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Visualisation of Train Punctuality – Illustrations and Cases

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Abstract

The purpose of this paper is to show relevant dimensions for presenting railway punctuality data. We discuss alternatives for visualisation and analysis, and show principles and practical examples. The study has benefitted from access to a complete database of Norwegian punctuality data including all data that have been automatically stored since the system was introduced in 2005. The applied data include information about train number, scheduled departure and arrival to each of the stations, as well as actual departure and arrival times. In addition, we have had access to infrastructure data from the Norwegian railway authority. Based on the available data, we developed a set of visualisations and analysis options. The tools were first implemented as a prototype, and then transferred to the Norwegian Railway Authority. This paper describes the principles applied in the tools, as gives a wide range of illustrations of actual implementation of the analyses. Three key dimensions in punctuality analysis are related to the line, time and selected trains. We use several tools that combine the time and line perspectives, including heat maps and correlations analysis between punctuality on different locations or points in time. Both experience-based knowledge and literature indicate a need for a practical method designed for use by practitioners in the railway sector. The main outcome of this research is the creation of an analysis tool case to meet these needs. The visualisations support informed and efficient identification of punctuality improvement measures.

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1. Introduction

The visualization of data is at the core of working with punctuality. Using data to uncover and understand wanted and unwanted traffic phenomena. Aiding in the process of analytical tasks (Tufte, 1986), visualization of otherwise quantitative sizes can aid in human cognition; comparison and assigning causality. Often making (statistically valid) relationships accessible to workers not necessarily skilled in descriptive statistics or the interpretation of statistical analysis. The advances in exploratory data analysis (Tukey, 1962) and computing power over the latter part of the 20th century helped pave the way for wide-spread use of visualization as a method for *discovery*, *understanding* and *communication*. Much of the reigning paradigm of modern quantitative graphics is summed up by Wilkinson (2005), and has been an inspiration for this work.

Visualization as a tool for exploratory data analysis can aid detection, isolation and ***discovery*** of interesting phenomena (or incomprehensible phenomena – often in terms of extreme values, percentiles and the likes) in larger amounts less interesting data. One visualizes to ***understand*** the context of a phenomena or - to see the lead up and the cause or the consequence of a phenomenon has on other parts of the rail system. This contrasts with *confirmatory data analysis* (i.e. traditional statistical hypothesis testing), the visual inspection of data can aid in identifying hypothesis' and ultimately guide in the study design and statistical modeling. Ultimately then visualizes one to ***communicate*** phenomena to others. They say that a picture is worth a thousand words, and likewise a cleverly designed visualization support the understanding of several statistical relationship considerably simpler than presentation of R^2 or measures of significance conveys. Visualization is also a good tool for communicating complex statistical relationship without the need to expose all the statistical hinterland.

Punctuality is related to trains running according to schedule (Palmqvist et al., 2017). Harris et al. (2016) discusses punctuality as a numerical measurement is usually the part of trains arriving on time to the stations. Railway organizations and staff working with punctuality issues in the organizations are the intended users of the proposed system. The developed system can be used to make decisions based on both empirical data and experience-based knowledge. The system can be used for large improvement projects with elaborate analyses, but can also be used to continuously improve the train service.

In relation to railways, Samuel (1961) highlights the need for statistics in railway management, as well as a thorough understanding of how to interpret and use the statistics. According to Bärlund (2000), benchmarking in transportation should visualize an organizations ability to achieve and support defined policy objectives. Data availability has been a common challenge in transport benchmarking (Deiss, 2000), and benchmarking parameters may not be directly comparable due to national, or regional differences in for example organizational culture and geography. Access to data has previously been a challenge in rail traffic analyses and punctuality work (Veiseth et al., 2011). However, railway traffic data is now relatively easily available (Olsson and Bull-Berg, 2015), creating a need for tools and methods for analysis and visualization.

The analysis methods we shall present now, representing different intentions in terms of what kind of insights they provide - this can also help to describe their scope. An analysis which gives good summary of current events, will not necessarily be particularly sensible if used to predict the future - unless one is sure that the future will turn out similar to a past event one has data about. The remainder of this paper is structured as follows; description of data sources and the technical setup used. This is followed by a set of illustrative cases where we describe a visualization tool along with exemplary cases where the tool has been used.

2. Material and Methods

The use of an amalgamation of open source software to construct similar exploration tools has been seen both in other transport forms, such as (Wang et al., 2016), as well as receiving significant research and industrial attention.

Unrelated to Wang et al, we have implemented a (technically) similar system for a different mode of transport. Our primary data source been punctuality data (passing of entry- and exit-signals at second-resolution) for each train every day, along with train information. The data is recorded in a central database. These records include scheduled and actual arrival and departure times for each train at every station, train number and operating company, and class information (e.g. freight, passenger service, running empty/positioning). The data describes the movements of the trains through the network, and are the basis of the visualisations in this paper.

The database contains just over 106 million records of train movements on block level movements from late 2006 up to now. This is collected via a EDI interface to the railway administration, and stored in a PostgreSQL database. In turn available for research and development using software such as the statistics software R and Shiny (Chang et al., 2016) as our web application framework. The development work was performed in a user-driven research project on Punctuality and socio-economic costs of traffic variations ("PRESIS"). The development was iterative with close collaboration with the punctuality and operations-environments of the railway administration and key Train Operating Companies (TOCs). We first developed the tools as prototypes for testing and feedback. They were then transferred to the Railway Authority (now BaneNOR) to be implemented in their IT environment.

3. Overview and examples of tools

We have developed and tested a set of tools. Table 1 show an overview of the applied tools. Some of them are relatively well known from disciplines such as six-sigma (Pepper and Spedding, 2010) and Total Quality Management (TQM) (Ryan, 1989), just used in a railway context. In table 1, this applies for example to trend diagrams. However, even for such well known visualization and analysis tools, there are a range of alternatives to how they are applied to study punctuality, and what are the strengths and benefits of different applications.

Table 1 also illustrates the type of questions that the different tools address, such as where and when delays occur. A key feature was the possibility to zoom between the larger picture down to stations and signaling block level.

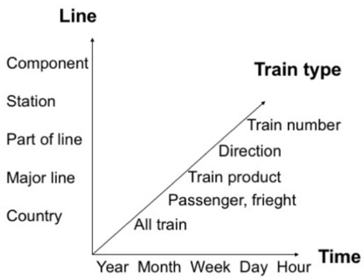
Table 1. Examples of Tools Ordered into Perspectives Covered.

Example Perspectives	Tool
The larger picture	Trend diagrams punctuality (on products)
	Trend diagram cumulative delays (on products)
Where are delays incurred?	Map visualizations
	Run charts
	Spatial Heatmap
	Correlation plots
When are trains delayed?	Temporal Heatmaps
	Cumulative Space-Time Diagrams
Systematic areas for improvement	What-if curves for punctuality margins
	Correlation and covariance plots for punctuality over distance
Which changes constitute a trend break?	Variation plots

In the following, we present relevant dimensions for presenting railway punctuality data, along with alternatives for visualisation and analysis and show principles and practical examples.

3.1. Relevant dimensions

Three key dimensions in punctuality analysis are related to the line, time and selected trains, as shown in figure 1a. These three dimension can then be applied to show different aspects of punctuality, such as punctuality in percentage, delays in minutes, running time and variation in running time (in seconds), as shown in figure 1b.



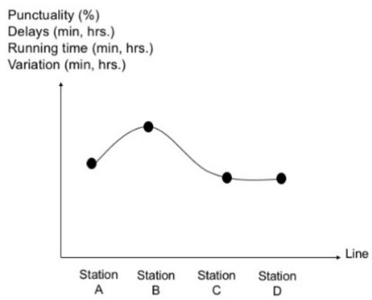
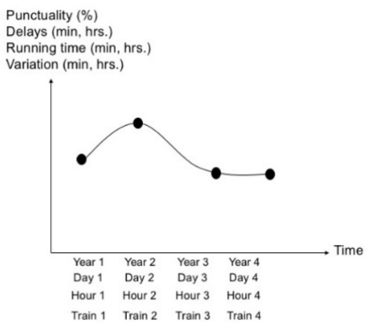


Fig. 1. (a) The three dimensions Line, Train Type, and Time; (b) Typical working visualization in two dimensions.

Common visualization formats for punctuality have been graphs showing punctuality development over time, such as within a year, or for a series of years, as shown in fig 2a. We developed several different graphs based on presenting time series. The y-axis can show punctuality in percentages or aggregated delay hours. Influenced by statistical process control, we used running time between selected points of measurement (typically stations). The highest resolution was for train numbers. Figure 2b shows a graph with departure and arrival punctuality, where the threshold for tagging a train as "delayed" can be adjusted, allowing for three different thresholds to be shown in one graph.



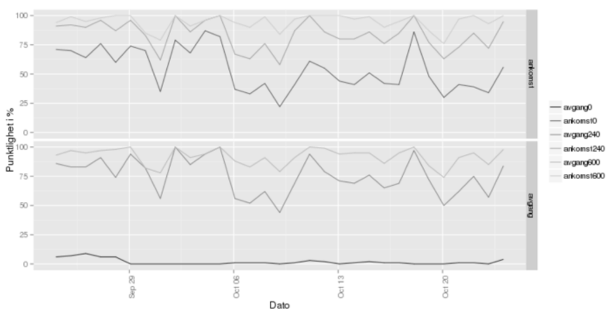


Fig. 2. (a) Conceptual Punctuality-Time; (b) Punctuality in practice, each line constitutes punctual within 600, 240, 0 seconds compared to plan.

We use several tools that combine the time and line perspectives, including heat maps and correlations analysis between punctuality on different locations or points in time. These tools are less generic than established tools from process analysis, TQM and six-sigma. We therefore give a brief presentation.

3.2. Heat maps – combining several dimensions

Heatmaps are a tiled two-dimensional graphic (x-y) with colored tiles that represents a third variable (often by binning, to force it into a discernable scale). It is simple to distinguish between several different patterns of correlated data in heatmaps (cf. Wilkinson's canonical patterns). Based on a need to examine several along several dimensions at simultaneously to navigate between patterns that are best described by variations over time (e.g. seasonal effects), geography (e.g. passenger loads, infrastructure related) or within time (e.g. rush hour effects, which occur twice daily). Most analyses have to deal with a combination of all three; it is difficult to isolate infrastructure effects from rush hour effects both of which would occur simultaneously. However, to detect patterns it would be necessary to look at both aspects simultaneously.

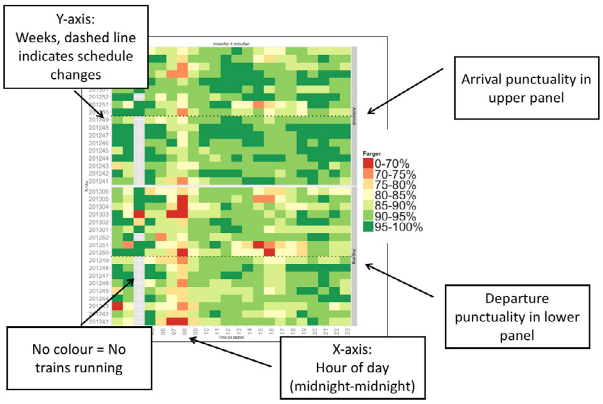


Fig. 3. Heat map explained.

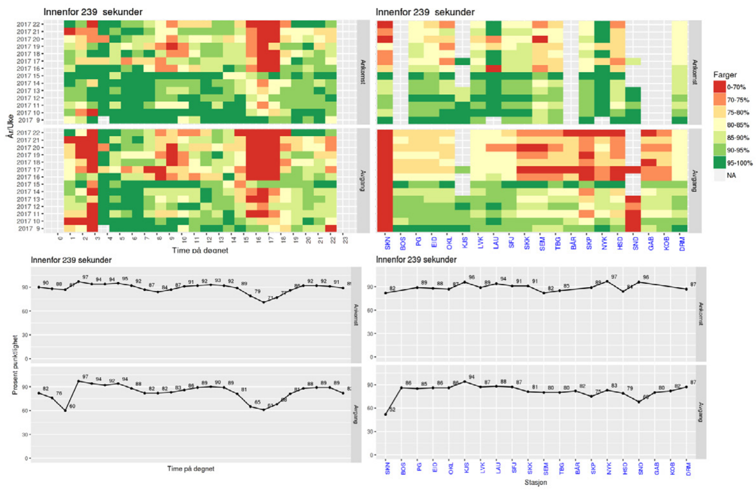


Fig. 4. (a)Spatio-temporal heatmap (y- weeks, x- stations); (b) Temporal-temporal heatmap (weeks vs time of day); (c) Spatio-temporal data shown as line graph (linked with vis. a-b, punctuality in % on y-axis)

We can see in the plots, breakdowns in punctuality along geography (POS-CKL) that are isolated by time (the latter weeks, the top of the graph), in Fig 4 (a). Similarly we can see seasonal effects in Fig 4 (b) with the punctuality improving in weeks 7-17; i.e. improvement in spring and then major disruptions over summer which coincides with periods of major infrastructure work. The variation throughout the day being visible as two distinct patches of red, one for morning rush and one for afternoon rush. The selection of head codes are important when performing such an analysis as head code, geography and time of day are explicitly linked through the running time table. Fig X (c) shows the simple, but linked to the same data set, line graph of punctuality for the same selection – quite strikingly indicating the reduction in expressiveness with regards to variation over the various axes in (a) and (b).

3.3. Arrival and departure

In several punctuality analyses we have had use for graphs that illustrate the relation between arrival and departure for a selected group of trains, such as a train number or all trains on a line. Such graphs are shown in figure 5 a and b. Figure 5a include an explanation of the four quadrants of such a diagram, including two situations in the late-late quadrant (typically the most populated one, unfortunately).

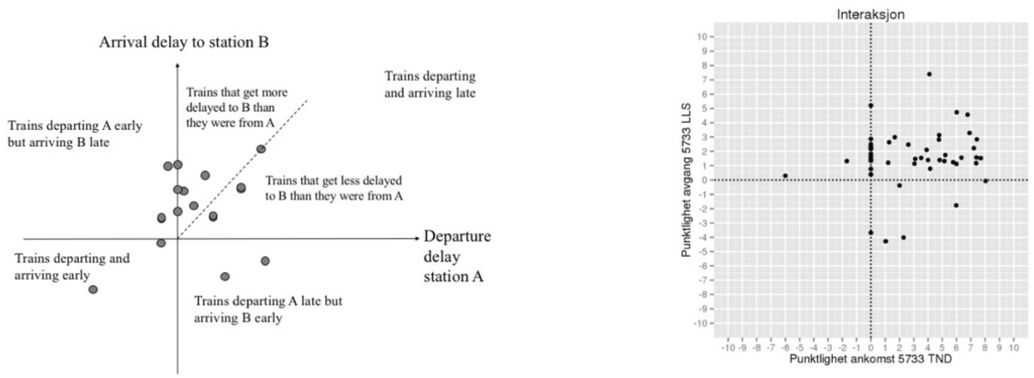


Fig. 5. (a) Conceptual x-y arrival departure delay; (b) Actual implementation showing interaction between two different stations – same train (configurable).

3.4. Train sequence

We found train sequence to be an issue that may not have received full attention in punctuality analyses. Trains not running in the planned sequence are not desired. We found it useful to design a tool that compares planned and actual train sequence, highlighting trains that run out of the planned sequence. This was of particular interest in central Oslo area. Official punctuality statistics and delay cause registrations focus on delays of 4 minutes or more. With train headways of 2 to 3 minutes, there can be irregularities that are not registered as delays, but still mean that the time table is not executed as planned. Train numbers that frequently run out of the planned sequence can be prioritized for punctuality improvement actions even if their official punctuality statics may not look particularly bad, because they cause troubles for the system as a whole.

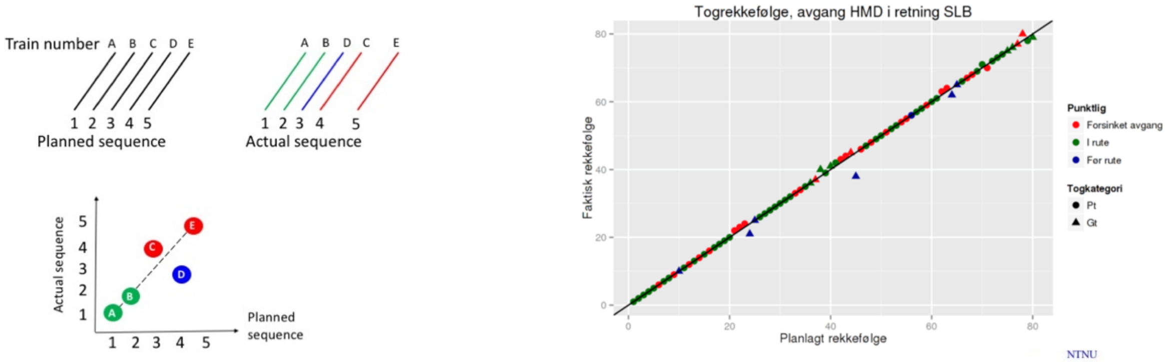


Fig. 6. (a) conceptual sketch; (b) actual data. Triangles are freight. Red running behind on time, blue ahead. Above the line indicates after original sequence, below ahead.

4. Concluding discussion

What we observe is that there are common lines of questioning and reasoning that can be supported through the same visualization. As an example; Time-distance graph has for long been the core visualization for train dispatching and corresponding traffic analysis; requiring quite a bit of training for a reader to become proficient and master the art of discovering, isolating, and understanding traffic problems in the graph. Similarly, we have used with success, the heat-map visualization of *punctuality* (with the ability to switch between spatio-temporal and temporal-temporal visualization) with great success in the analysis and monitoring of major timetable changes – allowing the user to quickly discover and isolate phenomena to either the spatial- or temporal domain. Thus, guiding any follow-up work and allowing for analysis over larger amounts of data than time-distance graphs easily can. The ability of modern graphical statistical software to provide *linked displays*, where interaction and selection/filtering may update several visualizations at once also provides additional drilling functionality that aids in both understanding and isolation; for instance, providing line-graphs of the same data as the heatmaps of punctuality in absolute terms (rather than by class).

User-involvement and a middling through approach to visualization design, has been key to the exploration of railway traffic visualization principles. What we have experienced is that scientific exploration of graphical representations of traffic phenomena has allowed us to converge on a set of tools that can describe and aid visual analytics for a range of underlying traffic phenomena. Having a set of related tools, obviously drawing upon the same data source with recognizable features between the user interfaces has the added benefit of stimulating users in exploring data and generating hypothesis and in the more advanced cases exhibiting *generative behavior* in generating new requirements and further development of new visualization and lines of analysis.

This is very much work in progress, and the availability of new data sources coming online with additional sensors that provide better granularity in both temporal and spatial domains – combined with higher quality geo-referencing of existing objects allows for further work towards a *grammar of train traffic analytics.* This is conducted in collaboration with research on punctuality improvement projects, and more recently infrastructure maintenance projects – with the user needs in practical projects defining the requirements for the visualization development.

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