A three-level framework for performance-based railway timetabling

24 March 2015

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Outline

• Timetable performance indicators
• Three-level timetabling framework
• Micro-macro iterations
• Corridor fine-tuning
• Conclusions
Introduction

Timetable performance indicators

- **Scheduled travel time**
  - Time scheduled between any OD incl. running, dwell and transfer times

- **Infrastructure occupation and stability**
  - Time required for a given timetable pattern on a given infrastructure
  - Sufficient time allowance to settle delays

- **Feasibility**
  - All processes realizable within their scheduled process times
  - Scheduled train paths are conflict free

- **Robustness**
  - Delay propagation behaviour kept within bounds

- **Energy-efficiency**
  - Timetable allows energy efficient train operations
Three-level timetabling framework

Performance-based timetabling

- Travel time efficiency
- Robustness
- Feasibility
- Capacity occupation
- Energy-efficiency
Three-level timetabling framework

Timetabling levels

Microscopic (track section level)
- Speed and running time computations incl. time supplements
- Conflict detection using blocking times
- Infrastructure occupation & stability tests by compression method
- Precision of 1 s

Macroscopic (network level)
- Network timetable optimization of journey times, transfer times, missed connections, cancelled trains, and settling times (ILP)
- Stochastic robustness analysis using Monte Carlo simulation
- Timetable precision of 5 s minimizing capacity waste

Fine-tuning (corridor level)
- Energy-efficient speed profiles using optimal control
- Stochastic optimization of time allowances for local trains
Micro-macro iterations

Dealing with running time supplements

- Fastest, non-coasting and energy-efficient speed profiles
Corridor fine-tuning

Trade-off: time allowance in dwell or running time

- Probability density of dwell time and consequently train departure
- Energy-optimal arrival time
- Published departure time at intermediate station
- Latest possible departure time to arrive on time and corresponding energy consumption
- Earliest possible departure time and corresponding energy consumption

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Corridor fine-tuning

Trade-off: time allowance in dwell or running time
Corridor fine-tuning

Generic model

- For each corridor between main stations (IC stops or overtaking)
- Distribute time allowances of local trains over intermediate stops with respect to stochastic dwell time distributions
- Start and end time fixed at main stations bounding the corridor
  - Total allowance time on corridor fixed
- Bandwidth of train trajectory defined by surrounding (intercity) trains
- Given empirical distributions of dwell times (stations and short stops)
  - Weibull 3-parameter distributions based on Dutch empirical data
Corridor fine-tuning

Multi-stage multi-objective optimization

- Decision variables
  - Scheduled arrival and departure times at intermediate stops in minutes
- Driving stage
  - Each departure/arrival time pair defines running time supplement
  - Optimal energy consumption computed using optimal control
- Dwelling stage
  - Each arrival/departure time pair defines scheduled dwell time
  - Convolution of all possible arrival times and dwell time distribution gives all possible departure times and their probability
- Cost function: weighted sum of expected arrival delays and energy
- Pre-processing
  - Generate all possible timetables within given bandwidth
  - Compute optimal speed profiles for all possible scheduled running times and the associated energy consumptions
Corridor fine-tuning

Multi-stage multi-objective optimization

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Corridor fine-tuning

Multi-stage multi-objective optimization

Cost criteria at each stop (arrival/departure stage) $i$
- Expected energy consumption until target station at stage $i$
- Expected delay at target station from stage $i$
- Expected total delay at intermediate stops from stage $i$

- Each cost at stage $i$ depends on the time allowance decision at stage $i$
- Each cost at stage $i$ is a recursive equation in the cost at stage $i + 1$

Dynamic programming solution approach
- Solve recursions backwards from target station back to begin
- At each stage find the optimal time allowance at that stage that minimizes a weighted squared sum of the three cost criteria at that stage
Case study

Dutch network around ‘s Hertogenbosch

- Infrastructure and line plan 2012
- Two intersecting corridors
  - Utrecht-Eindhoven and Tilburg-Nijmegen
- Hourly timetable pattern with
  - 2 x 8 ICs per hr
  - 2 x 10 local trains per hr
  - One freight path (Ut-Ehv)
  - Many transfers in ‘s Hertogenbosch (and elsewhere)
A three-level framework for performance-based railway timetabling
# Case study

## Performance measure results

### Maximum capacity consumption

<table>
<thead>
<tr>
<th></th>
<th>Corridor</th>
<th>Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ut-Ht</td>
<td>34.7</td>
<td>35.0</td>
</tr>
<tr>
<td>Ht</td>
<td>34.7</td>
<td>57.8</td>
</tr>
</tbody>
</table>

### Journey time

<table>
<thead>
<tr>
<th></th>
<th>Minimum journey time [min]</th>
<th>Scheduled journey time [min]</th>
<th>Supplement [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ut-Ehv</td>
<td>44.9</td>
<td>48.2</td>
<td>7.3</td>
</tr>
<tr>
<td>Ehv-Ut</td>
<td>47.6</td>
<td>51.3</td>
<td>7.8</td>
</tr>
</tbody>
</table>

### Energy consumption

<table>
<thead>
<tr>
<th></th>
<th>Energy consumption [kWh]</th>
<th>Energy saving [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal-Time</td>
<td>64 395</td>
<td>-</td>
</tr>
<tr>
<td>Reduced cruising speed</td>
<td>58 800</td>
<td>8.7</td>
</tr>
<tr>
<td>Energy-optimal</td>
<td>41 667</td>
<td>35.3</td>
</tr>
</tbody>
</table>
## Case study

### Computation time results

<table>
<thead>
<tr>
<th></th>
<th>Iterations</th>
<th>Mean time [s]</th>
<th>Total [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial microscopic computations</strong></td>
<td>1</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td><strong>Micro-macro iterations</strong></td>
<td></td>
<td></td>
<td>1080</td>
</tr>
<tr>
<td>Macro (1000 macro iterations)</td>
<td>9</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Micro computations</td>
<td>9</td>
<td>40</td>
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<tr>
<td><strong>Finetuning</strong></td>
<td></td>
<td></td>
<td>215</td>
</tr>
<tr>
<td>Micro computations</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Energy-efficient speed profiles</td>
<td>1</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>1330</td>
</tr>
</tbody>
</table>

*Excluding stochastic optimization of local trains*
Conclusions

Performance-based railway timetabling

• Integrated method for computing optimal, stable, robust, conflict-free and energy-efficient railway timetables

• Modular implementation of three-level timetabling approach

• Standardized RailML input data (Infrastructure, Rolling Stock, Interlocking, Timetable)

• Output in (extended) standardized RailML Timetable file with scheduled train paths and speed profiles at section level