Analysis of scheduled and real capacity utilisation at a major Dutch railway station

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Abstract

Currently, an optimal utilisation of station capacity at a predefined punctuality level of train operations is generally not yet achievable. Based on train detection data of the Dutch Railways, an empirical investigation and analytic estimation has been performed with respect to the capacity utilisation of The Hague HS station. It has been found that the real capacity utilisation is much higher than the planned level if train delays and the early setting of train routes are incorporated. From a planning point of view, the remaining capacity that can be used by extra trains is less than 30% at some parts of the station. We show that the utilisation of station capacity, particularly the buffer time between a pair of trains and its distribution affect considerably the propagation of train delays and the punctuality level of train operations. A number of strategies are proposed to realise an optimal trade-off between the utilisation of station capacity and the punctuality level of train operations.

Keywords: capacity utilisation, buffer time, delay propagation, punctuality, railway station.

1 Introduction

With the growth of traffic demand, railways strive to use rail transit capacity as much as possible. On the other hand, slack times and buffer times have to be incorporated in a timetable to prevent severe propagation of train delays over the network and assure a high punctuality level of train operations. Thus, it is important for train schedulers or dispatchers to achieve an optimal trade-off between capacity utilisation and quality of services. In practice, this trade-off is by rule of thumb and there is generally not yet an optimal solution adopted. To
reach an optimal trade-off, it is necessary for railway researchers to get insight
the current realisation and then find a best solution. It is well known that the
bottlenecks of a railway system are generally located in or nearby stations, where
platform tracks, switches or crossings are the most probable conflict points.
Therefore, our research has first focused on stations.

Based on train detection data of the Dutch Railways, logged by a train
describer system in September 1999, an empirical investigation and analytic
estimation of capacity utilisation has been carried out at a major Dutch railway
station The Hague HS. This paper presents the results of this research. At first,
an analytic approach for calculating station capacity utilisation is presented.
Then, a brief description of this case station and the calculation results of the
station are given. Furthermore, the impact of capacity utilisation especially the
buffer time between a pair of trains on the propagation of train delays and the
punctuality level of train operations is discussed. A number of strategies are
proposed to realise an optimal utilisation of station capacity. Finally, conclusions
are drawn.

2 Analytic approach of capacity utilisation

For analytic capacity research it is necessary to determine capacity measures for
different parts of a network. In case of the analysis of a station, platform tracks
and routes are tackled separately. Moreover, the layout of an interlocking
arrangement is divided into smaller track layout elements called route nodes
(RN) [1, 2]. The route of each train that runs through a route node has to be
locked against possible conflicting routes of any other trains running through this
element. Adopting this analytic approach for the partitioning of a station, we
estimate analytically the utilisation of station capacity at two levels: 1) route
nodes and platform tracks; 2) the signal blocks between the entrance and
departure signal of the station, which are referred to as station blocks.

The scheduled capacity utilisation rate of each route node or platform track is
calculated by

\[ \eta = \left( \sum_i (1 + \alpha) \frac{t_{\text{block}}^i}{t_c} \right) / t_c \]

where

- \( \eta \) Scheduled utilisation rate of the route node or platform track
- \( t_{\text{block}}^i \) Theoretical blocking time of train i at the station element
- \( \alpha \) Coefficient of slack time
- \( t_c \) Cycle time of the planned timetable

The theoretical blocking time consists of sight and reaction time, approaching
time, physical occupation time, and the switching time to release the interlocking
route [2]. A slack time coefficient of 0.07 and the cycle time of 1 hour are used
in the Dutch railway timetable.
It is important to recognise that some trains cross the route nodes included in certain station block, but they don’t use the corresponding platform track sections. Consequently, the capacity utilisation of the station block is higher than that of the platform track only. In addition, once a train releases a route node, other trains may occupy it. It means that when a train dwells at platform, other trains may already occupy the route nodes included in the corresponding station block. In case of this specific situation, the scheduled capacity utilisation is calculated on the basis of a pair of trains.

The real utilisation of station capacity is determined by the actual blocking times of the trains. In this paper, the start of actual blocking time of a train is calculated from the arrival of the train at sight distance of the approach signal or from the setting of route for the train in case this happens later. The end of actual blocking time of a train is regarded as the train release at the block. Considering a pair of trains, the start of actual blocking time of the following train depends not only on the “ready to block”, but also on the “release of track section” by the preceding train.

In general, the route of a train is set somehow earlier than the start of actual track blocking as long as large time headway exists between this train and the preceding one. Once the route is set up, it is locked by signals and flank protection to prevent simultaneous occupancy by other trains. Including the setting of train routes, the real utilisation of station capacity may increase remarkably.

For a late train, the actual blocking time and the early setting of route may be less than that of a punctual train. However, from a planning point of view, other trains cannot occupy the track sections from the start of the scheduled track occupancy until the start of the actual occupancy of a late train, except perhaps also delayed trains. Therefore, the scheduled track occupation times, which are not used due to train delays but cannot serve other trains, are to be included in the calculation of station capacity utilisation. For a pair of trains, the actual end of blocking time of the preceding train might be later than the scheduled start of blocking time of the following train in case of short time headway. Thus, each train pair is analysed separately to avoid double counting.

Figure 1 visualises the blocking times, route setting time, and buffer times between a pair of trains. The buffer time between a pair of trains is regarded as the difference between the start of blocking time of the following train and the end of blocking time of the preceding train. If the buffer time is actually available, the *remaining buffer time* is referred to as the earlier of the scheduled start of blocking time and the moment of route setting of the following train minus the end of actual blocking time of the preceding train. Certainly, other trains may use the remaining buffer times.

For each route node, platform track and station block, the real capacity utilisation is to be calculated as follows. First, the calculation is based only on the actual blocking times. Second, the early setting of train routes is included. Third, train delays are incorporated. Finally, both the early setting of train routes and train delays are taken into account. In other words, the final calculation is based on the remaining buffer times between each train pair.
3 Case station: The Hague HS

The presented analytic approach has been applied in a case study at The Hague HS (see Figure 2). Each hour 24 trains arrive in and depart from the station. These trains correspond to 9 different series in both northbound and southbound directions, including 1 high-speed train (HST) series, 1 international (INT) series, 4 intercity (IC) series, 1 interregional (IR) series and 2 local (AR) series.

![Figure 2: Routes, route nodes, tracks and station blocks of The Hague HS.](image)

To identify the route nodes, the use of 7 routes through the station has been confirmed based on the empirical analysis by means of TNV-Prepare [3]. Most interesting are the following facts. First, trains leading to The Hague CS (Gvc)
make level crossings with trains coming from Amsterdam (Asd) / Leiden (Ledn). Second, a part of trains leading to The Hague CS shares a single track with trains coming from The Hague CS. Considering these facts, 4 critical route nodes have been identified on the north of The Hague HS. In addition, it has been found that 4 platform tracks and 5 station blocks are mainly used during the time period of investigation. Table 1 indicates the train series visiting The Hague HS, used train routes, route nodes, platform tracks, and station blocks respectively. All elements of the station mentioned above have been shown in Figure 2.

### Table 1: Train series, routes, route nodes, tracks and station blocks (1999).

<table>
<thead>
<tr>
<th>Train series</th>
<th>Train type</th>
<th>Hour freq.</th>
<th>Route node</th>
<th>Northbound track</th>
<th>Block</th>
<th>Route node</th>
<th>Southbound track</th>
<th>Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>IC</td>
<td>1</td>
<td>c</td>
<td>1, 2</td>
<td>5</td>
<td>3f, 4, 5</td>
<td>3f, 3g</td>
<td>g</td>
</tr>
<tr>
<td>2100</td>
<td>IC</td>
<td>1</td>
<td>a</td>
<td>-</td>
<td>6</td>
<td>6 e</td>
<td>1, 3</td>
<td>4</td>
</tr>
<tr>
<td>2200</td>
<td>IR</td>
<td>2</td>
<td>a</td>
<td>-</td>
<td>6</td>
<td>6 e</td>
<td>1, 3</td>
<td>4</td>
</tr>
<tr>
<td>2400</td>
<td>IC</td>
<td>1</td>
<td>a</td>
<td>-</td>
<td>6</td>
<td>6 e</td>
<td>1, 3</td>
<td>4</td>
</tr>
<tr>
<td>2500</td>
<td>IC</td>
<td>1</td>
<td>c</td>
<td>1, 2</td>
<td>5</td>
<td>3f, 4, 5</td>
<td>3f, 3g</td>
<td>g</td>
</tr>
<tr>
<td>5000</td>
<td>AR</td>
<td>2</td>
<td>b</td>
<td>-</td>
<td>5</td>
<td>5 f</td>
<td>2, 4</td>
<td>3</td>
</tr>
<tr>
<td>5100</td>
<td>AR</td>
<td>2</td>
<td>d</td>
<td>3, 4</td>
<td>5</td>
<td>3f, 3g,</td>
<td>4, 5</td>
<td>3</td>
</tr>
<tr>
<td>600</td>
<td>INT</td>
<td>1</td>
<td>a</td>
<td>-</td>
<td>6</td>
<td>6 e</td>
<td>1, 3</td>
<td>4</td>
</tr>
<tr>
<td>9300</td>
<td>HST</td>
<td>1</td>
<td>a</td>
<td>-</td>
<td>6</td>
<td>6 e</td>
<td>1, 3</td>
<td>4</td>
</tr>
</tbody>
</table>

### 4 Calculation results of capacity utilisation

Table 2 lists the calculation results of the scheduled and real utilisation of station capacity at The Hague HS. The scheduled capacity utilisation is lower than 50% at most parts of the station, whereas it is about 60% for platform track 3 and the corresponding station blocks. Due to the dwell of trains, the capacity utilisation of platform tracks is higher than that of route nodes. The frequency of trains occupying station blocks is the same as or higher than that of trains dwelling at platform tracks, resulting in a capacity utilisation of station blocks sometimes being beyond that of platform tracks. The relatively high capacity utilisation at RN 4, platform track 3 and station block 3f & 3g is related to the low design speed of 40 km/h between The Hague CS and The Hague HS and the long total scheduled dwell time of 12 minutes at platform track 3.

Due to the variation of the train dwelling and running times, the real capacity utilisation based only on the blocking times is generally 5 to 15% higher than the scheduled one. But, it is lower than the scheduled one at each route node, platform track 3 and station block 3f & 3g, which is mainly caused by the simultaneous claim of train routes on these elements. In addition, it is also contributed to the frequent late setting of the train routes including platform track 3, where the design speed is only 40 km/h. In this case, a little bit late setting of train routes does not cause knock-on delays. Certainly, this is a very specific situation. The early setting of train routes and train delays generate additional
capacity utilisation, which can be up to 20% at some parts of the station. Finally, if the blocking time, route setting, and train delays are all included, the real capacity utilisation can be more than 70% at some parts of the station. From a planning point of view, there is less than 30% remaining capacity that might be used by extra trains.

Table 2: Capacity utilisation at The Hague HS (1999).

<table>
<thead>
<tr>
<th>Station elements</th>
<th>Number of trains per hour</th>
<th>Scheduled capacity utilization (%)</th>
<th>Figure 3:</th>
<th>Real capacity utilisation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN 1</td>
<td>8</td>
<td>19.3</td>
<td>BT¹</td>
<td>19.0</td>
</tr>
<tr>
<td>RN 2</td>
<td>4</td>
<td>14.6</td>
<td>BT+R²</td>
<td>12.1</td>
</tr>
<tr>
<td>RN 3</td>
<td>8</td>
<td>20.7</td>
<td>BT+D³</td>
<td>19.2</td>
</tr>
<tr>
<td>RN 4</td>
<td>8</td>
<td>34.2</td>
<td>BT+R+D⁴</td>
<td>24.6</td>
</tr>
<tr>
<td>Track 3</td>
<td>6</td>
<td>59.2</td>
<td>BT¹</td>
<td>49.7</td>
</tr>
<tr>
<td>Track 4</td>
<td>6</td>
<td>38.5</td>
<td>BT+R²</td>
<td>44.5</td>
</tr>
<tr>
<td>Track 5 (Block 5)</td>
<td>6</td>
<td>38.2</td>
<td>BT+D³</td>
<td>52.6</td>
</tr>
<tr>
<td>Track 6 (Block 6)</td>
<td>6</td>
<td>36.2</td>
<td>BT+R+D⁴</td>
<td>51.0</td>
</tr>
<tr>
<td>Block 3f</td>
<td>10</td>
<td>62.5</td>
<td>BT¹</td>
<td>57.7</td>
</tr>
<tr>
<td>Block 3g</td>
<td>8</td>
<td>59.2</td>
<td>BT+R²</td>
<td>50.1</td>
</tr>
<tr>
<td>Block 4</td>
<td>10</td>
<td>48.3</td>
<td>BT+D³</td>
<td>55.7</td>
</tr>
</tbody>
</table>

¹ BT: based only on track blocking times
² BT+R: early route setting included
³ BT+D: train delays included
⁴ BT+R+D: both early route setting & train delays included

5 Impact of capacity utilisation on delay propagation

The impact of capacity utilisation on delay propagation is analysed in this section. For a single train, the propagation of train delays at stations is mainly determined by the scheduled dwell time, as discussed in [4, 5]. The influence of the total buffer time and the distribution of buffer times on delay propagation are studied.

For a pair of trains, if the actual buffer time is zero, the delay of the following train is certainly correlated to the preceding trains. In the following, we use the term knock-on delay to refer to the part of a train’s delay that is caused by the preceding trains. The official punctuality level of the Dutch Railways is defined by the threshold of delays less than 3 minutes. To get a clear view of the effect of capacity utilisation and buffer time, the train delays less than 1 minute are also considered.
Table 3 lists the capacity utilisation of station blocks, the knock-on delay resulted from the simultaneous claim of route occupancy, and the punctuality level of the corresponding trains, which may arrive at or depart from The Hague HS. It is confirmed that a higher capacity utilisation or shorter total buffer time leads to larger probability of knock-on delays and lower punctuality level of train operations.

Table 3: Effect of capacity utilisation on knock-on delays and punctuality (1999).

<table>
<thead>
<tr>
<th>Station blocks</th>
<th>Scheduled capacity utilisation (%)</th>
<th>Prob. of simultaneous claim of occupancy</th>
<th>Prob. of knock-on delays</th>
<th>Mean of knock-on delays (sec)</th>
<th>Train delays &lt; 1 min. (%)</th>
<th>Train delays &lt; 3 min. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 3f</td>
<td>62.5</td>
<td>0.47</td>
<td>0.20</td>
<td>56</td>
<td>53</td>
<td>91</td>
</tr>
<tr>
<td>Block 3g</td>
<td>59.2</td>
<td>0.40</td>
<td>0.22</td>
<td>48</td>
<td>52</td>
<td>92</td>
</tr>
<tr>
<td>Block 4</td>
<td>48.3</td>
<td>0.18</td>
<td>0.18</td>
<td>95</td>
<td>69</td>
<td>91</td>
</tr>
<tr>
<td>Block 5</td>
<td>38.2</td>
<td>0.02</td>
<td>0.02</td>
<td>32</td>
<td>76</td>
<td>92</td>
</tr>
<tr>
<td>Block 6</td>
<td>36.2</td>
<td>0.04</td>
<td>0.04</td>
<td>47</td>
<td>83</td>
<td>92</td>
</tr>
</tbody>
</table>

The effect of the distribution of scheduled buffer times is analysed based on two typical train pairs. The first pair of trains is the intercity and interregional trains from Amsterdam, whose scheduled buffer time is nearly 10 minutes at platform track 4. The second pair of trains is the local train leading to The Hague CS and the high-speed train from Amsterdam. The scheduled buffer time between them is only about 1 minute at RN 3.

The release of the preceding train at the station block and the arrival of the following train at sight distance of the approach signal vary remarkably, which leads to a stochastic distribution of the time lag between a pair of trains. Figure 3 and 4 show the probability density function (PDF) curve of the time lag for both train pairs. Clearly, the area at the left of the line “the zero time lag” and below the PDF curve represents the probability that the following train suffers the knock-on delay caused by the preceding train. For the first pair of trains, the probability is only 0.4%. However, for the second pair of trains, the probability is more than 90% and the average knock-on delay is around 2 minutes. It is thus confirmed that the knock-on delay is considerably influenced by the scheduled buffer time between pair of trains.

Actually, the departure of the local train leading to The Hague CS is subject to knock-on delay caused by the local train coming from The Hague CS, whose scheduled buffer time is zero at RN 4. In addition, the local train from The Hague CS often suffers knock-on delay caused by the preceding intercity train leading to Venlo (VI) or Heerlen (Hrl), whose scheduled buffer time is about 1 minute at platform track 3. It seems that a chain of delay propagation exists at The Hague HS. To decrease the probability of knock-on delays and remove the chain of delay propagation, it is necessary to improve the distribution of scheduled buffer times. Particularly, for the high-speed train series with a high
operation priority, it is necessary to increase the scheduled buffer time to decrease the chance of knock-on delays and assure a higher punctuality level.

Figure 3: Empirical PDF curve of time lag between IC and IR trains from Amsterdam.

For the first pair of trains from Amsterdam, the preceding train releases the station block with an average delay of 0.5 minutes and the following train arrives 0.1 minutes later at sight distance of the approach signal. As a result, the mean
actual buffer time is 94% of the scheduled buffer time. For the second pair of trains, the preceding train releases RN 3 (also station block 4) with a mean delay of 0.7 minutes whereas the following train arrives on average 2.4 minutes early at sight distance of the approach signal. Consequently, there is no buffer time between this pair of trains in practice and the following train with a high priority is forced to decelerate rather often. It appears that the actual buffer time and knock-on delay depend not only on the scheduled buffer time, but also on the variation of train arrivals and departures, which may be caused by the train operations further upstream.

6 Strategies for an optimal utilisation of station capacity

For an optimal utilisation of station capacity, a heuristic approach may be a good solution. Given the frequency of trains visiting a station, we aim at operating extra trains as much as possible at a required punctuality level. To this end, it is necessary to increase the total remaining buffer time and decrease the delay propagation for all train pairs.

To avoid delay propagation and assure a high punctuality level of a train series, we may increase the scheduled dwell time or buffer time. However, if this is done, the total remaining buffer time or the buffer times between other train pairs will be reduced, which certainly affects the utilisation of station capacity and the punctuality level of other train series. To achieve an optimal trade-off, it is necessary to develop an optimisation tool to determine scheduled dwell times, buffer times and their distributions taking into account the priority of train series. A prediction model of train delay propagation is intended, as part of the optimisation tool, for estimating the remaining buffer time and the punctuality level. In addition, the delay propagation model would be able to support a duly setting of train routes and avoid the waste of capacity utilisation due to the setting of train routes.

An advanced information system would support the on-line data communication between drivers and dispatchers to decrease the variation of train operations and assure efficient capacity utilisation and high punctuality level. To this end, a further optimisation of the block signal spacing corresponding to the local design speed would reduce the blocking times and increase the total remaining buffer time, which decreases the probability of knock-on delays.

7 Conclusions

In summary, the real utilisation of station capacity appears higher than the scheduled one, if train delays and the early setting of train routes are considered. From a planning point of view, the remaining capacity that may be used by extra trains is less than 30% at some parts of the case station. The utilisation of station capacity, particularly the scheduled dwell times, buffer times and their distributions affect considerably the propagation of train delays and the punctuality level of train operations.
It is suggested to develop a prediction model of delay propagation and an optimisation tool to improve the determination of the scheduled dwell time, buffer time and their distributions. The delay propagation model can also support a duly setting of train routes. In addition, on-line data communication between train drivers and dispatchers is advised to decrease the variation of train operations. In case of the track sections with low design speed, the signal spacing should be adapted as much as possible. Finally, it is also important to recognise that the optimal utilisation of station capacity will improve the operations on adjacent links and nodes, too.

Acknowledgement

This publication is a result of the spearhead research programme Towards Reliable Mobility, carried out within the TRAIL Research School for Transport, Infrastructure and Logistics, and financed by Delft University of Technology.

References