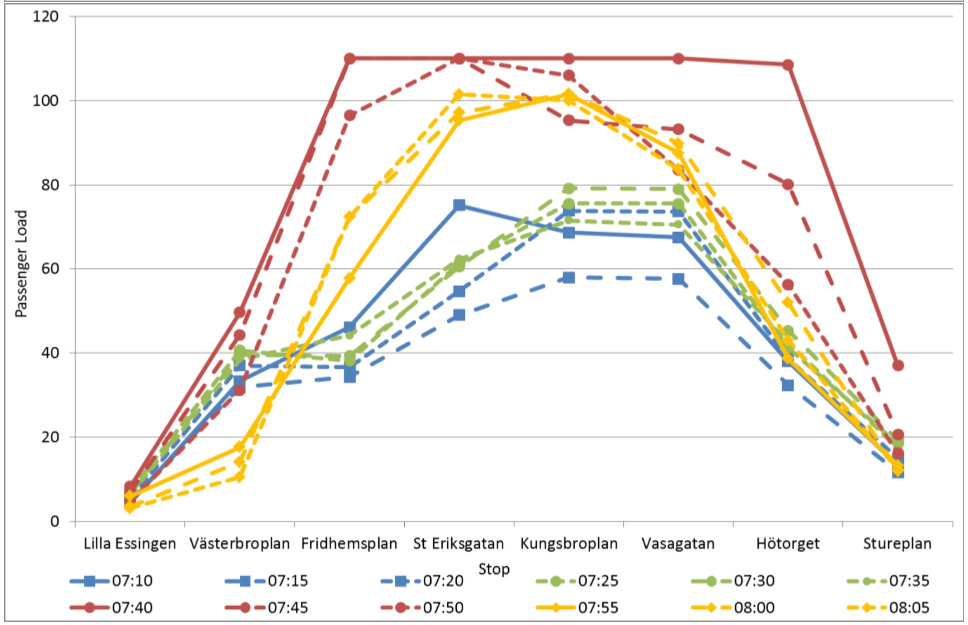


Value of Real-time information: Relative welfare gain



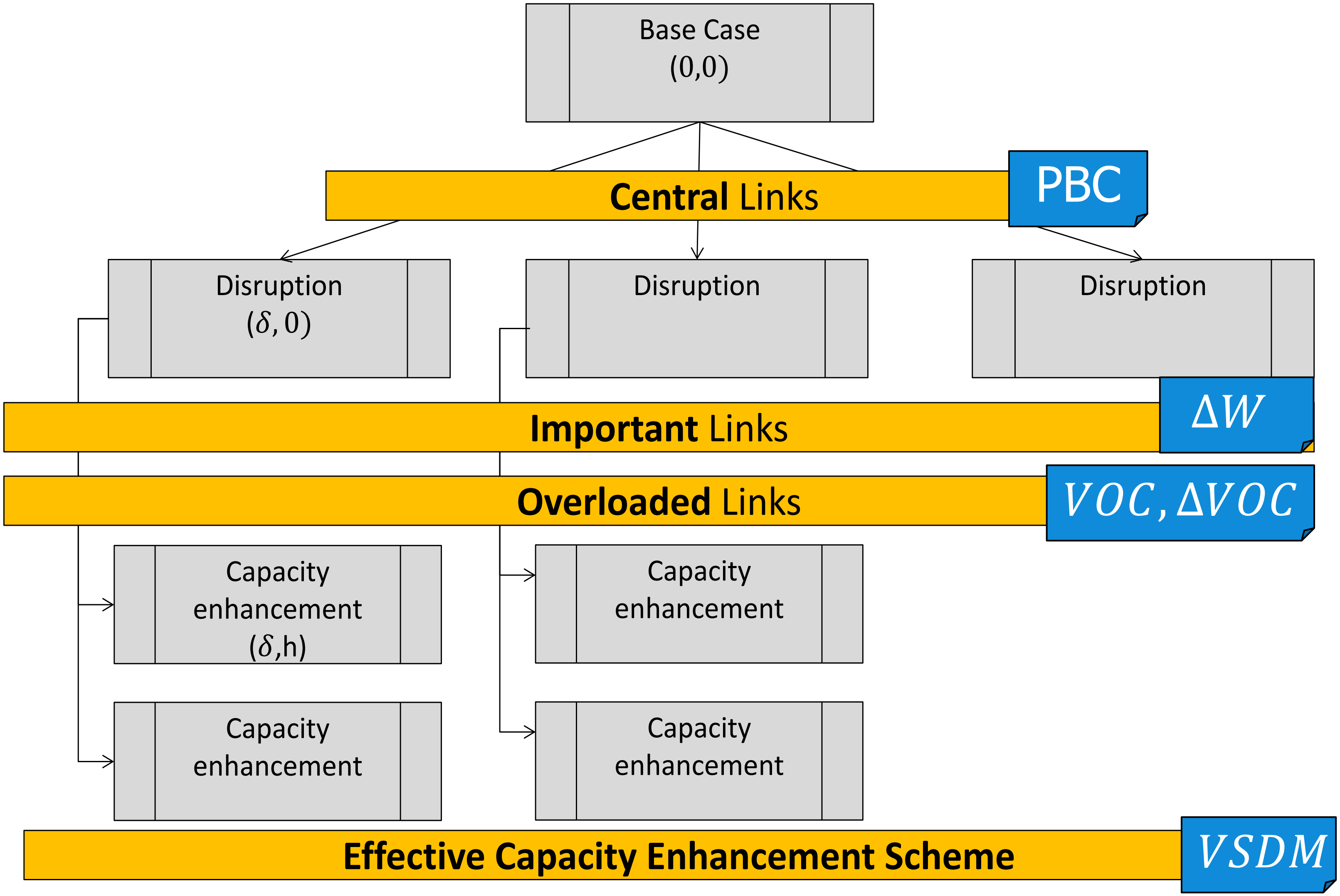
Normal operations





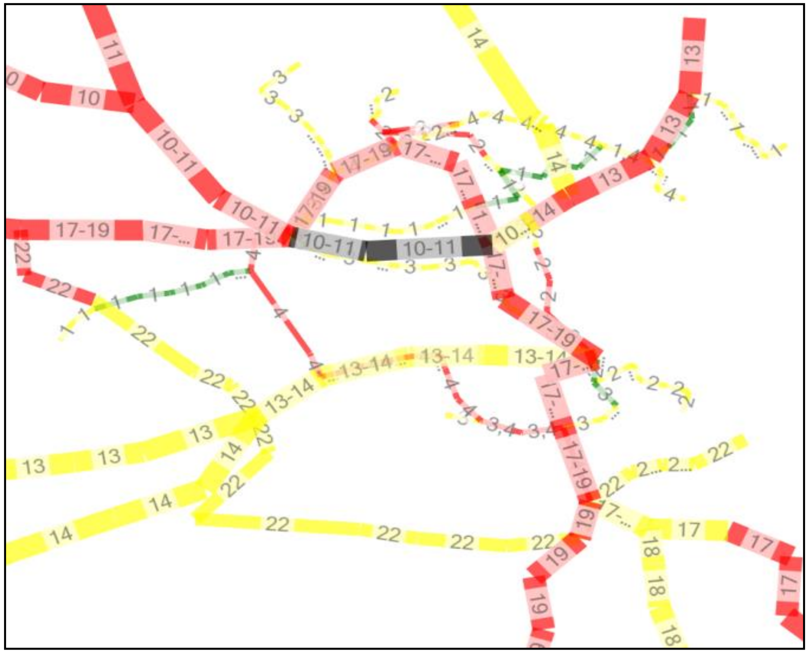
Disruption (D4)

Evaluation framework

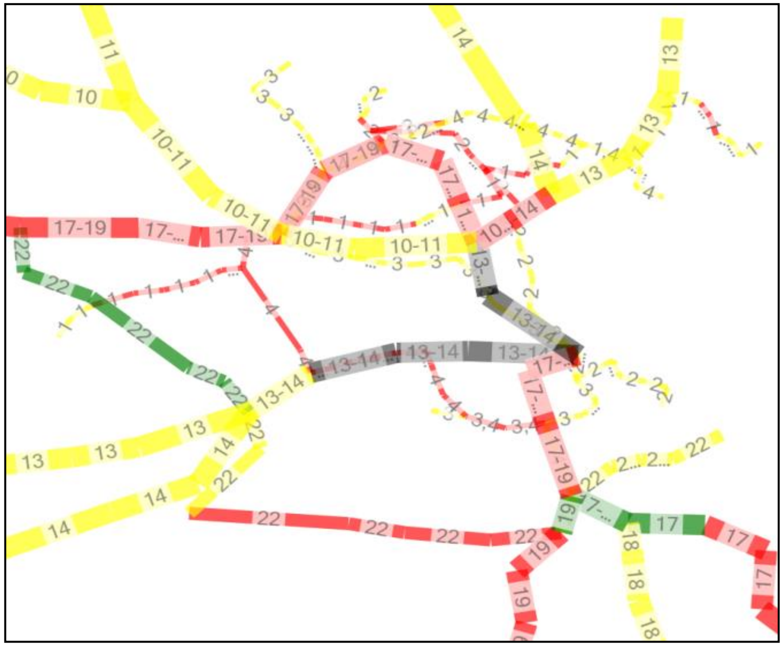


VOC change due to disruptions

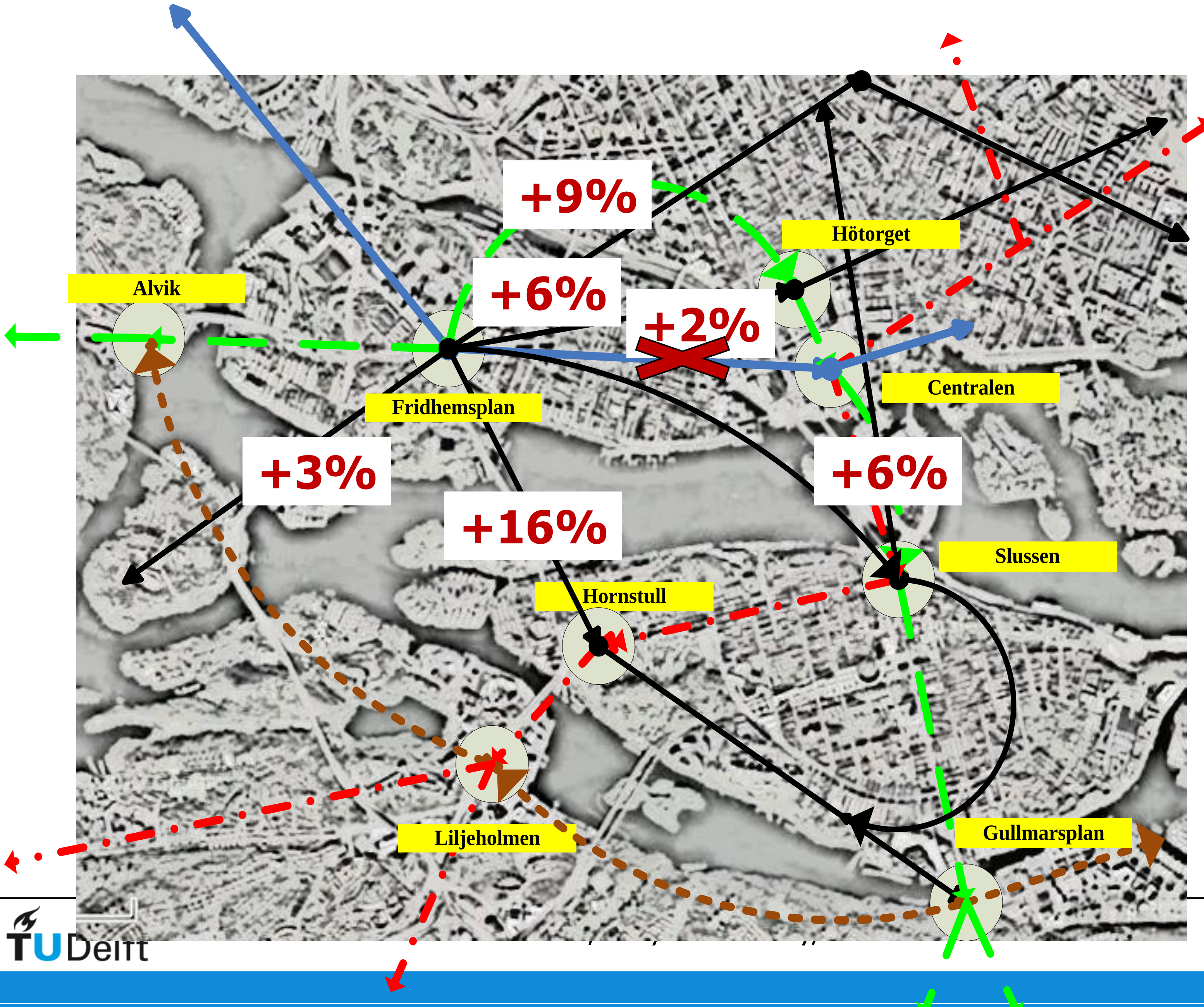
Disruption on 10-11, southbound



Disruption on 13-14, southbound



Where shall we increase capacity?



Impact indicators

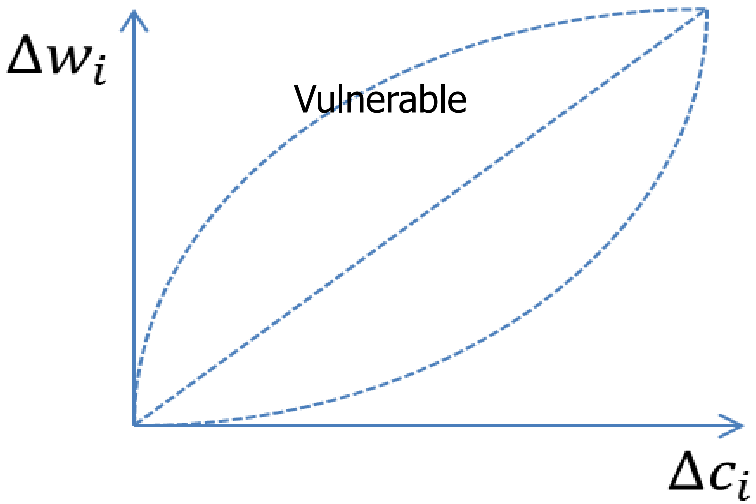
	$h = 0$ Base network	$h \neq 0$ Extended network	VCE Value of capacity enhancement
$\delta = 0$ Undisrupted	$W(0,0)$	$W(0,h)$	$VCE(h\|0) = W(0,h) - W(0,0)$
$\delta \neq 0$ Disrupted	$W(\delta,0)$	$W(\delta,h)$	$VCE(h\|\delta) = W(\delta,h) - W(\delta,0)$
PI Passenger importance	$PI(\delta\|0) = W(\delta,0) - W(0,0)$	$PI(\delta\|h) = W(\delta,h) - W(0,h)$	
$VSDM$ Value of strategic disruption mitigation	$VSDM(h\|\delta) = PI(\delta\|h) - PI(\delta\|0)$		

Evaluation example

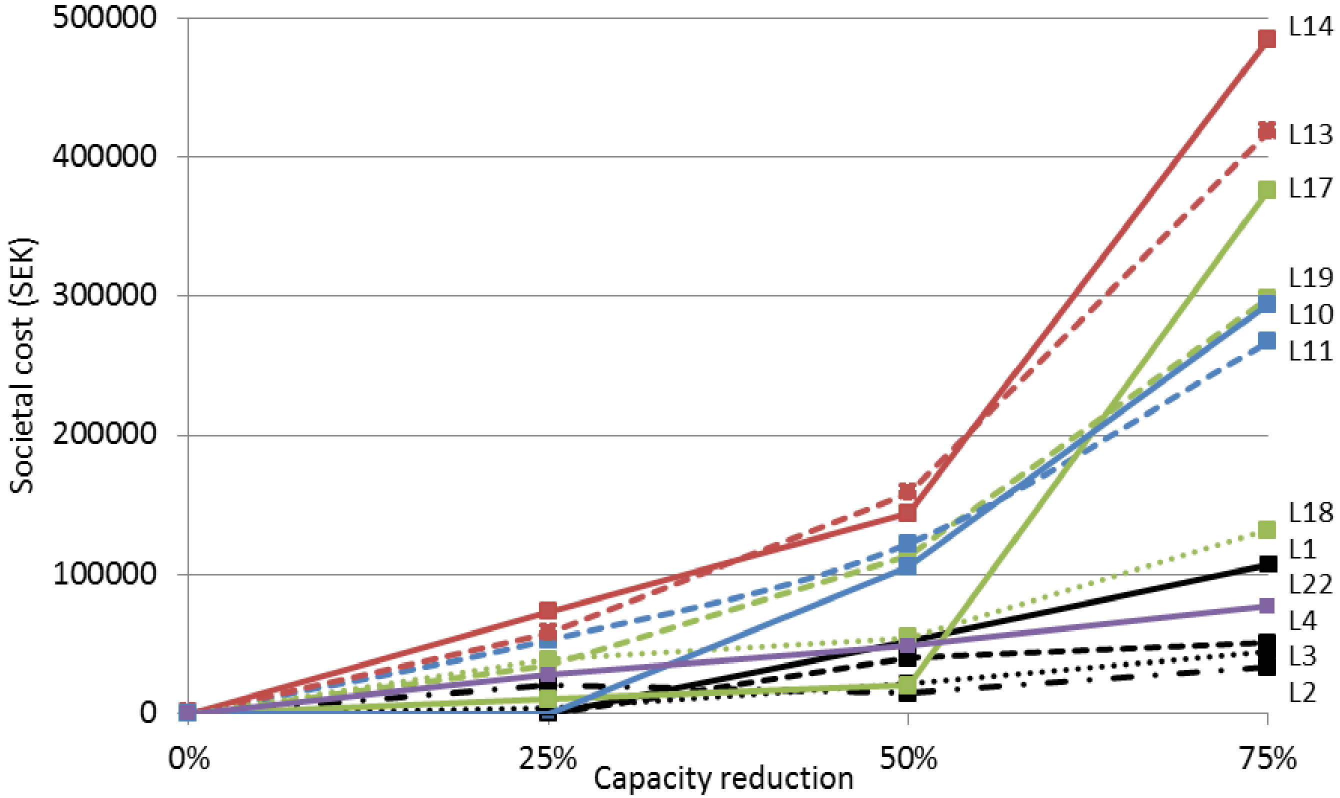
R – Stop-level		Disruption (D-Blue)		Value of strategic disruption mitigation
		No	Yes	
Capacity enhancement (C-Green)	No	$w(0,0)$	$w(\delta,0)$	+7.06%
	Yes	$w(0,h)$	$w(\delta,h)$	+2.77%
Value of capacity enhancement		-24.67%	-27.69% (planned)	

Beyond a complete failure

- Most disruptions do not amount to complete breakdowns (maintenance and construction works, traffic incidents or cancelled services)
- Vulnerable systems - greater negative impacts in a disproportional relation to the increase in the original capacity reduction
- Non-linear properties of network effects, traffic dynamics and route choice -> non-trivial relation?
- Systems that operate close to capacity
- Line-level; full-scan; dynamic assignment



Relation between capacity reduction and change in societal cost



- Long and small rather than short and large capacity reductions
- The same capacity increase counts more when relieving a larger capacity reduction

On-going research

- Modelling
  - Day to day congestion equilibrium conditions
  - Habit formation and limited adaptation
  - Passenger groups
  - Real-time dynamic control optimization

- Applications
  - Transfer coordination strategies
  - Fleet management strategies
  - Paris and Amsterdam networks

Thank you! Questions?

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