Assessment of Turnout-Related Derailments by Various Causes

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Abstract. Train derailments can mainly result in not only financial losses in the form of damaged rolling stock and infrastructure, but also more importantly in causalities and operational shut-down. Therefore, it is crucial for the railway industry to sustain a reliable and efficient operation and eliminate safety concerns. Analysis of accidents caused by train derailment is highlighted as one of the most crucial steps in the risk management chain. Considering various operational environment, the analysis enables reduction in the occurrence of derailment and prevents derailments in the most cost-efficient manner, as a variety of different causes and their frequency and severity are determined. In this paper, the methodology includes gathering and analysis of information on major derailments occurring at the turnouts from the UK. The causes have been categorised and then prioritised in accordance with the proportion of train derailments occurring within each category. The research objective is to determine the proportion of train derailments at turnouts and provide a starting point for the detailed analysis. In short, the aim of the paper is firstly to understand which factors under which circumstances pose the greatest risk at turnouts, secondly to quantitatively evaluate the relationship between derailment severity and frequency and thirdly, to determine the characteristics that cause major derailment and compare results with the characteristics in mainlines. The review analyses train derailments in UK over the last 15 years and demonstrates that the overall number of derailments have declined gradually and most derailments have occurred in yards. The dominant causes are identified as operational failures and component faults during track-train interaction, and track geometry problems are also seen to have a significant impact on derailment at turnouts, particularly in shunting yards. Furthermore, literature-based recommendations are used to address the issues arising from risks. The research outcomes are expected to aid the rail industry in developing, evaluating, prioritizing and gaining different perspective of derailment at turnouts to efficiently improve transportation safety and also to open a new gate to better understand the existing risk on railway turnouts.

1 Introduction

Train derailments are one of the major undesirable events to be considered in railway safety system and potentially pose serious hazards to human health and safety. A derailment might occur through many reasons, including operational error, environmental

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impacts, collision, various mechanical failures, etc. Additionally, it is notoriously familiar phenomenon likely to occur on all railway infrastructures, such as turnouts, track rails, etc. As a result, any risk mitigation of the occurrence of a derailment requires a broad knowledge.

In recent years, domestic scholars have conducted several researches related to the statistical assessment of train derailments. Liu et al. (2012) firstly analysed of train derailments by accident cause. This research proposed a model assessing derailment risk by accident cause and FRA track class. The same research group (Liu et al. 2011) subsequently indicated the statistical results of major train derailments and their effect on accident rates. However, the research only dealt with railway freight train safety, excluding other types, such as passenger trains and engineering trams. It is worth noting that there is no significant conclusion of any relationship between causes and turnout-related derailments.

On the other hand, it has been revealed that an effective and sustainable risk management of derailments at turnouts might be achieved through individual investigation of all railway infrastructures (Dindar and Kaewunruen 2016). As a consequence, turnouts, as one of the most complex railway engineering systems, should be taken individually into account, considering a variety of factors, e.g. type of equipment, line, along with immediate cause, causal and contributory factors of accidents investigated, as reported by a reliable and unbiased organisation.

Turnout-related derailments collectively cause almost the half of all train derailments in the UK (Ishak et al. 2016). Understanding what types of causes contribute to derailments at turnouts is highly likely to provide the fundamentals for preventing such accidents as well as developing cost-effective maintenance strategies. This also results in reducing railway transportation risk, allowing the railway operators to sustain a smooth operation.

The study illustrates the statistical results of derailments at turnouts, and then evaluates and discusses the results to achieve the initial step in a systematic process of quantitative risk analysis and risk management for all operational conditions.

2 Turnouts

In railway engineering, the term turnout, as shown in Fig. 1, is used to describe a mechanical installation by means of which flanged vehicles are able to be diverted from one track to another. Although turnouts have a close similarity in their design and method of installation, the engineering process in building their constituents may be vastly different, giving rise to their complexity.

The various constituents of a turnout are shown in Fig. 1. A brief definition of the each is given below along with a technical explanation of the significant details

Stock rail: the main rail of the track to which the tongue rails are closely fit.

Points or switch: Steel blocks formed by the combination of a pair of tongue and stock rails with the necessary connections and fittings.

Crossing: an arrangement of rails introduced at the junction where two rails cross each other to allow the wheel flange of a vehicle to be moved from one track to another.

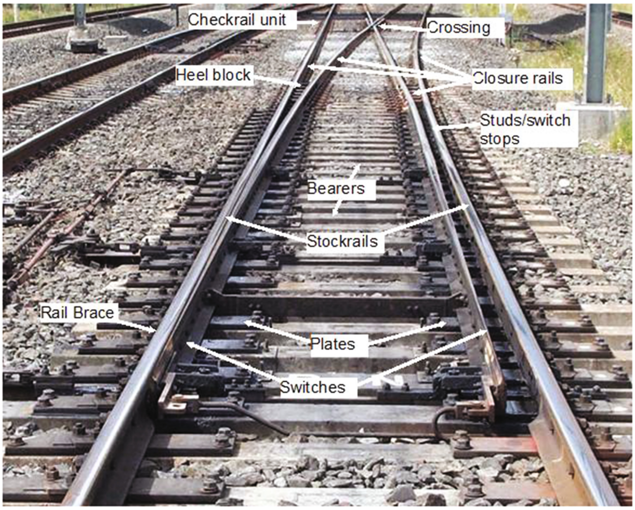

Fig. 1. Typical components of a turnout

A switch motor: an electric, hydraulic or pneumatic mechanism used to align the switch with one of the possible routes.

Stretcher Bar: a steel bar used to keep the switch rails in the correct position under the passage of a rolling stock.

Sleepers: They are generally laid perpendicular to the rails and transfer loads from the rails to the track ballast and subgrade. Their further benefits are to hold the rails upright and keep them spaced to the correct gauge.

Closure rail: the piece of fixed rail between the points and frog of a turnout to provide the passage of a rolling stock from switches to crossings.

Heel block: a unit providing a splice with the contiguous closure rail and a location for the switch point rail.

Check rail: a short piece of rail placed alongside the stock rail opposite the frog to ensure that the appropriate flange way through the frog is followed by wheels

Turnouts are operated in a variety of ways in accordance with type of turnouts, type of line and operational environment. Switch rails can be moved by a human operator or a switch motor. Although some switches, in particularly light and tram lines, are still controlled by humans, most, situated on high speed, new and heavy lines, is preferred to have a remotely controlled electric or hydraulic or pneumatic motor.

3 Data Analysis

To achieve generalisability of the paper and targeting identification of specific risk levels of railway turnout systems, it is essential to argue how reliable, sufficient and accurate data are used in this research and to what degree data give an insight into railway safety industry. This section offers a response to such concerns.

3.1 Data Source

The research is limited to investigation of UK-based accident causes. Therefore, there is a variety of British sources presented for this analysis. The Rail Accident Investigation Branch (RAIB) is one such and is a British government agency that conducts enquiry into various types of train accidents in the UK. Created in 2005, the agency has official authority to investigate accidents that cause death, serious injury or extensive damage to infrastructures. It more specifically focuses on accidents and incidents on mainline railways, metros, tramways and heritage railways throughout the UK, operating as an independent body.

Composed of a total of 43 persons, their inspecting team comprises experienced rail or investigation specialists. Accident reports are officially reliable and controlled by the Secretary of State for Transport. The accident reports of RAIB include as follows;

- the immediate cause, causal and contributory factors of railway incidents and accidents
- identifying risks which might result in a similar accident or make an accident worse and making recommendations to prevent reoccurrence
- detailed information about how railway accidents happen

All types of accidents occurring at turnouts in the UK since 2006 have been investigated.

3.2 Data Categorisation

Rail Accident Investigation Branch reports are formed from a wide range of safety events, including accidents, incidents and near misses, and extend beyond the operation-focussed requirements of Railway Group Standard GO/RT3119 and Accident and Incident Investigation Guidance (RSSB 2016). It is found that RAIB has published over 130 derailment reports related to accidents occurring on heavy, light, metro and heritage lines. It is determined that there are 45 turnout-related accidents occurring on such all lines. These reports have also been investigated as to whether these are accidents with a monetary threshold of damage to infrastructure and rolling stock. Lastly, it is decided that 44 derailments meet the principles by which risk assessment may be judged to be initiated.

A method is developed to categorise immediate, causal, contributory and underlying factors of accidents (Marshall and Healey 2008). It is observed that RAIB and RSSB largely work from a model and a similar methodology, modified to take account specifically turnout-related problems in the context of technical rail categorisation, is used for this study. The classification is represented in Fig. 2. The main difference between the modified model and the model currently in use is that the new model proposes the separation of infrastructure component failures from non-infrastructure component failures, e.g. bogie faults, wheel defects, etc. As it is noticed that there have been many human-based failures, the failures were handled separately without adding to any major category.

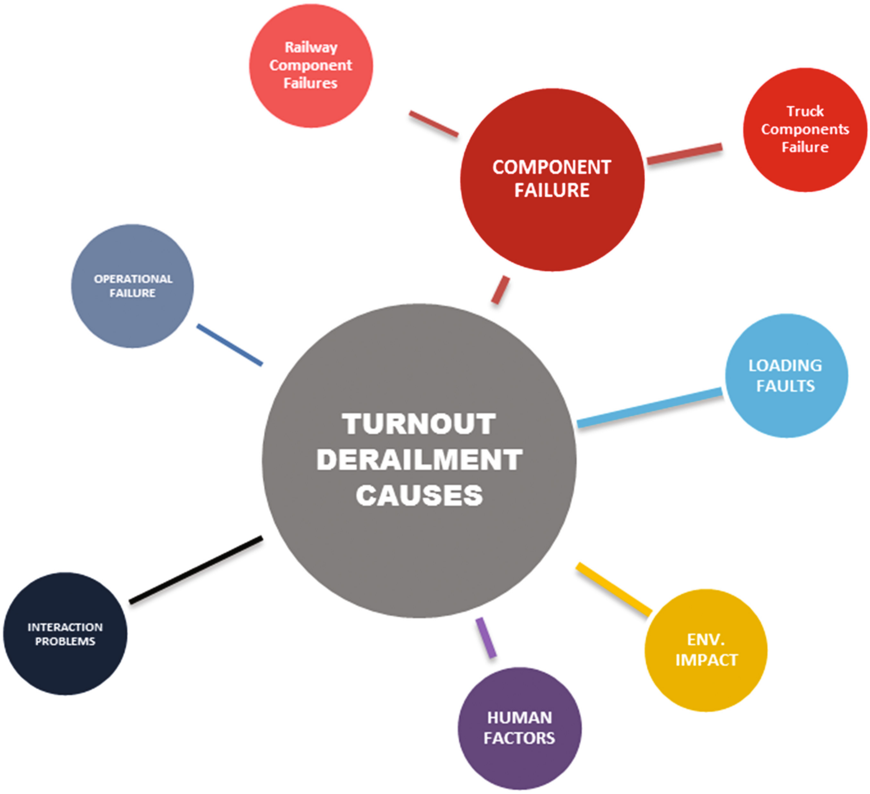

Fig. 2. Representation of proposed framework for categorisation

Briefly, all major categories, including operational failures, environmental impacts, interaction problems, and human factors, are given along with their subcategories in Table 1.

Table 1. Subcategories of all major accident nodes

Infrastructure	Interaction	Environmental	Operational	Loading	Human
Switch	Obstruction	Rain	Signal	Malicious	Speed
Points	W/R	Snow	Use of switch		Br.Rules
Stretcher Bar	Flange Climb	Mud	Brake operation		Fatigue
Geometry	Hunting	Wind	Train handling		Vandalism
Ballast					

The paper also attempts to categorise railway type, e.g. heavy, light, metro and heritage lines. Furthermore, the location of accidents, e.g. yard, siding, plain line, is taken into account. This could be useful for determining to what degree the risk levels change in accordance with the characteristics of location.

3.3 Limitation

To understand better the work developed here, this is the section established for further studies in the field. The authors obtained data from only RAIB as data source, without comparing the results with another database. Although this external constraint present, it is considered that the results can probably be addressed to the issues in general all over the world.

On the other hand, the database has been formed only of UK-based reports. The UK railway industry is one of leading expert regarding minimising railway accidents, e.g. derailment, collusion. Hence, where any developing country are studied, the results of this study are likely to be different. Although this study are designed well for future risk method and reliability assessment, it is limited to advanced countries in railway sector.

4 Results

4.1 Derailments by Railway Type

Four types of railway types are recorded in the RAIB reports, namely heavy, light, metro and heritage rails. Different operational functions might be executed through these different railway types and, consequently, are expected to lead to different causes, accident types and consequences.

Heavy rail refers to conventional railways forming part of the national network, including high-speed rail, freight, intercity, commuter and rural services. RAIB and RSSB use the term light rail to express high capacity lines on which urban public transport, using rolling stock similar to a tramway, are used and are generally established on an exclusive right-of-way. Metro might be seen as underground light rail, but cannot be accessed by pedestrians or other vehicles of any sort. As for heritage rails, the means that volunteers or non-profit organisations take over or re-open railway lines which were once run as commercial railways.

Figure 3 shows accident frequency and wagon derailment by railway type, considering all reported cases in the UK from 2006 to 2016. It provides evidence that the distribution of accident types varied in accordance with railway type. Train derailment on heavy lines is seen to dominate the overall accidents. Over the last ten years, 35 significant derailment cases, accounting for 77% of all, have occurred on such lines. The most common railway type, it is found to be followed by light rail, metro and heritage railways.

Risk comprises two fundamentals; likelihood and consequences/severity. As the report does not include cost of accidents, e.g. track or rolling stock maintenance expenditure, it is assumed that accident severity is determined in this research by the

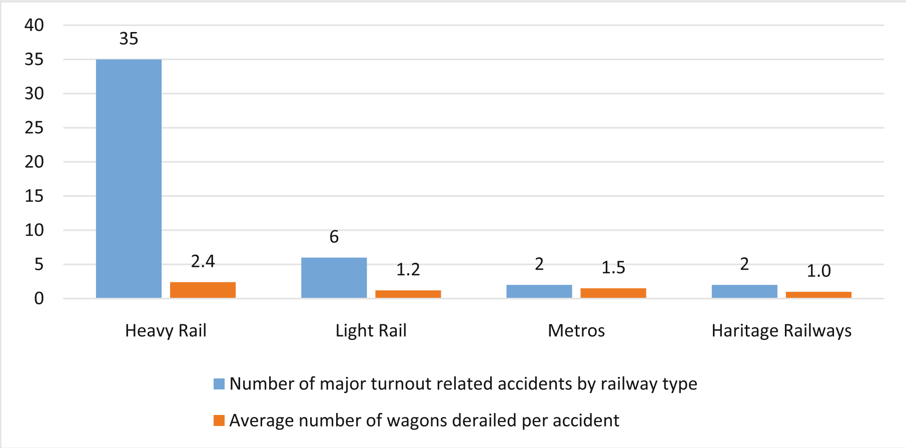

Fig. 3. The accidental characteristics of turnouts by railway type

number of wagons derailed per accident. Similarly, train derailments on heavy lines, an average number of 2.4 per accidents, have had a greater average accident severity than other railway types, namely metro, light rail, and heritage rail, at 1.5, 1.2., 1, respectively.

4.2 Derailments by Railway Location

Three types of railway line location are recorded in the RAIB database, namely main, siding, yard and industry line. As with railway type, these are necessary for achieving different operational functions and, as a result, have different associated accident causes and consequences. Considering the many variants in railway terminology, main line, in this research, refers to a stretch of railway track that is away from yards and sidings. Yards are a complex series of railway tracks used for loading/unloading, sorting or storing railway trucks, while sidings, in British terminology, are tracks where railway vehicles can be left, i.e. are not serving as an operating train for the time being. There are some lines that are not for public transportation, but for serving a particular industrial, logistic or military purpose. These lines are addressed as Industry lines.

RAIB turnout-related accident reports covering the period 2006 to 2016 were compiled to illustrate the number of major accidents by railway type, the average number of wagons derailed per accident and average speed of derailed vehicles (Table 2). It is worth noting that accidents resulted by railway locations include both passenger and freight trains.

These three statistical categories were dominated by accidents on main lines, as expected due to their high traffic density. On the other hand, although yards are equipped with small pneumatic, hydraulic or spring-driven braking retarders to slow train speed, given the British speed regulations, and that these are very common railway areas, there seems to be a relatively greater number of turnout-related accidents

Table 2. Statistical results by railway location

	Main	Yard	Siding	Industry
Number of major turnout related accidents by railway type	28	10	7	1
Average number of wagons derailed per accident	2.4	1.6	1.5	2.0
Average speed of derailed vehicles (mph)	14.9	10.5	5.6	N/A

than expected. This will be discussed later. As for industry lines, these have been added to make the findings usable for US researchers. However, as only one accident has so far been recorded, it is quite difficult to make any conclusion on the line.

Although serious accidents are seen likely to occur on the yards and siding areas of a railway line, main line operation needs to be considered carefully to maintain a smooth operation of the entire railway network, because heavy trains on this part travel at high frequency and higher speed. Another feature of the table is shows the explicit relationship between speed and number of accidents/average number of wagons derailed per accident. The higher the speed at which the rolling stock travels, the more accidents and derailed wagons are highly likely to occur. It could be considered that the rolling stock on main lines are of greater mass than those on other lines. The greater mass and speed signifies that the rail-wheel interaction forces and potential impact in regard to casualties, property and environmental damage, are expected to be all correspondingly greater. This could be an explanation in the logarithmic rise in the number of derailed wagons against rolling stock speed.

4.3 Derailments by Accident Cause

Derailments are the most common type of train accident type in the United Kingdom. The rail industry and government-based organisations concentrate on preventing them to provide a high standard of railway operation and eliminate potential safety concerns. Several researches have focused on train derailment and causes, using often the Federal Railroad Administration (FRA) database. The administration reports a large number of accidents covering almost the last three decades in the United States, and these reports, each of which is of one or two pages, are as detailed as RAIB reports. On the other hand, the U.S. has a length of nearly 150,000 miles and over 1.2 billion tonne miles of freight rail usage, which is remarkably higher than the statistics in the UK (about 20,000 miles, 23 tonne miles of freight rail usage, respectively) (NS 2015). Considering the relation between the figures and accidents, the study has dealt with a considerable low number of accidents. However, reports present much more detailed information on immediate causes, causal factors and contributory factors. The latter two have not been included in FRA reports.

Most previous studies have concentrated on main line, yard and sidings derailments; however, in this research, the paper only focuses on turnout-related derailments which demands for elaborated explanation on how a rolling stock is derailed at turnouts. Each accident has been investigated to rank immediate causes, causal factors and contributory factors of derailment at turnouts.

In this study, immediate causes are defined as substandard acts or various conditions that lead directly to the derailment. In the event of avoiding or eliminating any immediate causes, associated accidents would be prevented from happening. Likewise, causal factors too are any condition, event or behaviour that was necessary for the occurrence of derailment and can be anyone of these factors. However, some conditions, events or behaviours might affect or sustain the occurrence, or exacerbate the derailment (contributory factors). Eliminating one or more of these factors would not prevent derailment, but their presence makes it more likely.

Figure 4 illustrates the percentages, by each immediate cause, leading to derailments at turnouts in the UK. Each has several subcategories, as shown in Table 1. Some accidents were reported with two or more immediate causes and those were added each by each into analysis in the figures and tables in this section.

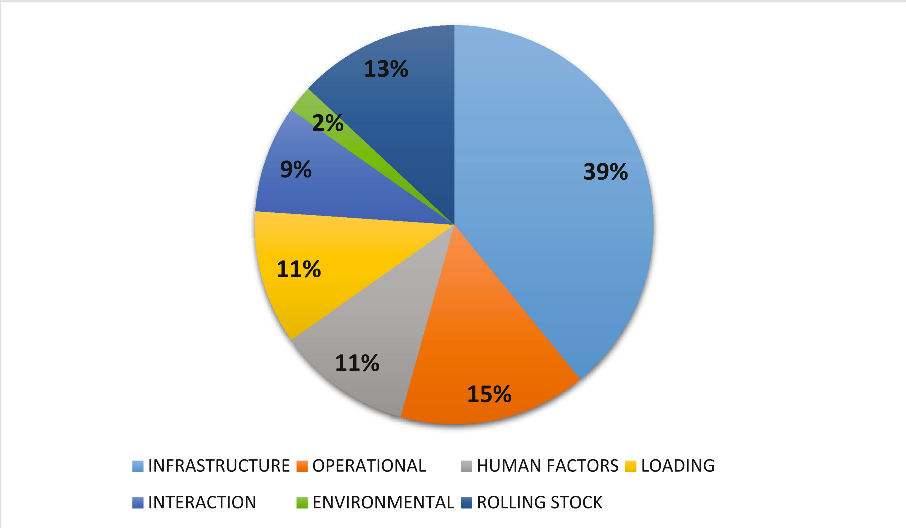

Fig. 4. Distribution of derailment frequency by various causes

Infrastructure associated problems, e.g. broken rail and various turnout component failures, have contributed to the majority of derailments. This could be expected due to the fact of the extreme force and potential impact in regard to turnout component damage as a result of discontinues on the rail line by railway turnout design itself. The results statistically express how vulnerable turnout components are to the forces of every passing rolling stock. Although the infrastructure failures account for the vast majority of derailment, operational and human factors are almost the same contribution, comprising 36% of accident rates combined. Of the two, 15% were caused by operational failures, while another 11% were caused by human factors. The rest were caused, in order, by loading faults (11%), interaction problems (9%) and environment (13%). As this study is limited by excluding rolling stock-based faults, which demand for a different expertise area, there is no discussion in regards to this.

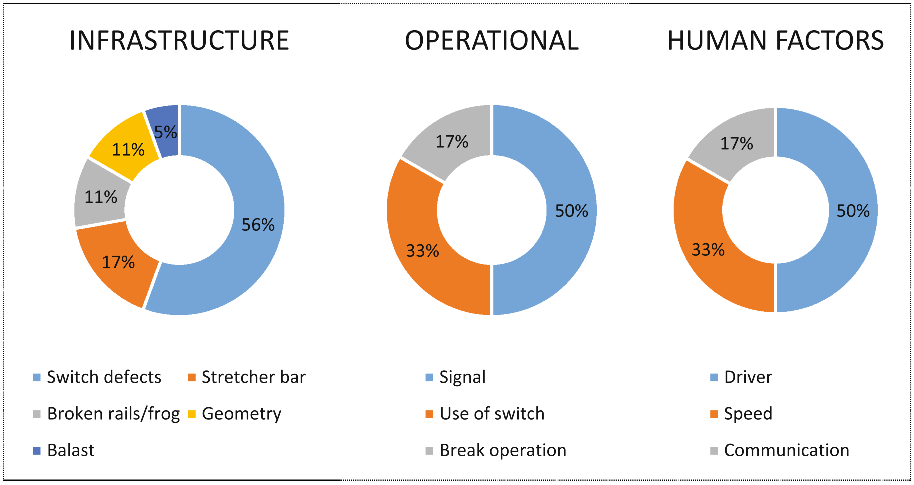

Fig. 5. Derailment frequency distribution by subcategory-indexed reasons of the top three factors

The top three categorised causes, namely infrastructure, operation and human factors, are given in detail in Fig. 5. Infrastructure-related causes mainly involve various switch defects. The defects seem to be switch damaged or out of adjustment, switch point gapped and switch rod worn, bent, broken, or disconnected. The second infrastructure-related causes are associated with the stretcher bar not working properly. The rest are broken rails and frogs, geometry problems and ballast.

Signal problems account for the half of operational-caused derailments. As such, causes include flagging, improper or failure to flag, or the restrictive indication of a block or interlocking signal or wrong indication of signal. Such problems were followed by use of switch and brake operational failures.

Lastly, human-caused derailments are mostly traced back to various driver-centred failures, i.e. failure in not reacting to the 'points not correctly set' indication on the signal or not immediately observing what was displayed by the signal's route indicator. Those are followed by disobeying the permitted speed and communication errors, such as improper radio communication or failure to comply or give/receive.

Aside from immediate causes, causal factors are very important in determining the cause or causes of the derailments so as to prevent further turnout-related accidents of a similar kind. Table 3 shows such groups, indicating how responsible each is for derailments. It is evident that derailments at turnouts are mostly a man-made crisis, with maintenance faults, human error and signalling problems accounting for over 50% of accidents. Among these causal groups, maintenance problems appear to be of most interest and need to be reviewed in current maintenance regimes due to the unacceptable frequency of occurrence. As a common result of the complexity of its geometry, with extreme unique internal/external forces, and vulnerability to environmental conditions, it is recommended that each individual turnout should be taken into account for maintenance strategies. The railway industry will obtain benefit from this in eliminating risk factors associated with derailments (Dindar and Kaewunruen, Investigation of

Table 3. Statistical results of causal factors

Causal Groups	Description	Number of derailments	Percentage
Maintenance	Installation/regime problems, insufficient inspection, undetected bearing/rail welding.	14	32.6%
Environment	Extreme rain, icing/snow on track, high temperature	7	16.3%
Human factors	Vandalism (e.g. by someone placing a stone), slow response to signs or communication	6	13.6%
Track geometry	Significant twist fault, widening has occurred, track gauge failures	5	11.4%
Rolling stock	Degraded bogie/wheel	5	11.4%
Sign problems	Wrong settlement of points set indicator/related signs, blocked signs	2	4.5%
Malicious	Train lateral/horizontal forces, vulnerable components, design problem	5	9.1%

Risk-based Maintenance Strategies 2016). Among outer factors, about 16% of derailments were related directly to environmental conditions as causal factors. A recent study (Dindar and Kaewunruen, Natural hazard risks on railway turnout systems 2016) has already provided the link between environmental factors, e.g. hot/cold temperature, and derailments at turnouts. Stretcher bars and turnout geometry have also been found to be vulnerable.

Table 4 gives information about the distribution of contributory groups analysing the 46 accident reports. The table is prepared to provide insight into how the likelihood or severity of derailments at turnouts escalates. Although some group names in Table 4 are the same as those in the previous table, the contents of each are different. For instance, environment is death as a contributory and causal factor. Extreme rain or icing/snow on track or high temperature is thought to directly cause derailment in Table 3, whereas moderate environmental patterns, such as low visibility due to fog, are considered to promote derailment accidents.

One of the contributor groups, maintenance, was the most frequently reported category, involved in 20% of all derailment reported by RAIB. This group is mainly built on the concerns described in the Table. It is seen that a low frequency of maintenance or an inappropriate inspection or the lack of independent inspection is often reported.

On the other hand, sign/signal-related factors were the second most frequently reported group, involved in 18% of all reported accidents. The group mainly concerns the close proximity of points to signal and the absence of an illuminated PSI (points set indicator). Only two accidents are reported by unseen railway lights (due to being blocked by a tree) and small size of railway sign.

Components as a contributor group were the next most frequently reported category, associated with 16% of the accidents. It is mostly reported that, firstly, various rolling stock components, such as a bogie, are not detected to be degraded; secondly,

Table 4. Statistical results of contributor groups

Contributory groups	Description	Number of derailments	Percentage
Maintenance	Lack of detailed inspections, low maintenance frequency, inspection error, inappropriate maintenance plan, etc.	10	20%
Sign/Signal	Location problems, size problems, absence of various aimed signal boxes, etc.	9	18%
Component	Stiffness-related failures, not-fitted-in-use, somewhat out of standard components, etc.	8	16%
Environment	Fog, rain, warm, cold weather patterns, etc.	7	14%
Human errors	Fatigue, mediating drug use, etc.	7	14%
Geometry	The design of the points, the presence of voids, etc.	5	10%
Operational	The failure of the control room, inaccuracy of appointments in inspection, etc.	4	8%

the bolt retaining plates on the field-sides of both switch rails have not been fitted properly; and, thirdly, the lack of support given by the stock rail to the switch because of loose fastenings.

The other groups in the Table, environment, human error, geometry, and operational, are responsible for some contribution to almost half of the accidents. The details of each are described in the Table.

5 Conclusion

A risk analysis often begins with identification of risks and their various contributing factors. The study determined risk groups and prioritised them to establish a most-to-least critical importance ranking. As a result, the outcomes of the study provide insight to risk analysis/management of railway turnout systems whereby their immediate, causal and contributory factors need to manage or mitigate the realisation of the high probability/high consequence of risk events.

Train derailments at turnouts are observed to account for the majority of accidents that occur on heavy lines. Although metro lines (underground) have as high a density of traffic as heavy lines, average derailments on metro lines are at a considerably lower rate. Light rail, as an urban transportation system at ground level, is also determined to be responsible for many turnout-related derailments and identified to be very vulnerable to such accidents.

It is illustrated that turnout location, e.g. siding and yard, is examined to determine its strong correlation with derailment rate. Rolling stocks on main line are at more risk than those on siding, yard or industrial lines. Moreover, the greater the permitted speed over turnouts, the larger number of accidents it yields. However, the relationship between speed and derailment is complex, and demands further work. Some accident causes are identified to show a strong relationship, but others do not.

The main statistical information on derailments at turnouts is illustrated in figures prepared through official accident reports published by the Rail Accident Investigation Branch. The top causes for derailments are infrastructure, operational and human factors, respectively. The proportion of infrastructure associated with various turnout component failures is the highest. The most failing component at turnouts is identified as switch. Stretcher-related failures are the second most common failure type. Aside from component failures, operational and human factors seem to contribute significantly to derailments.

The most significant causal factor is maintenance, accounting for one-fourth of all. The major reason is reported as an undetected failing element or, in other words, problems in maintenance procedures. This is followed by environmental factors and human factors. Turnouts seems to very vulnerable to cold/hot weather, causing various geometry problems, and to driver faults such as communication.

The paper also dealt with contributory factors. Maintenance is the most common type and, among the reasons, low rate maintenance frequency is reported; therefore, increasing the frequency is recommended by British derailment experts.

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