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ARTICLE

Improving the understanding of SPAD risks using red aspect approach data

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ABSTRACT
This paper describes a novel technique for estimating the frequency with which trains approach signals showing a red aspect. This knowledge is potentially important for understanding the likelihood of a signal being passed at danger (SPAD) at individual signals and also for normalisation of SPAD data, both locally and nationally, for trending and benchmarking. The industry currently uses estimates for the number of red aspect approaches based on driver surveys, which are considered to have significant shortcomings. Data for this analysis is sourced from publicly available live feeds provided by Network Rail which give information on train movements and signal states. The development of the analysis model is described and a case study presented. The case proves that there are large variations in the red approach rates between individual signals. SPAD risk assessment at individual signals may be significantly enhanced by the ability to estimate red approach rates for individual signals using the techniques described.

KEYWORDS SPAD; risk; red aspect approach

1. Introduction

An event where a train passes a signal showing a stop aspect without authorisation is known as a signal passed at danger (SPAD). SPADs can range from minor incidents where a signal is passed by only a few metres to serious incidents where longer overruns give rise to the chance of collision with other trains. The causes of SPADs can vary widely from driver error to degraded braking performance as a result of low adhesion (RIAC Human Factors Working Group, 2014). Driver error is frequently cited as a primary cause, often described in terms of the failure to take sufficient action at preceding warning signals (misread) or failure to control the train on the approach to the red signal (misjudgement) (Nikandros & Tombs, 2007).

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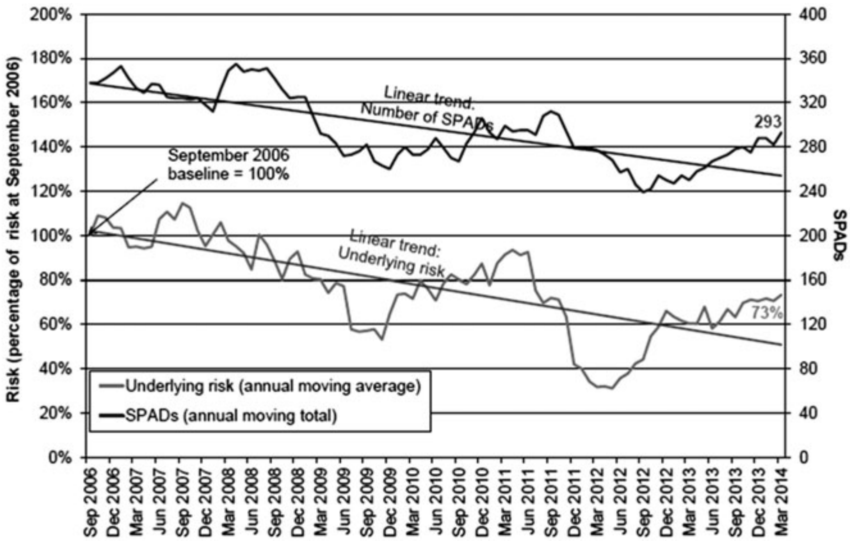

Figure 1. Number of SPADs and SPAD risk – 2006 to 2014 from (RSSB, 2004).

However, it is recognised that there are many underlying technical, organisational and human factors related causes which can contribute to the eventual failure of a driver to stop at a red signal (Pasquini & Rizzo, 2004; RSSB, 2004). An example of this is the accident at Ladbroke Grove, UK, in 1999 in which there were 31 fatalities. The accident report (HSE Books, 2000) identified key failings in the design of the signalling system, signal sighting and driver training.

Following Ladbroke Grove, the GB rail industry made significant efforts to reduce the rate of SPADs and the consequential risks. Since 2001, the overall risk from SPADs has reduced by 90% (Clinton, 2014). Figure 1 shows trends for SPADs and SPAD risk since 2006. Each SPAD is assessed using the industry's SPAD risk ranking tool (Clinton, 2014) and assigned a score of between 0 (very low risk) and 28 (very high risk). An increase of one point corresponds to a doubling of risk. The score reflects the accident potential of each SPAD (for example, how close it came to the potential conflict point) and the potential consequences of the accident if it had occurred (in the case of a collision, this takes into account speed, crashworthiness and passenger loadings). During 2013/14, there were 293 SPADs but only 16 of these were classified with a score of at least 20, placing them in the potentially severe risk category. These SPADs contribute the most to the underlying risk metric, which is sensitive to how many of these occur in a given period. This is why the green line (showing the underlying risk) follows a different profile to the red line (showing the number of SPADs).

This highlights that it is important not only to reduce the number of SPADs that occur, but also their potential severity.

2. The need to quantify red signal approaches

For a SPAD to occur, a train must approach the signal at red in the first place. It follows that knowing the number of trains which approach signals displaying a red aspect (the red approach rate) is fundamental to the understanding of SPAD risk at individual signals and the normalisation of SPAD data, both locally and nationally, for trending and benchmarking. SPAD risk has been studied previously using several techniques including fault tree analysis and Bayesian Belief Networks (for example, by Marsh and Bearfield (Marsh & Bearfield, 2004)). These techniques require prior knowledge of the red approach rate to provide an accurate quantification of the resulting SPAD risk.

Nikandros and Tombs (2007) note that unless SPAD count data are normalised in a meaningful way (i.e. by the red approach rate) they are not useful for benchmarking safety performance. This applies not only to international comparisons but within the same railway administration, for example, when comparing suburban passenger services with long distance freight trains. Similarly, van der Weide, Frieling, and De Bruijn (2009) found their efforts to explain the apparent differences in SPAD rates for freight and passenger trains in the Netherlands frustrated by the lack of data on red approach rates and concluded that considering train kilometres alone does not constitute an adequate measure of exposure to red signals. Industry guidance from the UK and Australia further supports this view (Australian Independent Transport Safety Regulator, 2011; Railway Group, 2003), for example, 'SPADs would, perhaps, be best normalised against the number of red signals approached. Such data cannot be easily obtained and, by its very nature, would be affected by changes in operational circumstances' (Railway Group, 2003). The body of published work on the causes and mitigations of SPADS contains little information on red approach rates, probably due to the difficulty in obtaining reliable data, which this paper addresses. However, Nikandros and Tombs (2007) present a graph showing SPAD probability versus approach rate for the Brisbane Metro area but do not explain how the red approach rate was obtained.

All these studies focus extensively on driver behaviour and the various factors which can cause SPADs but are unable to use red approach rates as a normaliser as such data is generally not available. Where normalisation is used, it is often on the basis of train km rather than the number of red signals approached is a suboptimal normaliser. This paper proposes a method to provide reliable estimation of the red approach rate using operational data on train movements and signal states to address this problem.

3. Methodology

Network Rail (the GB mainline railway infrastructure manager) assesses the SPAD risk associated with every signal on the network using a process which examines the frequency and the potential consequences of passing that signal at danger. The risk assessment considers factors such as distance to a conflict point (such as a junction), train speed and passenger loading. This process does not currently incorporate any estimates for the number of red aspect approaches to a signal within the risk assessment; however it has aspirations to do so if such information was readily available. Other tools within the rail industry have attempted to do this. The Railway Action Reliability Assessment tool (RSSB, 2015) uses estimates for the red aspect approach rate based on driver surveys for various classes of train (suburban, inter-city, freight, etc.). In this way they intend to capture the likely variation in red approach rates for different types of train service. However, this approach also has some drawbacks. In particular, it does not reflect the considerable variability in the red approach rate that might be expected between signals, whilst the extrapolation of relatively small surveys to give national red demand rates may not provide a reliable estimate.

Network Rail provides publicly available live data feeds which give various information on the movement of trains (Network Rail, 2015). At the most fundamental level, the source of the information used in this paper is Train Describer (TD) data. A TD is an electronic device connected to each signalling panel which provides a description of each train (it's headcode) and which section of track (or berth) it currently occupies. The TD is responsible for correctly displaying the train movements from berth-to-berth to the signaller and for ensuring that the train's identity is correctly passed to the next signaller's panel when it leaves the current signalling area.

3.1 The data

The work presented in this paper used two separate TD data feeds, termed C-class and S-class messages. TD C-class messages record train movements between individual track berths, whilst S-class messages record the times at which signal aspects change. Both are transmitted through the live feed with a total of approximately 5.2 million C-class and S-class messages being sent per day. As such, it has many of the characteristics normally associated with big data such as high volume, high velocity and significant value as specified by Attoh-Okine (2014).

The TD messages are sent in Java-Script Object Notation (JSON) format, which is an open standard data-interchange format.

An example of raw C-class messages is given below, which shows the train movement between two berths:

{"CA_MSG":{

"time":"1454422520000",

"area_id":"EA",

"from":"F507",

"to":"0523",

"descr":"1D84"}

}

The timestamps in TD messages are in UNIX timestamp format, which is a way to track time as a running total of seconds from 1st January 1970. The timestamps are sent in milliseconds but the actual resolution is one second because the last three digits of all the timestamps are 0. The ID of the TD area is EA which stands for Edinburgh IECC A. The values for the from-and-to fields represent the berths the train moves from-and-to. The described field represents the 4-digit train describer ID. Therefore, this message means train 1D84 moved from berth F507 to 0523 in the area controlled by London Victoria at 2016-02-02 14:15.

An example of raw S-Class messages is given below, which shows the status of signal elements:

{"SF_MSG":{

"time":"1454422520000",

"area_id":"EA",

"address":"16",

"data":"43"}

}

There are eight signal elements under address 16. The data field is filled with a hexadecimal number, which can be converted into eight-digit binary number. Each of these eight digits represents the status of each one of the eight signal elements under the address. In this case 0x43 equals 01000011. Therefore, the 1st, 2nd and 7th signal elements of address 16 in Edinburgh IECC A are showing off (not red) and the others are off (not red) at 2016-02-02 14:15. Network rail has supplied a table with the information of the signal IDs under each address.

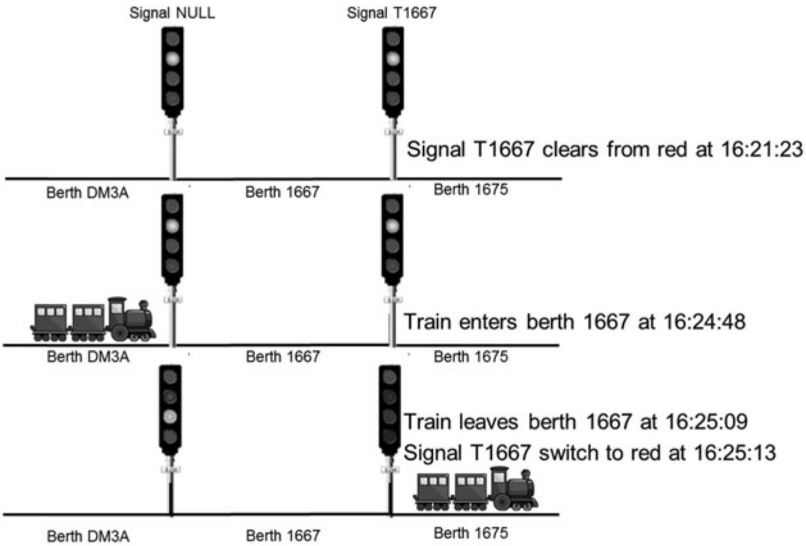

Figure 2. Example of a CS message.

3.2 Data processing

The received C-class and S-class messages are cleaned, pre-processed and then these two classes of messages are combined to analyse red aspect approaches. The combination of C-class and S-class messages is achieved using the berth and signal element relationship, which is provided by Network Rail. An example of the combined messages (denoted as CS messages) is given below:

CTime1 and CTime2 are the time when the train enters and leaves Berth1. TD is the TD area the train movement happened in. Headcode is the four-digit ID for the train. Berth0 is the proceeding berth and Berth2 is the following berth. Signal0 is the signal between Berth0 and Berth1, and Signal1 is the signal between Berth1 and Berth2. The status of Signal1 switched to Status0 at Stime0, switched to Status1 at Stime1, and switched to Status2 at Stime2. This example message can be illustrated in Figure 2, where train 1D47 entered berth 1667 from DM3A in area D1 at 2015-01-31 16:24:48, when signal T1667 at the end of berth 1667 was displaying a non-red aspect. Train 1D47 stepped into berth 1675 from berth 1667 and passed signal T1667 21 s later. Signal 1667 switched to red 4 s after the train passed it to prevent other trains stepping into berth 1675.

3.3 Red aspect approach identification

The CS messages are initially classified into NRA, RED and ERR classes using the decision tree in Figure 3. The first criterion is that the signal must follow

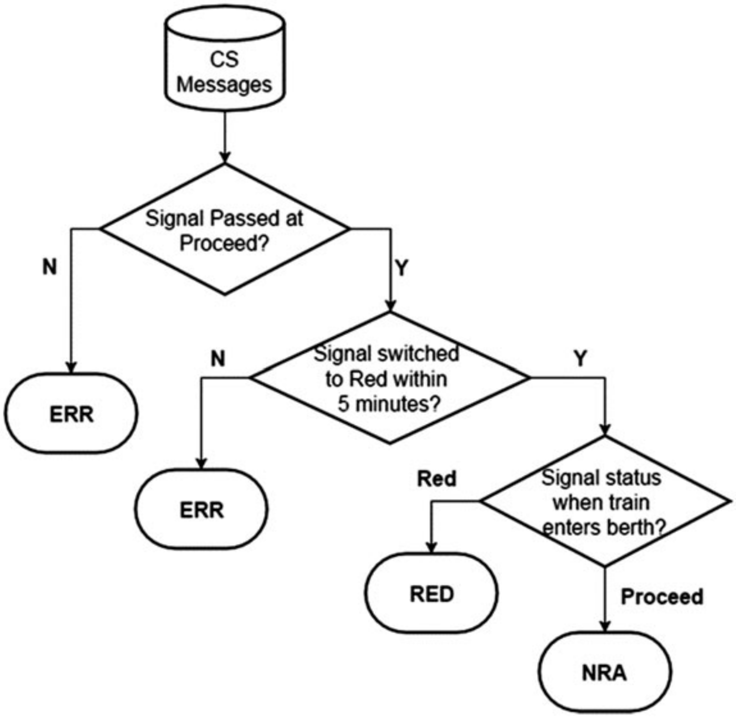

Figure 3. Identification model for red aspect approaches.

the expected sequence by changing from a proceeded aspect to a red aspect as the train passes. Any instance where this is not the case is classified as an error. After the train passes the signal aspect, the signal aspect should return to red within 5 min. This value is specified based on the knowledge of the railway signalling system. If the signal is off when the train enters the berth, the approach is classified as NRA or Non Red Approach. If not, the approach is classified as RED.

4. Validation and performance

4.1 Software validation

Four separate approaches have been used to verify the accuracy of the data processing procedures and red aspect approach identification algorithms. Initially, manual calculations were undertaken for a number of signals using the raw data from the live data feed to confirm that the analysis model correctly counts and classifies signal approaches. The manual check gave exactly the same classification results as using the analysis model.

Following this, Network Rail Control Centre of the Future (CCF) software was used to manually count signal approaches to a number of signals in the Merseyrail Electrics signalling area. CCF allows the user to replay the sequence of trains moving through a signal area, using a display that mimics the actual signaller's panel for the chosen area. CCF cannot show whether the train stopped at a red signal or not, and can only, therefore, confirm the correct separation between NRA and RED events. Five-hundred and fifty-one train approaches to 13 signals from the analysis model were compared to the CCF replays. Five hundred and twenty-six (95.4%) of them matched the analysis model; 4 of them were not matched and 21 of them were not found in the database.

The reason for these 25 exceptions (not matching and not found) is that the data feed drops messages occasionally and therefore some train movements or signal status updates cannot be received from the server. Omitting train movement messages will lead to the not found exception, and omitting signal status messages will lead to the not match exception. No classification errors, i.e. NRA being labelled as RED or vice-versa, were found.

The third approach involved several days of cab riding to generate a log of signal aspects approached and the related timings and once again these were compared to the output of the analysis model. One hundred and eighteen signals were passed and the model correctly classified all of these approaches.

The fourth approach involved two days of OTMR (On-board Train Monitoring Recorder) data on 2015-01-07 and 2015-01-08 provided by Virgin Trains. The OMTR data includes 145 selected approaches for Class 390 and Class 221 trains which stopped at red aspects. One hundred and thirty-eight of the 145 train approaches are classified as RED and the remaining 7 train approaches are classified as ERR. These 7 approaches are most likely shunting movements and the ground position signals are not included in the signal messages, thus leading to ERR messages.

4.2 Software performance

One hundred and thirty-seven million train approaches at 9386 signal IDs in 83 TD areas dated from 25/3/2014 to 30/11/2015 (420 days) are analysed. 86% (116 million) of these train approaches are classified as NRA, 10% (13 million) of them are classified as RED and 4% (8 million) of them are classified as ERR.

The 8 million ERR messages can be divided into 2 sub-classes:

ERR1: Train appeared to pass signal at red

ERR2: Signal did not return to red within five minutes after train passed.

The ERR1 class has 5 million messages. It should be stressed that these do not represent actual SPADs, but are mainly caused by the following factors:

Mismatched signal ID: The C-class and S-class messages are joined using the information on train movement direction, which is only available for some berths. When the train movement direction is unknown, the C-class messages can be incorrectly joined with signals facing both directions. Therefore, a train movement can be associated with a signal facing the opposite direction, which results in a timing error which suggests the train has passed a red signal before it leaves the berth.

C-class or S-class timestamp offset: Normally the signal switches to red after the train passes it. If the timestamp of the S-class message is offset by a negative value or the C-class message is offset by a positive value; then the CS message could show that the signal switched to red before the train passed.

The ERR1 messages caused by C-class or S-class timestamp offset are corrected by applying a fixed negative 10s offset to the S-class messages and then re-joining them with the C-class messages. This threshold was chosen using the distribution of the time difference between the times trains pass signals and the time the signal switches to red. The time difference for 37% train approaches of this error class is less than 10 s, and the time difference for the remaining 63% approach varies widely up to 86,000 s. The number of ERR1 messages is reduced to 5 million after this error correction is applied and most of them are classified as NRA, thus the number of total ERR messages is reduced to 6 million from the original 8 million.

Figure 4 shows how error rates vary between different signals, where the width of area represents the number of signals. The error rates for 80% (7495 out of 9386) of all signals are less than 5%. The error rates for 7% (668 out of 9386) of all signals are more than 95% and they contribute 70% (3.5 million) of all ERR1 messages. This proves that ERR1 messages are mainly introduced by the two factors as discussed above.

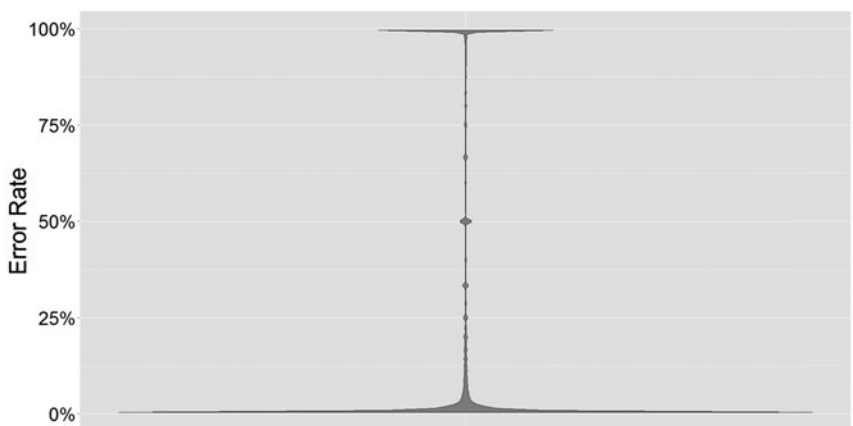

Figure 4. Error rate distribution for all signals.

There are one million ERR2 messages where the signals failed to switch to red within five minutes after trains passed. ERR2 messages are mainly caused by the disruptions in receiving S-class messages where the right STime2 information cannot be found.

The analysis above shows that discarding the ERR messages from further analysis does not introduce errors or loss of useful information. Therefore, they are not included in further analysis.

5. Case study

5.1 Analysis of individual signal ET776

Signal ET776, which is located on the up Cowdenbeath line at Redford is analysed. It was chosen because it saw two separate SPADs on 13/7/11 and 30/1/14 (Information on multi-SPAD signals). Figure 5 shows that after passing ET776, trains can take one of three routes:

Remain on the Up Cowdenbeath line toward signal ET772;

Cross over to the Down Cowdenbeath line toward signal ET774;

Cross over both lines to the carriage sidings.

Figure 6 shows the train approach identification results broken down by train headcode (type). The results show that the express and local passenger trains rarely approach signal ET776 when it is showing red. However, nearly 80% of empty coaches and rolling stocks approach signal ET776 when it is showing red.

5.2 Analysis of routes along ET776

Figure 7 shows the results for Cowdenbeath broken down by the route. The results show that trains that remained travelling on the Up Cowdenbeath line toward signal ET772 rarely enter the berth (T776) when ET776 is

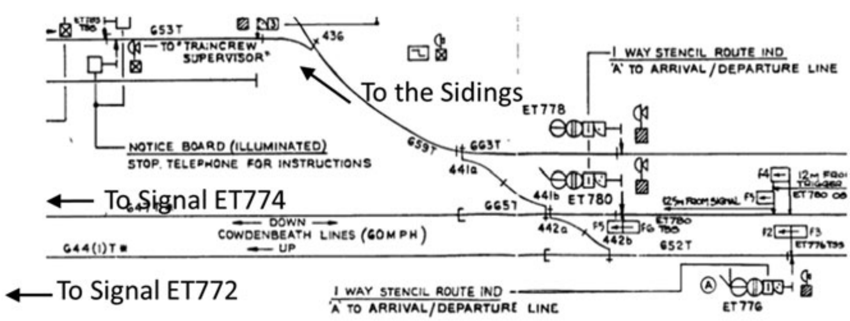

Figure 5. Signal plan for signal ET776.

showing red. In contract, if the train is diverted to Down Cowdenbeath line or the sidings then it will almost invariably be halted before a red at ET776.

This example illustrates that red approach rates at individual signal level can vary widely from the average values. It also shows that geographic and/or operational factors, especially the routes can significantly alter the conditions under which red approaches occur. This has significant implications for the understanding and calculation of SPAD risk at individual signals. Not only does it permit the risk to be based on the individual red demand rate for a particular signal, but it also offers the possibility of refining the modelling for a signal. In this example the majority of red approaches are by empty stock and freight trains that would not be carrying passengers when passing a signal at red.

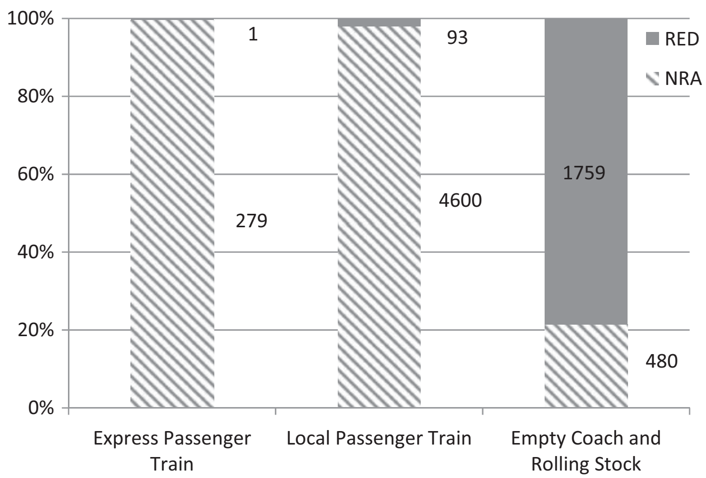

Figure 6. Results for intercity trains, local commuters and empty coaches.

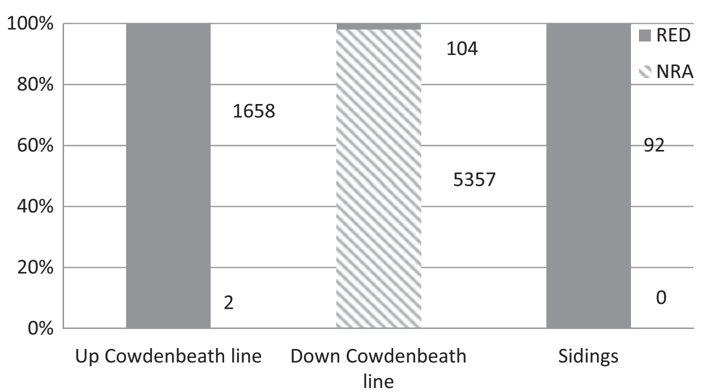

Figure 7. Results broken by routes.

6. Further work

One of the problems is that it cannot be determined conclusively whether a train actually stood still at a red signal. This is an important factor for determining SPAD risks as stationary trains cannot SPAD. A key element of future work is to discriminate the RED class train approaches by if the train stopped at the red respect or the signal has been cleared before the train stops. Several options exist for this, depending on the addition information available. Simply knowing the length of each berth would permit the berth transit times to be used to compare the likely approach speed with an idealised braking curve. This would permit better discrimination between trains which were likely to have stopped and those where the signal was likely to have cleared when the train was relatively close to it. It is thought that some uncertainty will always remain even with an enhanced model but that this can be reduced significantly.

It is also intended to widen the case-study approach for other signals where SPADs have occurred. Ultimately, the aim is to determine the causal relationship between SPAD approaches and the probability and potential consequences of SPADs. Such knowledge is invariably required to progress the current signal risk assessment process.

7. Conclusion

An analysis model has been developed that allows the number of red signal approaches to be determined at individual signals, groups of signals or over a whole TD area or many TD areas. The tool provides the basis for a better understanding of SPAD risk at individual signals and for improved normalisation of SPAD data for trending and benchmarking nationally.

Preliminary results for 83 TD areas showed that approximately 10% of all trains entered the berth while signal showing red. However, it also highlighted that there is a large variation in the red approach rates between individual signals. Further refinement of the model may be required to identify whether the train stopped at the red aspect or not.

There are a number of other potential uses of the data. The analysis has the potential to assist with understanding performance and capacity constraints on the network. This could be achieved by comparing the theoretical timetable against what actually occurs and assessing if there are areas where could be optimised or designed better.

Another use could be in understanding the routing of trains, the positions of points at junctions along with the frequency of their use. Better knowledge of these would improve the estimates of parameters in risk models that account for these in their algorithms.

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Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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Julian Stow, is Assistant Director at the University of Huddersfield's Institute of Railway Research. He has 20 years' experience in the areas of rail vehicle dynamics and wheel-rail interface engineering and has led a range of consultancy and research project for the industry in these areas, both in the UK and abroad. These have included work for Network Rail, RSSB, Ove Arup and a range of light rail and metro operators. He has led work to specify the wheel-rail interface requirements for new build light rail systems in the UK and Australia. He currently leads the Strategic Partnership between the University and RSSB which undertakes a range of projects in the field of railway engineering simulation and railway safety and risk. Julian is a Chartered Mechanical Engineer and a Fellow of the Institution of Mechanical Engineers.

Chris Harrison, is currently a Senior Risk Analyst working in the Risk Department at RSSB. He is the technical lead on the Safety Risk Model, the GB rail industry's network wide model of safety risk which is recognised as being the world leading model of its type. He has undertaken a wide range of projects analysing and modelling risk for problems encompassing the full range of railway technology and operations over many years. Prior to joining RSSB he worked as an analyst at National Air Traffic Services. Chris graduated from Oxford University in 2000 with a degree in Physics and has been a Chartered Physicist since 2007.

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