ROBUSTNESS IMPROVEMENTS IN A TRAIN TIMETABLE WITH TRAVEL TIME DEPENDENT MINIMUM HEADWAYS

Fahimeh Khoshniyat
Anders Peterson

Dept. of Science and Technology (ITN/KTS)
Linköping University, Norrköping, Sweden

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Introduction

- What is robustness and why is it important?
- How to improve robustness?
  - One approach is to add more buffer times
Introduction

- Assumption in this study is that as trains travel longer, they lose precisions
On-time performance en route

Dotted line = average performance
Doubled line = 75th percentile
Purpose

To implement travel time dependent minimum headways between succeeding trains in a timetable and to measure and evaluate the effects.
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\[ T_o \]  
Location

\[ \text{Origin station} \]

\[ \text{Station j} \]

\[ T_0 \]

\[ T_1 \]

Time

\[ H_0 \]

Reserved time slot for Train 1

Technical minimum headway (\( H_s \))

\[ H_m = \alpha (T_1 - T_0) \]
Purpose

To implement travel time dependent minimum headways between succeeding trains in a timetable and to measure and evaluate the effects.
Overall approach

Step 1: Timetable construction
- Initial timetable
- The modified MILP model
- The modified Timetable

Step 2a: Measuring the effects
- Measuring the effects in heterogeneity, number of trains and total travel times

Step 2b: Timetable evaluation
- The original MILP model + delay
- Initial timetable in case of disturbances
- The modified timetable in case of disturbances

Performance comparison
Approach for the model adjustments

• MILP model
• Discrete variables represent order of trains and track allocations
• Continuous variables represent time
• Correlate headways to trains’ travel times


The experiments in this part are based on the timetables produced with regards to $\alpha=1 \text{ min/h}$ and fixed order of trains.
Evaluations

<table>
<thead>
<tr>
<th>Performance measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total delays</td>
</tr>
<tr>
<td>Total amount of runtime margin (T AoRM)</td>
</tr>
<tr>
<td>Total incurred secondary delays</td>
</tr>
<tr>
<td>Recovery time</td>
</tr>
<tr>
<td>Number of delayed trains</td>
</tr>
<tr>
<td>Punctuality</td>
</tr>
<tr>
<td>Additional running times</td>
</tr>
<tr>
<td>Deviation from an initial timetable</td>
</tr>
<tr>
<td>Buffer time reductions</td>
</tr>
<tr>
<td>Number of violations in overtaking</td>
</tr>
</tbody>
</table>
Disturbance scenarios

- Single delayed train (SD)
- Speed reduction for one single train (SRT)
- Speed reduction for one section (SRS)
Real case study: Swedish Southern Mainline

- Alvesta–Lund (a part of the Southern Mainline)
  - Ca. 200 km long.
  - Double track.
  - Mixed traffic, fast and slow passenger trains and cargo.
## Timetable instances

<table>
<thead>
<tr>
<th>Timetable instances</th>
<th>Trains (#)</th>
<th>Train events (#)</th>
<th>Sections (#)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011, 11:00-13:00</td>
<td>71</td>
<td>994</td>
<td>45</td>
</tr>
<tr>
<td>2011, 16:00-18:00</td>
<td>89</td>
<td>984</td>
<td>45</td>
</tr>
<tr>
<td>2014, 11:00-13:00</td>
<td>81</td>
<td>1110</td>
<td>53</td>
</tr>
<tr>
<td>2014, 16:00-18:00</td>
<td>102</td>
<td>1312</td>
<td>53</td>
</tr>
</tbody>
</table>
Experiments
Single delayed train (SDT)

a) Initial timetable

b) Initial timetable in case of 7min disturbance

c) Modified timetable

d) Modified timetable in case of 7min disturbance
Speed reduction for one train (SRT)

Fixed order

Flexible order
Speed reduction for one section (SRS)
<table>
<thead>
<tr>
<th>DS</th>
<th>DR</th>
<th>DIT (min)</th>
<th>TD (min)</th>
<th>D(#)</th>
<th>P(#)</th>
<th>V(#)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDT (2min)</td>
<td>F</td>
<td>105 (146)</td>
<td>53 (75)</td>
<td>2 (5)</td>
<td>71 (71)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SDT (5min)</td>
<td>F</td>
<td>3,175 (4,385)</td>
<td>158 (223)</td>
<td>2 (5)</td>
<td>71 (71)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SDT (7min)</td>
<td>F</td>
<td>504 (686)</td>
<td>251 (348)</td>
<td>2 (6)</td>
<td>71 (69)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SRT (70km/h)</td>
<td>F</td>
<td>6,556 (7,173)</td>
<td>3,370 (3,696)</td>
<td>9 (10)</td>
<td>63 (63)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SRT (70km/h)</td>
<td>NF</td>
<td>3,951 (2,190)</td>
<td>2,012 (4,293)</td>
<td>3 (5)</td>
<td>69 (69)</td>
<td>48 (50)</td>
</tr>
<tr>
<td>SRT (50km/h)</td>
<td>F</td>
<td>14,732 (15,345)</td>
<td>7,599 (7,924)</td>
<td>10 (11)</td>
<td>61 (61)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SRT (50km/h)</td>
<td>NF</td>
<td>7,713 (8,025)</td>
<td>3,934 (4,094)</td>
<td>2 (4)</td>
<td>69 (69)</td>
<td>83 (86)</td>
</tr>
<tr>
<td>SRS (70km/h)</td>
<td>F</td>
<td>6,018 (6,623)</td>
<td>3,105 (3,423)</td>
<td>30 (31)</td>
<td>57 (55)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SRS (70km/h)</td>
<td>NF</td>
<td>5,766 (6,790)</td>
<td>2,997 (3,509)</td>
<td>25 (27)</td>
<td>57 (56)</td>
<td>17 (11)</td>
</tr>
<tr>
<td>SRS (50km/h)</td>
<td>F</td>
<td>13,004 (13,612)</td>
<td>6,714 (7,033)</td>
<td>35 (36)</td>
<td>41 (41)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>SRS (50km/h)</td>
<td>NF</td>
<td>10,642 (11,003)</td>
<td>5,516 (5,726)</td>
<td>25 (26)</td>
<td>50 (51)</td>
<td>39 (43)</td>
</tr>
</tbody>
</table>
To summarize

• In most of the experiments, timetables with travel time dependent minimum headways outperform the initial ones.

• In single delayed train (SDT) scenarios, the modified timetables have better robustness.

• In the scenario for speed reduction for a single train (SRT), although we have reached to a better performance in the modified timetables, the flexible order of trains has also a significant role to improve the performance.

• In scenario for speed reduction in a single section for all trains (SRS), the modified timetables perform better but the improvements are small.
Thank you!

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