Modelling Railway-Induced Passenger Delays in Multi-Modal Public Transport Networks: An Agent-Based Copenhagen Case Study Using Empirical Train Delay Data

Mads Paulsen, Thomas Kjær Rasmussen & Otto Anker Nielsen

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July 25, 2018
Outline

1. Motivation
2. Literature
3. Methodology
4. Case Study & Results
5. Conclusions & Future Work
Outline

1. Motivation
   - Relevance
   - Problem Definition
2. Literature
3. Methodology
4. Case Study & Results
5. Conclusions & Future Work
Railway Reliability

What to Measure?

- Public transport operators are generally evaluated on vehicle reliability and punctuality – not passenger punctuality.
  - Sooo easy to measure...

- Some research on passenger perspectives in timetabling *(Schoebel, 2018)*.
  - Very hard to solve.

“If a tree falls in the forest, and no one is around to hear it, does it still make a sound?”
"If a train is delayed, and no one is around to be delayed, does it still matter?"
“If a train is delayed, and no one is around to be delayed, does it still matter?”

- Public transport system should be judged by its passengers delays – not vehicle delays.
- A consistent method for determination of passenger delays is needed.
Passenger Delays: What’s the Deal?

- Vehicle delay information have become widely available through Automated Vehicle Location (AVL) data.
- Passenger delays are difficult to measure.
  - Not just a sum of vehicle delays... (except for last trip segment).
Passenger Delays: What’s the Deal?

- Passenger delays increase when missing a connection...
  - ... or catching an earlier connection (negative delay).
- I.e. transfers plays an integral role.
Passenger Delays: What’s the Deal?

- Possible transfers are numerous...
Aim

Establish a Model That Can:

- Infer door-to-door passenger delays from vehicle delays:
  - At a large scale.
  - In multi-modal networks.
Outline

1 Motivation

2 Literature
   - Traditional Passenger Delay Models
   - Personal Data Models
   - Contribution

3 Methodology

4 Case Study & Results

5 Conclusions & Future Work
Traditional Passenger Delay Models

**Hickman and Bernstein, 1997**
- Proposes 4 principles of adaptive passenger route choice.
- Applied to a toy network.

**Nielsen et al., 2009**
- A model with full adaptive route choices, corresponding to the most advanced principle of Hickman and Bernstein, 1997.
- Applied to realised delays of suburban train network of Copenhagen.

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Models Using Personal Data

Smartphone Location Data
- Carrel et al., 2015*
  - Combined with AVL data.
  - Data rarely made available due to privacy issues.

Tap-In, Tap-Out Data (AFC)
- E.g. Antos and Eichler, 2016†
  - Only available for closed systems.
  - Station-to-station.

* Carrel, Andre, Lau, Peter S.C., Mishalani, Rabi G, Sengupta, Raja, and Walker, Joan L (2015). “Quantifying transit travel experiences from the users’ perspective with high-resolution smartphone and vehicle location data: Methodologies, validation, and example analyses”. In: Transportation Research Part C: Emerging Technologies 58, pp. 224–239

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What’s Missing?

Contribution

- Door-to-door passenger delays.
- Combining:
  - Readily available AVL data.
    - Easily transferable to other cities.
  - Multi-modal network.
  - Larger variety of transfer types.
Outline

1. Motivation
2. Literature
3. Methodology
   - MATSim
   - Framework
   - Levels of Adaptiveness
4. Case Study & Results
5. Conclusions & Future Work
The Multi-Agent Transport Simulation MATSim

MATSim*
- Open source.
- Agent-based.
- Door-to-door.
- Activity-based.
- Large-scale applicable.
- Scenarios around the world.

A PT leg consists of a series of stops.
Connected by either walking or PT.
First feasible PT vehicle is used.

The plan can be altered between iterations based on performance of previous iteration.

- Waiting time penalised 1.6 times harder.
- Additional transfer penalty of 6 regular minutes.
Framework

- Base Scenario (Planned Timetable)
- Intended Routes
- Realised Timetables
  - Realised Routes
  - Realised Routes
  - Realised Routes
- Levels of Adaptiveness
  - Non-Adaptive
  - Semi-Adaptive
  - Full-Adaptive
- Passenger Delays
  - Passenger Delays
  - Passenger Delays
Levels of Adaptiveness: Why?

What Do Passengers Do?

- Do they...
  - ... stick to their intended route?
  - ... rely on real-time traffic information and minimise their travel time?
  - .. a trade-off between the two?
Levels of Adaptiveness: Which?

We propose three strategies:

- **Non-Adaptive**
- **Semi-Adaptive**
- **Full-Adaptive**
Levels of Adaptiveness: The Non-Adaptive

- Conservative, upper bound estimate.
- No information passed on to passengers.
- No flexibility in stop pattern.
Levels of Adaptiveness: The Semi-Adaptive

Semi-Adaptive

- Compromise estimate.
- Full information gained when reaching first stop.
- First stop fixed, the rest are flexible.
Levels of Adaptiveness: The Full-Adaptive

- Optimistic, lower bound estimate.
- Full information gained when at start of leg.
- Full stop pattern flexibility.
Algorithm

1: Create the planned timetable, $S^p$.
2: Run MATSim with the events-based public transport router extension (Ordóñez, 2016) using $S^p$ to get the intended travel times, $t^I_T$, for all trips, $T \in T$.
3: Create realised timetables, $T^R_D$, for all historical weekdays, $D \in D$.
4: for all days, $D \in D$ do
5: for all levels of adaptiveness, $A \in A$ do
6: Simulate $D$ in MATSim using realised timetable, $T^R_D$, and intended routes from 2, while allowing adaptive choices of agents according to level of adaptiveness, $A$, to obtain corresponding realised travel times, $t^{RA}_T$, for all trips, $T \in T$.
7: for all trips, $T \in T$ do
8: Find the corresponding passenger delay of $T$, $d^A_T$, as the difference between the intended travel time from 2 and realised travel time from 6,
9: end for
10: end for
11: end for

$$d^A_T = t^{RA}_T - t^I_T.$$
Algorithm

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   - Case Study
   - Results
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### Delay Data

- Delay data was provided by the national railway infrastructure manager, Rail Net Denmark.
- All 65 weekdays of the autumn of 2014.
- All railway lines except metro and small privately owned local lines.

<table>
<thead>
<tr>
<th>September 2014</th>
<th>October 2014</th>
<th>November 2014</th>
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</thead>
<tbody>
<tr>
<td><strong>Mon</strong>&lt;br&gt;1&lt;br&gt;8&lt;br&gt;15&lt;br&gt;22&lt;br&gt;29</td>
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Model was applied to the metropolitan area of Copenhagen:

- All PT lines: Train, Metro, Bus.
- 1% population sample: 3,747 (2,272) agents, 7,889 (5,316) PT trips per day.
Aggregate Results

The diagram illustrates the CDF (Cumulative Distribution Function) of delay for different train systems:
- Trains
- Non-Adaptive
- Semi-Adaptive
- Full-Adaptive

The x-axis represents the delay in minutes, while the y-axis represents the CDF. The curves show the proportion of delays that are less than or equal to a given delay value.

The non-adaptive system has the highest CDF, indicating a higher proportion of delays, while the full-adaptive system has the lowest CDF, indicating fewer delays. This suggests that adaptive systems can reduce delays compared to non-adaptive systems.
## Aggregate Results

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Break-Even Points

Survival Function

Time [minutes]

0.6
0.5
0.4
0.3
0.2
0.1
0.0

0
1
2
3
4
5

Train Delays
Train Savings
Non-Adaptive Delays
Non-Adaptive Savings
Semi-Adaptive Delays
Semi-Adaptive Savings
Full-Adaptive Delays
Full-Adaptive Savings

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Break-Even Points

- Train Delays
- Train Savings
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- Semi-Adaptive Delays
- Semi-Adaptive Savings
- Full-Adaptive Delays
- Full-Adaptive Savings

Survival Function vs. Time [minutes]
Break-Even Points

Graph showing the survival function over time for different delay and savings scenarios.
Day-to-Day Variations

Case Study & Results
Conclusions & Future Work

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   - Discussion
   - Future Work
   - Conclusions
Nielsen et al., 2009*

- ~ 15% of passengers are delayed by at least one minute.
- The adaptive strategies showed a similar proportion of passengers saving time (~ 18%).
- Magnitude of passenger delays exceeds train delays.

Non-Adaptive as Subset of Adaptive

- Large delays are most likely for adaptive strategies.
  - Optimised with respect to generalised travel cost.
  - Optimised with respect to entire day plans.

![Graph showing survival function and train delays and savings for different strategies: Non-Adaptive, Semi-Adaptive, Full-Adaptive delays and savings.](image)
Realised vs Planned Operations

- Realised outperforms planned.
  - If agents can obtain and react on such information.
  - Ignores robustness.
- Supported by e.g. Fonseca et al., 2018*.
  - Excess waiting time between trains and buses can be reduced by 2 minutes.


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Future Work

Extensions
- Include AVL data from buses.
- Use larger population sample (10%).

Further Analysis
- Spatial analysis.
  - Which parts of the network are most vulnerable?
Findings

- Passenger delays were modelled for 65 weekdays in Copenhagen using three levels of adaptiveness.
- Passengers delays vary more than train delays.
- Small time savings are more likely than small delays.
  - Opposite is generally true when magnitude increases.
Conclusions & Future Work

Conclusions

Implications

- The adaptive strategy generally saves time.
  - Realised operations are better for passengers than the planned.
- Model may be used to evaluate timetable performance.
  - Suggests room for improvements concerning transfer times.
Thank You for Your Attention

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The plan can be altered between iterations based on performance of previous iteration. Waiting time penalised 1.6 times harder. Additional transfer penalty of 6 regular minutes.
