Evaluating the Quality of Railway Timetables

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Supply $\times$ Demand

**Figure**: Calvin and Hobbes by Bill Watterson
Purely commercial rail passenger services in Europe

- **Market closed for commercial national rail passenger services.**
- **Open access, but no external RUs providing commercial national rail passenger services.**
- **Open access with external RUs providing commercial national rail passenger services.**
- **AT and CZ: commencing end of 2011, external RUs providing purely commercial national rail passenger services.**
TOC Point of View

\[ \text{Profit} = \text{Revenue} - \text{Cost} \]

- To increase this...
- ...increase this...
- ...or decrease this...
Transport Demand

Mode Choice

Motorized

Non-Motorized

Public Transport

Route Choice

Itinerary

Traveller
Passenger Point of View

Speed (Time)
Waiting Time
Transfers
Being On Time
Timetable
Waiting Time
Transfers
Being On Time
Passenger Satisfaction

Satisfaction of a passenger \((i, t)\) for a given alternative/path \(p\):

\[
U_i^t = - \sum_{\ell \in L^p} r_i^{p\ell} + \beta_W \cdot w_{i}^{tp} + \beta_T \cdot (|L^p| - 1) + \beta_E \cdot \delta_i^{tp} + \beta_L \cdot \gamma_i^{tp} \text{ [min]}
\]

where:

- \(L^p\) – set of lines in path \(p\)
- \(r_i^{p\ell}\) – in-vehicle-time of a train line \(\ell\)
- \(w_{i}^{tp}\) – total waiting time along path \(p\)
- \(|L^p|\) – number of lines in path \(p\)
- \(\delta_i^{tp}\) – early scheduled delay
- \(\gamma_i^{tp}\) – late scheduled delay

\[
\beta_W = -2.5 \text{ (Wardman (2004))}
\]

\[
\beta_T = -10 \text{ (de Keizer et al. (2012))}
\]

\[
\beta_E = -0.5 \text{ (Small (1982))}
\]

\[
\beta_L = -1 \text{ (Small (1982))}
\]
Monetarization

We can multiply the whole equation by the Value of Time:

\[
\frac{\beta_{\text{time}}}{\beta_{\text{value}}} = 27.81 \text{ Chf/hour (Axhausen et al. (2008))}
\]
References


Update of Planning

STRAIGHTRIC - several years

TACTICAL - >= 1 year

OPERATIONAL - < 1 year

Demand ➔ Line Planning ➔ Lines ➔ PCTTP ➔ Train Timetabling ➔ Train Platforming ➔ Rolling Stock Planning ➔ Crew Planning

- TOC
- IM

- Passenger Centric Timetables
- Actual Timetables

Platform Assignments ➔ Train Assignments ➔ Crew Assignments

Passenger Centric Timetables

Actual Timetables

PDF file version:
Inputs

Passenger
- OD Matrix
- Desired arrival time to D
- All paths
- Behavior

Operator
- Network
- Fare structure
- Cost structure
- Rolling stock
Decision Variables

\[ U_i^t \quad - \quad \text{passenger satisfaction (utility)} \]
\[ w_i^t \quad - \quad \text{the total waiting time of a passenger with ideal time } t \text{ between OD pair } i \]
\[ x_i^{tp} \quad - \quad 1 \quad - \quad \text{if passenger with ideal time } t \text{ between OD pair } i \text{ chooses path } p; \]
\[ 0 \quad - \quad \text{otherwise} \]
\[ \lambda_i^t \quad - \quad \text{the scheduled delay of a passenger } (i, t) \]
\[ d_\ell^v \quad - \quad \text{the departure time of a train } v \text{ on the line } \ell \text{ (from its first station)} \]
Decision Variables II

\[ y_{i}^{tplv} \quad – \quad 1 \quad \text{if a passenger with ideal time} \quad t \quad \text{between OD pair} \quad i \quad \text{on the path} \quad p \quad \text{takes the train} \quad v \quad \text{on the line} \quad \ell; \quad 0 \quad \text{– otherwise} \]

\[ z_{\ell}^{v} \quad – \quad \text{dummy variable to help modeling the cyclicity corresponding to a train} \quad v \quad \text{on the line} \quad \ell \]

\[ \omega_{v}^{l} \quad – \quad \text{train occupation of a train} \quad v \quad \text{of the line} \quad \ell \quad \text{on a segment} \quad s \]

\[ \mu_{v}^{\ell} \quad – \quad \text{number of train units of a train} \quad v \quad \text{on the line} \quad \ell \]

\[ \alpha_{v}^{\ell} \quad – \quad 1 \quad \text{if a train} \quad v \quad \text{on the line} \quad \ell \quad \text{is being operated}; \quad 0 \quad \text{– otherwise} \]
Model

\[ \text{max (revenue } - \text{ cost)} \] \hspace{1cm} (1)

\( \text{passenger satisfaction } \geq \epsilon \) \hspace{1cm} (2)

satisfaction function \hspace{1cm} (3)

at most one path per passenger \hspace{1cm} (4)

link trains with paths \hspace{1cm} (5)

cyclicity \hspace{1cm} (6)

train scheduling \hspace{1cm} (7)

train capacity \hspace{1cm} (8)

scheduled delay \hspace{1cm} (9)

waiting time \hspace{1cm} (10)
Case Study – Switzerland

0 source: www.myswitzerland.com
SBB 2014 (5 a.m. to 9 a.m.)

- OD Matrix based on observation and SBB annual report
- 13 Stations
- 156 ODs
- 14 (unidirectional) lines
- 49 trains
- Min. transfer – 4 mins
- VOT – 27.81 CHF per hour
- 3 scenarios – SBB 2014, cyclic PCTTP, non-cyclic PCTTP
# Current Timetable (Morning Peak)

<table>
<thead>
<tr>
<th>Line</th>
<th>ID</th>
<th>From</th>
<th>To</th>
<th>Departures</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1</td>
<td>Yverdon-les-Bains</td>
<td>Villeneuve</td>
<td>6:19, 7:19, 8:19</td>
</tr>
<tr>
<td>S1</td>
<td>2</td>
<td>Villeneuve</td>
<td>Yverdon-les-Bains</td>
<td>5:24, 6:24, 7:24, 8:24</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>Vallorbe</td>
<td>Palézieux</td>
<td>5:43, 6:43, 7:43, 8:43</td>
</tr>
<tr>
<td>S2</td>
<td>4</td>
<td>Palézieux</td>
<td>Vallorbe</td>
<td>6:08, 7:08, 8:08</td>
</tr>
<tr>
<td>S3</td>
<td>5</td>
<td>Allaman</td>
<td>Villeneuve</td>
<td>6:08, 7:08, 8:08</td>
</tr>
<tr>
<td>S3</td>
<td>6</td>
<td>Villeneuve</td>
<td>Allaman</td>
<td>6:53, 7:53, 8:53</td>
</tr>
<tr>
<td>S4</td>
<td>7</td>
<td>Allaman</td>
<td>Palézieux</td>
<td>6:41, 7:41, 8:41</td>
</tr>
<tr>
<td>S4</td>
<td>8</td>
<td>Palézieux</td>
<td>Allaman</td>
<td>6:35, 7:35, 8:35</td>
</tr>
<tr>
<td>S11</td>
<td>9</td>
<td>Yverdon-les-Bains</td>
<td>Lausanne</td>
<td>5:26*, 6:34, 7:34, 8:34</td>
</tr>
<tr>
<td>S11</td>
<td>10</td>
<td>Lausanne</td>
<td>Yverdon-les-Bains</td>
<td>5:55, 6:55, 7:55, 8:55</td>
</tr>
<tr>
<td>S21</td>
<td>11</td>
<td>Payerne</td>
<td>Lausanne</td>
<td>5:39, 6:39, 7:38*, 8:39</td>
</tr>
<tr>
<td>S21</td>
<td>12</td>
<td>Lausanne</td>
<td>Payerne</td>
<td>6:24, 7:24, 8:24</td>
</tr>
<tr>
<td>S31</td>
<td>13</td>
<td>Vevey</td>
<td>Puidoux-Chexbres</td>
<td>–, 6:09, 7:09, 8:09</td>
</tr>
<tr>
<td>S31</td>
<td>14</td>
<td>Puidoux-Chexbres</td>
<td>Vevey</td>
<td>6:31*, 7:36, 8:36</td>
</tr>
</tbody>
</table>
Results – Current Demand SBB 2014 (cca. 11 000 pax)

<table>
<thead>
<tr>
<th>$\varepsilon$ [%]</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>100*</th>
</tr>
</thead>
<tbody>
<tr>
<td>profit [CHF]</td>
<td>53 067</td>
<td>52 926</td>
<td>50 730</td>
<td>49 564</td>
<td>13 826</td>
<td>4 211</td>
<td>-27 168</td>
</tr>
<tr>
<td>ub/lb [CHF]</td>
<td>54 046</td>
<td>54 598</td>
<td>54 776</td>
<td>54 394</td>
<td>54 600</td>
<td>51 195</td>
<td>168 016</td>
</tr>
<tr>
<td>gap [%]</td>
<td>1.84</td>
<td>3.16</td>
<td>7.98</td>
<td>9.74</td>
<td>294.91</td>
<td>1115.74</td>
<td>3.30</td>
</tr>
<tr>
<td>gap [CHF]</td>
<td>979</td>
<td>1 672</td>
<td>4 046</td>
<td>4 830</td>
<td>40 774</td>
<td>46 984</td>
<td>5 742</td>
</tr>
<tr>
<td>drivers [-]</td>
<td>17</td>
<td>17</td>
<td>22</td>
<td>22</td>
<td>46</td>
<td>48</td>
<td>49</td>
</tr>
<tr>
<td>rolling stock [-]</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>46</td>
<td>55</td>
<td>98</td>
</tr>
<tr>
<td>covered [%]</td>
<td>99.35</td>
<td>99.34</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Pareto Frontier

TOC profit [kCHF]

Passenger Satisfaction [kCHF]
Sensitivity Analysis on Passenger Congestion

![Graph showing the relationship between the number of passengers and passenger coverage percentage.](image)
Sensitivity Analysis – Operator

TOC profit [kCHF]

Number of Passengers [thousands]

Difference in Profit [kCHF]

Number of Passengers [thousands]
Sensitivity Analysis – Passenger

Graph 1: Passenger Satisfaction [MCHF] vs. Number of Passengers [thousands]

Graph 2: Difference in Pax Satisfaction [kCHF] vs. Number of Passengers [thousands]

- Red line: non-cyclic
- Blue line: cyclic
Sensitivity Analysis – Pareto Frontiers

![Graph showing sensitivity analysis of TOC profit vs. Passenger Satisfaction, differentiated by cyclic and non-cyclic categories for SBB 2014.](image-url)
Summary

- **Current demand**
  - cyclic timetable is by 3 000 CHF better than the SBB 2014 timetable
  - the non-cyclic timetable is by 4 000 CHF better than the cyclic timetable

- **Most congested**
  - cyclic timetable is by 55 000 CHF better than the SBB 2014 timetable
  - the non-cyclic timetable is by 110 000 CHF better than the cyclic timetable
Conclusions

- It is possible to find a good trade-off between the operator and the passengers (around $\varepsilon = 40\%$)
- Even at $\varepsilon = 100\%$ the improvement is so large, that running this timetable with an increased ticket price can be justified
- The non-cyclic timetable is more flexible and can account better for high demand in high density network than the cyclic timetable

Future Work

- Heuristics to solve for a full day
- Estimate the cost of cyclicality
Cost of the Cyclicity

\[ U_t = \ldots + \beta_C \cdot \text{cyclic} \]

where:

- \( \text{cyclic} \) – distance from cyclicity in %
- \( \beta_C \) – cost of additional planning

\[ \beta_C = \frac{27.81}{60/5} = 2.3175 \]
Thank you for your attention.