GIS Analyses of Railroad Capacity and Delays

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1 Abstract

Railroad capacity, train delays and passenger delays are correlated. If there is lack of capacity (or the capacity is poorly utilized) there is high risk of train delays and thereby passenger delays. Only few GIS-approaches concerning visualization of railroad capacity (and its utilization) exist. For delays, GIS-approaches of visualizing train delays exist while hardly any GIS-approach for passenger delays exists.

In Europe, rail authorities, infrastructure managers and train operating companies need to communicate about railroad capacity and delays. Consequently, analytical descriptions of railroad capacity and its utilization have been developed. Also models analyzing train and passenger delays have been developed for follow-up on performed operation and for forecasting delays in the planning process. However, hardly any GIS-systems are used to ease the communication of delays and railroad capacity – and its correlation. This paper illustrates how railroad capacity can be visualized, analyzed and communicated together with train and passenger delays. This paper gives an overview of how GIS-systems can be used to present railroad capacity and delays.

Keywords: ArcGIS, Network Analyst, railroad capacity, train delay, passenger delay

2 Introduction

The deviation of the railroad sector in Europe into rail authorities, infrastructure managers and train operating companies results in need to communicate about railroad capacity and delays. To ease the communication of railroad capacity analytical descriptions of railroad capacity and its utilization have been developed but only few methods on how to visualize and communicate capacity using GIS have been developed.

To communicate railroad capacity using GIS it is necessary to understand what capacity is. In fact, railroad capacity is a complex, loosely defined term that has numerous meanings (Krueger 1999), and the definitions differ by country (Rothengatter 1996). In

2004 the International Union of Railroads (UIC), therefore, (re)defined railroad capacity as (UIC 2004):

Capacity as such does not exist. Railroad infrastructure capacity depends on the way it is utilized.

This definition of railroad capacity is followed by a guideline for how railroad capacity can be measured given the actual infrastructure and the actual timetable.

Railroad capacity is difficult to state and visualize because there are several parameters that can be measured, cf. figure 1. The parameters seen in figure 1 (number of trains, stability, heterogeneity and average speed) are dependent on each other which further complicates the statement and visualization of railroad capacity.

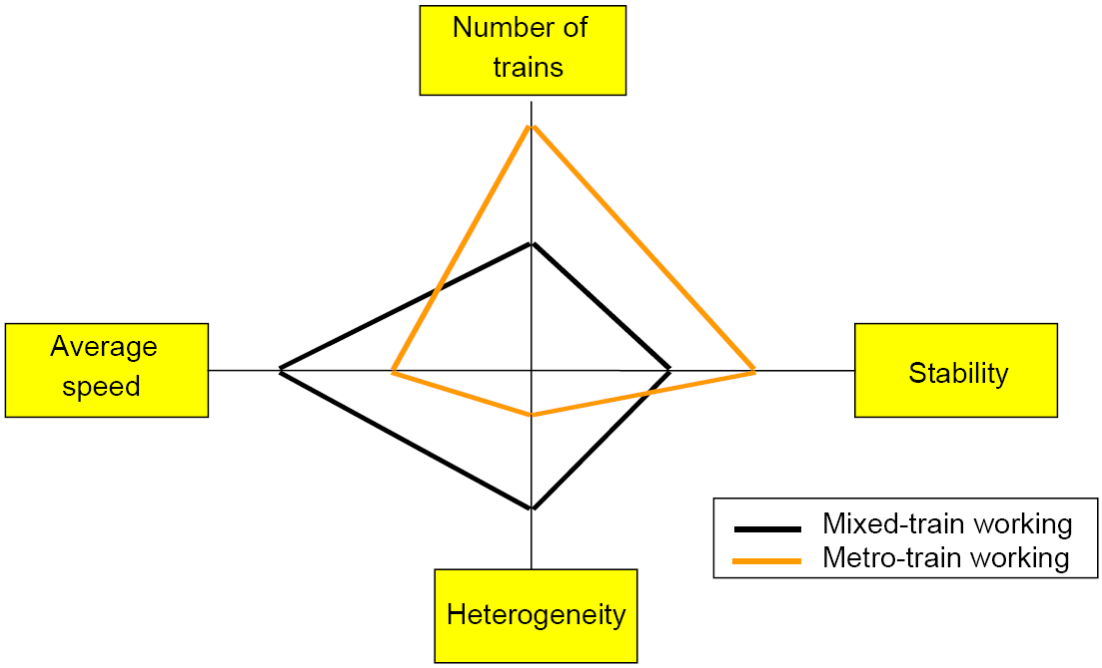

Figure 1: The balance of capacity (UIC 2004).

Figure 1 shows that capacity is a balanced mix of the number of trains, the stability of the timetable, the level of average speed achieved and the heterogeneity of the operation. It may, for instance, be possible to satisfy a market demand for a high average speed by having high heterogeneity—a mix of fast Intercity Express, Intercity, slower Regional trains serving all stations, and freight trains. However, the consequence of having high average speed and high heterogeneity is that it is not possible to operate as many trains with a high stability (punctuality) as when all trains are operated with the same speed and stop pattern. If there is market demand for operating more trains, it may be necessary to have a less mixed operation and thereby have a lower average speed (assuming that the fast trains are adapted to the slower trains) as it is known from, for example, metro systems.

Besides the number of trains, average speed, heterogeneity, and stability also the capacity consumption (and thereby the infrastructure and the characteristics of the rolling stock) is an important measurement. This is because high capacity consumption leads to a high risk of knock-on delays (or secondary delays) for the following train(s), cf. figure 2.

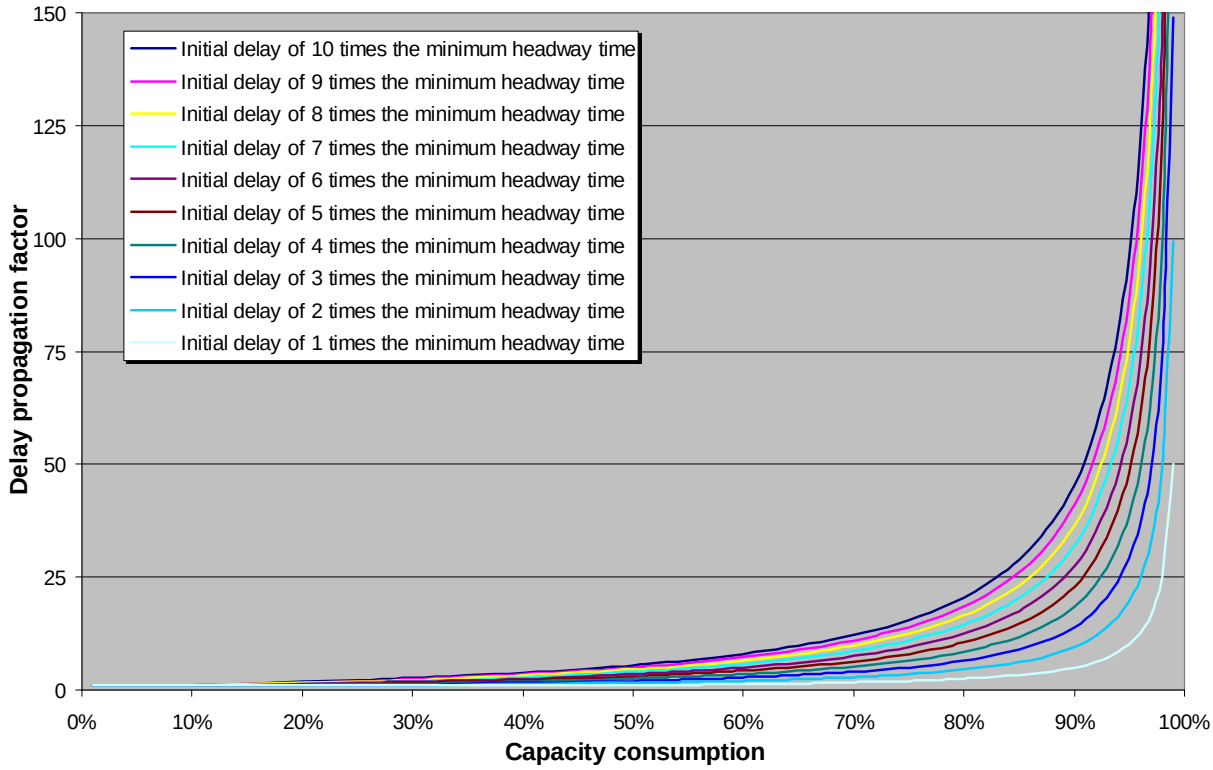

Figure 2: The delay propagation factor as a function of capacity consumption and initial delays (Landex 2008).

High capacity consumption and thereby high risk of train delays often lead to passenger delays. Generally the passenger delays are larger than train delays (Nielsen & Frederiksen 2005) but for high frequent railroad systems the passenger delays can be smaller than the train delays since the passengers can take the first train in their direction. Train delays may even result in passengers arriving before time as the passengers catch an earlier but delayed train.

The paper presents methods to visualize and analyze railroad capacity and delays for both trains and passengers. The structure of the remaining paper is:

- Section 3: Capacity consumption of railroads
- Section 4: How the capacity of railroads is utilized
- Section 5: Delays for trains and passengers
- Section 6: Perspectives for more intensive use of GIS in the railroad sector
- Section 7: Summary of the paper

3 Capacity consumption

Railroad capacity is based on hard facts such as infrastructure and actual timetables and is a useful tool for infrastructure managers, operators and rail authorities, who need an overview of the possibility to operate more trains. For this GIS maps illustrating the state of capacity consumption are an important tool, cf. figure 3.

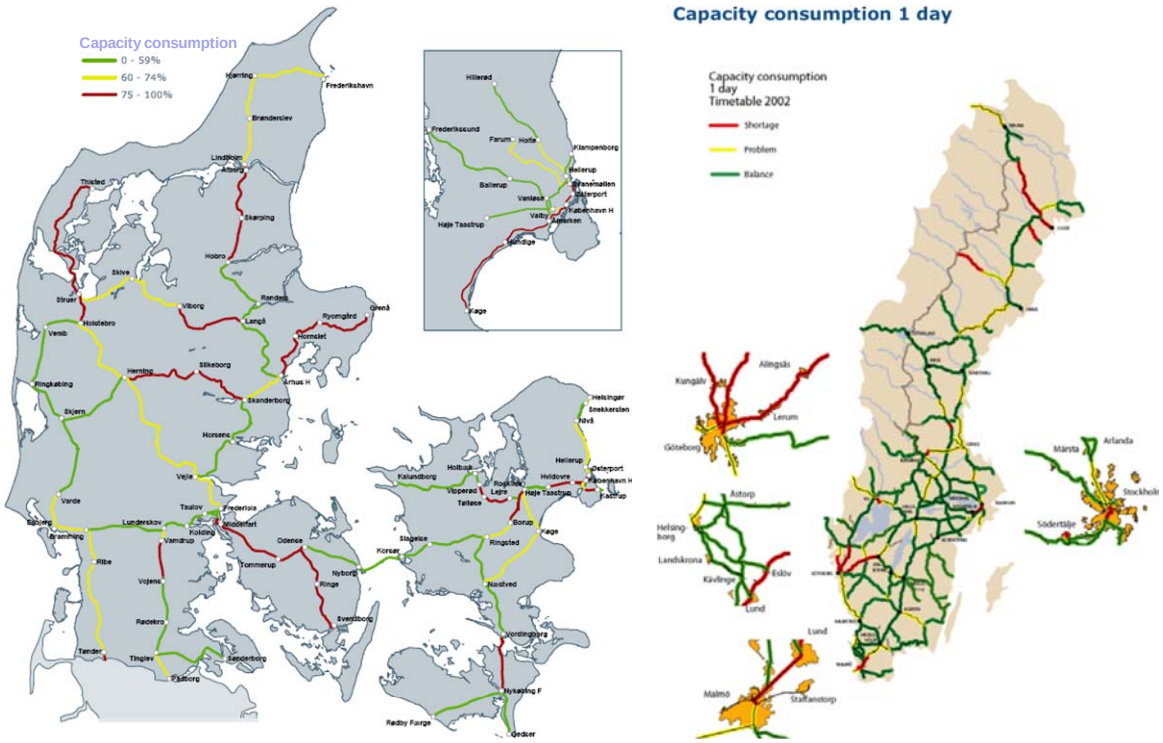

Figure 3: Capacity consumption in Denmark (left—based on (Rail Net Denmark 2008)) and Sweden (right—(Wahlborg 2005)).

It is not only the present, or previous, capacity consumption that can be presented on GIS maps. The Austrian railroads (ÖBB) also present future scenarios based on traffic forecasts and a combination of macro and micro simulation (Radtke 2008, Sewcyk, Radtke & Wilfinger 2007), cf. figure 4. Using GIS maps to present future bottlenecks to the decision makers is a simple and easy way to communicate complex forecast calculations in an understandable way.

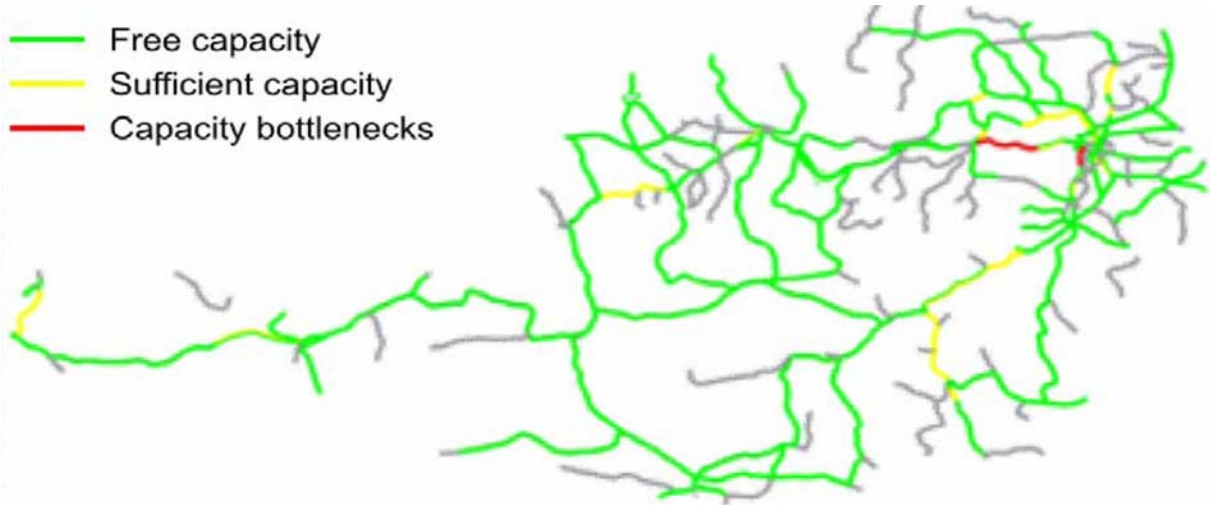

Figure 4: Capacity utilization for a fictitious scenario on the Austrian railroad network (Sewcyk, Radtke & Wilfinger 2007).

For large rail networks like the European with several possible routes for freight trains from e.g. Sweden to Italy GIS maps can give an idea of the routes where it is possible to acquire train slots. Using the ArcGIS extension Network Analyst operators can find the cheapest route e.g. in terms of time, length and capacity for the trains taking barriers and restrictions into account, cf. figure 5.

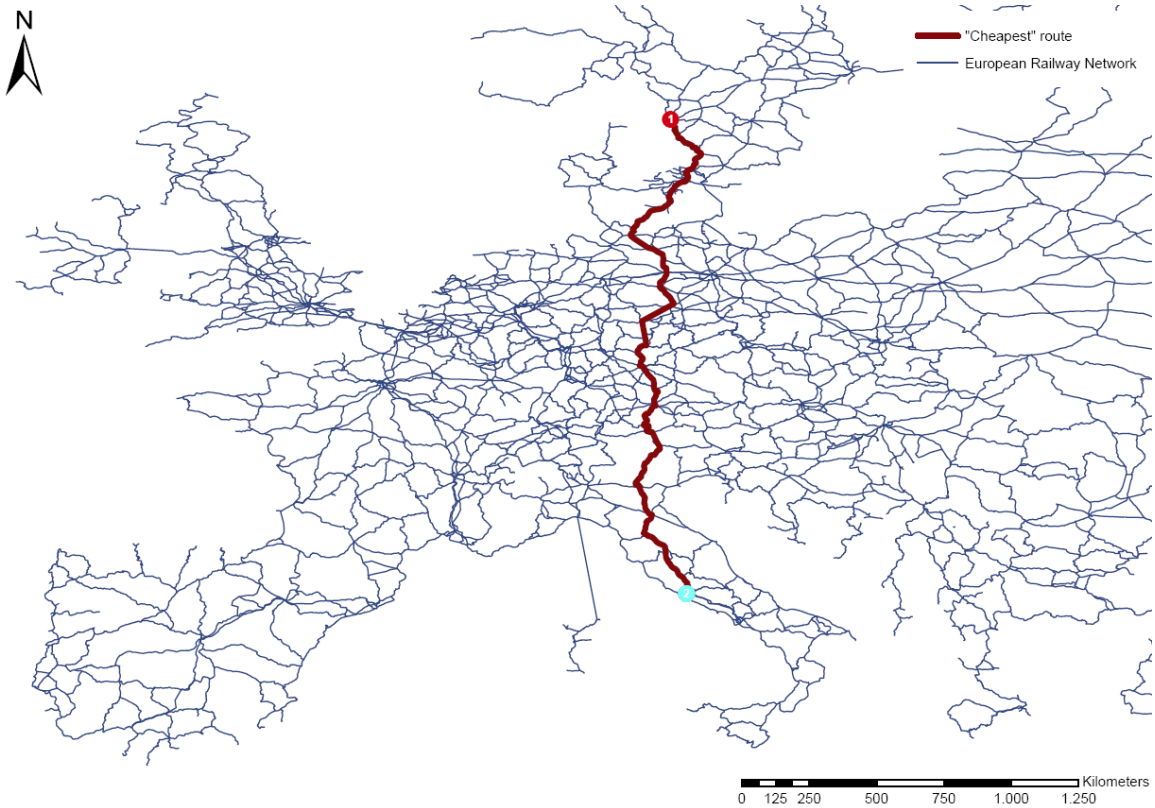

Figure 5: Example of route search (on the main railroads) from Sweden to Italy (fixed rail connection across Femern Belt assumed).

4 Capacity utilization

The previous section showed the capacity consumption of railroad lines and how Network Analyst can be used to search for train routes, but it is not shown how the capacity is utilized. Not showing how the capacity is utilized makes it difficult to analyze the possibilities for operating more trains. This is because more trains may be operated if the timetable is homogeneous instead of heterogeneous, cf. figure 6.

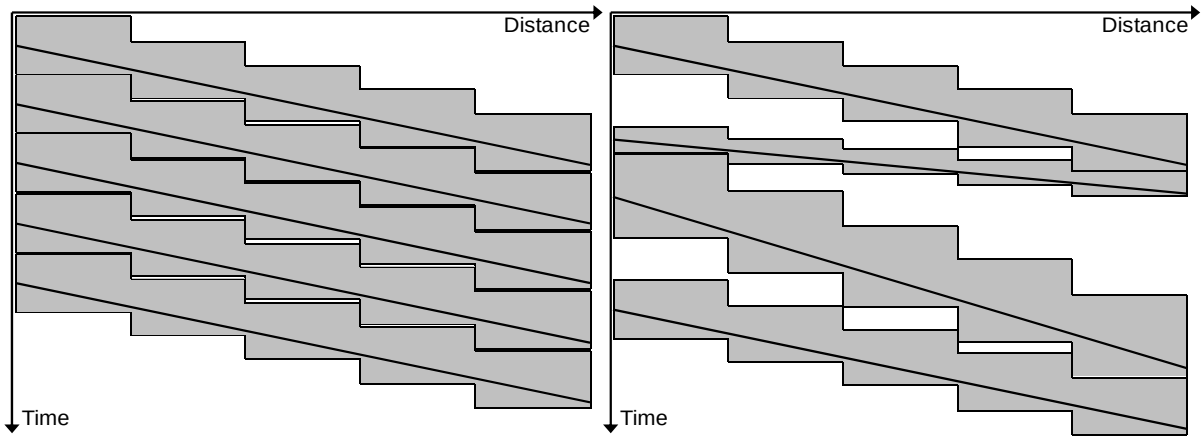

Figure 6: Homogeneous timetable with many trains (left) results in lower capacity consumption than a heterogeneous timetable with fewer trains (right) (Landex 2008).

To assess the possibility to operate more trains on the railroad network it is necessary to incorporate how the capacity is utilized. The UIC 406 capacity leaflet (UIC 2004) defines the parameters of capacity utilization in the "balance of capacity" (number of trains, average speed, heterogeneity and stability), cf. figure 1. To describe both the capacity consumption and the capacity utilization it is necessary to add an extra dimension (the capacity consumption) to the balance of capacity (Landex 2008), so that a capacity pyramid is achieved, cf. figure 7. From this pyramid it is possible to read both the capacity consumption and how the capacity is utilized.

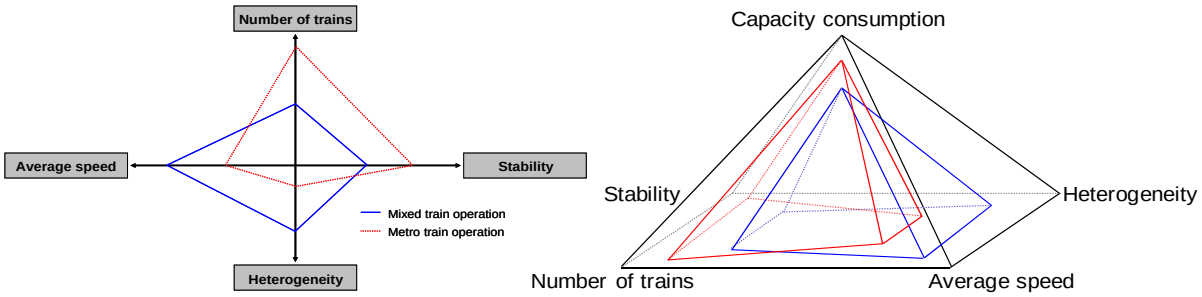

Figure 7: Railroad capacity – the UIC 406 balance of capacity to the left and the capacity pyramid to the right (Landex 2008).

It is not possible to visualize all the elements from the capacity pyramid on a GIS map at the same time—in a straightforward way—unless a weighted average is calculated. However, the elements in the capacity pyramid can be weighted differently in different situations, which is why it is difficult to find the right weights when calculating an average (Landex 2008). Instead, GIS makes it possible to visualize the most interesting

element from the capacity pyramid (often the capacity consumption) with the possibility to click on the line sections to examine all the elements of the line section as shown in figure 8.

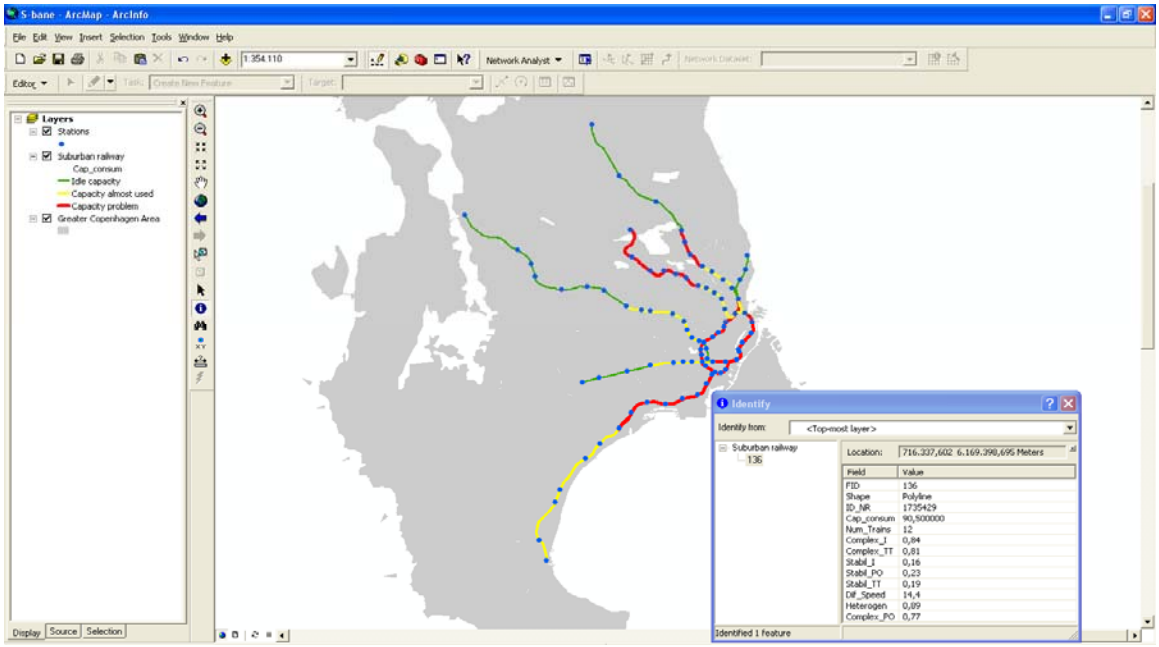

Figure 8: Visualization of railroad capacity on the suburban railroad system of Copenhagen and a list of parameters describing how the capacity is utilized[1].

By describing the railroad capacity analytically in GIS more information is generated than merely the capacity consumption. It is possible to describe why a certain line section has high capacity consumption, e.g., due to high heterogeneity or many trains. In this way the analyst/planner can communicate the reason for the high capacity consumption and how it is possible, for example, to operate more trains.

By collecting a large statistical sample of the capacity consumption and how it is utilized, and combining it with the punctuality, it might be possible to predict resulting punctuality of a future timetable. The resulting punctuality of the trains might even be the basis of calculating the delays of the passengers (Nielsen, Landex & Frederiksen 2008) and in this way be an input for planning better timetables.

5 Delays

Rail authorities, operators and infrastructure managers monitor delays on railroads. This monitoring is in Europe often used for contract based rail operation to ensure a satisfactory quality of the operation – and in many cases it results in fines/bonuses for the operation quality. However, the monitoring of delays is also an economical concern since it is possible to attract more passengers/freight with better punctuality and at the same time make the best possible use of rolling stock and crew. As a result, the better punctuality can result in higher profits.

[1] For information about the parameters describing how the capacity is utilized see (Landex 2008).

Traditionally, punctuality of the railroad system has been measured as delays of trains or the number of trains arriving within a certain threshold of time. These measurements do not take the passengers/customers experiences of the punctuality into account. To overcome this problem the suburban railroads of Copenhagen has implemented a tool to calculate the passenger punctuality based on the train delays[2]. This passenger delay model has been implemented as a geoprocessing tool in ArcGIS. This integration of the passenger delay model with ArcGIS results in easy evaluation and presentation of the punctuality for both trains and passengers, figure 9.

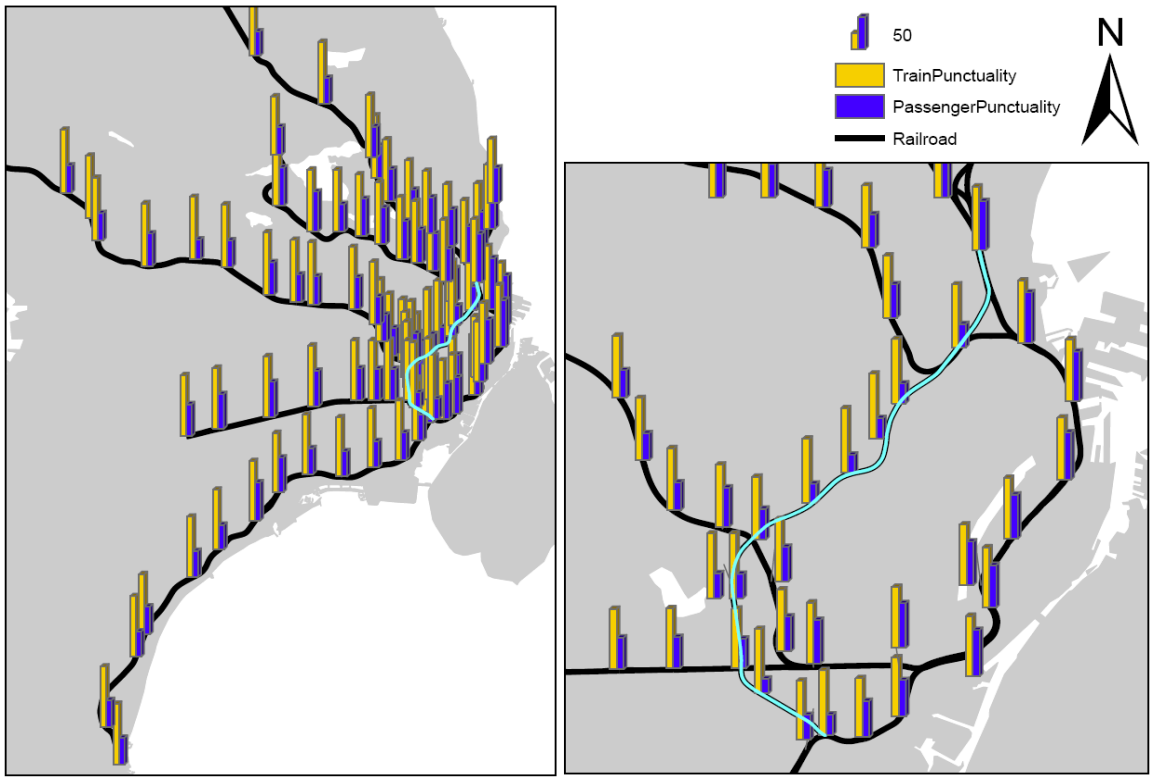

Figure 9: Punctuality for trains and passengers visualized in GIS (punctuality measured as percentage of trains/passengers arriving within 5 minutes of the scheduled time).

Delay analyzes as the one in figure 9 can be used to evaluate the delays and identify areas where more effort should be put into e.g. maintenance, planning or operation. In general, the passenger punctuality of the suburban rail network in Copenhagen is lower than the train punctuality but the closer to the city centre (with higher frequency) the higher passenger punctuality. However, the stations on the ring line around Copenhagen (marked on figure 9) has much worse passenger punctuality (compared to train punctuality) than the surrounding stations. The train punctuality on the ring line is high, so the explanation of the low passenger punctuality is most likely lost transfers to/from other lines why effort should be concentrated here.

[2] The passenger delays are calculated based on a 3rd generation passenger delay model—see (Nielsen, Landex & Frederiksen 2008) for a classification of passenger delay models together with their advantages and disadvantages.

6 Perspectives

At present capacity analyzes on railroads are conducted in separate programmes such as timetable and/or micro simulation systems for railroads (e.g. TPS (Kaas, Goossmann 2004)[3], RailSys (Siefer, Radtke 2005), SIMU (Höllmüller, Klahn 2005), and OpenTrack (Nash, Huerlimann 2004)). Some of the programs have simple functions that can visualize some of the capacity results but for more advanced visualizations and analyzes a GIS is needed.

Most timetable and micro simulation systems for railroads have the ability to export (result) data. These data can then be imported in GIS and linked to geographic data so the results can be visualized. However, today many timetable and micro simulation systems need continuous input from the user with no—or limited—possibility for predefined batch jobs. This complicates the combined use of traditional railroad software and GIS. For a better combination of railroad software and GIS the railroad software should be improved with better batch job functionalities and/or better data structures.

When GIS becomes more widely used in the railroad sector and more data is shared between the countries in Europe (e.g. via Rail Net Europe – a "common" European rail infrastructure manager), it will become easier to get data for analyzing the railroad infrastructure. This is beneficial for potential new operators but can also be used to improve intelligent transport solutions on the railroad. One way of sharing the data could be via internet based GIS applications like ArcIMS.

7 Summary

The paper has briefly described railroad capacity and shown examples on how GIS can be used to visualize the capacity consumption. Furthermore, it has been illustrated how GIS can be used to examine the utilization of capacity and how Network analyst can be used to search the cheapest route in terms of time, length and capacity taking barriers and restrictions into account.

Models analyzing train delays are common and often the results are visualized in GIS while passenger delays are rarely described. The paper shows an example of an analysis of passenger delays carried out using a 3rd generation passenger model implemented in ArcGIS' geoprocessing framework. The result of the passenger delay analysis is illustrated together with the matching train delays.

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