Robustness and Resilience of Multi-Modal Public Transport Networks

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Outline

- Importance and challenges
- Identifying critical links
- Measuring the impact of disruptions
- Accounting for exposure
- Understanding disruption dynamics
- Value of increased capacity
- On-going and research outlook

Why public transport vulnerability?

- Recurring, costly and induce disproportional uncertainty
  [e.g. cost of PT disturbances in Stockholm region = 650 million €]

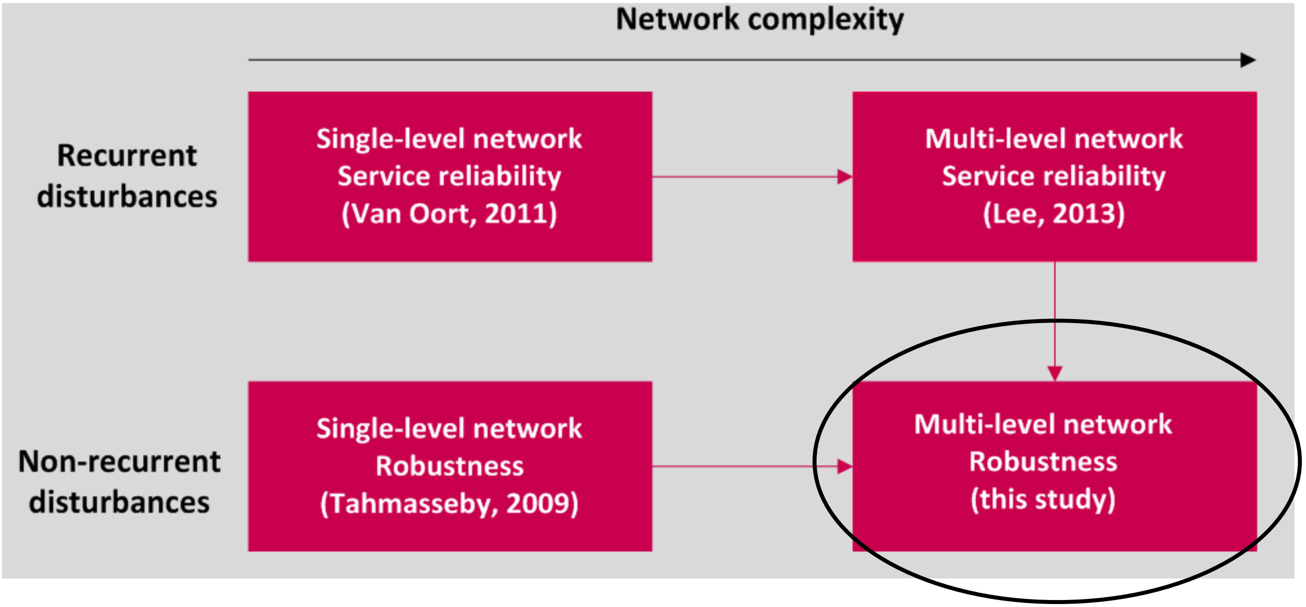
- Limited transferability from car networks
  - Interaction between infrastructure and service layers
  - Multi-modality, importance of transfers
  - Spatial and temporal availability
  - Lower connectivity
  - Operational constraints
  - Centralized control and management

- PT investments increasingly driven by reliability, congestion and vulnerability considerations

- Diversity: exogenous/endogenous; planned/unplanned; link/line

Limitations current approach robustness

- Everyone knows the costs of robustness measures, but:
  - Hardly insights in (societal) costs of disturbances
  - Hardly insights in (societal) benefits of measures aiming at improving PT robustness
- Focus on small disturbances which do not influence infrastructure availability
- Focus on mono-level / mono-operator PT networks



Yap, van Oort, van Nes and van Arem (2015). Robustness of multi-level public transport networks: A methodology to quantify robustness from a passenger perspective. The 6th International Symposium on Transportation Network Reliability (INSTR).

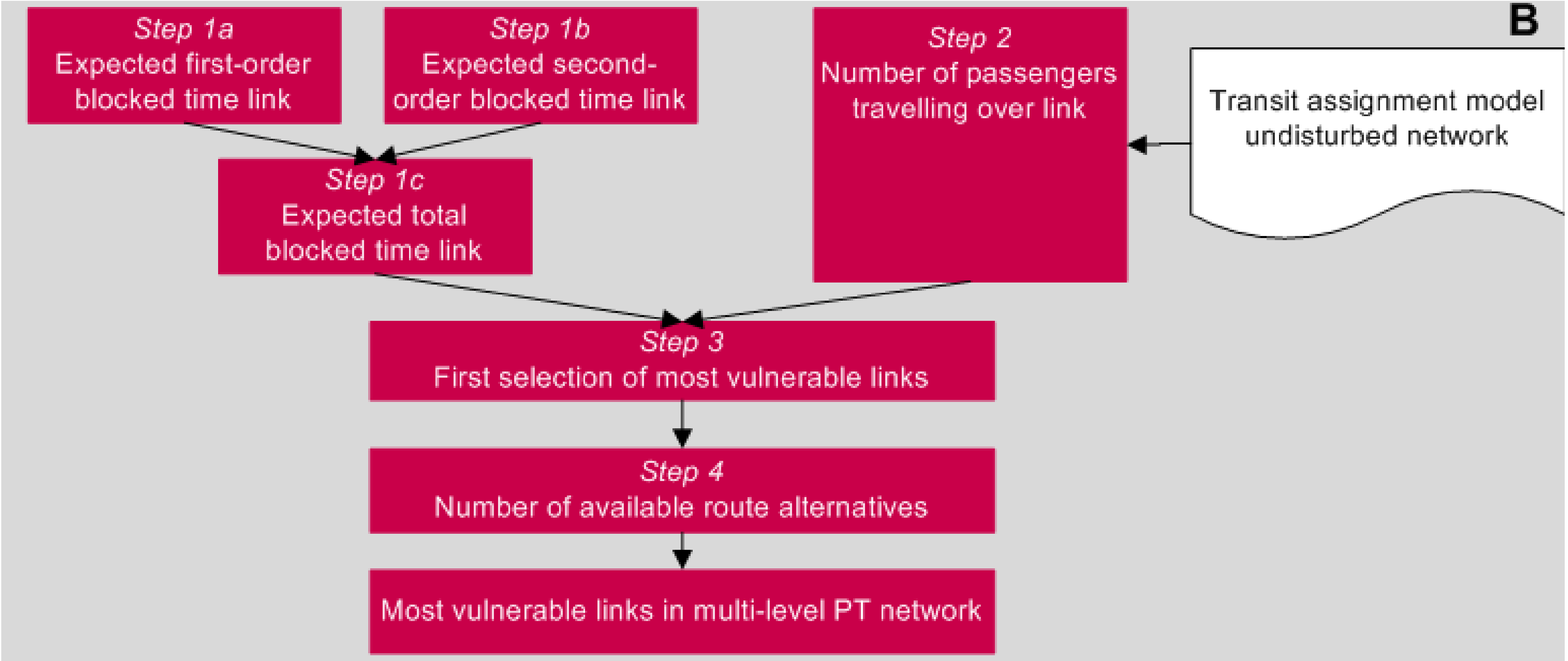
Vulnerable links from a passenger perspective

- Link vulnerability and robustness
  - From a passenger perspective, link vulnerability is the product of
    - Frequency
    - Duration
    - Impact

- For PT networks, a method is lacking to identify the most vulnerable links in the network from a passenger perspective: analogy road networks
  - Disturbances on the link it self → first-order effects
  - Spillback effects → second-order effects
  - Approximation of impact of disturbances using the I/C ratio → passenger volume

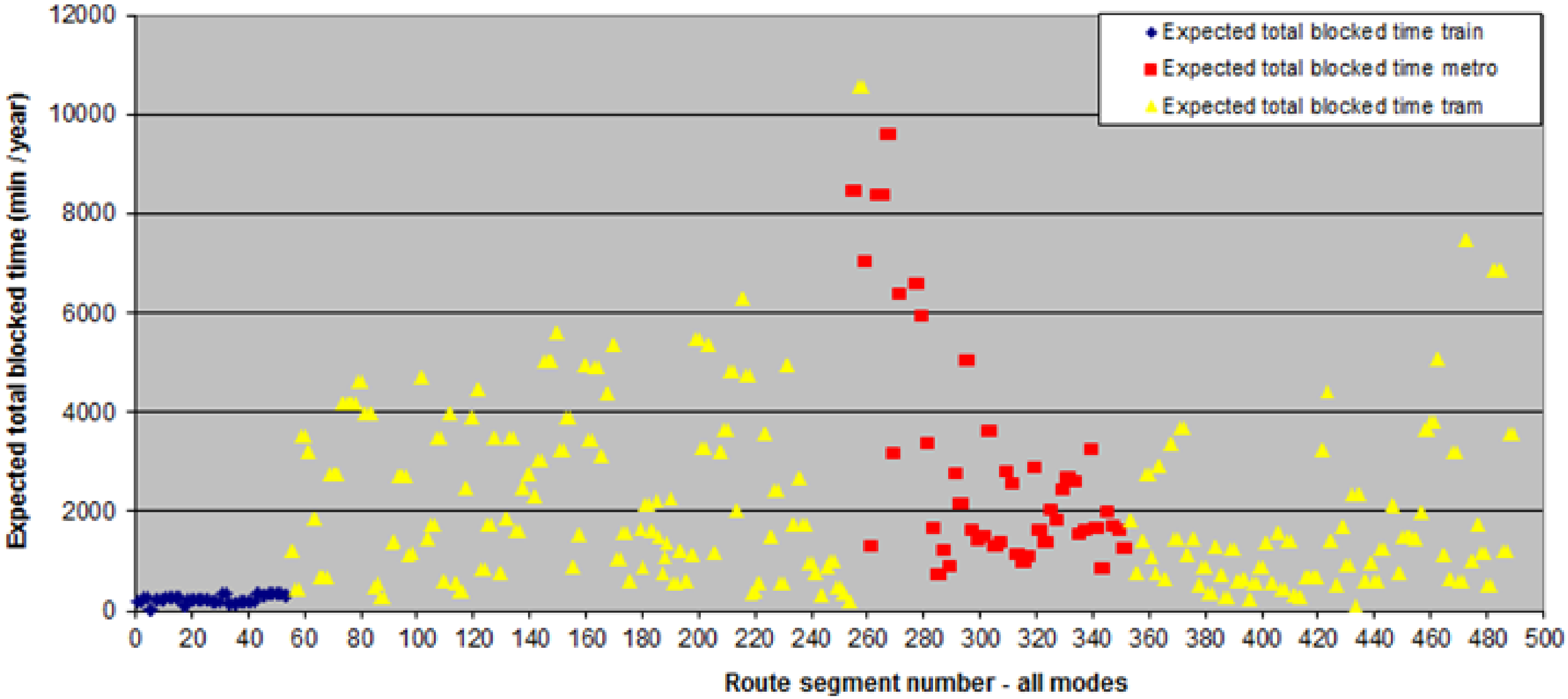
Identification of vulnerable links

- Developed method to identify the most vulnerable links in the multi-level PT network:



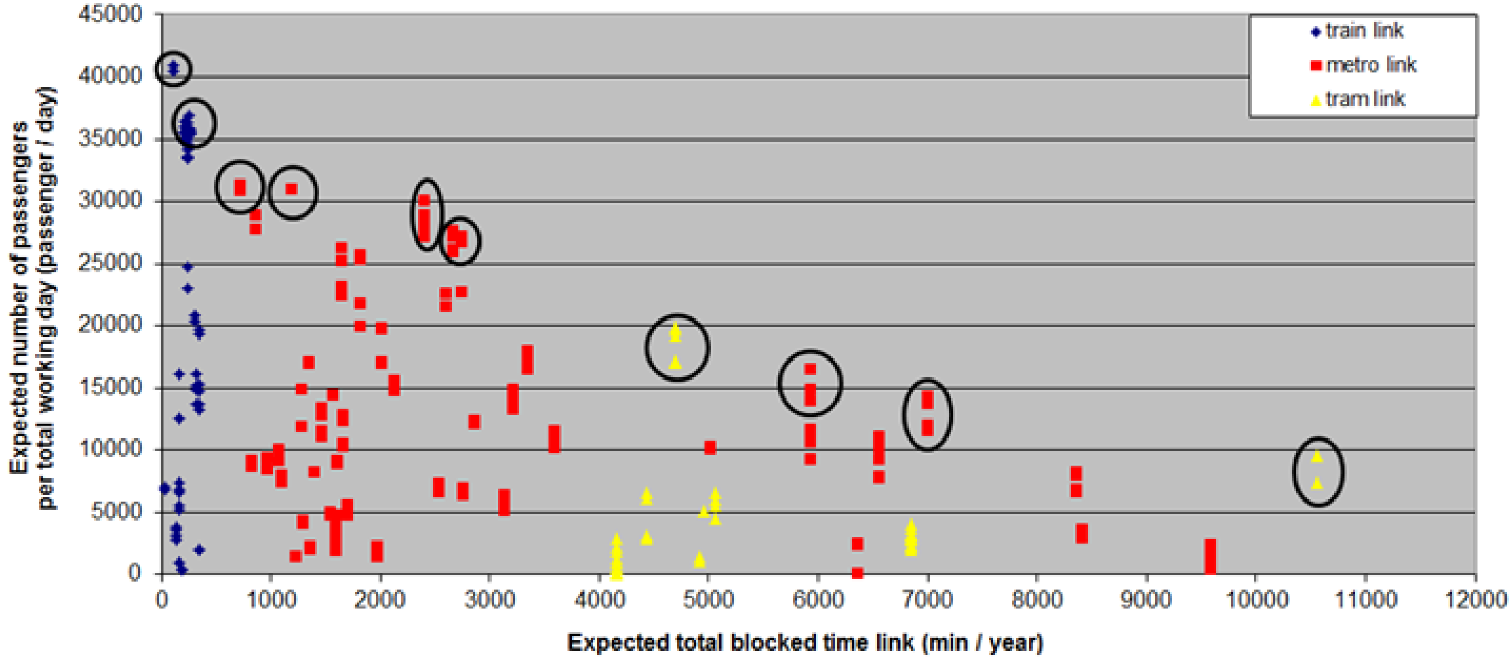
Case study Randstad Zuidvleugel (1)

- Expected blocked time for train link segments ≪ metro / light rail and tram
- On average: expected blocked time on tram links The Hague > Rotterdam
- Expected blocked time on metro / light rail links The Hague > Rotterdam
  - Switch density metro network Rotterdam > light rail network The Hague



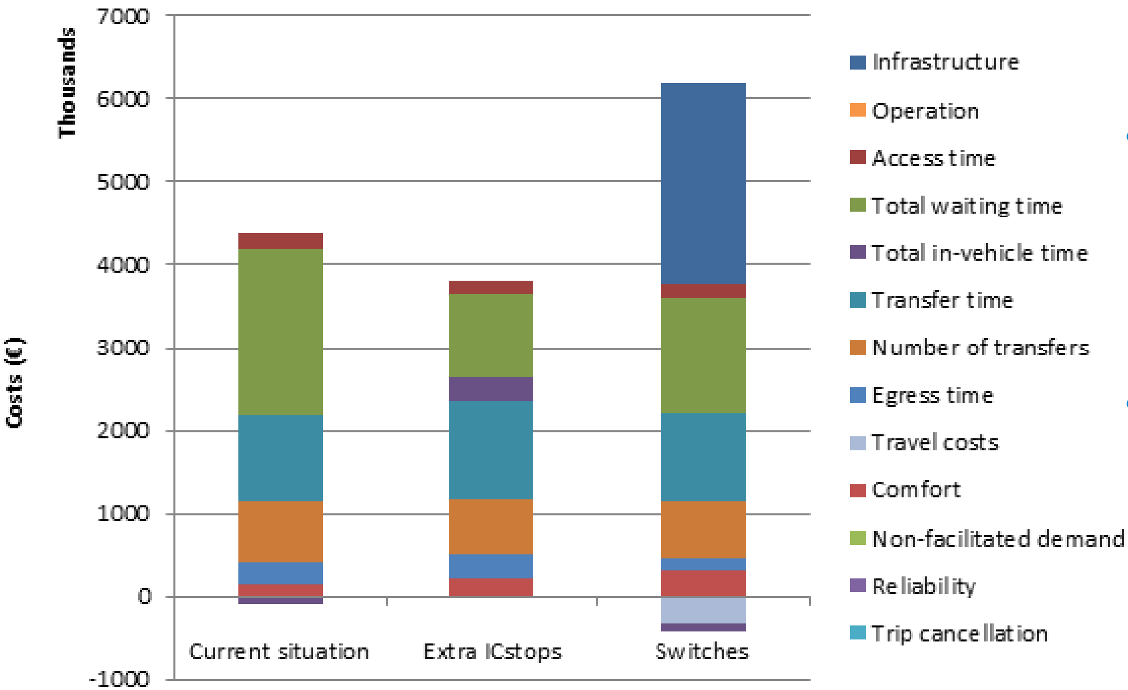
Case study Randstad Zuidvleugel (2)

- Most vulnerable links are from different network levels
- Train links are vulnerable because of the large impact on many passengers
- Metro/light rail and tram links suffer more often from disturbances than train
- Busy metro / light rail and tram links are especially vulnerable



Case study RR Laan van NOI – Forepark

- Costs and benefits of robustness measures expressed in monetary terms



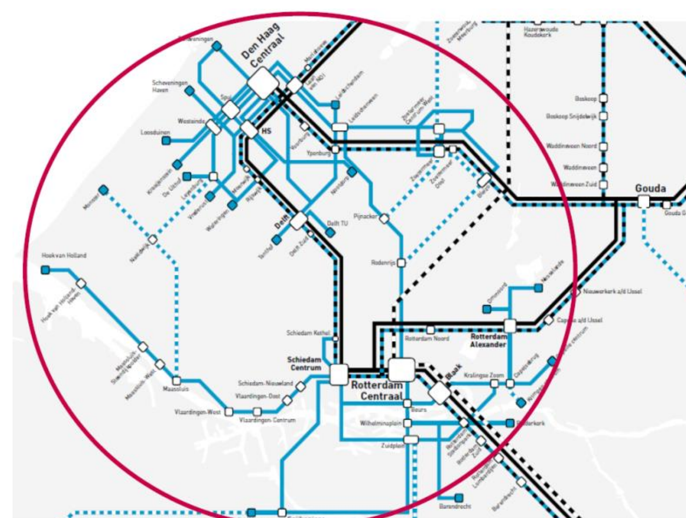
- Temporary extra IC stops:
  - Waiting time ↓
  - In-vehicle time + discomfort ↑
- Extra switches
  - Travel time ↓
  - Infrastructure costs ↑

Link segment	Measure	Total costs 10 years (€*10^6)	Effect on societal costs (%)
Laan van NOI - Forepark	No measure	4.3	
Laan van NOI - Forepark	Extra IC stops	3.9	- 8%
Laan van NOI - Forepark	Switches	5.8	+ 35%

Exposing the role of exposure

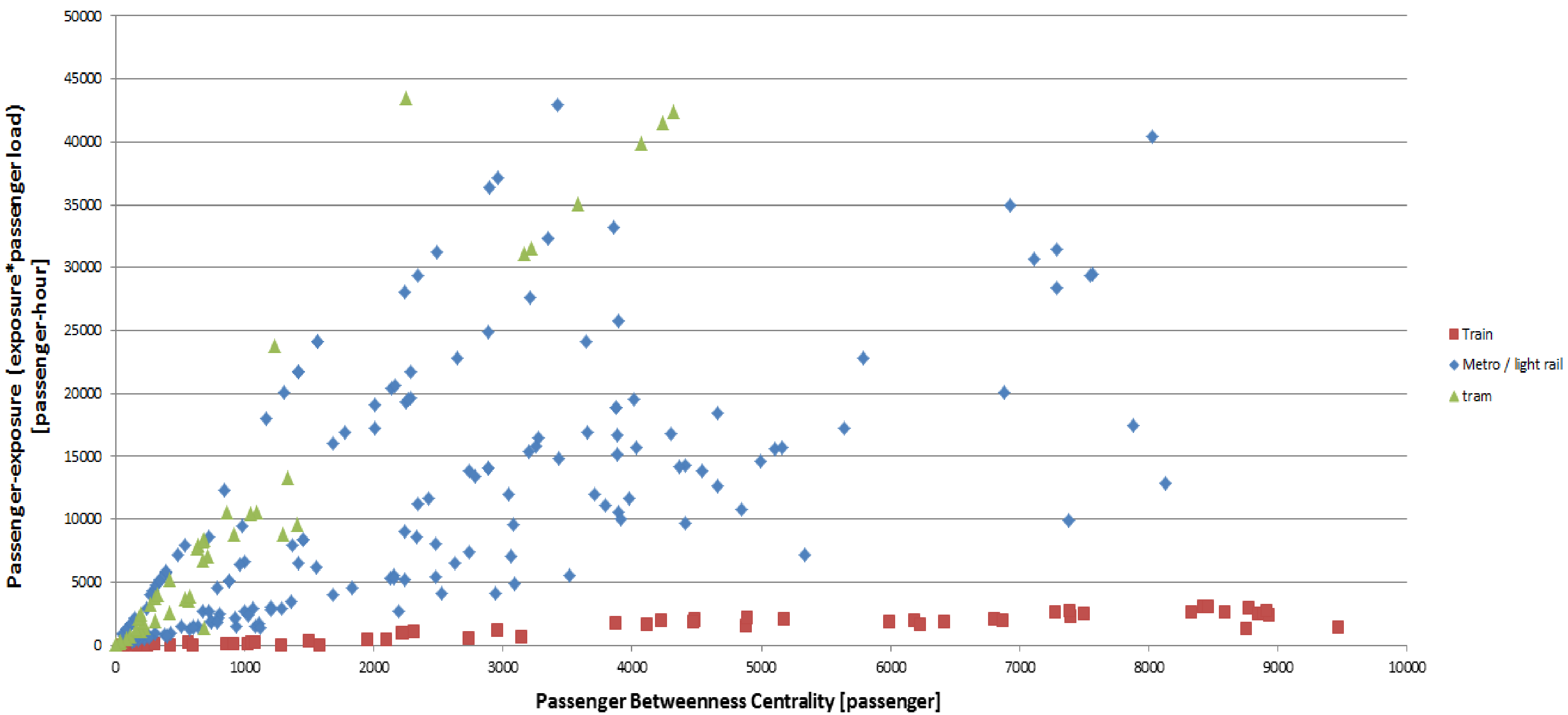
- Link criticality depends on both impacts when a disruption occurs as well as the likelihood of its occurrence
- Difficult to obtain and analyse data concerning disruptions

- Estimate frequencies and durations of various disruption types
- Link-specific parameters based on length, veh-km, crossings…
- Static assignment: OmniTRANS, frequency-based TAM



Cats, Yap and van Oort (2015). Exposing the role of exposure in public transport network vulnerability analysis. The 6th International Symposium on Transportation Network Reliability (INSTR).

Identifying critical links
Passenger load vs. Passenger exposure



Load

1. Rotterdam Centraal - Schiedam Centrum
2. Rotterdam Zuid - Rotterdam Lombardijen
3. Rotterdam Lombardijen - Barendrecht
4. Rotterdam Blaak - Rotterdam Zuid
5. Rotterdam Centraal - Rotterdam Blaak

Exposure

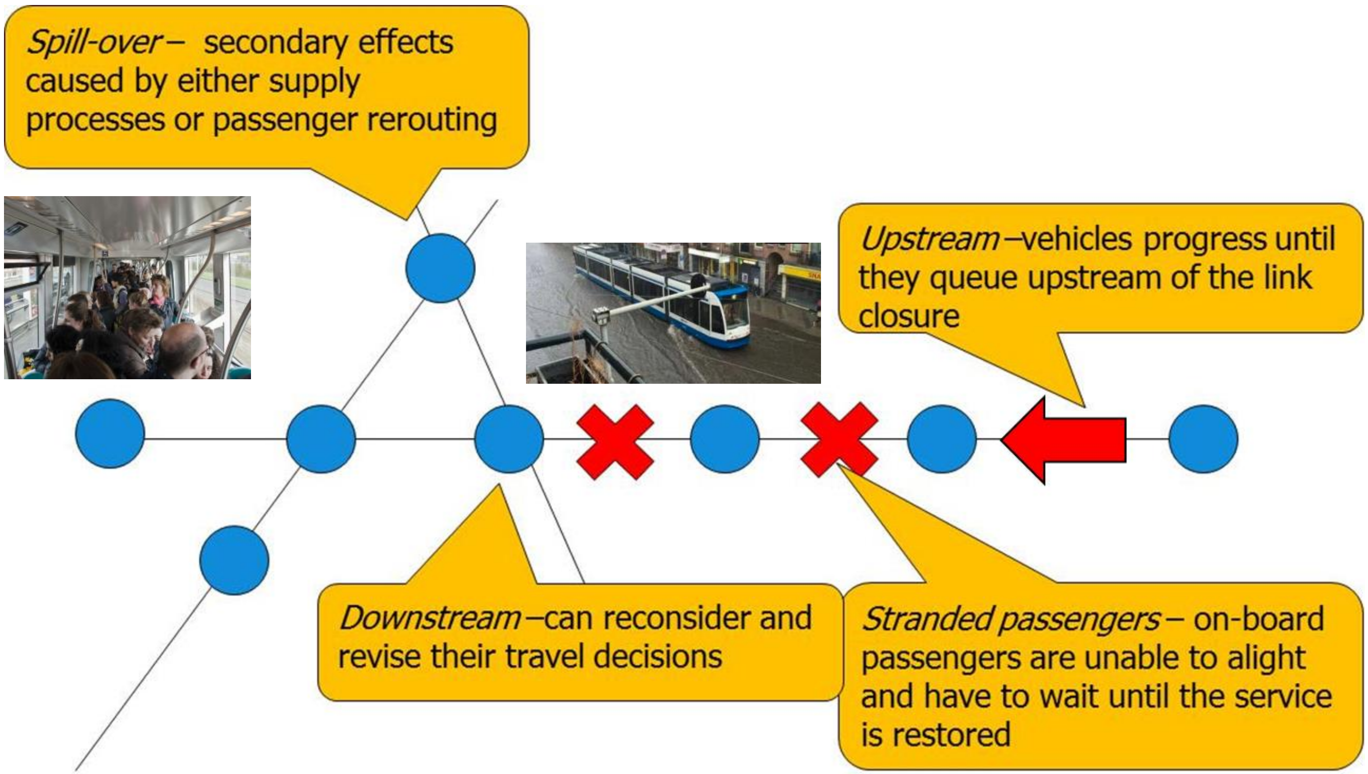
1. Ternoot - Laan van NOI (T)
2. Laan van NOI - Voorburg 't Loo (R)
3. Spui - Grote Markt (T)
4. Grote Markt - Brouwersgracht (T)
5. Rijnhaven – Maashaven (M)

Evaluating link criticality Passenger load vs. Passenger exposure

Link segment	Mode	Welfare change [€]	Ranking based on impact for an average disruption, c_l	Annual expected welfare change [€/year]	Ranking based on annual expected impact, $E(c_l)$
Rotterdam Zuid - Rotterdam Lombardijen	Train	€ 64 102	1	€ 11 574	9
Rotterdam Centraal - Rotterdam Zuid	Train	€ 56 183	2	€ 30 499	6
Rijswijk - Delft	Train	€ 56 180	3	€ 26 045	7
Rotterdam Centraal - Schiedam Centrum	Train	€ 39 385	4	€ 11 287	10
Rijnhaven – Zuidplein	Metro	€ 33 489	5	€ 266 235	3
Rotterdam Lombardijen - Barendrecht	Train	€ 27 134	6	€ 14 885	8
Ternoot - Laan van NOI	Tram	€ 26 840	7	€ 931 873	1
Laan van NOI – Forepark	Light rail	€ 14 175	8	€ 281 226	2
Melanchtonweg – Pijnacker Zuid	Light rail	€ 13 931	9	€ 189 173	4
Brouwersgracht – CS	Tram	€ 10 038	10	€ 176 821	5

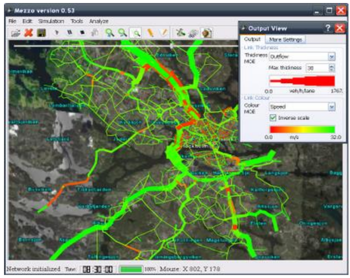
Capturing disruption dynamics

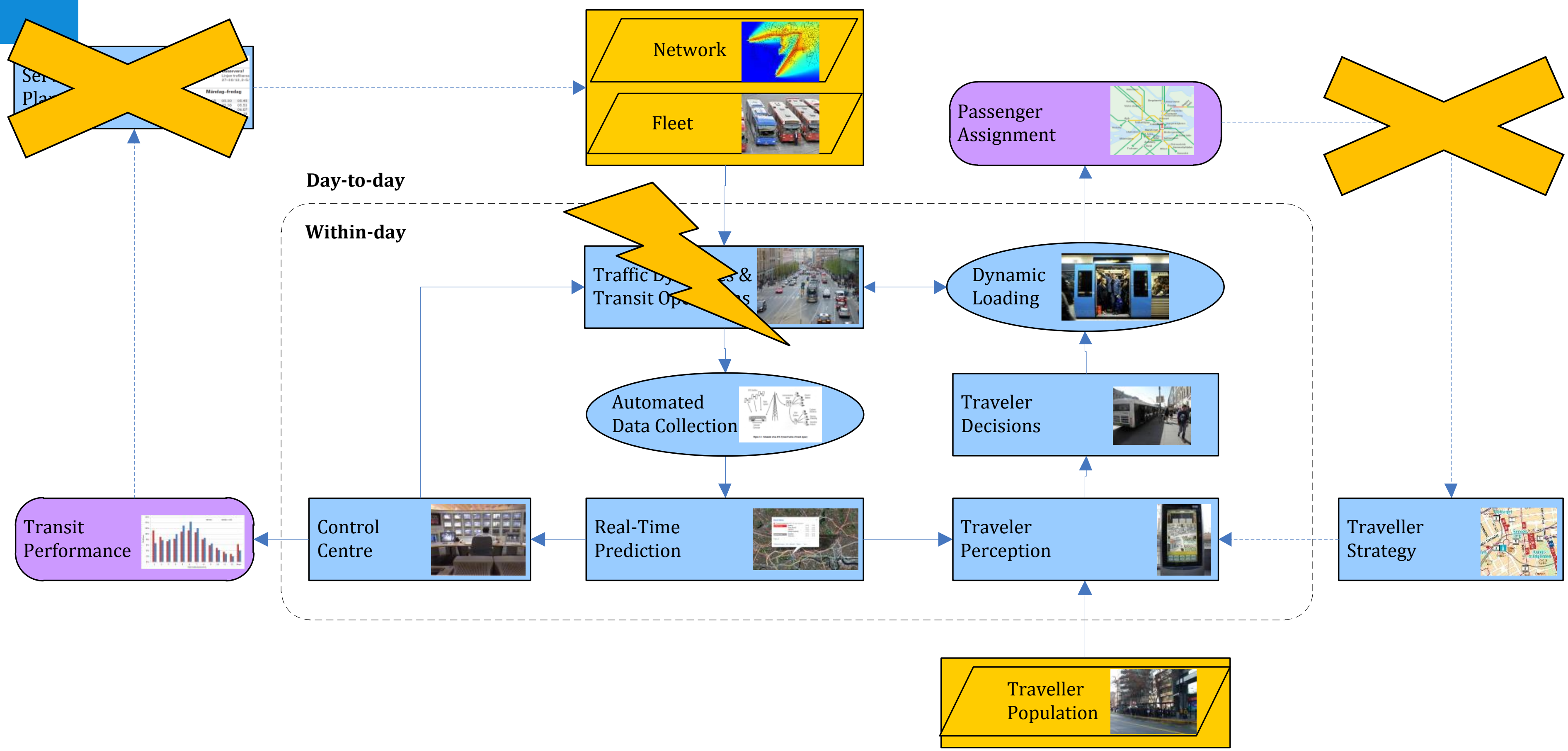
- Static model: underestimation of disruption effects
- En-route decisions, imperfect information
- Both passengers and operators can respond to disruptions



Cats and Jenelius (2014). Dynamic vulnerability analysis of public transport networks: Mitigation effects of real-time information. Networks and Spatial Economics.

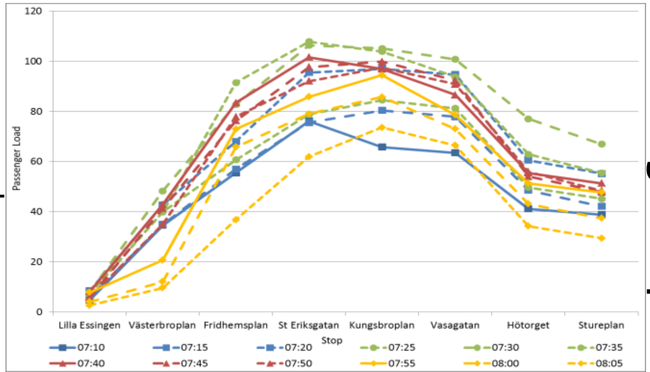
Transit Assignment and Operations Simulation Model (BusMezzo)



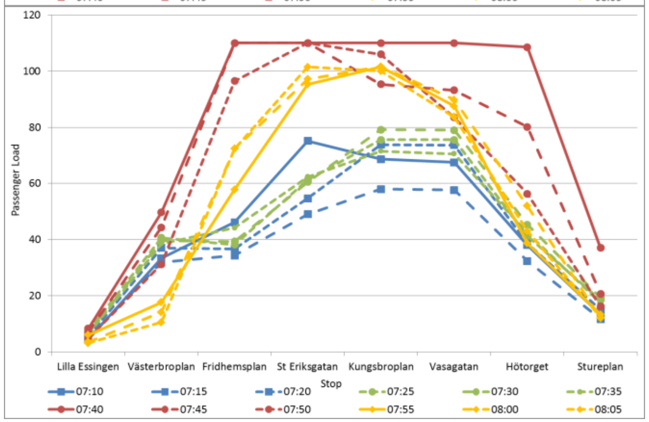


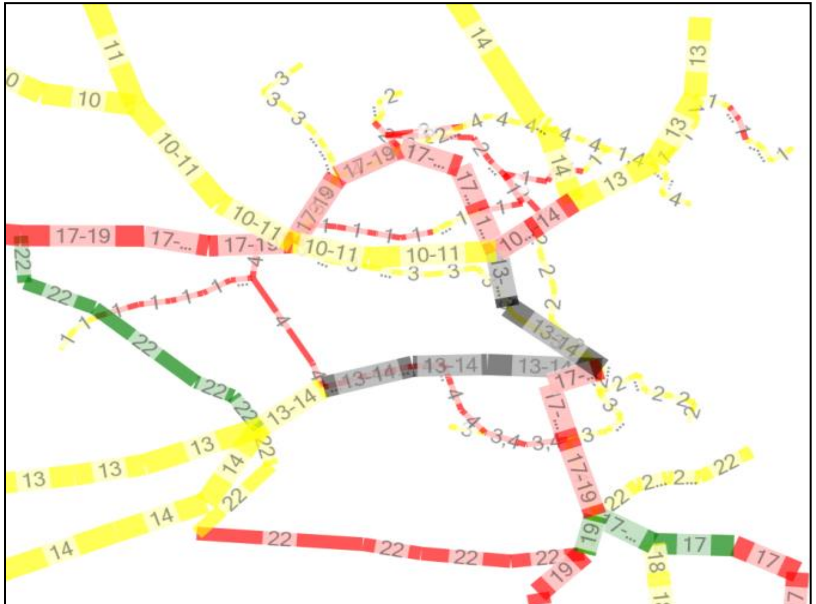
Passenger trip-loads

Normal operations

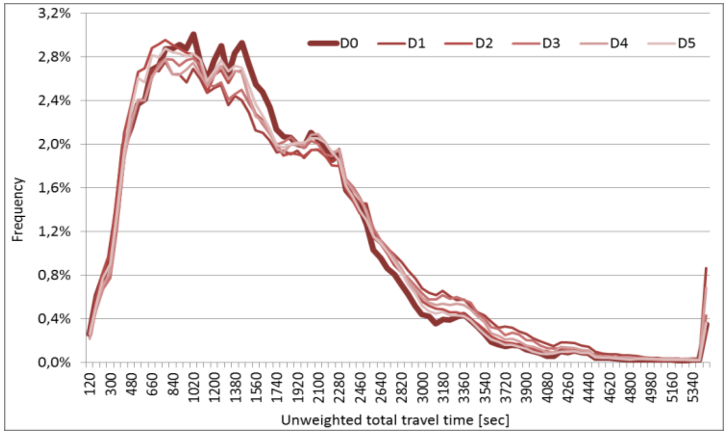


Disruption (D4)



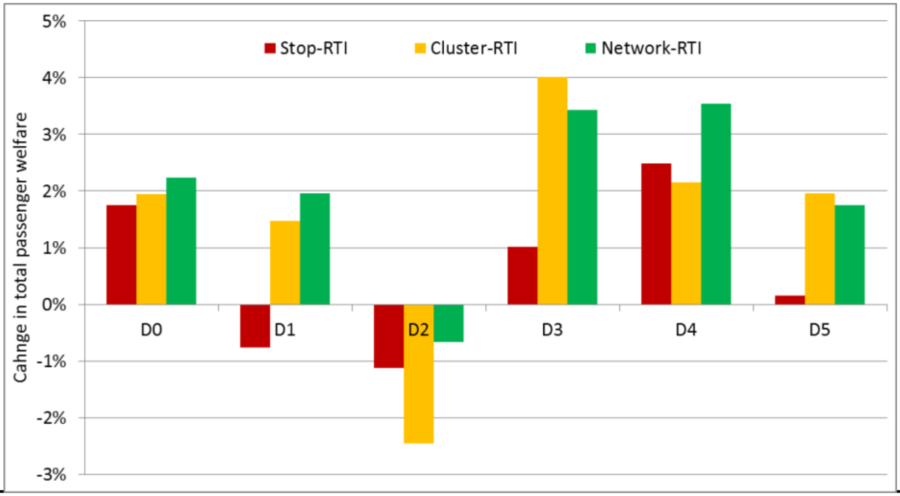


Change in flow/capacity

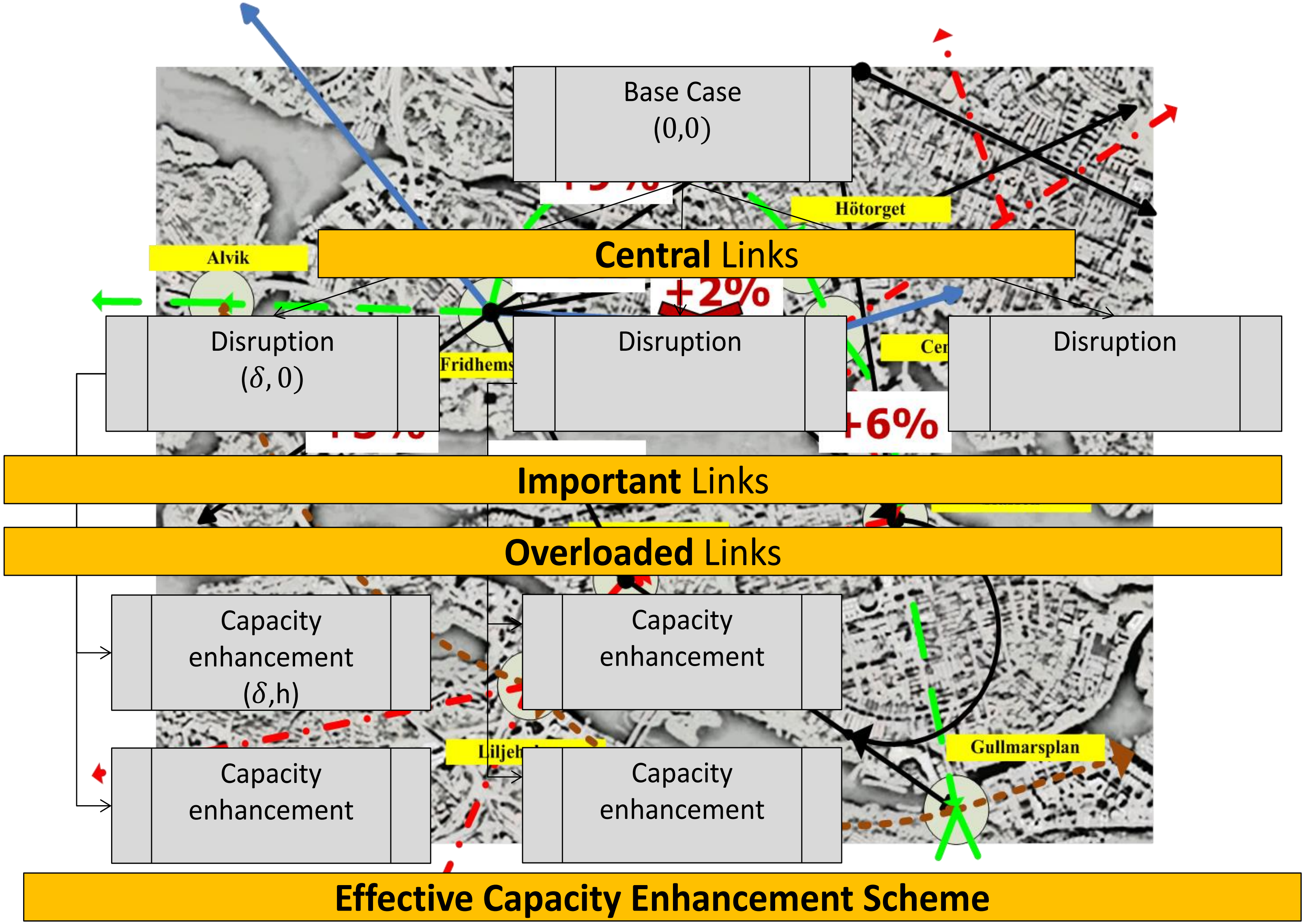


Travel time distribution

Impacts of information provision



Where shall we increase capacity?



Cats and Jenelius (2015). Planning for the unexpected: The value of reserve capacity for public transport network robustness. Transportation Research Part A.

Evaluation example

Stockholm case study		Disruption (D-Blue): No	Disruption (D-Blue): Yes	Relative travel times change due to disruption
Capacity enhancement (C-Green)	No	$w(0,0)$	$w(\delta,0)$	+7.06%
	Yes	$w(0,h)$	$w(\delta,h)$	+2.77%
Relative change in total travel times due to capacity enhancement		-24.67%	-27.69%	

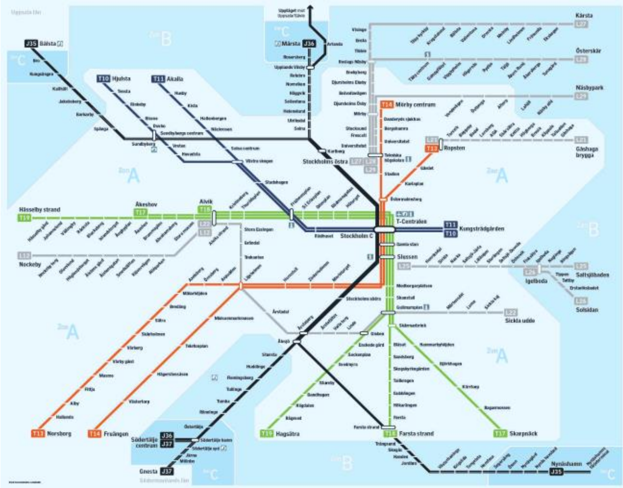
Welfare gain increase from 1.7 to 2.0 million Swedish Crowns for all passengers during a single rush hour of operations

Evaluating the robustness value of new investments

- Comparing alternative (baseline and extended) networks performance in case of disruptions

- Normal operations: LRT welfare gain of 150,000 SEK during a single rush hour

- Disruptions:
  - Critical links: welfare loss of 470,000-760,000 SEK, better off with LRT;
  - LRT: slightly worse-off than without it



- Incorporating into cost-benefit analysis

Jenelius and Cats (2014). The value of new cross-radial links for public transport network robustness. ICVRAM.; Cats (2015). The resilience value of public transport development plans. The 6th International Symposium on Transportation Network Reliability (INSTR).

Plenty of open questions!

- What characterizes robust network design? (structure, operations)
- How can we incorporate robustnes[...] appraisal?
- What a[...]ruptions on travelle[...]
- How ca[...]
- Not onl[...]
- How ca[...]ational mitigati[...]
- Multi-lay[...] network vulnerability
- …

Suggestions on how together make it a robust research plan?

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