How Accident Investigation Can Influence Railway Technology

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Abstract

This paper discusses how accident investigation can contribute positively to the development of safety related railway technology. It explains what guides the accident investigator's decisions when formulating investigation recommendations. The paper then considers how existing and potential routes from investigation to research and technological development can be improved in order to maximise the safety benefit from investigations. This will require wider and better communication between accident investigation bodies and the railway industry than purely formal, legal routes. The paper includes four case studies based on the RAIB's experiences which demonstrate how accident investigation can positively influence railway technology to bring about safety improvements. The case studies cover improving the integrity of critical final drive gearbox bearings, reducing freight train derailments, controlling post-derailment vehicle behaviour, and improving the survivability of passengers in high speed derailments.

Keywords: railway accidents, investigation, railway technology, derailments.

1 Introduction

Throughout railway history, lessons learned from accidents have driven many aspects of railway design and technology, relating to both active and passive safety. As more and more countries establish their own independent rail accident investigation bodies, it is useful to review how safety lessons from accident investigations are disseminated to respective rail industries and their supporting academic and technology companies, and to ask if the dissemination of safety lessons can be improved.

This paper is based on the experience of the Rail Accident Investigation Branch (RAIB) which began its operations in October 2005. The views expressed here are therefore based on UK experience and do not necessarily reflect the situation in other countries. However, given EU Safety Directive 2004/49/EC, which requires the establishment of national investigation bodies, experience in other EU countries should be similar.

2 The role of the accident investigator

The role of an independent accident investigation body is to identify safety lessons and make recommendations to improve safety by reducing the chance of recurrence or minimising consequence. Reports may be published or not, depending on the legal framework in the country concerned. National rail accident investigation bodies, like the RAIB, are not concerned with matters of blame or liability.

In the UK, safety recommendations arising from investigations undertaken by the RAIB are addressed to duty holders and standards setting bodies through the national safety authority, which is responsible for ensuring that each recommendation is duly considered in the context of applicable legal health and safety requirements, as shown in Figure 1.

Figure 1: The legal route for handling RAIB recommendations

When formulating recommendations, the RAIB considers a number of questions:

- Does the recommendation address the findings of the causal analysis (which itself should reflect the evidence)?
- Has the same or a similar recommendation been made before?
- Will the recommendation help to prevent a recurrence or minimise the consequence?
- Is the recommendation proportionate to the accident and the ongoing risk?
- Is the recommendation SMART (i.e. specific, measurable, achievable, relevant and time-bound)?

By the time a recommendation is made in a published report, it will have been tested against the above questions and will have been consulted upon with the intended recipients.

The majority of safety recommendations made by the RAIB involve improvements to management processes, standards, procedures, training, design or maintenance, and cover railway operations, infrastructure and rolling stock. However, sometimes, safety improvements can only be achieved by improving knowledge or applying novel technological solutions to bring about the necessary changes. In such cases fundamental research and/or development of existing technology may be required.

3 From accident investigation to improved railway technology

Generally, improvements in railway technology are introduced to achieve better safety, performance or efficiency. The investigation of accidents provides safety lessons which can be a valuable input into the development of safety related railway technology and therefore the output of accident investigations should be seen as a help and not a hindrance.

There are four potential routes from accident investigation to research and technology development, as shown in Figure 2:

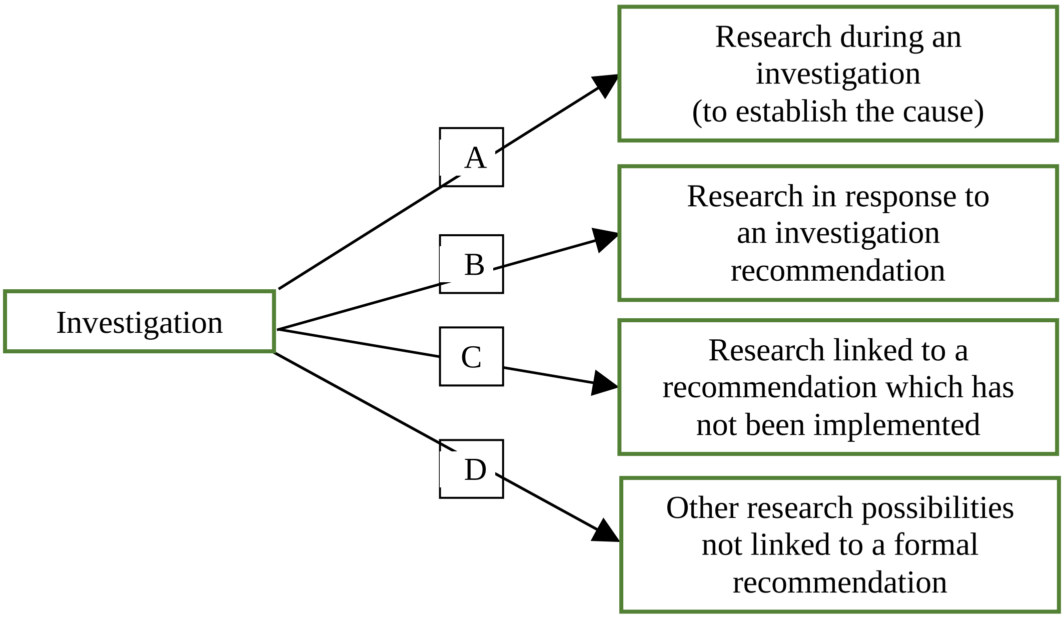

Figure 2: Routes from accident investigation to research and technology development

a) Route A involves research during the course of an investigation which is led by the accident investigation body and supported by industry. In the UK, the RAIB will take the lead in carrying out the required research to fulfil its duty to establish the causal chain of an accident to a sufficient degree that it can make evidence based recommendations. By its nature, the scope of such research will be limited to meet the requirements of the investigation and will need significant further work to develop into useful technology (case study 6.1).

b) Route B is the most common route, and involves research and development undertaken by the industry as part of its implementation of a safety recommendation from the RAIB (or potentially from the industry's own investigation). In such cases the RAIB will have made the recommendation because it considers it is necessary to bring about a required safety improvement. The research could be undertaken in house by the duty holder or by a consultancy or academia; depending on resources and skills (case study 6.2).

c) Route C involves research areas linked to safety lessons or recommendations from the RAIB which have been considered by industry but not implemented on the grounds that it considers the costs are likely to be disproportionately greater than the benefits. As a consequence of the non-implementation, significant areas of understanding and knowledge may not be developed because those ideas are not sufficiently aired for others (e.g. academia) to consider (case studies 6.3 and 6.4).

d) Route D involves research which the circumstances of a single accident may not justify, and therefore the RAIB may decide it is not appropriate to make a formal recommendation for the research. In such cases the RAIB may highlight the potential for safety learning in its report in a separate section from the recommendations.

Currently, there are well proven mechanisms for routes (a) and (b). However, there remains a need for developing routes (c) and (d) so that academia, and research and technology organisations are kept informed of potential research ideas, which they may consider fit better with their own goals than those of industry duty holders. For example, a research idea may be suitable for undergraduate or post graduate projects to take forward. If early research finds that some of these projects have significant merit, it could spawn more significant programmes of research and innovation, which could then filter back into industry.

4 Improving communication

The key to developing routes (c) and (d) in Figure 2 is good communication of ideas for research and technology between the accident investigation body, industry and academia. This could include the provision of assistance by the accident investigation body to aid understanding and define the issues which led to the accident(s), without becoming involved in solutions which could compromise the accident investigation body's independence.

In addition to the legal route shown in Figure 1, there are other ways in which the accident investigator can disseminate safety learning to organisations interested in developing safety related railway technology:

- Through the accident investigation body's website, where investigation reports and any other publications are freely available, and which can be searched for specific topics of interest, recommendations and research ideas. The RAIB is currently looking into ways of improving the report search facility on its website and also how best to rapidly disseminate safety learning arising from lower risk accidents which it has decided not investigate but which nonetheless may have useful safety learning.

- Participation of the accident investigation body in safety related research and technology forums and conferences in which it can convey relevant safety learning for academia and industry to consider.
- Having an "open door" policy so that research and technology organisations can have direct contact with the accident investigation body in order to understand the issues arising from an investigation.
- Direct input from accident investigation bodies to standards setting bodies so that the formulation and modification of standards includes consideration of all relevant information from accident investigations, since standards are a key driver of railway technology. However care should be taken here to ensure that independent accident investigators do not become involved in the formulation of the requirements in standards.

The above is not intended to be an exhaustive list of possibilities; rather it sets out the types of initiatives that accident investigation bodies can take to facilitate better communication between them and those who drive the development of railway technology.

5 Thinking wider than the accident

A pre-requisite for developing routes (c) and (d) in Figure 2 is also the willingness of research and technology organisations and rail industry sponsors to think wider than an individual accident that has been investigated. Historically, the UK rail industry would not have achieved current levels of active and passive safety for example, if the safety authority and industry had not thought wider than the watershed accidents which drove forward the key changes that were necessary at the time. Two examples of this are:

- Train protection and warning system (TPWS) and other measures to reduce incidents of signals passed at danger (SPADs) were introduced in the UK following Lord Cullen's Inquiry into the Ladbroke Grove rail accident of 5 October 1999, in which 31 people died and hundreds suffered injury. Since the introduction of TPWS in 2002-03, there have been very few collisions and none involved loss of life or serious injury. By comparison, during the 17 year period 1981-97, there were 649 collisions comprising end-on, side-on and buffer stop collisions, resulting in over 100 weighted equivalent fatalities [1].
- Passive safety (crashworthiness) measures were introduced in UK rolling stock following the Clapham accident of 12 December 1988, in which 35 people died, 69 and 415 people suffered serious and minor injuries respectively [1]. Safety improvements to both vehicle structures and interiors were introduced following a significant programme of crashworthiness research and development.

Although those measures were designed principally to mitigate the consequences of end-on collisions, they have shown significant benefits in a high speed derailment (case study 6.4).

In both the above cases a significant level of 'safety vision', beyond the circumstances of the actual accidents themselves, was required to provide the necessary impetus for change. Those changes were arguably greater than could be readily justified by standard industry cost-benefit analyses alone, and were driven, in part, by the high consequence of the accidents.

Sometimes, a series of similar lower consequence accidents occur, which show up a weakness in railway safety and which investigators and the railway industry collectively feel must be addressed urgently with a cross-industry effort in order to prevent the frequent recurrence of smaller accidents or prevent a much larger accident from happening. An example of each is given below.

- Between April 2003 and April 2013 there were 30 passenger fatalities at the platform train interface (PTI) at stations. On 22 October 2011 at James Street station in Liverpool, a sixteen year old girl was struck and killed by the train which she had left 30 seconds earlier. She was leaning against the train as it began to move out of the station and when she fell, the platform edge gap was wide enough for her to fall through and onto the track. Post mortem results recorded her blood alcohol level to be three times the UK legal drink drive limit and she was wearing high-heeled shoes at the time. The guard had dispatched the train while the person was still leaning against it. Following the RAIB's investigation of this accident [2], the UK rail industry set up a working group in December 2013 to tackle PTI risk. The group published its strategy [3] to investigate PTI risk and support the industry in managing the PTI and work is ongoing.
- Freight train derailments on the UK rail network over the past decade have tended to be relatively low consequence events, but they do occur frequently. Between October 2005 and March 2015, there were 38 freight train derailments. Although none resulted in serious or fatal injuries, some caused significant track damage and delays. The RAIB determined that 17 of these derailments were caused by a combination of vehicle and track factors. One of these derailments and its subsequent investigation, highlighted in case study 6.2 below, initiated a much needed cross-industry programme to tackle the problem of derailments caused by a combination of vehicle and track factors.

6 Case studies

Four examples of accident investigations which have resulted in research either during the investigation or as a result of recommendations, are discussed below. They demonstrate how the thorough investigation of rail accidents can be a useful input to safety improvements in the future through technological development.

6.1 Understanding the effect of inadequate fits for critical bearings of final drive gearboxes

On 20 February 2010, a seven-car passenger train derailed by one axle, while travelling at 94 mph (151 km/h) near East Langton, Leicestershire [4]. The train ran on for a distance of around 2 miles (3.2 km) before it stopped but remained upright and in line. There were no injuries among the 190 passengers and 5 crew who were on board.

The derailment was caused by the fracture of a powered axle on the fourth vehicle (Figure 3) which occurred because the gear-side output bearing of the final drive had stiffened up to the point it could not rotate normally. When this happened the axle spun within the inner race of the bearing. The consequent generation of a large amount of frictional heat between the axle and bearing resulted in the axle being locally heated to a high temperature and weakened to the point it could no longer carry its normal loading.

Figure 3: Passenger train derailment at East Langton; the derailed wheel (left) and the fractured axle (right)

Key evidence about the condition of the bearing and its fit onto the axle was destroyed in the failure but it was possible to identify that the failed output bearing probably had a loose fit on the axle. It became apparent during the investigation that little was known about the effect of loose fits on final drive output bearings and whether it could lead to a catastrophic failure of an axle rather than failure of the bearing only, and if so, the precise mechanism of failure. Tests, procured by the vehicle manufacturer in support of the investigation were carried out at the gearbox manufacturer’s testing facility to investigate the failure mechanism. Unfortunately the tests proved inconclusive and although it was not possible to be certain that a loose bearing fit could lead to a catastrophic failure, there was however sufficient evidence in the RAIB’s view for it to conclude that the failure was probably caused by the loose bearing fit.

This is an example of research carried out during the course of an investigation to establish the causal chain. However, such research is by nature limited in scope and by the timescales of an investigation. It is a good example of an issue which would benefit from more comprehensive research by academia in the interests of improving knowledge of bearing performance and vulnerabilities, which could have benefits for railway gearbox design, maintenance and safety in the future.

6.2 Understanding derailment margins and the effect of offset loads

At about 02:40 hrs on 15 October 2013, a train carrying freight containers from Birmingham to Felixstowe, derailed close to the former Primrose Hill station [5]. The rear bogie of the fifth wagon had derailed on curved plain line and ran derailed for approximately 0.6 miles (0.9 km) before reaching Camden Road West Junction. At this location, the leading bogie of the same wagon also derailed and an empty container toppled from the wagon (Figure 4). The train stopped shortly afterwards, when its brakes applied automatically due to the damage it had sustained when the leading bogie derailed.

No injuries resulted from this accident but there was damage to the track, electrification equipment, a viaduct wall, the derailed wagon, and the containers it was carrying. The affected lines were subsequently closed for six days with a significant impact on rail services.

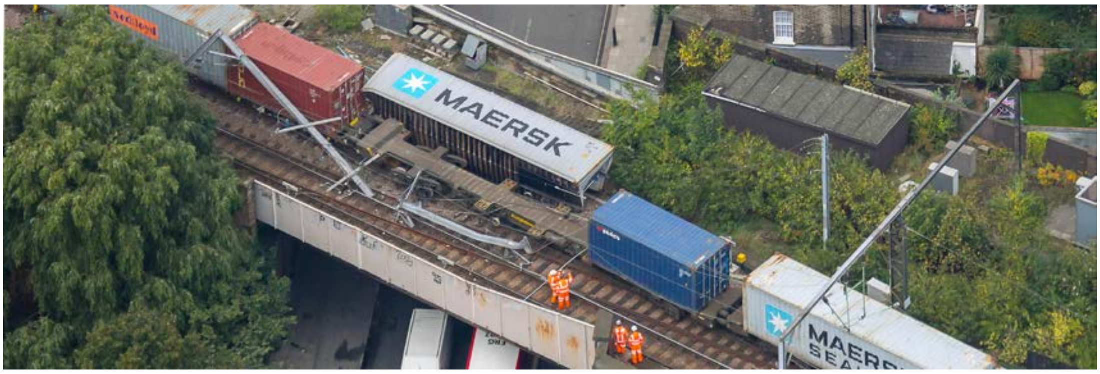

Figure 4: Freight train derailment at Camden Road Junction

The RAIB investigation found that the derailment was caused by a combination of track twist and asymmetric loading of the derailed wagon, which resulted in one of the leading wheels of the wagon becoming unloaded and flange climbing. The RAIB made two recommendations relating to the asymmetric loading of wagons. One recommendation was for the railway industry to work together to assess the risk from asymmetric loading and to identify and adopt reasonably practicable control measures to mitigate that risk. The other recommendation related to clarifying the requirements for the design and acceptance of freight wagons, taking account of the possibility of asymmetric loading.

Asymmetric loading had also been found to be a factor in a previous wagon derailment at Duddeston Junction in 2007 [6]. However, a research proposal put forward by the operator in response to an RAIB recommendation arising from that investigation, had not been taken forward by the industry because it was deemed that the cost of undertaking the research would be disproportionate to the likely benefits. In the light of these and other derailments, the national safety authority instigated a cross-industry meeting in March 2015 to discuss a system wide approach to the problem.

The implementation of the recommendations from the derailment at Camden Road Junction will lead to a better understanding of how asymmetric wagon loading can increase derailment risk and allow appropriate controls to be put in place. It is an example of research which is necessary to prevent future derailments and therefore it has a direct bearing on the safety of the railways.

6.3 Lateral retention of bogies in derailments

On 1 February 2008, a two-car passenger train travelling from Nottingham to Norwich, collided with debris from a footbridge that had been knocked down by the raised body of a tipper lorry at Barrow upon Soar, Leicestershire [7]. The train derailed at a speed of around 65 mph (105 km/h) and ran for a distance of around 170 metres before stopping. While running derailed it passed under a road traffic bridge which was open to traffic (Figure 5). The leading cab was severely damaged and the driver became trapped but survived without significant injury.

Figure 5: Derailment at Barrow on Soar; damaged leading end of train (left); guidance provided by the brake discs (right)

The relatively low consequence of this accident was attributed to two principal factors. Firstly, the strength of the driver’s cab was sufficient to prevent the driver sustaining more serious injuries due to loss of survival space. Secondly, following derailment, the wheels of the leading bogie ran close to the running rails without deviating laterally, despite the track being curved. This was because the running rail had become trapped between the wheel and left-hand brake discs on each of the two derailed wheelsets (Figure 5). The wheelset design was such that the cast iron axle-mounted brake discs extended just below the head of the running rail when the derailed wheels were running on the sleepers, and hence the derailed bogie was effectively guided by the running rails. The guidance provided by the brake discs probably prevented a secondary collision with the road bridge near the stopping position.

The observation that brake discs and some axleboxes can provide effective guidance to derailed bogies, even though they had not been specifically designed to do so, has also been noted by the RAIB in other derailments.

In view of the likely safety benefit of having such a capability in future rolling stock, the RAIB made a recommendation that the industry should investigate the practicability of design elements on the bogie that limit the degree of deviation from the track following derailments. The industry rejected the recommendation following a preliminary assessment on the grounds that any resultant solution may increase the risk of a derailment in the vicinity of points or crossings.

The RAIB considers there are significant safety benefits to having such derailment mitigation devices and still believes research by academia into the safety benefits and any potential drawbacks would be worthwhile. Research has already been undertaken in this field in Sweden, and in Japan some high speed trains are already fitted with these devices.

6.4 Effect of multi-axial acceleration pulses on passengers in derailments

On 23 February 2007, a nine-car passenger train, travelling from London to Glasgow on the West Coast Main Line, became derailed at a set of faulty facing points near Grayrigg in Cumbria [8]. The train speed at the time was 95 mph (153 km/h). All nine vehicles derailed; eight vehicles fell down the nearby embankment and five of these vehicles rolled over onto their sides (Figure 6). The train came to rest within a distance of around 320 metres from the point of derailment. The leading vehicle became detached from the rest of the train and came to rest at the bottom of the embankment, having rotated through 190 degrees.

Figure 6: Derailment at Grayrigg

The train was carrying four crew and 105 passengers. One passenger was fatally injured; 28 passengers, the train driver and one other crew member suffered serious injuries and 58 passengers suffered minor injuries. The principal cause of injuries at Grayrigg was the secondary impact of occupants against the vehicle interior and other occupants. The leading vehicle was subjected to the most extreme movements of any of the vehicles and it had the highest concentration of injuries. Simulations showed there had been significant vertical and lateral accelerations (Figure 7) in addition to the longitudinal forces associated with retardation from bogies. Current UK standards for interior crashworthiness are based on longitudinal accelerations and do not specifically consider accelerations in the lateral and vertical directions.

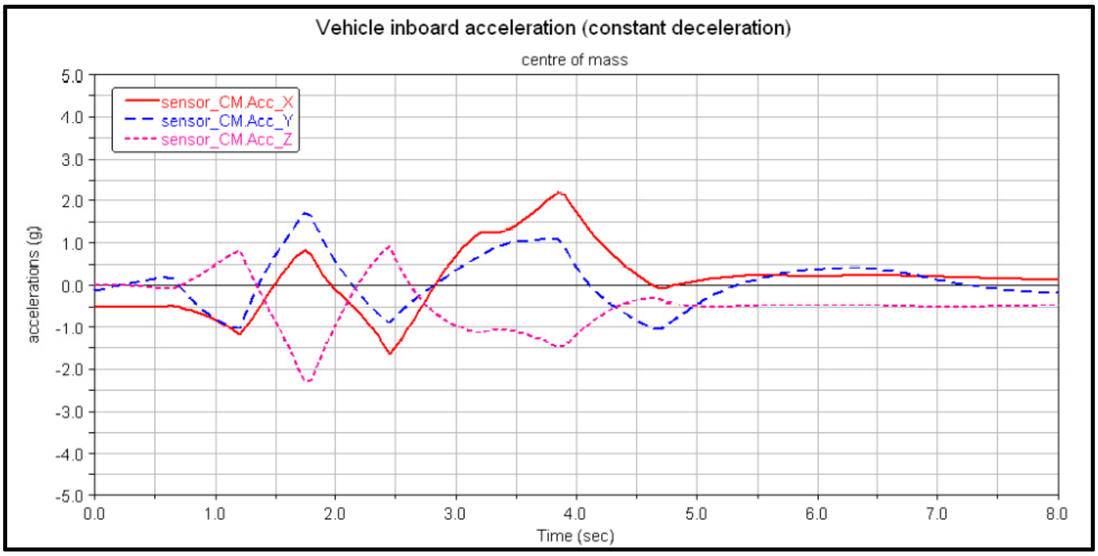

Figure 7: Estimated acceleration pulses for the leading vehicle at Grayrigg

The subsequent RAIB investigation report [8] made five recommendations related to improving passive safety, which included research to study the effect of multi-axial pulses on passengers and interior safety. It is not unreasonable that in the future, vehicle designers should routinely include consideration of vertical and lateral accelerations pulses when they design interior fixtures and fittings such as seats, luggage racks and tables, in order to minimise the risk of serious injury in high speed derailments.

7 Conclusions

Accident investigation can and does make a useful contribution to the development of railway research and technology and should be seen as a potential help and not a hindrance to the development of safety related railway technology.

Apart from the necessary legal route for the dissemination of safety learning through formal investigation recommendations, safety learning should also be disseminated in other, less formal ways, to research and technology organisations whose aims and objectives may be better suited to taking forward research ideas arising from recommendations than railway duty holders.

The paper suggests that to achieve wider dissemination of safety learning from investigations, there need to be better channels of communication between the accident investigation body, research and technology organisations and standards setting bodies. Some possibilities for achieving this are discussed in section 4.

Another requirement for promulgating safety learning is the willingness to think wider than the individual accident which resulted in the recommendation, to undertake a particular programme of research or a technology improvement. Examples from history (discussed in section 5) have shown that significant safety benefits can be gained when safety vision is exercised and used to drive through improvements.

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