Railway Passenger Service Timetable Design

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15th Swiss Transportation Research Conference
April 15 – 17, 2015

April 17, 2015
Where Do the Babies Come From?

Figure: Calvin and Hobbes by Bill Watterson
Where Do the Timetables Come From?

- In the industry – historical
- Timetable design in the literature
  - non-cyclic: using so called "ideal timetables"
  - cyclic: does not take into account anything
Update of Planning

**STRATEGIC** - several years

**TACTICAL** - >= 1 year

**OPERATIONAL** - < 1 year

- Demand
- Line Planning
- Lines
- Ideal Train Timetabling
- Ideal Timetables
- Train Timetabling
- Actual Timetables
- Train Platforming
- Rolling Stock Planning
- Crew Planning
- Actual Timetables
- Platform Assignments
- Train Assignments
- Crew Assignments

**TOC**

**IM**
TOC Point of View

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

↑

To increase this...

... increase this...

... or decrease this.

PARTTIMEWEBPRENEUR.COM
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
Passenger Cost

Perceived cost of a given path using a given timetable (a path is defined as a sequence of train lines, in order to get from an origin to a destination):

\[ C = \arg\min \left( \alpha \cdot \sum_{i \in \mathcal{I}} VT + \beta \cdot \sum_{j \in \mathcal{J}^I} WT + \gamma \cdot NT + \min(\epsilon \cdot SD_e, \eta \cdot SD_l) \right) \]

for all possible sets \( \mathcal{I} \), where:

- \( \mathcal{I} \) – set of possible trains in a given path
- \( \mathcal{J}^I \) – set of transfers in a given path using given trains
- \( \alpha \) – value of time (monetary units per minute)
- \( \beta \) – value of waiting time (monetary units per minute)
- \( \gamma \) – penalty for having a transfer (monetary units)
- \( \epsilon \) – value of being early (monetary units per minute)
- \( \eta \) – value of being late (monetary units per minute)
Decision Variables I

\begin{itemize}
  \item \( C^{t}_{i} \) – the total cost of a passenger with ideal time \( t \) between OD pair \( i \)
  \item \( w^{t}_{i} \) – the total waiting time of a passenger with ideal time \( t \) between OD pair \( i \)
  \item \( x^{tp}_{i} \) – 1 – if passenger with ideal time \( t \) between OD pair \( i \) chooses path \( p \); 0 – otherwise
  \item \( s^{t}_{i} \) – the value of the scheduled delay of a passenger with ideal time \( t \) between OD pair \( i \)
  \item \( d^{l}_{v} \) – the departure time of a train \( v \) on the line \( l \) (from its first station)
\end{itemize}
Decision Variables II

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

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

\[ o_{vg}^{l} \quad \text{train occupation of a train} \quad v \quad \text{of the line} \quad l \quad \text{on a segment} \quad g \]

\[ u_{v}^{l} \quad \text{number of train units of a train} \quad v \quad \text{on the line} \quad l \]

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

\[ \text{max} \ (\text{revenue} - \text{cost}) \]  
\[ \text{passenger cost} \leq \epsilon \]  
\[ \text{cost function} \]  
\[ \text{at most one path per passenger} \]  
\[ \text{link trains with paths} \]  
\[ \text{cyclicity} \]  
\[ \text{train scheduling} \]  
\[ \text{train capacity} \]  
\[ \text{scheduled delay} \]  
\[ \text{waiting time} \]
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 models – current (SBB), cyclic (60 min cycle optimal), non-cyclic
## 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</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Villeneuve</td>
<td>Yverdon-les-Bains</td>
<td>6:24</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Vallorbe</td>
<td>Palézieux</td>
<td>5:43</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Palézieux</td>
<td>Vallorbe</td>
<td>6:08</td>
</tr>
<tr>
<td>S2</td>
<td>5</td>
<td>Allaman</td>
<td>Villeneuve</td>
<td>6:08</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Villeneuve</td>
<td>Allaman</td>
<td>6:53</td>
</tr>
<tr>
<td>S3</td>
<td>7</td>
<td>Allaman</td>
<td>Palézieux</td>
<td>6:41</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Palézieux</td>
<td>Allaman</td>
<td>6:35</td>
</tr>
<tr>
<td>S11</td>
<td>9</td>
<td>Yverdon-les-Bains</td>
<td>Lausanne</td>
<td>6:34</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Lausanne</td>
<td>Yverdon-les-Bains</td>
<td>6:55</td>
</tr>
<tr>
<td>S21</td>
<td>11</td>
<td>Payerne</td>
<td>Lausanne</td>
<td>5:39</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Lausanne</td>
<td>Payerne</td>
<td>5:24</td>
</tr>
<tr>
<td>S31</td>
<td>13</td>
<td>Vevey</td>
<td>Puidoux-Chexbres</td>
<td>6:09</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Puidoux-Chexbres</td>
<td>Vevey</td>
<td>6:31</td>
</tr>
</tbody>
</table>
There was a Bug

DEBUGGING
To catch a bug, you've got to learn to think like a bug
There is a Ghost Train in the Network

- Unlimited capacity
- Single departure time
- Pax on the board don’t need to pay for the service
Results of the Current Model for the Base Case

<table>
<thead>
<tr>
<th>$\epsilon$ [%]</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>52 764</td>
<td>52 538</td>
<td>48 487</td>
<td>46 965</td>
<td>9 507</td>
<td>3 205</td>
<td>-33,726</td>
</tr>
<tr>
<td>cost [CHF]</td>
<td>564 597</td>
<td>486 438</td>
<td>408 278</td>
<td>330 119</td>
<td>251 959</td>
<td>173 800</td>
<td>173 797</td>
</tr>
<tr>
<td>lb [CHF]</td>
<td>53 771</td>
<td>54 153</td>
<td>54 259</td>
<td>54 627</td>
<td>54 615</td>
<td>50 527</td>
<td>168 153</td>
</tr>
<tr>
<td>gap [%]</td>
<td>1.91</td>
<td>3.07</td>
<td>11.90</td>
<td>16.31</td>
<td>474.47</td>
<td>1 476.51</td>
<td>3.25</td>
</tr>
<tr>
<td>gap [CHF]</td>
<td>1 007</td>
<td>1 615</td>
<td>5 772</td>
<td>7 662</td>
<td>45 108</td>
<td>47 322</td>
<td>5 644</td>
</tr>
<tr>
<td>time [s]</td>
<td>7 200</td>
<td>7 200</td>
<td>7 200</td>
<td>7 200</td>
<td>7 200</td>
<td>7 200</td>
<td>7200</td>
</tr>
<tr>
<td>drivers [-]</td>
<td>16</td>
<td>16</td>
<td>22</td>
<td>21</td>
<td>44</td>
<td>44</td>
<td>48</td>
</tr>
<tr>
<td>rolling stock [-]</td>
<td>31</td>
<td>30</td>
<td>32</td>
<td>30</td>
<td>49</td>
<td>51</td>
<td>96</td>
</tr>
<tr>
<td>served [%]</td>
<td>98.48</td>
<td>98.68</td>
<td>100.00</td>
<td>99.98</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Pareto Frontier of the Current Model for the Base Case
TOC Profit as a Function of the Demand

Number of Passengers [thousands]

TOC profit [kCHF]

\[ \epsilon = 0 \]
\[ \epsilon = 100 \]
Passenger Cost as a Function of the Demand

- **current**
- **cyclic**
- **non-cyclic**

Number of Passengers [thousands]

Passenger Cost [kCHF]
Pareto Frontiers of the Congested Case
Passenger Cost Density of the Current Timetable

- Min – 2.78 CHF
- Mean – 27.40 CHF
- Max – 125.14 CHF
Passenger Cost Density II

- Min – 2.78 CHF
- Mean – 25.71 CHF
- Max – 170.10 CHF
Passenger Cost Density III

Passenger Cost Density of the Non-Cyclic Timetable

- Min – 2.78 CHF
- Mean – 25.71 CHF
- Max – 166.86 CHF

Number of Passengers
Passenger Cost [CHF]
Better Cycle?

Cycle Density of the Non−Cyclic Timetable

- Mean – 35.72 min
Conclusions

- We formulate the ITTP problem
  - max profit or min pax cost
  - cyclic or non-cyclic timetables
  - pax flows (connections)

- Biased – Ghost Train

- TOC can choose the best trade-off between cost and profit
- Non-cyclic timetable is better
- Shorter cycle can reach the costs of the non-cyclic timetable (need to verify on a full day)

Future Work

- Heuristics
- Full day
Thank you for your attention.