Robustness and Resilience of Multi-Modal Public Transport Networks

Oded Cats, Menno Yap and Niels van Oort
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

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 itself → 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 $\ll$ 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 ↑

<table>
<thead>
<tr>
<th>Link segment</th>
<th>Measure</th>
<th>Total costs 10 years (€*10^6)</th>
<th>Effect on societal costs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laan van NOI - Forepark</td>
<td>No measure</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Laan van NOI - Forepark</td>
<td>Extra IC stops</td>
<td>3.9</td>
<td>- 8%</td>
</tr>
<tr>
<td>Laan van NOI - Forepark</td>
<td>Switches</td>
<td>5.8</td>
<td>+ 35%</td>
</tr>
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</table>
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

Identifying critical links
Passenger load vs. Passenger exposure

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

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)

Railforum seminar, 08-July-2015
Evaluating link criticality
Passenger load vs. Passenger exposure

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

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

Transit Assignment and Operations Simulation Model (BusMezzo)
Normal operations

Disruption (D4)

Passenger trip loads

Travel time distribution

Impacts of information provision

Change in flow/capacity

Railforum seminar, 08-July-2015
Where shall we increase capacity?

## Evaluation example

<table>
<thead>
<tr>
<th>Stockholm case study</th>
<th>Disruption (D-Blue)</th>
<th>Relative travel times change due to disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Capacity enhancement (C-Green)</td>
<td>No</td>
<td>$w(0,0)$</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>$w(0, h)$</td>
</tr>
</tbody>
</table>

Relative change in total travel times due to capacity enhancement:

- No: -24.67%
- Yes: -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

Plenty of open questions!

- What characterizes robust network design? (structure, operations)
- How can we incorporate robustness into project appraisal?
- What are the short-term and long-term impacts of disruptions on traveller behaviour?
- How can we analyse and shorten the recovery period?
- Not only complete breakdown – partial reductions
- How can we support the deployment of real-time operational mitigation measures and resource allocation?
- Multi-layer multi-modal network vulnerability
- ...

Suggestions on how together make it a robust research plan?

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