Outlining the timetable of a railway system according to its capacity computation

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Abstract

The paper concerns the outlining of a timetable for a railway line in order to maximize the exploitation of its capacity. The application examined is the line Bern-Thun of the Swiss Federal Railways (FFS), characterized by heavy heterogeneous traffic. Long and complex computer-aided calculations on the capacity of stretches and stations on the line showed that there are further utilization margins; hence the wish to reset the timetable to maximize the utilization of the line capacity. This implied the complete repositioning of trains on station tracks and a relevant change in managing the railway station plan of the city of Bern. The results thus obtained can be generalized: an “optimal” timetable - that can combine the max transport capacity and the users demands - exists for any railway line.

1 The line Bern-Thun: features and current timetable

The line Bern-Thun is located on the north-south axis of the Swiss Federal Railways (FFS) along the route Basel-Bern. Along this 32-km-long stretch there are 9 railway stations (see figure 1).

This line is particularly important within the federal railway network because it is traveled by international traffic (to Germany and Italy) as well as by metropolitan traffic serving the city of Bern.

Therefore, the current timetable includes fast passenger trains (Intercity) and through trains serving national traffic, and Eurocity, Cisalpino and ICE trains serving international traffic, commuter trains (S-Bahn) from/to Bern and also national and international freight trains (see figure 2) [5].
Heterogeneous traffic sets big management problems and also problems related to the introduction of new time windows required by the increase of passengers as well as freight trains in the next few years. Table 1 shows the traffic according to the daily timetable referring to the different sections in which the line is divided. In 1982, the cadenced timetable was adopted and then changed in time: a certain train offer, that can be called “basic”, is placed in an hour-time unit. In certain hours, other cadenced time windows can be added to the basic offer according to the scheme in figure 3 and figure 4.
Figure 2: Current timetable for the line Bern-Thun.
Figure 3: Basic module of train timetable on the line Bern–Thun: Leaving timetable from Bern.

Figure 4: Basic module of train timetable on the line Bern–Thun: Arriving timetable from Bern.
Table 1: Traffic composition for 1997 timetable.

<table>
<thead>
<tr>
<th>Route</th>
<th>Comuters</th>
<th>Fast</th>
<th>IC/EC</th>
<th>CTS/ICE</th>
<th>Freight</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bern–Wylerfeld</td>
<td>211</td>
<td>133</td>
<td>170</td>
<td>19</td>
<td>79</td>
<td>612</td>
<td></td>
</tr>
<tr>
<td>Wylerfeld–Wankdorf</td>
<td>128</td>
<td>36</td>
<td>66</td>
<td>1</td>
<td>24</td>
<td>255</td>
<td></td>
</tr>
<tr>
<td>Wankdorf–Gümligen</td>
<td>128</td>
<td>36</td>
<td>66</td>
<td>33</td>
<td>26</td>
<td>289</td>
<td></td>
</tr>
<tr>
<td>Gümligen–Thun</td>
<td>73</td>
<td>15</td>
<td>66</td>
<td>34</td>
<td>7</td>
<td>195</td>
<td></td>
</tr>
</tbody>
</table>

The timetable reveals the choice of organizing train circulation in batteries, which means planning circulation with homotachyc train windows (trains traveling at the same speed) following one another. Usually, Intercity and regional trains travel with a 4-minute interval (2-minute interval sometimes). The timetable is structured in a way that it does not allow train overtaking but it observes connections with other means of transport (bus, steamboats etc.).

2 Computation of the line capacity

It is more correct to speak about capacity of the “railway system constituted by nodes (areas where a traveling train prevents another train from traveling) and the railway sections in between”. Therefore, each unit considered - line track, station track or node - has its own capacity value. These values are expressed as number of trains/h. To carry out this totally computerized computation, following hypotheses were made:

- the line examined was isolated from the Swiss network, that is to say, it was not affected at all by other lines;
- the well known UIC calculation method for capacity [4] was used for the single stretches between stations;
- the Florio-Mussone method [1] [2] [3] was used for the overall “railway system” in exam. This method is based on an iterative calculation of constraint optimization to identify the max number of trains in the system or, more exactly, the max number of trains in each part of the system, harmonized with the line capacity value (UIC method);
- current timetable for the line was used for capacity computation and, more precisely, the timetable for the peak hour between 7 and 9 a.m.;
- only legal tracks were considered for train circulation; concerning railway yards, only those track sections really used were considered;
- to calculate the traveling time, common characteristics of acceleration, deceleration, max. speed and length for each train category were hypothesized;
- the sign placement assumed - necessary to calculate the track occupation time of line and station - was the real one, identified time by time on the spot;
the minimum interval between trains (necessary to apply the UIC method) was set also considering the potential delays for each train category. So, for example, it was verified that a 4-minute interval between trains was enough to guarantee the regular traffic, as the delay accumulated by 95% of the trains is smaller than that.

Figure 5: Scheme of Ostermundigen station and labeling of variables.
Line capacity, computed with the UIC method, resulted of 12 trains/h in the section Bern-Gumlingen and of 9 trains/h from Gumlingen to Thun. The computation of the 9 stations and of the nodes was more difficult. It requires the solution by iterations of a constraint optimization problem, with a relevant number of variables (number of trains on each track). As an example, consider the railway station of Ostermundigen (figure 5): it implies the solution by iteration of a problem of optimum with 13 variables (number of trains divided in categories on each track) reproduced on the same figure. Once the optimum problem was solved, the percentages of occupation of the railway yards in table 2 were reconstructed.

Similar computations were carried out for all the other stations and for the Wankdorf fork.

Table 2: The percentages of occupation of the railway yards of Ostermundigen station.

<table>
<thead>
<tr>
<th>Tracks</th>
<th>Occupation%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line from Bern</td>
<td>100.00</td>
</tr>
<tr>
<td>Line from Thun</td>
<td>100.00</td>
</tr>
<tr>
<td>track 1</td>
<td>28.72</td>
</tr>
<tr>
<td>track 2</td>
<td>9.81</td>
</tr>
<tr>
<td>track 3 - 4</td>
<td>28.50</td>
</tr>
<tr>
<td>node a</td>
<td>20.14</td>
</tr>
<tr>
<td>node b</td>
<td>7.72</td>
</tr>
<tr>
<td>node c</td>
<td>13.50</td>
</tr>
<tr>
<td>node d</td>
<td>17.17</td>
</tr>
</tbody>
</table>

3 The timetable deriving from capacity computation

The capacity computed in chapter 2 is a kind of “upper limit” in the utilization of the system, based on the hypotheses made on traffic divided in the different train categories. The shift from this stage to the timetable, that is the exact temporal placement of a train, requires an analysis of the users needs and of possible interference between trains.

It had been preliminarily decided to adopt a “repetitive rigid mnemonic cadenced” timetable distributing all trains traveling in a day with a rigid frequency. It follows that capacity and timetable must be harmonized: usually, this implies having a lower number of trains traveling than it would theoretically be possible, but a frequency of trains that can be easily memorized by users.

The timetable also has to eliminate possible interference in the circulation of trains in the nodes, meaning that each train arriving in a node at the scheduled time must find it free. This aspect imposes precise bonds in creating time windows; these must be realized in such a way that they would not cause possible delays; alternatively, right of way must be given to certain train categories.
Figure 6: Proposed timetable for the line Bern-Thun.
Using those approaches, a complex analytical job that was possible only with the support of specific computer programs showed that it was possible to add one more train per category from Bern to Thun between 7 and 9 a.m. It also showed that it was possible to create a new timetable using the above stated principles, originating the chart in figure 6. As it can be observed in figure 6, the minimum spacing between trains is 3 minutes, with cases of 6 minutes to be able to limit the propagation of any delay. As a result, a metropolitan management, that is necessary to meet the increasing passenger demand on that line, is possible along the whole line. As a consequence of adopting the new timetable, a further change with respect to the current situation consisted in a different utilization of railway yard tracks in Bern and Thun.

4 Conclusions

Making a railway timetable is a complex operation, that is usually carried out in different ways using one or more factors as: simulation, analysis of the users needs, experience, lines and stations capacity, observation of the features of lines and of trains. The complex job carried out on the line Bern-Thun demonstrates that it is possible to define an optimal timetable exploiting the limits imposed by capacity (of lines and nodes) as much as possible, also taking into account the wishes of the users, who prefer repetitive and easily understandable timetables. In the case examined, the most limiting bond is represented by line capacity. This implies that, if the offer per hour is to be incremented in the future, it would be necessary to improve the line or quadruple the tracks. But it emerged also, that there are still utilization margins in big stations and at forks (where the nodes are), that it would be advisable to place the trains on the tracks in big stations in a different way, aiming at a homogeneous utilization of the tracks and at eliminating any cause of delay.

In the application carried out by us, also a stochastic element was considered in the form of possible causes of delay for each train. For this reason, according to the rules of stochastic, in the peak hours it is advisable not to exceed the utilization factor of the line track, which is given by the ratio between its occupation time and the time available, \( p = 0.75 \). This further limitation is implicit in the method we adopted and is consequential to the adoption of a rigid, repetitive cadenced timetable. At the end of our long job, we can state that the method we adopted is valid and can be applied to any situation. The statistic distribution of delay for each train category, limiting considerably the capacity values due to the prolonged track occupation time it involves, is still to be investigated thoroughly. In the meantime, it is necessary to examine closely the causes of delay and/or the temporal reduction of the delay.

Nevertheless, we believe that the principle we verified is valid, that is to say that it is possible to get to the timetable from the capacity of railway systems by solving a constraint optimization problem. This is the only way to consider globally and simultaneously the high complexity and peculiarity of railway systems.
References


