Railway Disruption Management with Viriato and Algorithm Platform

*Oliver Buschor, Meritxell Pacheco, Stefano Bortolomiol, Michel Bierlaire*
Transport and Mobility Laboratory TRANSP-OR
École Polytechnique Fédérale de Lausanne EPFL

*Nikola Obrenović*
Faculty of Technical Sciences, University of Novi Sad, Serbia

*Matthias Hellwig*
SMA und Partner AG, Zürich, Switzerland

nextRail19, Zürich, Switzerland
Outline

1. Introduction
2. State of the art
3. Data preparation
4. Algorithm implementation
5. Conclusions and future work
Introduction

- Disrupted train network
  - rearrange timetable
  - reroute trains
  - respect capacity
  - keep cost moderate
  - satisfy passenger comfort
  - flexible route choice
Recovery problem

- Recovery problem in 3 phases (Binder et al. (2017b), Veelenturf et al. (2015), Cacchiani et al. (2014)):
  
  1. Timetable rescheduling
  2. Rolling stock allocation
  3. Crew assignment
Timetable rescheduling problem

- Overview and Classification (Cacchiani et al., 2014)
  - Perturbation
  - Network
  - Approach

Disturbance

- Microscopic
- Operation centric
- $3 \text{ min}$

Disruption

- Macroscopic
- Passenger centric
- optimising railways
Timetable rescheduling problem

- Corman et al. (2016)
- Kroon et al. (2015)
- Hao et al. (2018)
- Binder et al. (2017a)
- Binder et al. (2017b)
- Zhu and Goverde (2019)
- Veelenturf et al. (2015)
Modelling approaches

Network Graph
- Space-time: Kroon et al. (2015), Binder et al. (2017a,b), Hao et al. (2018)

Passenger Groups
- Dividable: Kroon et al. (2015), Hao et al. (2018)
- Not dividable: Corman et al. (2016), Binder et al. (2017a, b), Zhu and Goverde (2019)
## Recovery decisions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Modify Rolling Stock</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Order</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Reroute</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cancel</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Emergency Trains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Additional stops</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Skip stops / short turns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Viriato and Algorithm Platform

Algorithm Platform

Abstract Intermediate Data Model

Algorithm Interface

Planning Tool

Timetable Data

Rolling Stock Data

Infrastructure Data

Routing Services

Running-Time Calculation Service

Conflict Detection Service

* Figure by SMA und Partner AG
Datasets

- **Passenger trips - ARE (2010)**
  - CH split into zones
  - Demand of trips between zones
  - Travel time and distance

- **Viriato - SMA und Partner AG**
  - Part of SBB railway network (stations, junctions, tracks, capacity)
  - Train schedule and paths
Data preparation

- Initial demand assignment

  - ARE dataset
  - Passenger demand between zones
  - Network graph consisting of zones and stations
    - Route choice of passengers
      - Adapted Dijkstra
    - Number of passengers on trains
  - Viriato database
  - Network topology, train paths and timetables

EPFL - TRANSP-OR

sma+ optimising railways
Assignment of stations to zones

• Demand of a zone is considered, if the distance to closest station is below a threshold

• Each zone is connected to several stations:
  • $n$ closest stations by Euclidean distance
  • All stations in the $k$ closest zones by travel time
  • Weighted connections with travel time by public transportation
  • $n$ & $k$ thresholds to be set
Adapted Dijkstra’s shortest path algorithm

- Do not put the zones into the queue
- Add $\frac{1}{2}$ of headway of 1st leg train to mimic waiting time at the first station
## Resulting path loads

<table>
<thead>
<tr>
<th>O - D</th>
<th>NPVM</th>
<th>Simulated</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZHDB - ZOER</td>
<td>46'575</td>
<td>58'059</td>
<td>+11'484</td>
</tr>
<tr>
<td>ZOER - ZHDB</td>
<td>47'810</td>
<td>46'221</td>
<td>- 1'589</td>
</tr>
<tr>
<td>ZSEB - ZOER</td>
<td>6'124</td>
<td>815</td>
<td>- 5'309</td>
</tr>
<tr>
<td>ZOER - ZSEB</td>
<td>6'050</td>
<td>940</td>
<td>- 5'119</td>
</tr>
<tr>
<td>ZWIP - ZOER</td>
<td>52'867</td>
<td>15'895</td>
<td>- 36'972</td>
</tr>
<tr>
<td>ZOER - ZWIP</td>
<td>51'689</td>
<td>5'542</td>
<td>- 46'147</td>
</tr>
</tbody>
</table>
Problem definition by Binder et al.

- Multi-objective railway timetable rescheduling problem as an Integer Linear Program:
  - $f_p$: minimization of passenger inconvenience,
  - $f_o$: minimization of operational costs, and
  - $f_d$: minimization of the deviation from the undisrupted timetable.
Network model

- Discretized planning horizon (1 minute period)
- Macroscopic model of railway network
  - Stations - with or without a shunting yard
  - Tracks – considered to be bidirectional
- Original and emergency trains
  - The latter deployed only from the shunting yards
Time-expanded network

Distance traveled

(\(s_0, t_0, k_0\))

(\(s_1, t_1, k_0\))

(\(s_1, t_2, k_0\))

(\(s_2, t_3, k_0\))

(\(s_2, t_4, k_1\))

(\(s_3, t_5, k_1\))_\text{egress}

\(N_d\)

\(N_o\)_\text{access}

In-vehicle

Waiting

Transfer

Travel time
Recovery decisions

• **Cancellation**: A train may be fully or partially canceled

• **Delay**: The arrival or departure may be delayed up to a maximal amount of time

• **Rerouting**: A train may be rerouted through another path than the originally planned one

• **Emergency train**: At every station with a shunting yard, a limited number of emergency trains is available

• **Emergency bus**: If the track between two neighboring stations is disrupted, an emergency bus may be scheduled to connect the two stations directly
Passenger travel choice

- Passenger: \((o_p, d_p, t_p)\)
- Travel options: \(\Omega(o_p, d_p)\)
- Generalized path cost for passenger \(p\) and path \(\omega \in \Omega(o_p, d_p)\):
  \[
  C_{\omega}^p = VT_{\omega}^p + \beta_1 \cdot WT_{\omega}^p + \beta_2 \cdot NT_{\omega}^p + \beta_3 \cdot ED_{\omega}^p + \beta_4 \cdot LD_{\omega}^p
  \]
Solution methodology (Binder et al.)

- In real cases, the problem is too big to be solved exactly
- Heuristic approach: generate a set of “good” disposition timetables, and quantify the trade-off between the objectives
Solution methodology

- Adaptive Large Neighborhood Search (ALNS) meta-heuristic is implemented to construct the disposition timetable
- Neighborhood operators are inspired from real-life recovery strategies
- Each operator is chosen with a certain probability
  - Probabilities are updated during the execution
- The algorithm keeps track of non-dominated solutions using an archive of solutions
Neighborhood operators

- Cancel trains completely
- Cancel trains after a given station
- Delay trains completely
- Delay trains after a given station
- Reroute trains between neighboring stations
- Add an emergency train
- Add an emergency bus
Passenger assignment procedure

- Passenger demand
- Passenger priority list
- Timetable
- Passenger assignment
- Passenger flows
Results

- The three-dimensional Pareto frontier allows to analyze the trade-off between the objectives.
Implementation with Viriato and Algorithm Platform

• Data:
  • Network data
  • Timetables

• Used REST API methods:
  • Data access methods
  • neighbor-nodes – nodes connected with a direct track
  • section-tracks-between – finding a sequence of tracks which link two nodes
  • section-tracks-parallel-to – finding a parallel section for a given input
  • set-section-track – defining the section tracts for a train path
  • reroute-train – set the new path and the used section tracks
  • Scenario definition methods
Conclusions

• From the previous research:
  • Proposed methodology gives satisfactory results and allows analysis of the trade-offs between the different objectives
  • Significant improvements can be achieved in passenger satisfaction with only a minor increase in the operational cost of the timetable
  • The higher the deviation from the undisrupted timetable is allowed, the better the timetable will perform in terms of passenger satisfaction and operational cost
Conclusions

• Viriato provides access to valuable data

• By using the Viriato environment and off-the-shelf methods of Algorithm Platform, algorithm development is faster
  • Expert can focus on the scientific work

• Faster industrial application of theoretical developments

• Viriato could be improved by including demand models
Future work

• H2020 project (or similar program) application:
  • *Intelligent algorithms for real-time railway management*
Thank you!

Questions?
nikola.obrenovic@uns.ac.rs
References


References


