Business Analytics of Railway Robustness

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Abstract

Purpose

The purpose of this paper is to describe an application of business analytics to support continuous improvement of railway infrastructure robustness.

Design/methodology/approach

The overall research strategy is a single case study of Trafikverket (Swedish transport administration). Quantitative data was collected, analysed and presented by using the organisation's tool for business intelligence within maintenance. The work was corroborated by interviews, document studies and observations.

Findings

The applied methodology and developed tools for presentation are valuable to systematise and improve the robustness of existing railway infrastructure and its maintenance.

Research limitation and implications

The single case study approach may decrease the validity of the achieved results. However, the foundation of a theoretical framework and best practice related to dependability and risk, with the usage of a commercial tool for business intelligence affect the validity positively.

Practical implications

By using a well-established tool for business analytics when working with robustness, it is possible to achieve transparency, traceability and reproducibility since different stakeholders can use the same data in a similar way.

Social implications

An enhanced railway infrastructure robustness contributes to improved safety, punctuality and costs. Hence, railway becomes a more attractive mode of transport. Thereby, it also supports a safety performance of the railway that society is willing to pay.

Originality/value

The approach is implemented in developed reports within a commercial tool for business intelligence and is founded on best practice within dependability and risk management.

Category of paper

Case study

Keywords: Business analytics, Railway infrastructure, Robustness, Delay, Sweden

Introduction

The European railway sector has undergone major changes during the last decades that have affected operation and maintenance of both railway infrastructure and trains (Alexandersson, 2009; Alexandersson and Rigas, 2013). Simultaneously, there is an increasing demand to use the railway for transports of both passengers and freight (Alexandersson and Rigas, 2013; eurostat, 2016). Unfortunately, slimmed timetables and limited capacity of railway infrastructure lead to decreased robustness of railway traffic, where disturbances escalate and spread throughout the network. Since punctuality, safety and price are what customers evaluate when choosing the mode of transport (EU, 2014; ERA, 2015; BCG, 2015), disturbances reduce the railway attractiveness. The disturbance sensitivity and budget restraints challenge the infrastructure managers. One prerequisite to manage this challenge is to improve the railway's robustness and thereby cope with disturbances by continued operation and short disruption times. The robustness can be improved by timetabling and scheduling of traffic (Bendfeldt et al., 2000; Salido, 2008; Fischetti et al., 2009; Dewilde, 2011). The robustness can also be improved by considering the railway infrastructure and its maintenance. It is, for instance, necessary to manage the reliability availability, maintainability and safety (RAMS) performance in a life cycle perspective (Zoeteman, 2001; Budai-Balke, 2009; IEC, 2009; Norrbin et al., 2016). Simultaneously, railway infrastructure managers have to fulfil internal control demands. The railway management needs to ensure effectiveness (achievement of goals, that is to do the right things), and efficient use of the state's resources (to do things in the right way). The management also needs to ensure process compliance (fulfils regulations), and transparency (of both budget-related and other documentation) see for example Söderholm & Karim (2010), Söderholm & Norrbin. (2013), and SFS(2007:515) at Riksdagen (2017). Transparency and traceability are something that business analytics bring and aid the work toward a robust and resilient railway infrastructure (Zhang & Karim, 2014; Thaduri et al., 2015; Karim et al., 2016; Söderholm & Bergquist, 2016)T. Business analytics, for instance, simplifies automated and standardised reports from multiple databases with diverse data and known quality levels (Candell & Söderholm, 2006; Candell et al., 2009; Karim et al., 2009). Hence, the purpose of this paper is to describe a business analytics application to support continuous improvement of railway infrastructure robustness.

The outline of the remaining part of this paper is as follows. First, there is a description of the applied method and material. Then, there is a short presentation of the achieved results. Finally, a discussion of the study and its results concludes the paper.

Method and material

The criteria given by Yin (2003) suggested that a single case study would be a proper research strategy to fulfil the purpose. We, therefore, used a single case study, performed at Trafikverket (Swedish transport administration) as our case.

Trafikverket's computerised tool for business intelligence within maintenance, that is SAP BusinessObjects Quantitative, provided the data and the analysis tools. Classical risk management and contingency management constitute the logic of the analysis model. To reflect best-practice, the foundation for each area is international standards, that is ISO 31000 (risk management), ISO 22313 and ISO/PAS 22399 (continuity management).

The risk analysis model is based on the bow tie logic with barriers. A bow-tie method can be used to analyse causal relationships in risk scenarios and is named by the shape of the method's diagram. A certain hazard (for example flooding) is analysed, and to the left of the hazard, all possible causes for this hazard (for example extreme weather) are plotted. The left side of the hazard displays all possible consequences of the hazard (for example cancelled and delayed trains), (Trbojevic and Carr, 2000; ISO 31010). The barriers may aim at reducing the occurrence of unwanted events by addressing their causes (for example installing and maintaining dewatering assets). The barriers may also aim at mitigating the consequences of unwanted events. This could, for instance, be done by directing trains trough an alternative route, using busses to transport travellers around the affected area, or having extra resources available to repair the damaged infrastructure quickly.

As a complement to risk management, which starts with unwanted events that may affect the aim of operations, continuity management focuses on the capability of the system (organisational and technical aspects) and related critical activities. The purpose is to manage any unwanted events, to achieve the operational aims. Hence, the system should be able to decrease the impact of unwanted events (for example cancelled and delayed trains). The system should deliver safe and punctual train traffic, and reduce the time the capacity is negatively affected (for example through plans for contingency and crisis). Hence, even though risk management and contingency management may result in the same solutions, they have different and complementary focuses.

The extracted events are classified as accidents, incidents or external factors. Omitted events are classified as related to traffic control, infrastructure, railway companies, follow-on causes or not classified at all. The reason for this limitation is that included events are seen as related to unwanted events that are unusual in some sense. These events are thereby related to robustness and managed by an extended operation, incident, accident, contingency or crisis management. In contrast, the omitted events are unwanted, but not so critical that normal or slightly modified operation and dependability management cannot manage them. Another limitation is that the study covers the five years of 2010-2014. The reason for this limitation is that Trafikverket changed their reporting system in 2009, and data earlier than 2010 are unreliable. The years of 2015 and 2016 could be added to the study. However, five years was considered to be sufficient for the stated purpose. Another choice is only to include events that cause a minimum of four minutes delay since causes for shorter delays are not registered.

The dimensions used in the analysis are related to time, geography, criticality, the technical system and type of event. The time is given as year and month, the geography through railway line and track section, the criticality through asset class 1-5, where 1 is major city areas and 5 is lines with little or no traffic. The technical system is described through different indenture levels of the railway infrastructure, and type of event on different levels (for example derailment/collision).

The variables used and developed are related to the consequences of the unwanted events (delays, disturbed trains, and train disturbing faults), and the capability of the organisation (recovery time).

Results

Two types of multivariate bubble plots display the analysis results. One focuses on the causes of unwanted events and their consequences. The other plots focus on the capability to manage unwanted events regarding their consequences. The principle of the first type of plot is illustrated in Figure 1. The horizontal axis of the plot shows the number of delay minutes, the vertical axis displays the number of disturbed trains, while the sizes of the bubble show the number of train disturbing events. Additionally, the colour and shape of the bubble indicate the type of event and related infrastructure code respectively. Hence, each bubble plot displays five different dimensions.

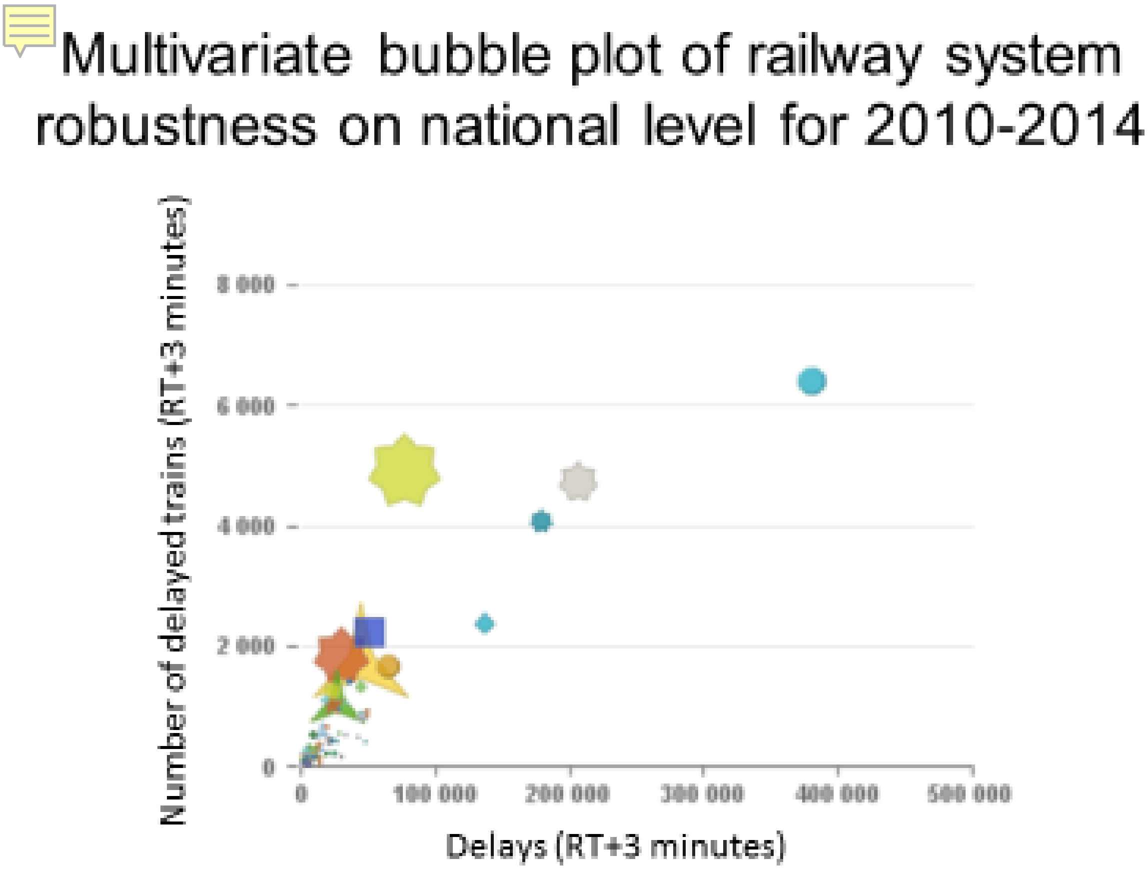

Figure 1. Multivariate bubble plot of railway system robustness nationally for 2010-2014.

Figure 1, shows the most severe consequences nationally in Sweden for the years 2010-2014 is related to derailments or collisions which occurred 225 times (blue bubble in the upper right corner). Derailments or collisions caused 381 481 delay minutes and 6 404 disturbed trains. The green star-shaped bubble in the middle of Figure 1 displays the more common event, unauthorised persons in track that result in fewer traffic disturbances. Unauthorised persons in track happened 628times and caused 77 100 delay minutes and 4 866 disturbed trains. The two other star-shaped bubbles near the green bubble also indicate persons in track. The blue bubble represents events where a train hit a person, and the grey bubble indicates events that have no further explanation.

A compassion of bubble plots for different time periods suggests if there are any changes in the temporal domain. As one example, see Figure 2, which displays bubble plots for the first (2010) and last (2014) year included in the study

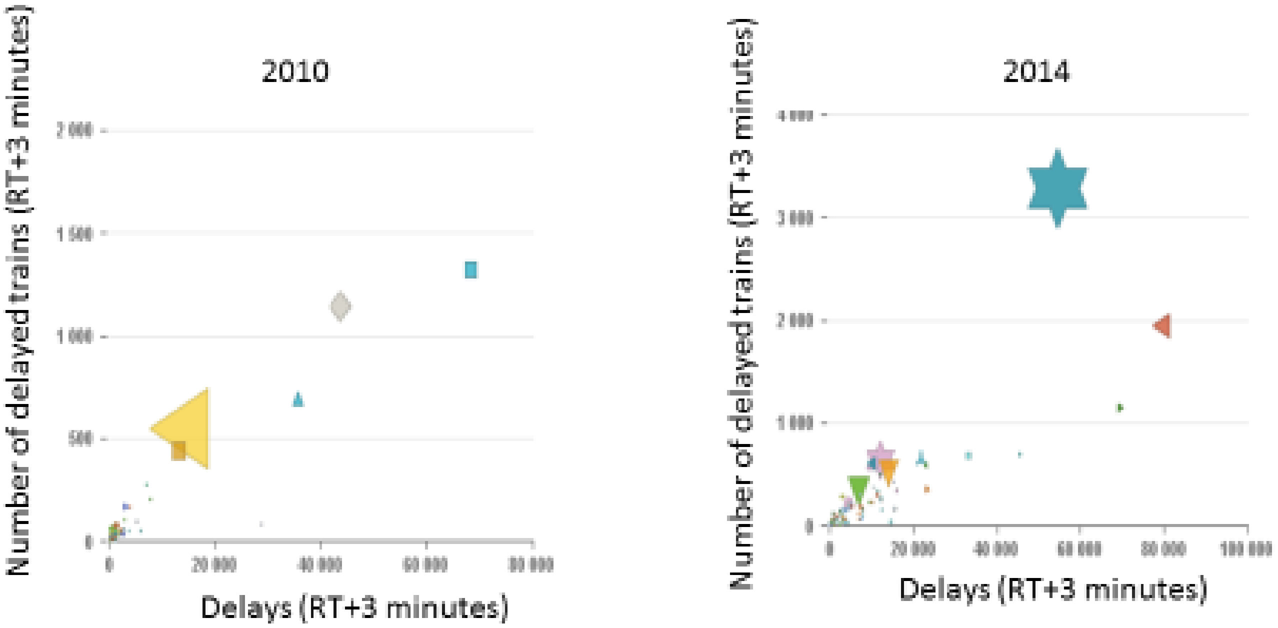

Figure 2. An example of multivariate bubble plots to evaluate railway system robustness in the temporal domain that is one plot nationally for the years 2010 and 2014 respectively.

As Figure 2 shows, there are some differences between 2010 and 2014. For example, the most frequent event in 2010 (left-hand side) is an animal in track (yellow triangle), while for 2014 (right-hand side) the most common unwanted event is a person in track (blue star).

A compassion of bubble plots for different geographical parts of the railway network shows differences in the spatial domain. As one example, see Figure 3 which displays bubble plots for two different track sections.

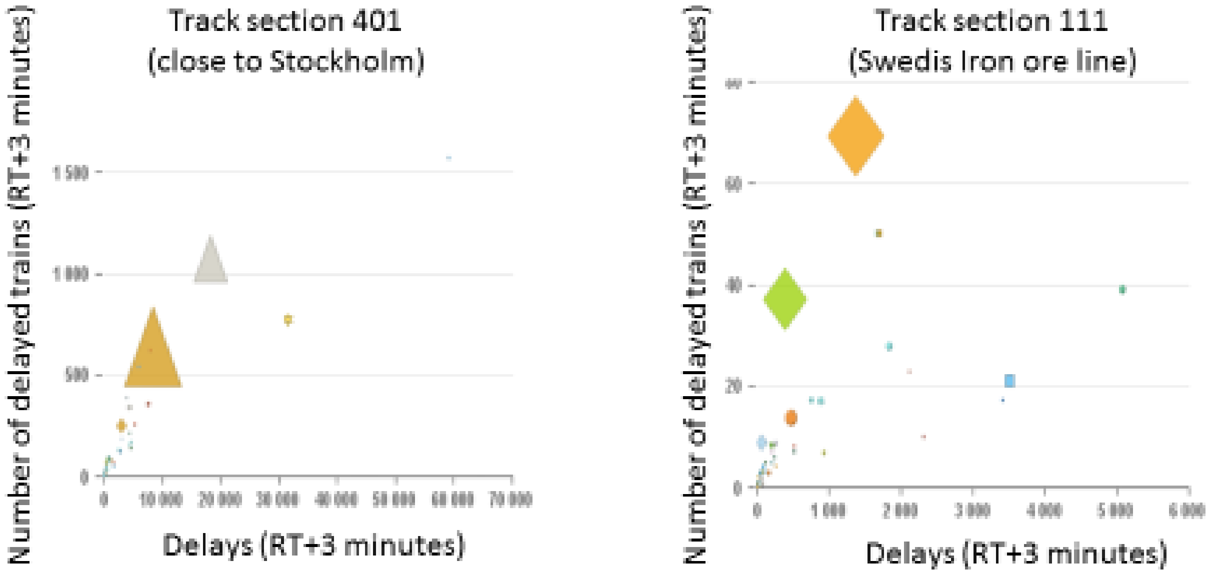

Figure 3. An example of multivariate bubble plots on track section level to evaluate railway system robustness in the spatial domain for 2010-2014. Track section 401 (near Stockholm, Sweden's largest city) is on the left-hand side. On the right-hand side, track section 111 (part of the Iron ore line in northern Sweden).

Figure 3 demonstrates that traffic consequences are more severe on track section 401 than on track section 111, which is indicated by the scales on the x-axis and the y-axis. Figure 3 also shows that there are different events that cause disturbances on the track sections. For track section 401 the most common unwanted events are persons in track, symbolised by the triangular-shaped bubbles. For track section 111, the most common unwanted events are an animal in track, which is illustrated by the two diamond-shaped bubbles.

The capability of the organisation to manage unwanted events can be judged by a bubble plot that displays the time to correct unwanted events. Figure 4 shows two maintenance contractors that are responsible for different parts of the same railway line. In the capability bubble plot, the axes are the same as in the cause bubble plot, but they have been normalised regarding the number of train disturbing events. The size of the bubbles in this plot illustrates the rectification time for different events and has also been normalised to the number of train disturbing events. The major reason to do this normalisation is to enable the addition of the capability measure into the plot.

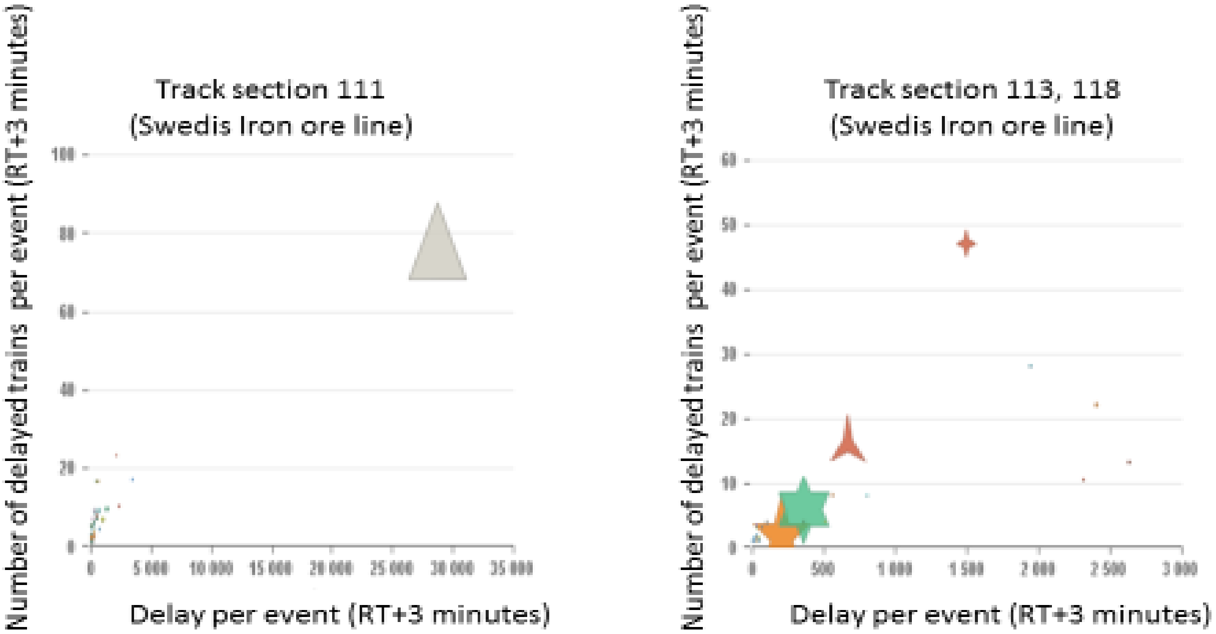

Figure 4. An example of multivariate bubble plots of the southern (left-hand side) and northern (right-hand side) parts of the Swedish Iron ore line managed by two different maintenance contractors. Such a presentation can aid evaluation of the capability to deal with unwanted events.

As Figure 4 shows, there are differences in the events that occur on the different parts of the same railway line. The left-hand side of Figure 4 reveals an unwanted event (grey triangle in the upper right corner) that has a major impact on the traffic, which dwarfs the other events. This event is a fire caused by lightning, which burned down a building with a signal box. Therefore, this event exposed a vulnerability in the infrastructure and lack of capability of the organisation to deal with this event. On the right-hand side of Figure 4, there are four events that result in fairly large delays, even though the number of disturbed trains are not extreme and the rectification time is rather low. These four events are related to the asset types contact wire, switches and crossings, and track. On the right-hand side, there are also two events that have large corrective times, even though the number of delays and disturbed trains is relatively small. Hence, the capability of the organisation to deal with these events seems to be well-adapted from a traffic perspective.

Discussion

By the relative position and size of different bubbles in the plot, it is possible to rank which events to address to improve the robustness of the railway system (see Figure 1). The ranking is possible since the bubble plot helps in classifying events into the vital few and trivial many (the Pareto principle). The vital few events are located in the upper right corner of the plot. This position means that events have consequences that can be measured through a high number of disturbed trains (y-axis), and many delay minutes (x-axis). The trivial events, on the other hand, are located in the lower left corner of the plot since they have opposite characteristics compared to the vital few events.

Further, the position and size of the bubble also suggest the nature of the event and therefore correct measures to improve the robustness of the railway system (see Figure 1). The positions and sizes are important since the bubble plot can be analysed similarly as a risk matrix. Note that risk management deals with combining the frequency or probability of potential events and their consequences, while this study deals with events that have happened. However, the future can be dealt with by learning from history. Historical analyses are also is an approach within risk management as a complement to for example expert judgements and simulations. The bubble size indicates the relative frequency of the unwanted event, while both the x-axis and the y-axis indicate similar, but complementary, consequences of these events. A large bubble in the upper right corner indicates relatively common events with major consequences, which is comparative with major unacceptable risks. Therefore actions should be taken to reduce both the causes and the consequences of these unwanted events. The causes can be managed through preventive maintenance and security measures, while the consequences can be managed through reactive measures such as corrective maintenance, but also incident, accident, contingency and crisis measures. There are also unwanted events that occur relatively seldom and that have small consequences, which is illustrated by the cloud of bubbles in the lower left corner. These events can be compared with acceptable risks, or the trivial many, where no actions is necessary. In addition to these two classes of risks that can be managed intuitively, there are also extreme risks that may be a little bit more cumbersome to manage.

Examples of events that can be related to extreme risks are those that corresponds to large sized bubbles close to the lower left corner, which indicate frequent occurring events that have relatively minor consequences. If these events are judged to be unacceptable, they should be managed through focusing on reducing their frequency, for example by preventive maintenance or security measures. One example of the latter are occurrences of animals in track, which is a common event (large bubble size), but result in a low number of delay minutes (x-axis) and disturbed trains (y-axis). The other class of events that can be compared to extreme risks are those that have a combination of a small frequency and major consequences. One example of this latter type of events is derailment due to track deficiencies. Since the consequences for traffic disturbances are major, it might be appropriate to further reduce their occurrence instead of focusing on reducing their consequences for traffic disturbances. One further reason for this approach is that derailments also have safety consequences (only considered indirectly in this study by classifying events as safety critical or not), which is unacceptable. Examples of appropriate measures are preventive maintenance by using different kinds of measuring waggons that will check rail defect occurrences through non-destructive testing. Another is measuring the width and buckling of the track by lasers and dynamic measurements. However, if the useful life of the track or rail is surpassed, it may be necessary to perform a track or rail renewal. Regarding persons or animals in track, fences can be installed to stop or reduce access to the track. Persons in track occurrences can be reduced through information campaigns about that it is illegal to climb onto the track. This may also reduce associated safety hazards.

It is also possible to analyse the robustness in the temporal domain. For example, by comparing the bubble plot of different years, it is possible to discover changes over time (see Figure 2), for example, due to improvement measures or changing external circumstances. In the studied case the unwanted events with largest consequences measured in disturbed trains (y-axis) and delay minutes (x-axis) are accidents manifested by derailments related to track and incidents due to unauthorised persons that are present in track. These two events take turns in causing most severe consequences for different years. Unauthorised persons in track tend to be more frequent (larger size of bubble) and seems to be increasing much the last year (2014) included in the study.

It is also possible to analyse the robustness in the spatial domain depending on interest, for example nationally, for different railway lines, or track sections (see Figure 3). Filtering on different track sections will, for instance, allow analyses of where to put fences to prevent persons are likely to enter the track (probably in populated areas). Another filter will show animals on track (probably in less populated areas, for example, a more detailed filtering of track section 111 in Figure 3). As another example, the spatial filtering may also reveal track sections where the condition of track requires tamping or renewal of track or rail.

As indicated above, the number of disturbed trains and delay minutes contains similar information which the positive correlation between these variables suggest. A straight line with positive slope can be fitted to the pattern the bubbles create. The slope of the fitted line, therefore, also contains information that is useful when comparing different bubble plots with each other, either in the temporal or in the spatial domains. A steep slope suggests a relatively high number of disturbed trains per delay minute, while a flat slope indicates a low number. How to evaluate the slope depends on the applied strategy to manage disturbances, for example, should the consequential delays of unwanted events be distributed on many or few trains? One example is occurrences of unwanted defects on rail that have surpassed its useful life, which can be managed by speed restrictions or renewal of track or rail. The speed restriction will result in a relatively small number of delay minutes per disturbed trains (until the rail or track is renewed), while the rail renewal will result in more delays than the speed restriction, but probably also affect a smaller number of trains (depending on time span). Finally, the track renewal will probably result in the highest amount of delays, and also affect more trains than the rail renewal. However, most often these alternatives are used in combination. First, there is a speed restriction, and then the renewal of rail or track is performed depending on available resources (for example regarding time in track and budget).

The capability plot can be used to compare different maintenance contractors or contract solutions from a robustness perspective. It may also be possible to deploy the total rectification time into its constitutive parts, to evaluate different time measures, for example, the time to be in place, the fault localisation time, and the fault correction time. As with the cause-related bubble plot, it is possible to plot the capability plot in the temporal and spatial domains to identify changes over time or geographical differences regarding infrastructure respectively.

By using a well-established computerised tool for business intelligence, it is possible to atomise the creation and distribution of reports, for example in connection with the cyclical planning and follow-up of operations. Another benefit is that it will support transparency, traceability and reproducibility since different stakeholders can use the same data in a similar way. Hence, this will be in line with the thought of standardisation of the information content and facilitate communication and benchmark in both the temporal and spatial domains.

Acknowledgement

We would like to thank Trafikverket for supporting this work both intellectually and financially.

References

Alexandersson, G. (2009), Privatisation and competitive tendering in Europe, *Built Environment*, 35(1), 43–58.

Alexandersson, G. and Rigas, K. (2013), Rail liberalisation in Sweden: Policy development in a European context, *Research in Transportation Business & Management*, 6, 88–98.

BCG (2015), “The 2015 European Railway Performance Index: Exploring the Link between Performance and Public Cost”, available at: https://www.bcgperspectives.com/content/articles/transportation_travel_tourism_public_sector_european_railway_performance_index/ (accessed 11 September 2016).

Bendfeldt, J. P., Mohr, U., & Muller, L. (2000). RailSys, a system to plan future railway needs. *WIT Transactions on the Built Environment*, 50.

Budai-Balke, G. (2009). *Operations research models for scheduling railway infrastructure maintenance* (No. 456). Rozenberg Publishers.

Candell, O. & Söderholm, P. (2006). A customer and product support perspective of e-Maintenance. *In International Congress on Condition Monitoring and Diagnostic Engineering Management*: 12-15 June 2006, Luleå, Sweden (pp. 243-252). Luleå University of technology.

Candell, O., Karim, R., & Söderholm, P. (2009). eMaintenance — Information logistics for maintenance support. *Robotics and Computer-Integrated Manufacturing*, 25(6), 937-944.

Dewilde, T., Sels, P., Cattrysse, D., & Vansteenwegen, P. (2011). Defining robustness of a railway timetable. *In 25th Annual Conference of the Belgian Operations Research Society* (pp. 108-109).

ERA (2015), *ERA-GUI-02-2015 - Implementation Guidance on CSIs*.

EU (2014), *Directive 2014/88/EU of the European Parliament and of the Council as regards common safety indicators and common methods of calculating accident costs*.

eurostat (2016), ”Railway passenger transport statistics: quarterly and annual data”, available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Railway_passenger_transport_statistics_-_quarterly_and_annual_data (accessed 11 September 2016).

Fischetti, M., Salvagnin, D., & Zanette, A. (2009). Fast approaches to improve the robustness of a railway timetable. *Transportation Science*, 43(3), 321-335.

IEC 31010:2009 *Risk management – Risk assessment techniques*.

ISO 31000:2009 *Risk management – Principles and guidelines*.

ISO 22313:2012 *Societal security - Business continuity management systems – Guidance*.

ISO/PAS 22399:2007 *Guideline for incident preparedness and operational continuity management*.

Kans, M., & Galar, D. (2017). The Impact of Maintenance 4.0 and Big Data Analytics within Strategic Asset Management. *In 6th International Conference on Maintenance Performance Measurement and Management*, 28 November 2016, Luleå, Sweden (pp. 96-103). Luleå University of Technology.

Karim, R., Candell, O., & Söderholm, P. (2009). E-maintenance and information logistics: aspects of content format. *Journal of Quality in Maintenance Engineering*, 15(3), 308-324.

Karim, R., Westerberg, J., Galar, D., & Kumar, U. (2016). Maintenance Analytics–The New Know in Maintenance. *IFAC-PapersOnLine*, 49(28), 214-219.

Norrbin, P., Lin, J. I. N. G., & Parida, A. (2016). Infrastructure robustness for railway systems. *International Journal of Performability Engineering*, 12(3), 249-264.

Riksdagen (The Swedish Parliament) (2017). Svensk författningssamling, available at: http://www.riksdagen.se/webbnav/index.aspx?nid=3910

Salido, M. A., Barber, F., & Ingolotti, L. (2008). Robustness in railway transportation scheduling. *In Intelligent Control and Automation*, 2008. WCICA 2008. 7th World Congress (pp. 2880-2885). IEEE.

Söderholm, P., & Bergquist, B. (2016). Rail Breaks—An Explorative Case Study. *In Current Trends in Reliability, Availability, Maintainability and Safety* (pp. 519-541). Springer International Publishing.

Söderholm, P., & Karim, R. (2010). An enterprise risk management framework for evaluation of eMaintenance. *International Journal of System Assurance Engineering and Management*, 1(3), 219.

Söderholm, P., & Norrbin, P. (2013). Risk-based dependability approach to maintenance performance measurement. *Journal of Quality in Maintenance Engineering*, 19(3), 316-329.

Thaduri, A., Galar, D., & Kumar, U. (2015). Railway assets: a potential domain for big data analytics. *Procedia Computer Science*, 53, 457-467.

Trbojevic, V. M., & Carr, B. J. (2000). Risk based methodology for safety improvements in ports. Journal of hazardous materials, 71(1), 467-480.

Zhang, L., & Karim, R. (2014). Big data mining in eMaintenance: An overview. *In International Workshop and Congress on eMaintenance*: 17-18 June 2014, Luleå, Sweden (pp. 159-170). Luleå University of Technology.

Zoeteman, A. (2001). Life cycle cost analysis for managing rail infrastructure. European Journal of Transport and Infrastructure Research, 1(4), 391-413.