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Identification of Bottlenecks in Rail Infrastructure

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Abstract

Bottlenecks have significant impact on routing options and network exploitation. Therefore, it is essential to know the location of critical areas in order to use the existing infrastructure more efficiently and to expand the network appropriately. This paper presents a method to identify bottlenecks based on delays and to weight them by their significance. As delays can be derived from operational data or from simulations, statements about past operating conditions or forecasts based on simulated operating conditions are possible.

The method considers the occurrence of delays at one location and delay increases based on trains' initial delays. It aims to weight additional delay increases higher for punctual trains compared to already heavily delayed trains. This reflects that a deviation from planned times of trains without initial delays has particularly negative impacts on operational quality as these disruptions are indicators for bottlenecks and can lead to delay propagations. Additional delays for already highly delayed trains however have lower significance for operational quality. Furthermore, such delays are often caused by the already existing deviation from the timetable and do not necessarily indicate a bottleneck. Therefore, delays are categorised.

Both delay increases and delay category changes can be weighted based on the affected train type to calculate the bottleneck's severity. This gives information on the specific infrastructure's significance concerning the networks performance. Sorting investigated railway lines and stations by their severity gives an overview on the most significant bottlenecks. Furthermore, the method's delay classification helps to analyse found bottlenecks. Based on the identification of bottlenecks, it will be possible to further analyse them using different data sources and methods of data analysis. Knowing the most critical areas enables infrastructure managers to take them into account while timetabling and prioritise expansion measures correctly.

Keywords: bottlenecks, capacity, data analysis, delays, operation, quality.

1 Introduction

Most rail networks are already heavily utilised in certain sections. The expected increase in passenger and freight transportation will raise the infrastructure usage and number of bottlenecks.
In order to meet these challenges, it is necessary to use the existing infrastructure more efficiently and to expand the network appropriately. Therefore, knowledge about the location of most critical areas of the network and the related causes of delays are essential.

Capacity bottlenecks are areas in the railroad network where high infrastructure utilisation or operational problems lead to significant train delays. In operation, high increases in delays can be observed regularly in or around these areas. Locations where delays occur are not necessarily the reason for bottlenecks but could rather represent the waiting area. Delays caused by bottlenecks often result in additional delays further on with other trains. Such a delay propagation leads to low operational quality in larger areas. Thus, solving bottlenecks has a high leverage effect on improving operational quality of entire networks.

It is therefore essential to identify critical areas in rail networks. For this purpose, *German Centre for Rail Traffic Research* has commissioned a project to identify, analyse and dissolve such bottlenecks automatically. This paper presents the developed method to identify bottlenecks and their severity based on occurring delays. Necessary information about delays can be derived from measured operational data or from simulations. Thus, depending on the data source, statements about past operating conditions or forecasts based on simulated operating conditions are possible. In order to systematically identify frequently occurring operating situations, it is recommended to evaluate long periods of time with comparable timetables and static infrastructure.

With the purpose of identifying bottlenecks, Section 2 presents a method for evaluating delay information. Results are discussed in Section 3 before conclusions and contributions are summarised in Section 4.

2 Methods

To identify and weight bottlenecks in the network, delays are evaluated. The method includes the occurrence of delays at one location ('delay-event') and weights delay increases based on a train's initial delay.

While the occurrence of large delays is a clear sign for a congested area, small time changes of few seconds are negligible. In rail timetabling, extra time between trains is scheduled to prevent secondary delays. Delays that do not exceed such buffer times are negligible. Therefore, a threshold for the consideration of delay-events is introduced. For Germany, a threshold of 90 s is recommended which exceeds minimum buffer times that need to be considered in German timetables [1].

In addition to the identification of delay-events, the method considers delay increases depending on trains' initial delays. It aims to weight additional delay increases higher for punctual trains compared to already heavily delayed trains. This reflects that a deviation from planned times for trains that have not been delayed so far has particularly negative impacts on operational quality as these disruptions can lead to delay propagations. Additional delays for already highly delayed trains however have lower significance for operational quality. Such delays are often caused by the already existing deviation from the timetable and do not necessarily indicate a bottleneck. In order to consider the trains' delay levels, they are categorised as shown in Figure 1. Furthermore, the categorisation identifies creepingly increased delays below the threshold.

Figure 1: Delay categories.

To identify bottlenecks, the number of delay-events and changes into higher categories are counted. Changes into lower categories are not considered to avoid delays to be balanced by other trains: In case of inhomogeneous operational quality, some trains' delay reductions would compensate for the delay suffered by other trains. Especially in the area of known bottlenecks, supplements are included in timetables, which distort their identification. Furthermore, delay changes from category 0 to category 1 are not counted as changes for premature trains are not caused by bottlenecks. Delay-events of trains running in category 5 are not considered due to their high deviation from their planned timeslot.

Both delay increases and category changes can be weighted based on the affected train type. It is advisable to weight them according to generally accepted priorities.

Considering the explained aspects, formula (1) to calculate a bottleneck's severity is derived. All used parameters can be defined individually depending on the given task.

$$S = k_{longd} \cdot \sum_{i=1}^{E} (E_{Zu} + E_{VKW,+}) + k_{local} \cdot \sum_{i=1}^{E} (E_{Zu} + E_{VKW,+}) + k_{subu} \cdot \sum_{i=1}^{E} (E_{Zu} + E_{VKW,+}) + k_{freight} \cdot \sum_{i=1}^{E} (E_{Zu} + E_{VKW,+}) + k_{other} \cdot \sum_{i=1}^{E} (E_{Zu} + E_{VKW,+}) \tag{1}$$

S	bottleneck's severity
k_{longd}	weighting factor - long-distance passenger trains
k_{local}	weighting factor - local passenger trains
k_{subu}	weighting factor - suburban trains
$k_{freight}$	weighting factor - freight trains
k_{other}	weighting factor - other trains
E	number of events
E_{Zu}	1 if delay increase ≥ 90 s, otherwise 0
$E_{VKW,+}$	category changes into higher categories

3 Results

With the presented method, bottlenecks and their severity are calculated for an investigation area such as a rail network. As part of the project, we have applied the method to the German rail network and calculated the severity of lines and stations. This gives information on the infrastructure's significance concerning the network's performance. Ordering the bottlenecks by severity gives an overview of the most significant locations. Two separate lists for lines and stations are created. It is possible to evaluate trains grouped by category, line or train number to enable a deep analysis of the infrastructural bottleneck.

The analysis of bottlenecks is supported by a visualisation of delay categories and their changes. Figure 2 shows a visualisation for an exemplary German rail station.

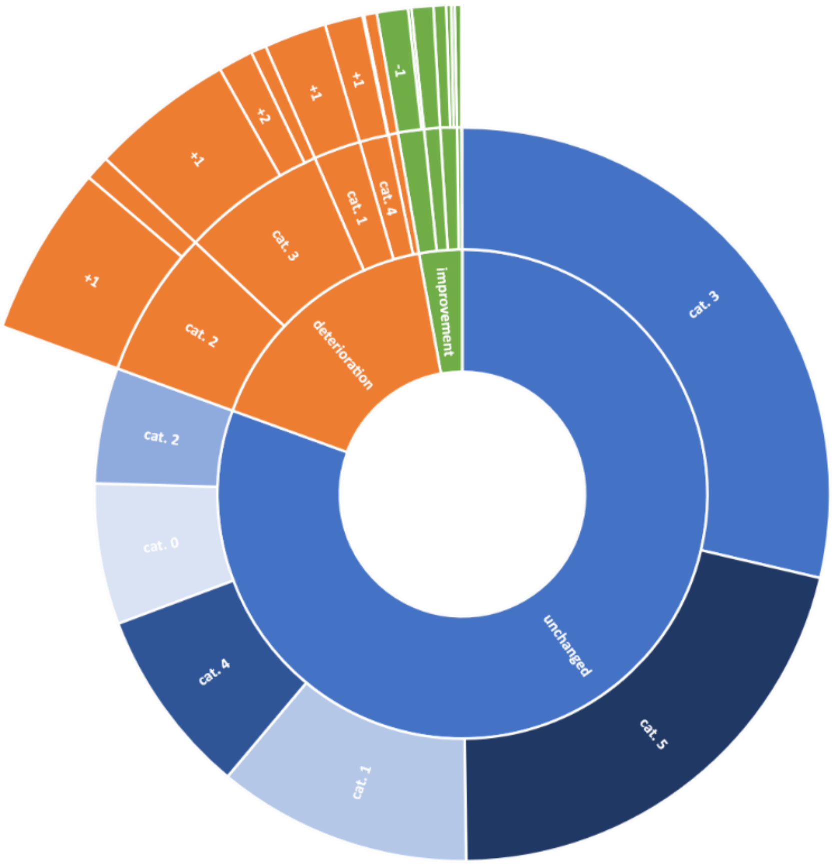

Figure 2: Visualisation of category changes

The figure illustrates that the station has a negative effect on operational quality as more trains gain delays (deterioration of delay categories) than reduce their delays (improvement of categories). Most trains remain in the same delay category. Categories 3, 5 and 1 are most common. Category 1 includes trains that deviate at most 30 s from the timetable. Many delayed passenger trains operate in category 3 (delay up to 390 s). Since the German threshold for punctuality roughly corresponds to the upper limit of category 3, passenger trains being classified in higher categories are avoided. Category 5 contains trains that are delayed more than 870 s. These trains have a significant deviation from the timetable. Mostly freight trains operate in this category. As these trains usually have lower priority compared to passenger trains, more delays are gained on the route. Delayed freight trains are indicators either for timetabling processes not fitting the needs of freight trains or for insufficient capacity in the network. Related to the investigated station, trains that remain in the same category are no indications for a bottleneck. Better suited are trains that gain delays at this location resulting in a deterioration of their category. In this example, delayed trains mostly change to categories 2 and 3 resulting in delays of 30 to 390 s. Such delays can have significant effects on the operational quality when propagating to following trains. The risk of delay propagations is particularly high on already heavily used lines and stations where buffer times are low.

4 Conclusions and Contributions

As the capacity of rail networks is limited by their bottlenecks, it is essential to identify these areas. Knowing the most critical areas enables infrastructure managers to optimise timetables accordingly and prioritise expansion measures correctly.

This paper has presented a method to identify bottlenecks. The method is based on occurring delays and allows the prioritisation based on train's initial delays and train types. Delays can be measured in daily operation or in simulations. That way, statements about past operating conditions as well as forecasts for different operating conditions are possible. Based on the exemplarily application on German rail network, it has been concluded that the method is suitable to identify critical areas in large networks.

Main contributions are the identification of bottlenecks in rail networks and giving the possibility to sort them by their relevance. Furthermore, the method's delay classification helps to analyse found bottlenecks.

Next steps of the project are to further analyse found bottlenecks using different data sources and methods of data analysis (especially a method called "Episode Mining" which aims to identify delay propagations between trains based on occurring delays). The objective is to complete the identification bottlenecks with an automatic analysis and development of suggestions to dissolve them. This will assist greatly in monitoring and improving a large rail network.

References

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