Adapting stopping patterns to improve robustness from the users’ perspective

Jens Parbo
PhD student
Technical University of Denmark
jepar@transport.dtu.dk
Outline

• Introduction & motivation

• Skip-stop optimisation

• Results

• Summary
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• Summary
Introduction & Motivation

- Stopping patterns of railway lines have a large impact on travel time, but also on system-wide delays
- Applying skip-stop optimisation intelligently enables:
  - The benefits of skip-stop services (reduced travel time)
  - Reduced heterogeneity (i.e. operation less vulnerable to delays)
- Homogeneous (solid lines) vs. heterogeneous (dashed lines) operation
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Skip-stop Optimisation

- Bi-level optimisation

Passengers’ travel behaviour

Railway lines’ stopping patterns
Mathematical Model (Upper level)

- Finding optimal stopping patterns.

Minimise

\[
\sum_i \sum_j \sum_c TT_{ij} * d_{ik} + \sum_k \sum_s \frac{1}{H_{s,k,k+1}}.
\]

Subject to

\[
H_{s,k,k+1} = ((b^{k-1,p} + t_z^{k-1,p}) - (b^{k,p} + t_z^{k,p})) * x^p, \forall k, p, s.
\]

\[
H_{s,k,k+1} \geq H, \forall s, k, k.
\]

\[
TT_{ij}^p = q_{ij}^p + M_1 * (1 - a_{ij}^p * x^p), \forall p, i, j.
\]

\[
TT_{ij}^p \geq TT_{ij}^p - M_2 * (1 - y_{ij}^p), \forall p, i, j.
\]

\[
\sum_p y_{ij}^p = 1, \forall i, j.
\]

\[
\sum_p x^p \leq TL.
\]

\[
y_{ij}^p \leq x^p, \forall p, i, j.
\]

\[
y_{ij}^p \in \{0,1\}, \forall p, i, j.
\]

\[
x^p \in \{0,1\}, \forall p.
\]

\[
t_z^{k,p} \geq 0, \forall k, p, s.
\]

\[
b^{k,p} \geq 0, \forall k, p.
\]

\[
TT_{ij} \geq 0, \forall i, j.
\]

\[
TT_{ij}^p \geq 0, \forall p, i, j.
\]
Public assignment model (Lower level)

- Deriving passengers’ travel behaviour.

- Utility-based approach.

\[ C_{ijc} = \beta_c \cdot \text{WaitingTime}_{ij} + \beta_c \cdot \text{WaitInZoneTime}_{ij} + \beta_c \cdot \text{WalkTime}_{ij} + \beta_c \cdot \text{ConnectorTime}_{ij} + \beta_c \cdot \text{NumberOfChanges}_{ij} + \beta_c \cdot \text{TotalInVehicleTime}_{ij}. \]

<table>
<thead>
<tr>
<th></th>
<th>WalkTime</th>
<th>Waiting Time</th>
<th>Connector Time</th>
<th>WaitInZone Time</th>
<th>Change Penalty</th>
<th>Train InVehicleTime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuter</td>
<td>0.633</td>
<td>0.633</td>
<td>0.75</td>
<td>0.28</td>
<td>8.8</td>
<td>0.45</td>
</tr>
<tr>
<td>Business</td>
<td>4.50</td>
<td>4.50</td>
<td>4.50</td>
<td>1.217</td>
<td>64</td>
<td>3.783</td>
</tr>
<tr>
<td>Leisure</td>
<td>0.467</td>
<td>0.467</td>
<td>0.33</td>
<td>0.117</td>
<td>4</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Heuristic solution algorithm - Framework

1. Run public assignment.
2. Calculate optimisation potential for each skip-stop.
3. Calculate elaborate optimisation potential for the most promising skip-stops (2)
4. Impose skip-stops.
5. Prohibit skipping stops in the sub network for imposed skip-stops.
6. If stopping criterion met, stop.
7. Otherwise, go to (1).
Heuristic solution algorithm –
Elaborate optimisation potential

- When skipping a stop on a line, trips to/from the considered station within the corridor are separated in 3 types.

- Benefit: reduced in-vehicle time (2 min.)

- Trip 1 costs (Waiting time)
  \[ \frac{1}{2} \times (\text{new}_\text{headway}_{ijk} - \text{headway}_{ijk}) \times (\text{VoT}_c \times \text{Passengers}_{ijk}), \forall i, j, k, c. \]

- Trip 2 costs (Waiting time + Transfer time)
  \[ \frac{1}{2} \times (\text{headway}_{ijk} + \text{headway}_{jk} + \text{transferpenalty}) \times (\text{VoT}_c \times \text{Passengers}_{ijk}), \forall i, j, k, c. \]

- Type 3 trips are PROHIBITED!

- Trips from outside the corridor (Waiting time)
  \[ \frac{1}{2} \times (\text{new}_\text{headway}_{ijk} - \text{headway}_{ijk}) \times (\text{VoT}_c \times \text{Passengers}_{ijk}), \forall i, j, k, c. \]
Heuristic solution algorithm - Tackling overtaking and heterogeneity

- Limitation on the number of skipped stops between parallel lines when considering the stops sequentially.

  ![Diagram of railway lines showing skipped stops and conflicts]

- Conflicts between railway lines from different corridors can be handled by adapting departure times or adding buffer time.
- Reduced capacity utilisation as a result of more homogeneous operations.
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Results - Passengers’ travel cost

- Passengers are marginally better of compared to the existing situation.

- The small reduction in Generalised travel cost is misleading

<table>
<thead>
<tr>
<th></th>
<th>Percentage change (Final solution)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Changes</td>
</tr>
<tr>
<td>Relative to existing stopping pattern</td>
<td>-0.18</td>
</tr>
<tr>
<td>Relative To All-stop Base</td>
<td>-1.51</td>
</tr>
</tbody>
</table>
Results - Heterogeneity of railway operations

- Existing vs. optimised
  - Time-space diagrams
  - Line diagrams

- Optimised -> homogeneous
  - More buffer time
  - Delays are absorbed
Results - Heterogeneity (Continued)

- Number of skipped stops per line in each corridor.
  - Average
  - Standard deviation

<table>
<thead>
<tr>
<th>Corridor No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway lines operating</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Average</td>
<td>4.25</td>
<td>4.75</td>
<td>1.00</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>3.50</td>
<td>0.96</td>
<td>1.73</td>
<td>0.58</td>
<td>2.31</td>
</tr>
</tbody>
</table>

- **SSHHR** (heterogeneity) values for each corridor.
- All-stop scenario serves as LB on SSHR.

<table>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>5</td>
<td>1.5</td>
<td>1.7</td>
<td>0.9</td>
<td>6</td>
</tr>
<tr>
<td>All-stop</td>
<td>2.4</td>
<td>1.35</td>
<td>1.35</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Optimised</td>
<td>3.5 (-30%)</td>
<td>1.43 (-5%)</td>
<td>1.43 (-16%)</td>
<td>0.6 (-33%)</td>
<td>2.55 (-55%)</td>
</tr>
</tbody>
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• Skip-stop optimisation solved as a bi-level optimisation problem taking passengers’ travel behaviour explicitly into account.

• Reduction equal to 1.01 % in in-vehicle time and 1.66 % in waiting time was obtained compared to existing network.

• Heterogeneity significantly improved in all corridors (5-55 %).

• Consequently, passengers get faster and more reliable from A to B.
Questions