Passenger-oriented railway disposition timetables in case of severe disruptions

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Outline

Motivation

Problem description
   Research question
   Assumptions
   Formal problem definition as an ILP

Solution approach

Case study

Conclusion
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Figure: Bray Head, Railway Accident, Ireland, 1867. The Liszt Collection.
Motivation

Figure: SBB Blackout, Luzern, June 22nd, 2005. AURA collection.
Brief literature review

<table>
<thead>
<tr>
<th>Disturbances</th>
<th>Disruptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microscopic</td>
<td>Hirai et al. (2009), Corman et al. (2011a), Wiklund (2007)</td>
</tr>
</tbody>
</table>

**Figure:** Classification of the recent literature on train rescheduling. (Cacchiani, V., Huisman, D., Kidd, M., Kroon, L., Toth, P., Veelenturf, L., and Wagenaar, J. (2014). An overview of recovery models and algorithms for real-time railway rescheduling. Transportation Research Part B: Methodological, 63:15–37)
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What are the impacts, in terms of passenger (dis-)satisfaction, of different recovery strategies in case of a severe disruption in a railway network?
A sample network
A disrupted sample network
Recovery strategies

- Train cancellation
- Partial train cancellation
- Global re-routing of trains
- Additional service (buses/trains)
- “Direct train”
- Increase train capacity
The two sides of the problem

Supply (Operator)
- Network
- Trains
- (Rolling stock / Crew)

Demand (Passengers)
- Origins / Destinations
- Preferences / Choices
Assumptions on the supply side

- Homogeneity of trains
- Passenger capacity of trains / buses
- Depots at stations where trains can depart
Assumptions on the demand side

- Disaggregate passengers: origin, destination and desired departure time
- Path chosen according to generalized travel time (made of travel time, waiting time and penalties for transfers and early/late departure)
- Perfect knowledge of the system
- No en-route re-rerouting
Sets

<table>
<thead>
<tr>
<th>Set Type</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stations</td>
<td>( s \in S )</td>
</tr>
<tr>
<td>Time steps</td>
<td>( t \in T )</td>
</tr>
<tr>
<td>Depots</td>
<td>( r \in R )</td>
</tr>
<tr>
<td>Passengers</td>
<td>( p \in P )</td>
</tr>
<tr>
<td>Nodes (representing station ( s ) at time ( t ))</td>
<td>( n^t_s \in N )</td>
</tr>
<tr>
<td>Train nodes</td>
<td>( i \in V = N \cup R )</td>
</tr>
<tr>
<td>Train arcs</td>
<td>( (i, j) \in A \subseteq V \times V )</td>
</tr>
<tr>
<td>Passenger ( p )'s nodes</td>
<td>( i \in V_p = N \cup O \cup D )</td>
</tr>
<tr>
<td>Passenger ( p )'s arcs</td>
<td>( (i, j) \in A_p \subseteq V_p \times V_p )</td>
</tr>
<tr>
<td>Disrupted train arcs</td>
<td>( (i, j) \in A_D \subseteq A )</td>
</tr>
</tbody>
</table>
Parameters

Number of trains available in depot $r$ $n_r \in \mathbb{N}$

Origin of passenger $p$ $o_p \in O$

Destination of passenger $p$ $d_p \in D$

Capacity of arc $(i, j) \in A$ $\text{cap}_{(i,j)} \in \mathbb{N}$

Passenger $p$’s cost on arc $(i, j) \in A_p$ $c^p_{(i,j)} \in \mathbb{R}^+$

Cost of starting a train $c_t \in \mathbb{R}^+$
Decision variables

\[ x(i,j) = \begin{cases} 
  1 & \text{if a train runs on arc } (i,j) \in A \\
  0 & \text{otherwise} 
\end{cases} \]

\[ w^p_{(i,j)} = \begin{cases} 
  1 & \text{if passenger } p \text{ uses arc } (i,j) \in A_p \\
  0 & \text{otherwise} 
\end{cases} \]
Objective function

\[
\min \sum_{p \in P} \sum_{(i,j) \in A_p} c_{(i,j)}^p \cdot w_{(i,j)}^p + \sum_{(i,j) \in A | i \in R} c_t \cdot X(i,j)
\]
Constraints

\[\sum_{j \in N} x(r,j) \leq nr \quad \forall r \in R \quad (1)\]

\[\sum_{i \in V} x(i,k) = \sum_{j \in V} x(k,j) \quad \forall k \in V \quad (2)\]

\[x(i,j) = 0 \quad (3)\]

\[\sum_{(i,j) \in A_p \mid i = o_p} w^p_{i,j} = 1 \quad \forall p \in P \quad (4)\]

\[\sum_{(i,j) \in A_p \mid j = d_p} w^p_{i,j} = 1 \quad \forall p \in P \quad (5)\]

\[\sum_{i \in V_p} w^p_{i,k} = \sum_{j \in V_p} w^p_{k,j} \quad \forall k \in V_p, \forall p \in P \quad (6)\]

\[w^p_{i,j} \leq x(i,j) \quad \forall p \in P, \forall (i,j) \in A \cap A_p \quad (7)\]

\[\sum_{p \in P} w^p_{i,j} \leq cap(i,j) \cdot x(i,j) \quad (8)\]

\[x(i,j) \in \{0, 1\} \quad \forall (i,j) \in A \quad (9)\]

\[w^p_{i,j} \in \{0, 1\} \quad \forall (i,j) \in A_p, \forall p \in P \quad (10)\]
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Adaptive large neighbourhood search (ALNS) is a common meta-heuristic used for train scheduling. It combines:

- Simulated annealing
- Destroy and Repair operators

⇒ Inclusion of recovery strategies
List of operators

The following operators were implemented:

- R1 — Remove trains randomly
- R2 — Remove trains with lowest demand
- I1 — Insert trains randomly
- I2 — Insert trains after highest demand train
Macroscopic timetable re-scheduling framework

- Initial timetable
- Add / Remove trains
- Evaluation (Passenger assignment)

Yes: Save current solution

No: Discard current solution
Adaptive large neighbourhood search

**input**: Initial solution $s$, Initial (final) temperature $T_0$ ($T_f$)

$T \leftarrow T_0$, $s^* \leftarrow s$

**while** $T > T_f$ **do**

$s' \leftarrow s$

Choose Removal and Insertion operator

Apply the operators to $s'$

Assign passengers on $s'$

if $z(s') < z(s)$ then

$s \leftarrow s'$

if $z(s) < z(s^*)$ then

$s^* \leftarrow s$

Update score of chosen operators with $\sigma_1$

else

Update score of chosen operators with $\sigma_2$

else

if $s'$ is accepted by simulated annealing criterion then

$s \leftarrow s'$

Update score of chosen operators with $\sigma_3$

if Iteration count is multiple of $L_s$ then

Update weights of all operators and reset scores

Update $T$

return $s^*$
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Case study characteristics

- **8 stations**: GVE, REN, LSN, FRI, BER, YVE, NEU, BIE
- **207 trains**: All trains departing from any of the stations between 5am and 9am
- **40’446 passengers**: Synthetic O-D matrices, generated with Poisson process
- **Disruption**: Track unavailable between BER and FRI between 7am and 9am
Case study network
Results — Simulated annealing

![Graph showing the results of simulated annealing with points indicating the number of iterations and total solution cost. The graph includes points for the best solution, accepted solutions, and rejected solutions.]
Results (2) — Comparison of algorithms

<table>
<thead>
<tr>
<th>Operators</th>
<th>$z$ [min] (Improv.)</th>
<th>$z_p$ [min]</th>
<th>$z_o$ [min]</th>
<th># DP</th>
<th># T</th>
<th>Time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disrupted</td>
<td>2,674,223.5</td>
<td>2,666,630.5</td>
<td>7,593.0</td>
<td>2,847</td>
<td>197</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>R1-I1</td>
<td>2,674,223.5 (0%)</td>
<td>2,666,630.5</td>
<td>7,593.0</td>
<td>2,847</td>
<td>197</td>
<td>663</td>
</tr>
<tr>
<td>R1-R2-I1</td>
<td>2,536,551.1 (-5.1%)</td>
<td>2,525,843.1</td>
<td>10,708.0</td>
<td>2,152</td>
<td>186</td>
<td>1,024</td>
</tr>
<tr>
<td>R1-R2-I1-I2</td>
<td>2,496,095.8 (-6.7%)</td>
<td>2,483,594.8</td>
<td>12,501.0</td>
<td>1,645</td>
<td>194</td>
<td>1,140</td>
</tr>
</tbody>
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Contributions of the present work:

- **Novel perspective**
  Demand-driven framework to generate disposition timetables

- **Passenger routing flexibility**
  Linear disutility function

- **Practice-inspired framework**
  Inclusion of operational recovery strategies as operators

- **Network considerations**
  Possibility of re-routing due to consideration of whole network (instead of a single line)
Further research

- Comparison between exact and heuristic approach
- More realistic operators for ALNS, based on operational recovery strategies
- Real data (up to now: proof-of-concept)
Thank you for your attention!

Questions?