

Rail Accident Report



Fatal accident at James Street station, Liverpool 22 October 2011

Report 22/2012
October 2012

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

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Fatal accident at James Street station, Liverpool

22 October 2011

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Summary

At 23:29 hrs on Saturday 22 October 2011, sixteen year-old Georgia Varley was struck and killed by the train 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. Her post-mortem toxicology report recorded a blood alcohol concentration nearly three times the UK legal drink drive limit and she was wearing high heeled shoes at the time of the accident.

The guard dispatched the train while the young person was leaning against it. It is possible that he did this because he had seen her but expected her to move away before the train moved. It is also possible that he looked briefly in her direction but did not see her ('looked but failed to see' is a known phenomenon in routine, repetitive tasks). It is also possible that he did not see her because his attention was on his control panel and a large group of people on the platform.

By the time the guard warned the young person to stand back she had been leaning against the train for approximately eleven seconds. It is not known when the guard saw her during this time or, if he saw her, whether he delayed taking action in the expectation that she would move away. Platform video camera footage shows him warning her to stand back in the moments before the train departs and it is likely he did this because he thought that it would be immediately effective and because he had no direct and immediate way to stop the train.

While the rail industry's overall safety record has improved in recent years, accidents at the platform/train interface have increased, even when accounting for an increased number of passenger journeys over a period of time which saw a known industry hazard (trains with slam doors but no central locking) withdrawn from service. This indicates that the industry's focus on operational matters has not delivered improved safety at the platform/train interface, which suggests that there is a need to consider technical solutions to reduce the risk.

This report makes three recommendations. The objective of recommendation one is for Merseyrail to reduce train dispatch accident risk by improving the way in which it operates its trains. The objective of recommendation two is for Merseyrail to reduce the likelihood of falls through the platform edge gap. The objective of recommendation three is for the Office of Rail Regulation to ensure that the findings of this report are taken into account in published guidance.

Introduction

Preface

- 1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability.
- 2 Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The accident

Summary of the accident

- 3 At 23:29 hrs on Saturday 22 October 2011, sixteen year old Georgia Varley was struck and killed by the train 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.

The location

- 4 James Street is an underground station on the city centre loop line of the Merseyrail network, which is made up of the Wirral and Northern Lines (see figures 1 and 2). The Mersey Railway Tunnel opened in 1886 and connects Liverpool with the Wirral; the underground loop line opened in 1977 and connects Liverpool's city centre stations (James Street, Moorfields, Lime Street and Liverpool Central) with the Wirral lines that converge at Hamilton Square.

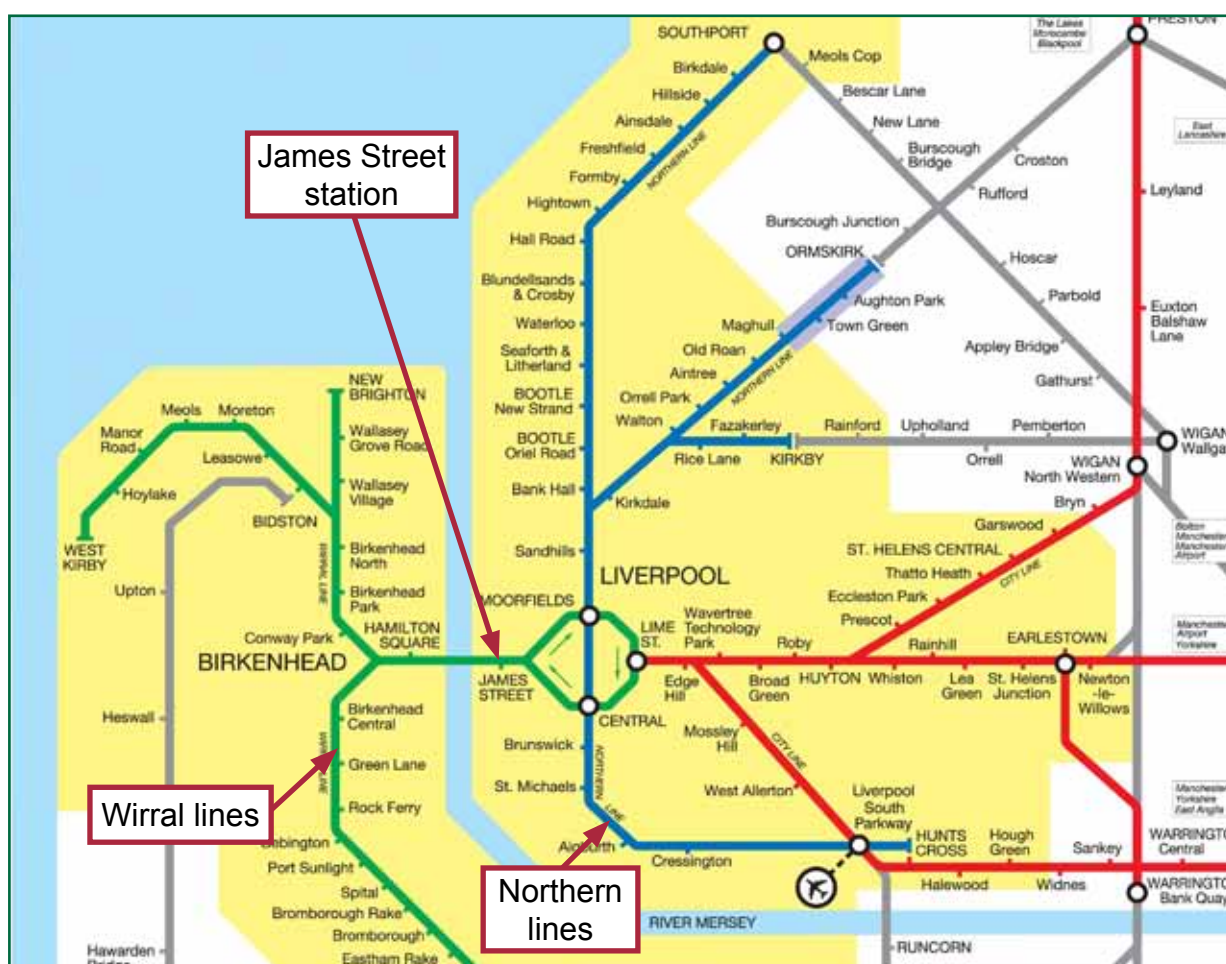


Figure 1: The Merseyrail network



Figure 2: James Street station platform 1

The organisations and employees involved in the accident

- 5 Merseytravel is the operating name of the Merseyside Integrated Transport Authority and Executive; it acts in partnership with private bus and train operators to provide public transport in Merseyside. Merseyrail was the operator of the train, the employer of the train driver and the employer of the guard. Network Rail is the manager of the infrastructure on which the accident happened and the employer of the signallers that control train movements in the area.

The train

- 6 Train number 2W58, the last train from West Kirby to Liverpool city centre and back, was formed by three-vehicle electric multiple unit number 508139. The train was scheduled to depart from West Kirby at 23:01 hrs, call at James Street at 23:29 hrs and terminate at West Kirby at 00:07 hrs Sunday morning. Merseyrail services are operated by class 507 and class 508 electric multiple units, all of which were manufactured in the late 1970s and early 1980s. Both types of unit comprise three vehicles, have a driving cab at each end and work as a single unit or coupled pair.

The events preceding the accident

- 7 The driver and guard reported for duty at 15:56 hrs on Saturday 22 October 2011 and were scheduled to operate trains from West Kirby to Liverpool Central and back until their shift ended with the last train. When the last train from West Kirby arrived at Manor Road, the young person was among a large group of people that boarded its centre vehicle. The driver and guard recalled that the train was full and many of the passengers were loud and boisterous, which was normal for the last train on a Saturday night.
- 8 The young person first left the train at Meols, the first stop after Manor Road. When the guard pressed the door close button on his control panel (figure 3), the young person's friends held the passenger doors open and called for her to rejoin the train. The guard walked down the platform from his position at the rear of the train to investigate why the passenger doors had not closed. However, the young person had boarded the train and the doors had closed before he reached them, so he returned to his control panel and dispatched the train. The guard recalled seeing the young person on the platform before she got back on board and recalled that she appeared to be under the influence of alcohol. Figure 4 shows the train's layout and the guard's position at the rear of the train in an area separate from the passenger saloon.

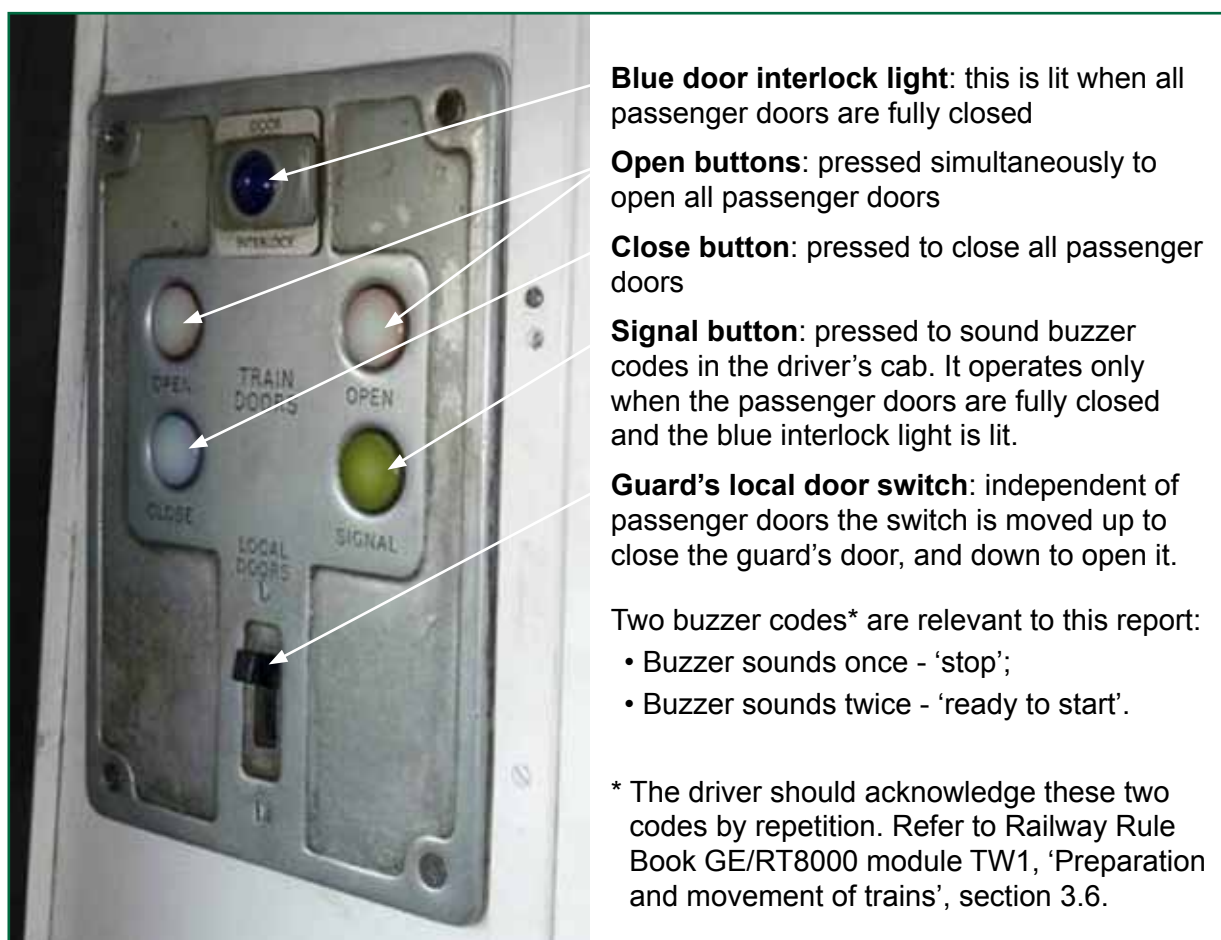


Figure 3: The guards' control panel

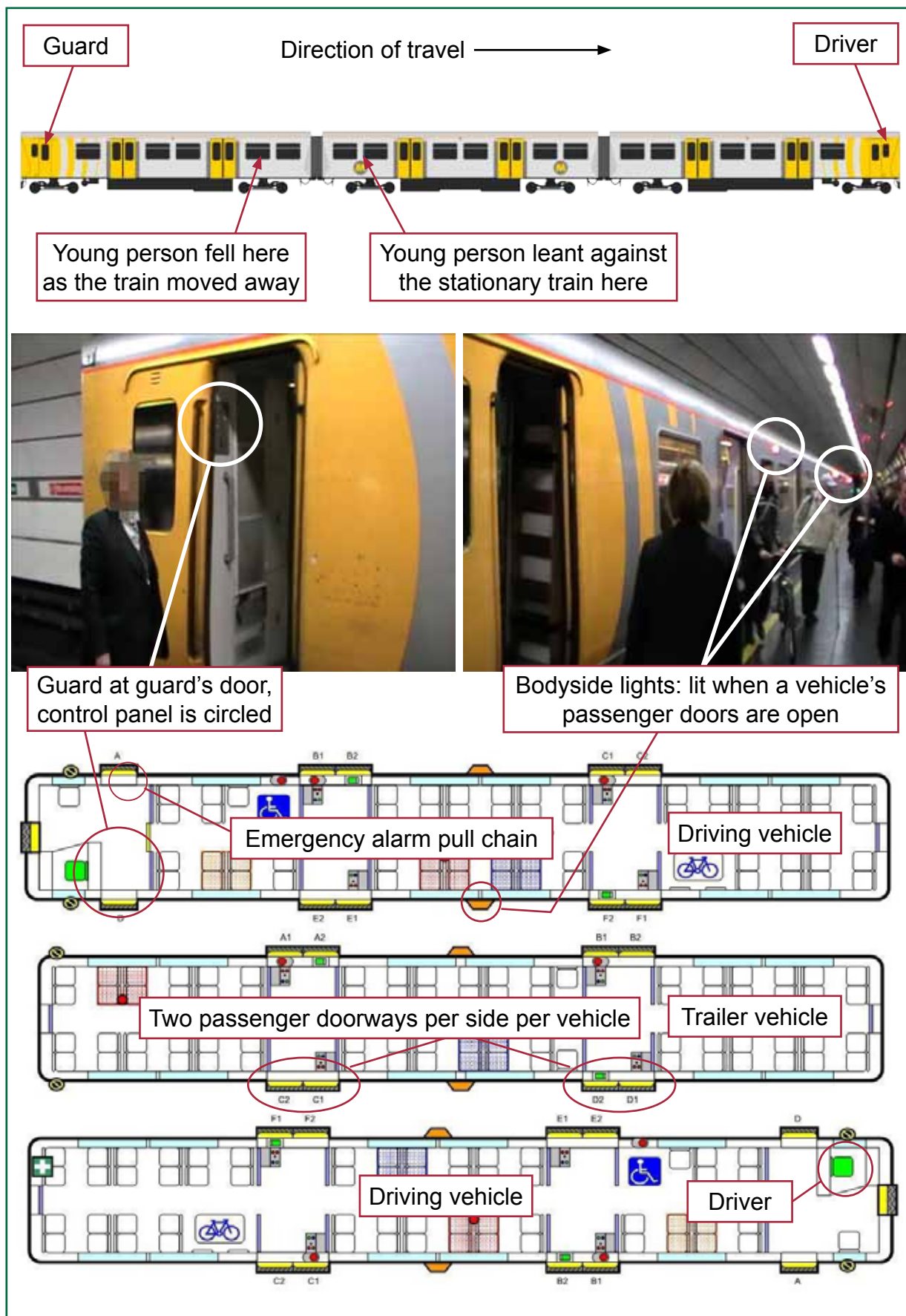


Figure 4: The Merseyrail unit and the locations of those involved in the accident (reader note – the people in the photographs were not involved in the accident)

The events during the accident

- 9 Figure 5 is a timeline of events recorded by the video camera on James Street platform 1 and the train's data recorder. The timeline begins with the train stopped at James Street at 23:28 hrs, at which time the guard was standing at his open door at the rear of the train in his area separate from the passenger saloon.
- 10 A large group of passengers left the train's centre vehicle and walked in the direction of the guard who stepped down from the train and faced in their direction (figure 5a). Between 40 and 50 passengers remained on board the train. The guard remained standing on the platform facing the large group as he pressed the door close button, which initiated the door close sequence and sounded audible warning devices for approximately four seconds.
- 11 Immediately the audible warnings stopped the passenger doors started to close, the guard stepped back into the train, the young person disembarked and went straight to the tunnel wall (figure 5b). At this time many of the large group of passengers turned to look in the young person's direction as they walked along the platform, possibly because she and her friends were shouting to one another at a level loud enough to be heard by the train driver in her cab.
- 12 Five seconds after the young person had disembarked the guard briefly re-opened and then closed the passenger doors, during which time no-one attempted to get on or off the train, the young person remained at the wall and the large group of passengers continued to walk towards the guard. A second after the audible devices began to sound, the young person began to walk towards the train but did not attempt to board it; instead, she placed her hands on a window near to the doorway and leant against the train (figure 5c). At this time, according to a statement obtained from the British Transport Police, a friend who was onboard told her to stand back and wait on the platform because she was going to come back for her.
- 13 From his position at the rear of the train the guard can only communicate with the driver by using the control panel to send and receive codes. The train's design ensures that the guard cannot send codes until the passenger doors are closed, the bodyside lights have gone out (see figure 4) and the blue interlock light is lit (see figure 3). Platform video camera footage shows that the young person placed her hands on the train before the doors had fully closed because the bodyside lights had not gone out. Therefore, the guard must have sent the 'ready to start' code after the young person had placed her hands on the train. The driver repeated the 'ready to start' code, released the train's brakes and prepared to set off.
- 14 The young person turned to look in the direction of the guard as the last person in the large group left the platform through the exit opposite the guard's door. The guard stated that he warned the young person to stand back and platform video camera footage shows that he gestured with his arm for her to move away from the train (figure 5d) but she continued to lean against it.

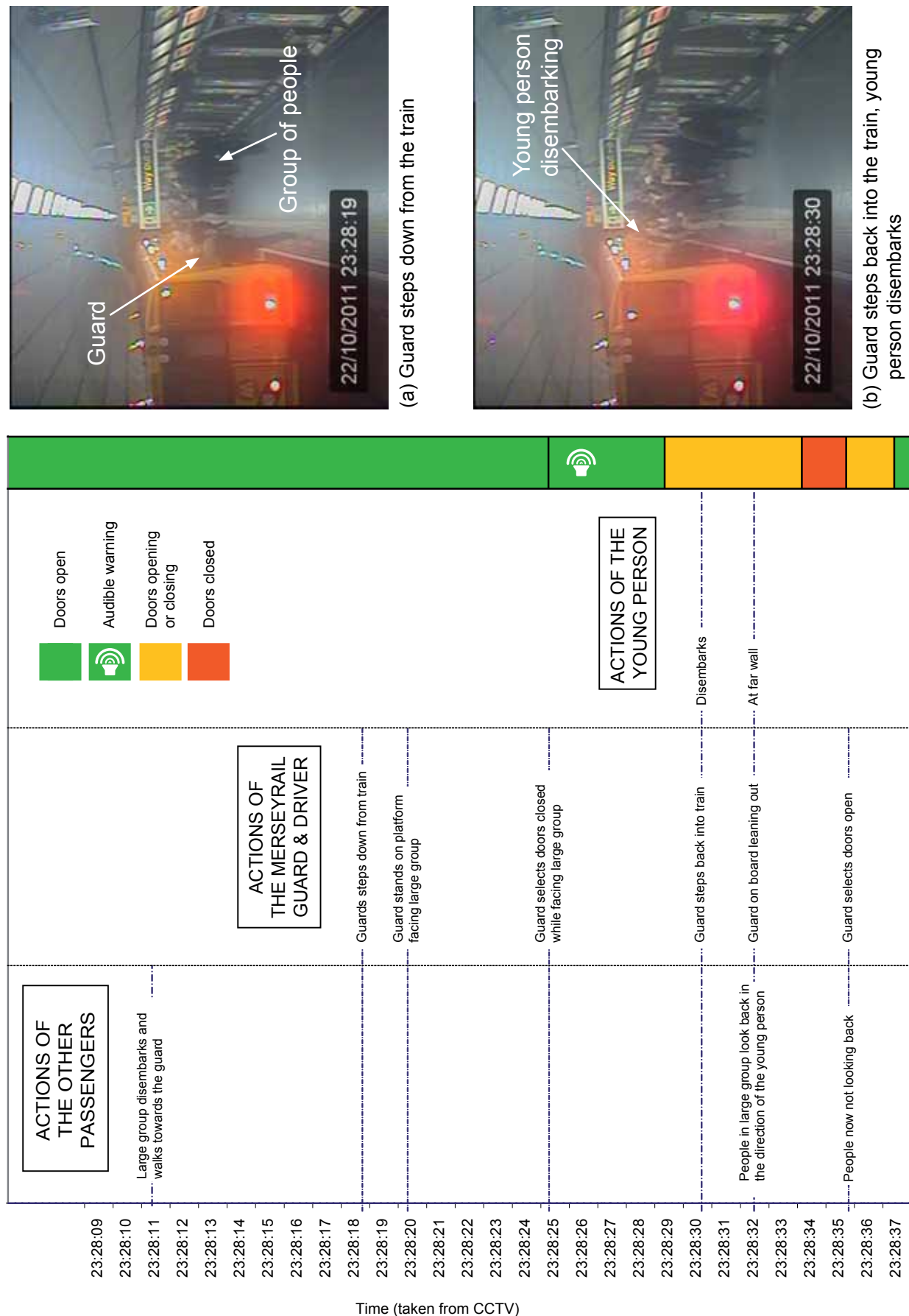


Figure 5: Timeline of events recorded by the video camera on platform 1 and the train's data recorder

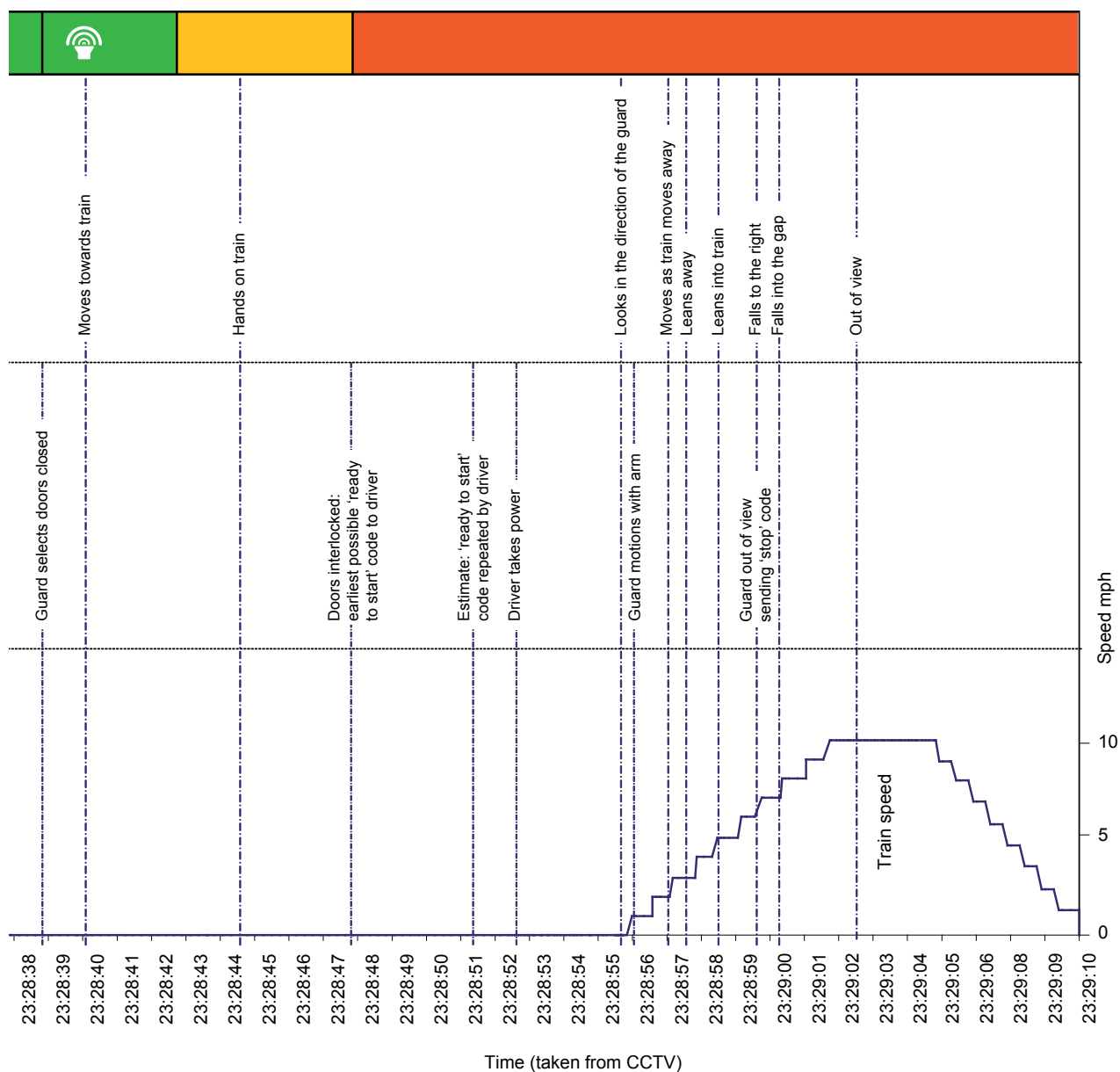


Figure 5 (continued): Timeline of events recorded by the video camera on platform 1 and the train's data recorder



(c) Young person leans against the train



(d) Guard warns the young person to stand back

- 15 When the train moved, the young person moved with it before leaning back and off the train. She then leant back into contact with the train, now travelling at approximately 5 mph (8 km/h) and fell to her right. On seeing her fall the guard pressed the signal button to send the 'stop' code to the driver. The driver made an emergency brake application and the train slowed from 10 mph (16 km/h) to a stop, by which time the young person had fallen through the platform edge gap onto the track and sustained fatal injuries. From start to stop the train travelled 33 metres.

The events following the accident

- 16 The guard stepped down from his open door to the platform and saw the young person on the track behind the train. He then went to the rear cab and used the cab-to-cab telephone to tell the driver that a person had fallen from the platform and been killed. The driver contacted Network Rail control to request an emergency isolation of electric power to the conductor rail. She then made an announcement over the public address system advising passengers that there had been an accident and that they should remain on the train.
- 17 The guard called Merseyrail control's emergency line to report the accident and request assistance, and the driver and guard were subsequently joined by two other Merseyrail employees and the emergency services. British Transport Police officers helped the Merseyrail employees with the passengers on the platform, took the first accounts of witnesses and helped evacuate the station before returning operation of the railway to Merseyrail at 01:00 hrs on Sunday 23 October.

The investigation

Sources of evidence

- 18 The following sources of evidence were used:
 - a. witness statements;
 - b. information from the train's data recorder;
 - c. footage from platform and on-train video cameras;
 - d. site photographs;
 - e. Merseyrail information on the train, the driver and its guard;
 - f. voice recordings of communications between the driver, the guard and the control room;
 - g. a review of similar accidents and incidents; and
 - h. a review of studies and research into train dispatch, accidents at the platform/train interface and the contribution of alcohol to railway risk.
- 19 The following organisations assisted the RAIB with advice and information during its investigation: RSSB¹, Transport for London, Newcastle Tyne and Wear Metro, Manchester Metrolink, the Mass Transit Railway Corporation Limited (MTRCL), the Kowloon-Canton Railway Corporation (KCRC), Mott MacDonald, Network Rail, the Office of Rail Regulation (ORR), the British Transport Police (BTP), ASLEF, the Operations Focus Group (OFG), the United States National Transportation Safety Board (NTSB), the U.S. Department of Transportation Federal Railroad Administration (FRA) and the European Rail Agency (ERA).

¹ The company that trades as RSSB is registered as the Rail Safety and Standards Board.

Key facts and analysis

Background information

Risk and passenger numbers

- 20 The number of passenger journeys per year on Merseyrail has increased from 28 million in 2002 to 42 million in 2011. While over time some stations have seen passenger numbers reduce and others increase, more passengers have always used Merseyrail's loop line underground stations than its outlying surface stations. This is because trains on the lines from West Kirby, New Brighton, Chester and Ellesmere Port all run into the loop line and because the city centre stations are near to many places of work, leisure and connections for the airport, buses and other trains.
- 21 Figure 6 shows that since 2008, James Street has seen the greatest increase in passenger numbers at an underground station. It also shows that since 2009 it has been the second busiest station on the loop line after Liverpool Central. This is because James Street is the nearest station to a recently redeveloped part of the city with attractions including Liverpool ONE², the Echo Arena³, the docks and city nightlife. The platforms at Merseyrail's underground stations are often more congested than those at its surface stations because trains are more frequent, many more people get on and off those trains and space to stand is limited.

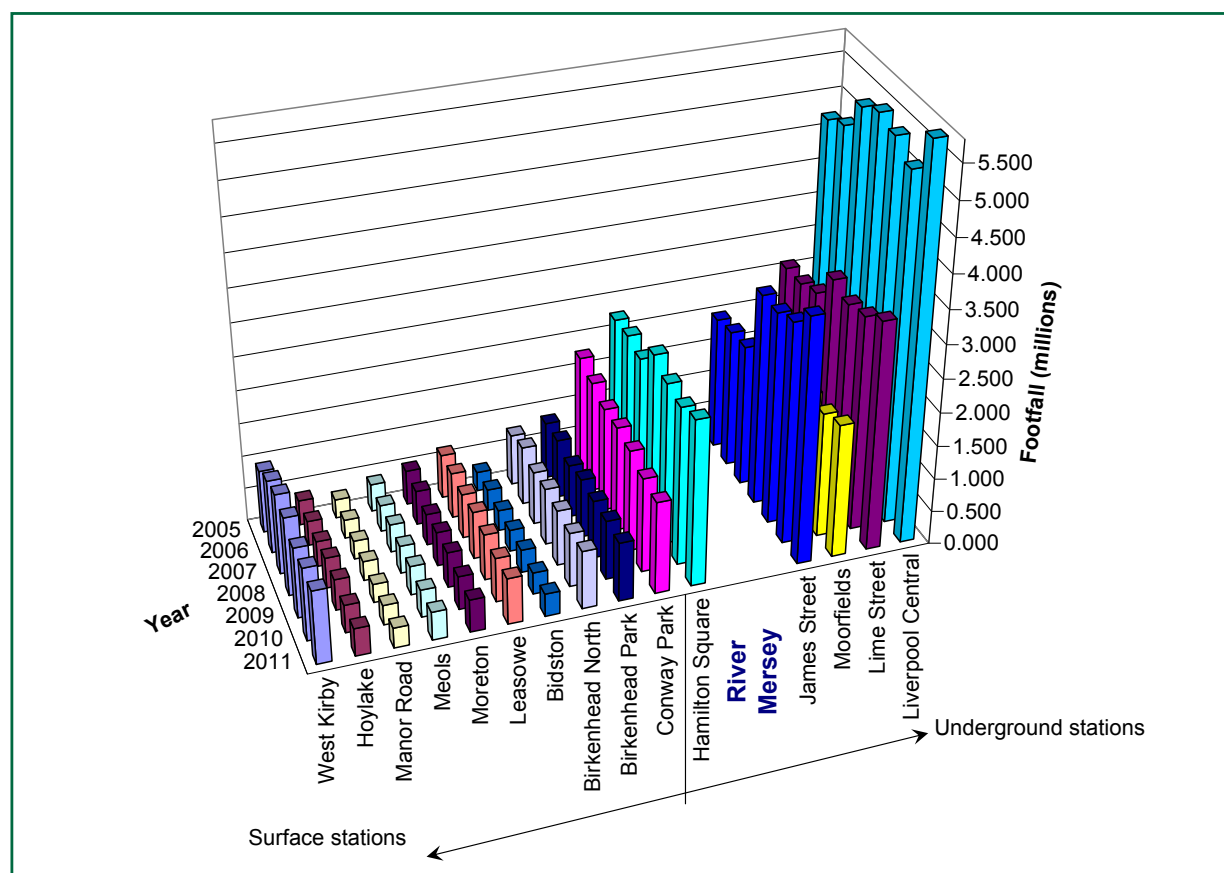


Figure 6: Passenger numbers using the stations on the West Kirby line

² Liverpool ONE, the UK's largest outdoor shopping centre, opened in 2008.

³ The Echo Arena, the UK's eleventh largest arena by capacity, opened in 2008.

- 22 RSSB published research in 2006⁴ which found that for a given location, the number of recorded platform/train interface incidents appeared closely linked to the number of platform/train interface movements. For this reason, RSSB's report concluded that the greatest benefit in terms of risk reduction was likely to be gained by focusing on the busiest stations. Merseyrail had not identified James Street as a station requiring particular focus for risk reduction.

Merseyrail's procedure for dispatch from underground stations

- 23 At the time of the accident, Merseyrail's published procedure for dispatch⁵ was the same as the procedure for dispatch in the Railway Rule Book⁶. The procedure requires a guard to close all doors except the door at which they are working, check that the door interlock light illuminates (see figure 3) and then stand on the platform to carry out a safety check along the whole length of the train. The guard then boards the train, closes the adjacent door and, once it is closed, sends the 'ready to start' code.
- 24 The RAIB used Merseyrail's video of best practice train dispatch to the published procedure to calculate that approximately 12 seconds passes between the guard boarding the train, waiting for the adjacent door to close, sending and receiving the 'ready to start' code and the train moving out of the station. This is a period of time during which serious accidents may occur because a guard may not be able to see and react to events at the platform/train interface because of the narrow field of view through the door's fixed window (see figure 12).

Unauthorised methods of dispatch

- 25 The RAIB viewed platform video camera footage from Merseyrail's busiest underground stations in the days before the accident which showed that some guards used unauthorised methods to dispatch trains. Under one unauthorised method, guards closed the passenger doors, boarded the train and sent the 'ready to start' code as their door began to close, which could reduce the station dwell time by up to 6 - 7 seconds and help trains keep to time. Merseyrail was aware of this unauthorised method but had not included it in its published procedure.
- 26 Platform video camera footage also showed some Merseyrail guards who briefly re-opened and then closed the passenger doors immediately before they dispatched the train. When guards were asked about this, they said they did it as a prompt, otherwise some passengers would not attempt to board or disembark until the train was about to leave, which caused delays. Some guards also remained at their open door as their train moved out of the station, which gave them the opportunity to see and react to events at the platform edge for the period of time during which serious accidents may occur.
- 27 After the accident, full compliance with Merseyrail's published dispatch procedure resulted in significant delay to trains. The service became more punctual after Merseyrail formalised the unauthorised method described in paragraph 25 and included it in their published dispatch procedure. See also paragraph 69.

⁴ T426 Minimisation of accidents at the platform/train interface Halcrow Group Limited. Published in 2006 by RSSB.

⁵ Merseyrail local instructions for working of trains, CSM/3.6 issue 10 December 2009.

⁶ Rule book GE/RT8000 module SS1, station duties and train dispatch, section 8.3. Published in 2003 by RSSB.

Identification of the immediate cause⁷

- 28 The young person fell through the platform edge gap and onto the track as the train began to move out of the station.

Identification of the causal factors⁸

- 29 The causal factors were that:
- The guard sent the driver the 'ready to start' code, and no subsequent 'stop' code, while the young person was leaning against the train;
 - The young person fell as the train was moving out of the station;
 - The platform edge gap was wide enough for her to fall through onto the track; and
 - The guard had no direct and immediate way to stop the train from moving.

The guard sent the driver the 'ready to start' code, and no subsequent 'stop' code, while the young person was leaning against the train

- 30 There are three possible reasons for why the guard sent the driver the 'ready to start' code, and no subsequent 'stop' code, while the young person was leaning against the train:
- he had seen her but expected her to move away (paragraph 31); or
 - he had not seen her because his attention was elsewhere, for example on a large group of passengers and on the train's door control panel (paragraph 32); or
 - he looked briefly in her direction but did not see her (paragraph 33).
- 31 With regard to the first possibility, video camera footage shows the guard at his open door and the young person leaning against the train approximately eleven seconds before he warned her to stand back. He therefore had sufficient time to carry out a safety check as required by the dispatch procedure (see figure 7 for an example of the safety check being carried out). It is probable that if the guard had carried out the safety check at this time he would have seen the young person because there was nothing between them to restrict his view.
- 32 The second possibility is that the guard had not seen the young person. A large group of passengers took up the width of the platform and restricted his view of her while she was at the wall and then as she approached the train (see figure 8). His attention may have continued to focus on this large group as they walked towards him and through the exit opposite his open door. It is also possible that his attention went from the platform to the control panel as he pushed the button to close the doors, watched for the blue interlock light and then pushed the signal button twice to send the driver the 'ready to start' code (see figures 3 and 9).

⁷ The condition, event or behaviour that directly resulted in the occurrence.

⁸ Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

- 33 The third possibility, that the guard had looked briefly in the young person's direction but did not see her, cannot be completely discounted because 'looked but failed to see' is a known phenomenon in routine, repetitive tasks. A study into road traffic accidents published in 2006⁹ stated that 'looked but failed to see' was a contributory factor in almost 21% of accidents at road junctions and in over 8% of accidents away from junctions. 'Looked but failed to see' was recorded most frequently at private drives or entrances, and almost as frequently at mini-roundabouts. Dispatching a train is a routine, repetitive task that the guard would have carried out several hundred thousand times in his career before the dispatch that caused the accident.
- 34 After the guard boards the train and stands at his open door, the platform video camera footage does not show him in enough detail for the RAIB to determine the direction in which he is looking or his line of sight at key times. Image clarity is further reduced by the periodic orange 'flare' from the train's lights and destination indicator (see figure 8)¹⁰. The RAIB could also not determine where the guard was looking at key times from his account of events because his recollections were not reliable or conclusive¹¹. For example he recalled that the young person came back to the train and was possibly knocking on the window when he closed the doors. However, video footage and information from the train's data recorder contradict this account because on both occasions the young person was at the platform wall and away from the train when he pressed the button to close the doors.

The young person fell as the train was moving out of the station

- 35 The young person was leaning against the train when it began to move out of the station and she moved with it before leaning back and off the train. She then leant back into contact with the train before falling to her right. The young person's post-mortem toxicology report recorded a blood alcohol concentration (BAC) of 236 milligrams of alcohol in 100 millilitres of blood and she was wearing high heeled shoes at the time of the accident.
- 36 The toxicology report concluded that her blood alcohol concentration was nearly three times the UK legal drink drive limit of 80 milligrams of alcohol in 100 millilitres of blood, which would cause a high level of intoxication in the average social drinker, most of whom would experience adverse effects including a lack of co-ordination and impaired judgement. The toxicology report also recorded evidence of mephedrone¹² in the young person's blood. However, the report concluded that the drug's influence on her behaviour was not known as there is little published information on expected blood concentrations following use or how quickly it is eliminated from the body.

⁹ The Department for Transport: A review of the 'looked but failed to see' accident causation factor.

¹⁰ The RAIB enhanced the video footage to improve its clarity by adjusting contrast, adjusting brightness and by using colour filtering to eliminate orange 'flare'. The RAIB also viewed video footage enhanced by a video specialist consultancy working on behalf of the British Transport Police.

¹¹ A clinical psychologist assessed the guard after the accident and prepared a psychological report on him. The report, which was made available to the RAIB, stated that discrepancies in the guard's account were highly likely to be due to psychological shock and distress.

¹² Mephedrone (4-methylmethcathinone) is a synthetic drug.

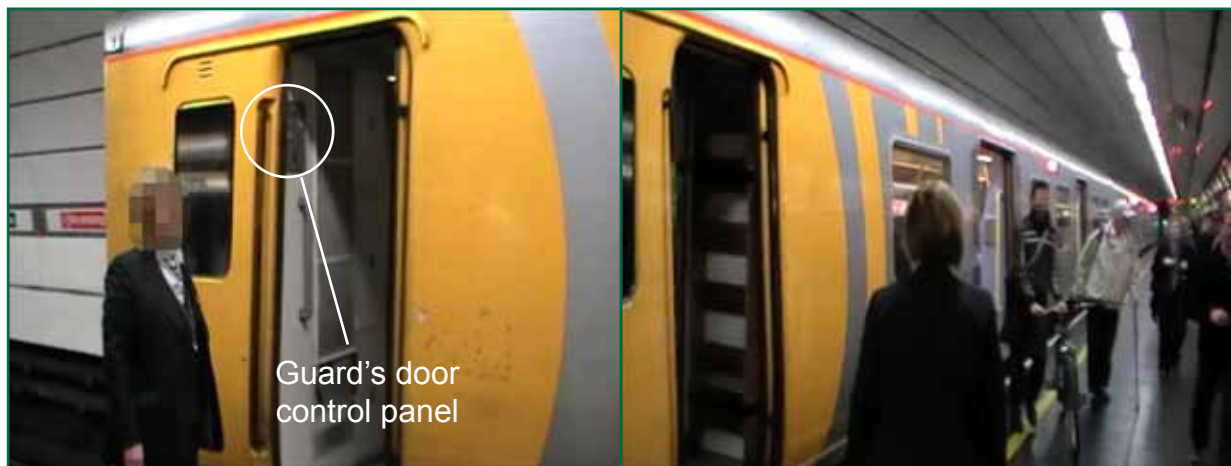


Figure 7: A guard carrying out a safety check



Figure 8: Train stopped at James Street station



Figure 9: A guard looking away from the platform to use the door control panel

The platform edge gap was wide enough for her to fall through and onto the track

- 37 The platform edge gap was approximately 300 mm measured diagonally as shown in figure 10; this was wide enough for the young person to fall through and onto the track. The rail industry does not set a limit on the size of the platform edge gap; instead it sets limits on the position of the passenger door footstep relative to the platform edge and the position of the platform relative to the track^{13,14}. Table 1 provides a comparison of James Street's platform 1 measurements with industry requirements, figure 10 is a photograph of the gap and figure 11 is a photograph of a police officer, similar in size to the young person, adjacent to the gap.
- 38 A platform edge gap is necessary for trains to operate. If the gap is too small trains would strike the platform as they pass through and if the gap is large people may fall through it. The gap varies because the main line railway was built over many years by many different organisations and so not all platforms were built to uniform dimensions. The gap may also increase to accommodate some or all of the following:
- freight, passenger and engineering trains of different sizes, if different types of trains operate on the same line;
 - trains that pass through at high speed, because their vehicles roll and sway laterally on their suspensions;
 - trains on curved track, because their vehicle centres and ends overhang the track by different amounts depending on their width, length and suspension geometry;
 - trains standing on canted (banked) track, because their vehicles tilt and move laterally on their suspensions; and
 - the position of the track relative to the platform allowed by maintenance tolerances.

The gap can be made much smaller on platforms with straight, level track served by trains of uniform size and suspension that do not pass through at speed. All these conditions prevail at James Street station platform 1.

The guard had no direct and immediate way to stop the train from moving

- 39 By the time the guard warned the young person to stand back she had been leaning against the train for approximately eleven seconds. It is not known when the guard saw her during this time or, if he saw her, whether he delayed taking action in the expectation that she would move away. Platform video camera footage shows him warning her to stand back in the moments before the train departs and it is likely he did this because he thought that it would be immediately effective and because he had no direct and immediate way to stop the train from moving.

¹³ Railway Group Standard GI/RT7016 'Interface between Station Platforms, Track and Trains'. Issue 4 published in 2010 by RSSB.

¹⁴ Railway Group Standard GC/RT5212 'Requirements for Defining and Maintaining Clearances'. Issue 1 published in 2003 by RSSB.

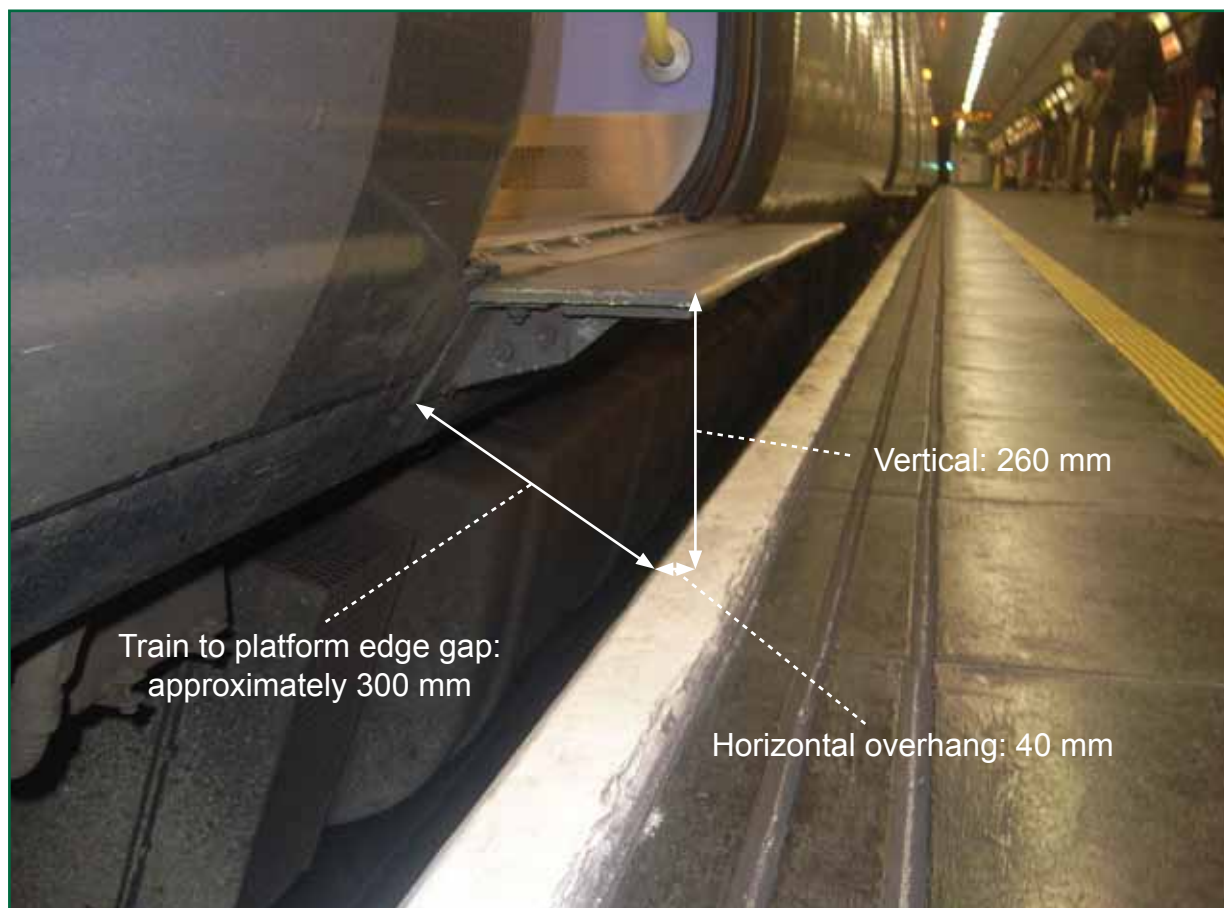


Figure 10: The train to platform edge gap and measurements to the footstep



Figure 11: The gap and a police officer similar in size to the young person (but wearing heavier, protective clothing) (courtesy of British Transport Police)

FOOTSTEP TO PLATFORM EDGE	James Street platform 1 measurements (mm)	Industry maximum dimensions (mm)	Comparison with requirements
Platform edge to footstep: vertical	260	250	Does not comply but reducing the dimension to 250 mm would have little effect on the platform edge gap
Platform edge to footstep: horizontal	40 (overhang)	275 (gap)	Complies
Platform edge to footstep: diagonal	Not applicable due to overhang	350	Not applicable
Platform edge gap	Approximately 300	No requirement	No requirement

PLATFORM EDGE TO TRACK	James Street platform 1 measurements (mm)	Industry maximum dimensions (mm)	Comparison with requirements
Platform edge to nearest rail	733 - 745	730 - 745	Complies
Platform height above rail level	890 - 912	890 - 915	Complies

Table 1: Measurements made at James Street platform 1 compared with industry requirements

Other areas considered by the investigation

Experience, competence and fitness for duty

- 40 The guard had worked on the Merseyrail network from 1990 and as a guard from 1992. Merseyrail trained and assessed the guard, certified that he was competent and medically fit for his duties, and confirmed that he had not had a safety related event until the accident in October 2011. Merseyrail's process for ensuring the competence of their guards is based on a two year repeating cycle of formal assessments and observations while on duty. In the 15 months leading up to the accident, the guard was formally assessed three times (he was last assessed on 19 October 2011) and observed during the course of his duties on nine occasions (he was last observed on 12 August 2011 at James Street).
- 41 The driver had worked on the Merseyrail network from 1989, first as a guard and from 1996 as a driver. Merseyrail trained and assessed the driver, certified that she was competent and medically fit for her duties and confirmed that she had not been involved in a safety related event until the accident in October 2011. The driver's actions are not factors in this accident.
- 42 Rail industry organisations usually test members of their staff for the presence of drugs and alcohol if they suspect that their performance may have contributed to an accident¹⁵. The driver and guard were not tested after the accident because British Transport Police initially concluded that the accident was non-suspicious (ie they had no reason to suspect that a crime had been committed). The driver and guard were seen by many people during the time that they were on duty and nothing was reported that would indicate that either was under the influence of drugs or alcohol.

¹⁵ Railway Group Standard GE/GN8570. Guidance on the Management of Drugs and Alcohol. Issue One December 2008. Published by RSSB.

The train and its operation

- 43 At the time of the accident neither the guard nor the driver used a mobile phone or any other device that could have affected their attention and there is no evidence that the guard or the driver were under any time pressure. The train was on time and its data recorder confirmed that it had travelled at or below its permitted speed on its journey into James Street. Both the driver and the guard considered the events of the journey into James Street as being normal for the last train on a Saturday night.

Alternative courses of action available to the guard immediately before the train's departure

- 44 The RAIB estimated that the guard sent the 'stop' code approximately four seconds after warning the young person to stand back. This is because he had moved into the train and out of view of the platform video camera after seeing her fall. If he had sent the 'stop' code instead of warning the young person he would have taken time to turn and locate the door control panel before pressing the signal button, which the RAIB estimates would have taken over a second to do. The driver would then receive the code less than 3 seconds earlier than she actually did and, if all other events remain the same, the train would have travelled approximately 30 metres before stopping, a distance 3 metres shorter than the actual stopping distance of 33 metres, which would not have affected the outcome of the accident.
- 45 The guard could have pulled the emergency alarm chain (see figure 4) instead of warning the young person to stand back. When the trains were first built this device interrupted the brake control wire and fully applied the train's brake. However the trains were modified for the device to sound an alarm in the cab warning the driver that an automatic brake application will take place within 3 - 4 seconds. Within this time the driver may brake immediately or override the automatic brake application and continue to a better place to stop. Crossing to the other side of the vehicle to pull the emergency alarm chain would not have affected the outcome of the accident because it would have resulted in the driver receiving the alarm later than she received the 'stop' code.
- 46 If the guard had seen the young person but delayed taking action in the expectation that she would move away then there were other alternative courses of action available to him. For example he could have walked along the platform and made sure that she moved to a position of safety or stepped back on board before he gave the 'ready to start' code. Alternatively, he could have called for assistance and had the young person taken away from the platform.

The platform

- 47 Evidence from a site visit, scene photographs and platform video camera footage confirm that at the time of the accident the platform was clean, dry and free from obstacles or contaminants that could have contributed to a slip, trip or fall hazard. Lighting was of a sufficient level to give good visibility at all locations along the platform and there were no fixed obstructions to interrupt the view over its length and breadth.

Observations¹⁶

Merseyrail's management of dispatch

- 48 The guard could have followed Merseyrail's published procedure to dispatch the train when the passenger doors first closed, as they were unobstructed and the platform adjacent to the train was clear. Under the Merseyrail procedure the guard would board and then wait until his door closed before sending the 'ready to start' code. He would not have been able to see the young person approach and come into contact with the train because of his narrow field of view through the door's fixed window (see figure 12) and, if all other events remain unchanged, the outcome would have been unchanged.



Figure 12: A guard viewing James Street station platform 1 from behind a closed door

¹⁶ An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

Train dispatch and passenger risk

- 49 Train dispatch on the mainline railway is a routine, repetitive task carried out many millions of times each year without incident. However there are occasions when people put themselves at heightened risk as a train departs, for example when they lean against it, bang on its side, attempt to board it or run alongside it. On such occasions the person responsible for train dispatch is forced to make a judgment call in a short space of time and in a rapidly changing situation. If they exercise too much caution and stop trains too readily then there is a risk of unnecessary delay. Some passengers would also realise that a way to stop a departing train would be to stand too close to it or to run alongside it and bang on its side.
- 50 Platform/train interface accidents represent the most significant fatality risk for passengers on the main line (see figure 13). RSSB records show that in the five years between April 2007 and March 2012, accidents at the platform/train interface were responsible for 14 fatalities (excluding four cases of electrocution) and over 6000 injuries. The RAIB carried out a review of this accident data to identify which of the accidents involved persons falling through the platform edge gap and found that this type of accident resulted in:
- Four fatalities (Hilsea in 2008, Angmering in 2009, Clapham in 2011 and Liverpool James Street in 2011);
 - 45 major injuries (10 of which involved a moving train);
 - 308 minor injuries; and
 - 1024 very minor injuries.
- The review also showed that the behaviour and actions of passengers were a factor in many of these accidents.
- 51 The railway industry records harm caused to people using a measure known as 'fatalities and weighted injuries'. The measure considers 10 major injuries, 200 minor injuries, or 1000 very minor injuries, each as equivalent to a single fatality. Between April 2007 and March 2012 the RAIB calculated the total number of fatalities and weighted injuries at the platform/train interface to be 50.1 (ie the total harm caused to people was deemed the equivalent of 50 fatalities). The number of fatalities and weighted injuries from falls through the platform edge gap was 11.1 (the equivalent of 11 fatalities), which represents 22% of the total harm caused to passengers at the platform/train interface.

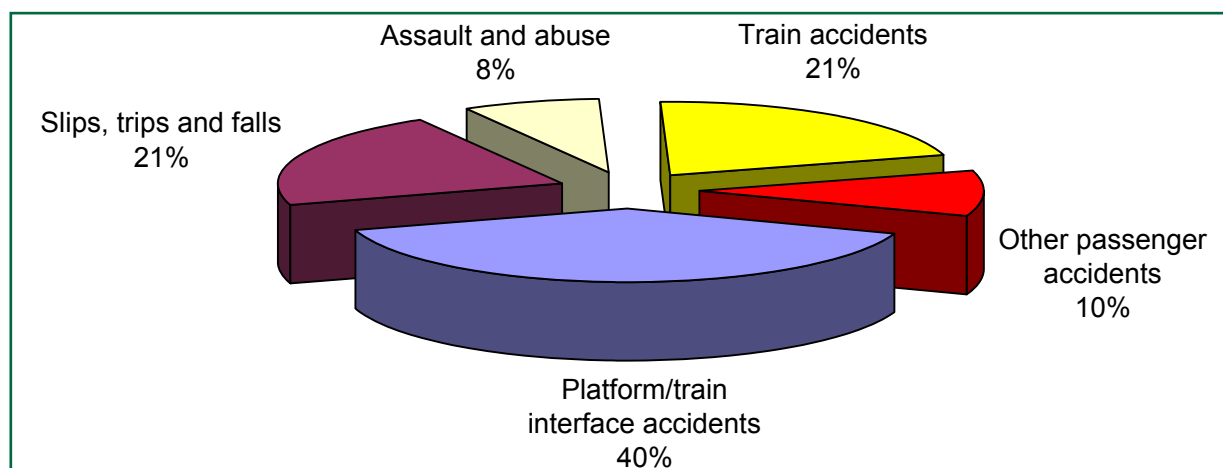


Figure 13: Passenger fatality risk. Information courtesy of RSSB's Safety Risk Model v7

The industry's awareness of platform/train interface risk

- 52 The industry has been aware of passenger risk at the platform/train interface and has worked to reduce it for many years. RSSB has published research on the subject including Minimisation of Accidents at the Train/Platform Interface¹⁷, A Review of Passenger Train Dispatch from Stations¹⁸, Passenger Risk at the Platform – Train Interface¹⁹ and the Rail Industry Standard for Passenger Train Dispatch and Platform Safety Measures²⁰. Red Alert was a four-monthly industry publication that aimed to reduce risk by using rail industry information to inform its readers: it featured platform edge risk in ten of its fifteen issues between February 2007 and November 2011²¹. It has since been replaced by a new rail industry publication called Right Track, issue 1 of which majored on platform/train interface risk.
- 53 The Operations Focus Group's (OFG) aim is to improve railway safety through the development and promotion of campaigns, programmes and tools. Its members include Network Rail, train and freight operating companies, trade unions, London Underground and the Office of Rail Regulation. The Operations Focus Group sponsors the production and distribution of the RED DVD series, which is produced by RSSB on its behalf. In 2011, the Operations Focus Group dedicated the RED 28 DVD to risk at the platform-train interface, including a dramatisation of how an accident can occur.
- 54 The industry's efforts to reduce risk have focused primarily on the operational aspects of train dispatch. For members of staff this has included training and assessment to improve awareness, competence and assertiveness, and briefings to remind them of the need to fully follow dispatch procedures. The guard involved in the accident had received at least eleven briefings on platform/train interface matters between August 2008 and October 2011 and had been shown the RED 28 DVD on risk at the platform/train interface.
- 55 In some organisations, focus on operational matters has resulted in procedures that require the safety check to be carried out several times before every dispatch in an effort to identify and address all possible adverse events, which makes the task more routine and repetitive than before. Some organisations also place additional members of staff on the busiest platforms to help supervise passengers and manage train dispatch. However this task too can become routine and repetitive for those carrying it out.

¹⁷ T426 Halcrow Group Limited and Human Engineering published in 2006 by RSSB.

¹⁸ T743 Transport Research Laboratory, Arthur D Little and Halcrow published in 2008 by RSSB.

¹⁹ A special topic report published in 2011 by RSSB.

²⁰ RIS-3703-TOM issue 1. The Rail Industry's [voluntary] Standard for Passenger Train Dispatch and Platform Safety Measures. Published by RSSB in June 2011.

²¹ See Red Alerts published in February, June and October 2007; March and November 2008; March and July 2009; March and November 2010; and November 2011.

The trend in platform/train interface risk

- 56 While the rail industry's overall safety record has improved in recent years, RSSB research shows that accidents at the platform/train interface have increased since 2005/2006, even when accounting for an increased number of passenger journeys²². The increase in this type of accident has taken place over a period of time which saw a known industry hazard (trains with slam doors but no central locking) withdrawn from service (see figure 14). The increase indicates that the industry's focus on operational matters has not delivered improved safety at the platform/train interface, which suggests that there is a need to consider technical solutions to reduce the risk.

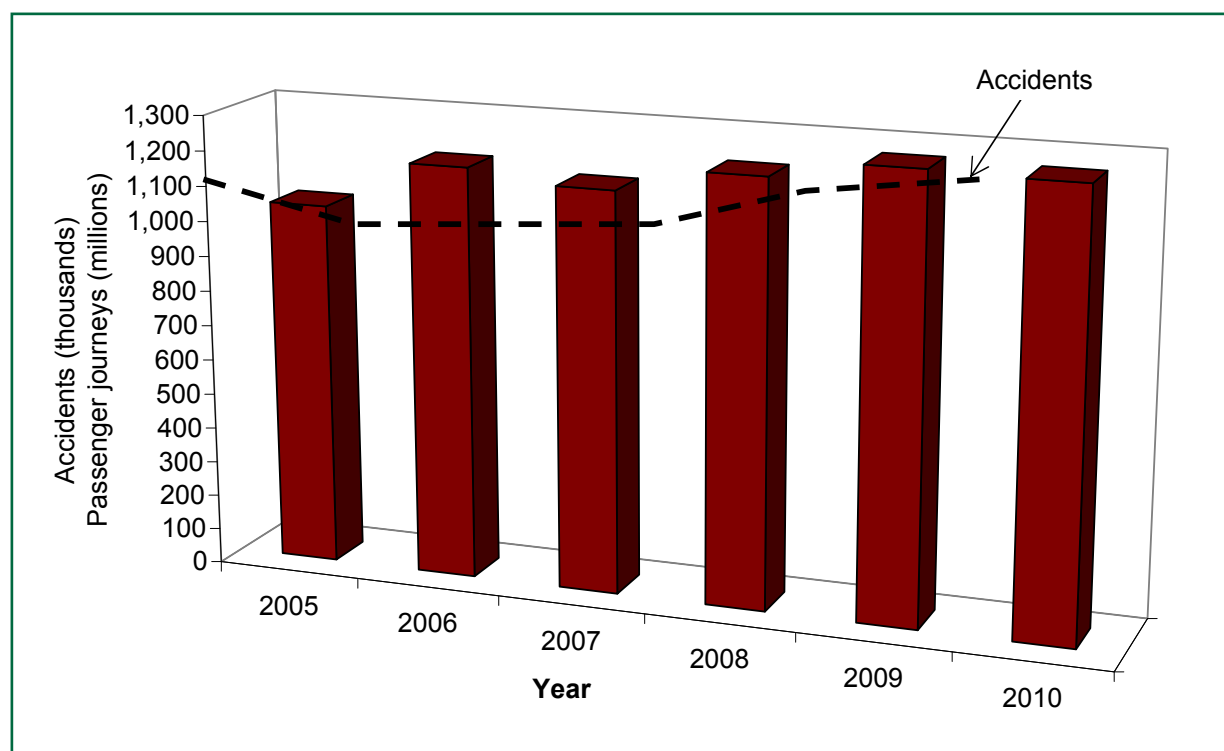


Figure 14: Passenger journeys 2002 to 2010²³ and accidents at the platform/train interface²⁴

Technical solutions

- 57 Some rail industry bodies may judge that technical solutions are not reasonably practicable to carry out when they compare safety benefits with the cost of implementation in a simplistic cost benefit analysis²⁵. However, technical solutions can bring operational benefits because they speed up train dispatch and give the people responsible for dispatch more confidence in the judgement calls they must sometimes make. Technical solutions that prevent accidents or mitigate their consequences also reduce train delays, service disruptions and associated costs. For these reasons, the operational benefits of technical solutions should be fully considered in any cost benefit analysis.

²² 'Passenger risk at the platform-train interface', a special topic report published in 2011 by RSSB 2011.

²³ The DfT's rail trends in Great Britain 2010/11.

²⁴ 'Passenger risk at the Platform-train interface', a special topic report published in 2011 by RSSB 2011.

²⁵ For more information on cost-benefit analysis and reasonable practicability see 'Taking Safe Decisions' published by RSSB in 2009.

- 58 The causal factors of the accident were that the guard sent the driver the 'ready to start' code and no subsequent 'stop' code while the young person was leaning against the train. He did this possibly because he expected her to move away or possibly because he had not seen her. When she did not move away, but instead fell through the platform edge gap, he was unable to stop the train directly and immediately. The following technical solutions are examples of measures that may be employed to address these causal factors.

Allow the person dispatching the train to observe the platform and train fully and without interruption for as long as possible, ideally until the train has left the platform

- 59 The current design standard for guard operated passenger doors requires the 'ready to start' pushbutton to have a tactile surface or surround to aid its operation by touch; it also requires door controls to be located in a position that provides an unobstructed view of the platform/train interface when those controls are used²⁶. Merseyrail's vehicles were built before this standard was in force; their vehicles have guard's controls that cannot readily be differentiated by touch and the controls are located in the opposite direction to the platform/train interface (see figures 3, 4, 7 and 9). The guard's door also only has a fixed window, which provides a very narrow view of the platform when the door is closed (see figure 12).
- 60 Allowing the person responsible for train dispatch to observe the platform and train fully and without interruption for as long as possible, ideally until the train has left the platform, gives them a greater opportunity to see and react to behaviour that would otherwise be unobserved. This could reduce the likelihood of this type of accident happening or the severity of its consequences. Ways to achieve this include:
- Using mirrors fitted to the outside of the train, or cameras that broadcast video footage to in-vehicle monitors (figure 15);
 - Using mirrors or monitors installed on the platform (figure 16);
 - Looking out of an open door (in which case there should be measures in place to prevent the dispatcher falling from the vehicle); or
 - Looking out of an open window (if the window is in a power operated door, there should be measures in place to prevent entrapment if the door were to power open with a person looking out).

Allow the train to be stopped directly and quickly in an emergency

- 61 Allowing the person responsible for dispatch to stop a train directly and quickly in an emergency may reduce the likelihood of this type of accident happening or the severity of its consequences. Ways to achieve this include:
- Providing the guard with an emergency stop button which interrupts the brake control wire and fully applies the train's brake in the same way that an automatic brake application protects the train in the event that its vehicles become separated.

²⁶ RSSB Railway Group Standard GM/RT2473 issue 1 published in 2003. Power Operated External Doors on Passenger Carrying Rail Vehicles.

- b. Providing members of staff that dispatch trains from platforms with an emergency stop button - see figure 17 for an example on London Underground. This solution is made possible because of the sophisticated signalling system; it would be more difficult to apply on conventionally signalled systems.
- c. Placing responsibility for dispatch with a member of staff who has brake controls immediately to hand. If this procedure is adopted it is often in combination with measures that allow the member of staff to observe the platform and train fully and without interruption for as long as possible.



Figure 15: In-vehicle monitor



Figure 16: Platform mirror and monitors



Figure 17: Platform mounted emergency stop button

Make it less likely that a person will fall through the platform edge gap

- 62 Making it less likely that a person will fall through a platform edge gap would reduce the likelihood of this type of accident happening and the severity of its consequences. Ways to achieve this include:
- a. Fitting platform screen doors that open when a train is stopped at the platform. At all other times, platform screen doors act as a barrier to prevent people going onto the track by accident, to retrieve something or in an attempt to commit suicide (see figure 18). It should be noted that the high cost of platform screen doors is sometimes justified on benefits other than safety, for example to control platform air flows or allow station air conditioning. In the UK, platform screen doors are most often installed at new stations and platforms.
 - b. Reducing the gap. A study carried out by the Kowloon-Canton Railway Corporation between 2001 and 2006 showed that where the gap was less than 160 mm the risk of an accident was low but that for gaps of 160 mm or more the accident rate increased²⁷ (see figure 19). Ways to achieve this include:
 - i. Adapting vehicle equipment. This was recognised many years ago by London Underground. Figure 20 shows a 1930s train fitted with a horizontal board that runs the vehicle's length; it acts as a footstep at doorways and elsewhere as a device to block the gap.
 - ii. Adapting the vehicle profile. Vehicles can be designed to suit the infrastructure they operate on, as seen with the Tyne and Wear Metro vehicles in figure 21. Since the late 1930s, trains on the Merseyrail network have been formed of vehicles built to a standard profile so that they can operate elsewhere on the mainline railway (see figures 22 and 23); before then the Merseyrail trains were built to a broader profile and so the platform edge gap was much smaller (see figure 24). It is feasible to fit body side panels to vehicles built to a standard design to reduce the gap. The panels could then be removed if the vehicles are used elsewhere.
 - iii. Adapting the infrastructure. Figure 25 shows a platform edge gap reduced by raising the platform edge. Figures 26 to 28 show the gap reduced by fitting gap fillers to the platform face. The gap fillers are made from blocks with rubber prongs: the prongs are able to support a person's weight vertically and deflect horizontally without damaging themselves or the trains that pass and contact them. The gap can also be reduced by moving the track closer to the platform, moving the platform coping stones closer to the track or both.

²⁷ Managing Railway Operations and Maintenance: Best Practices from KCRC. Edited by Robin Hirsch. Published 2007. ISBN 9780952999720.



Figure 18: Platform edge doors on London Underground (Courtesy of Transport for London)

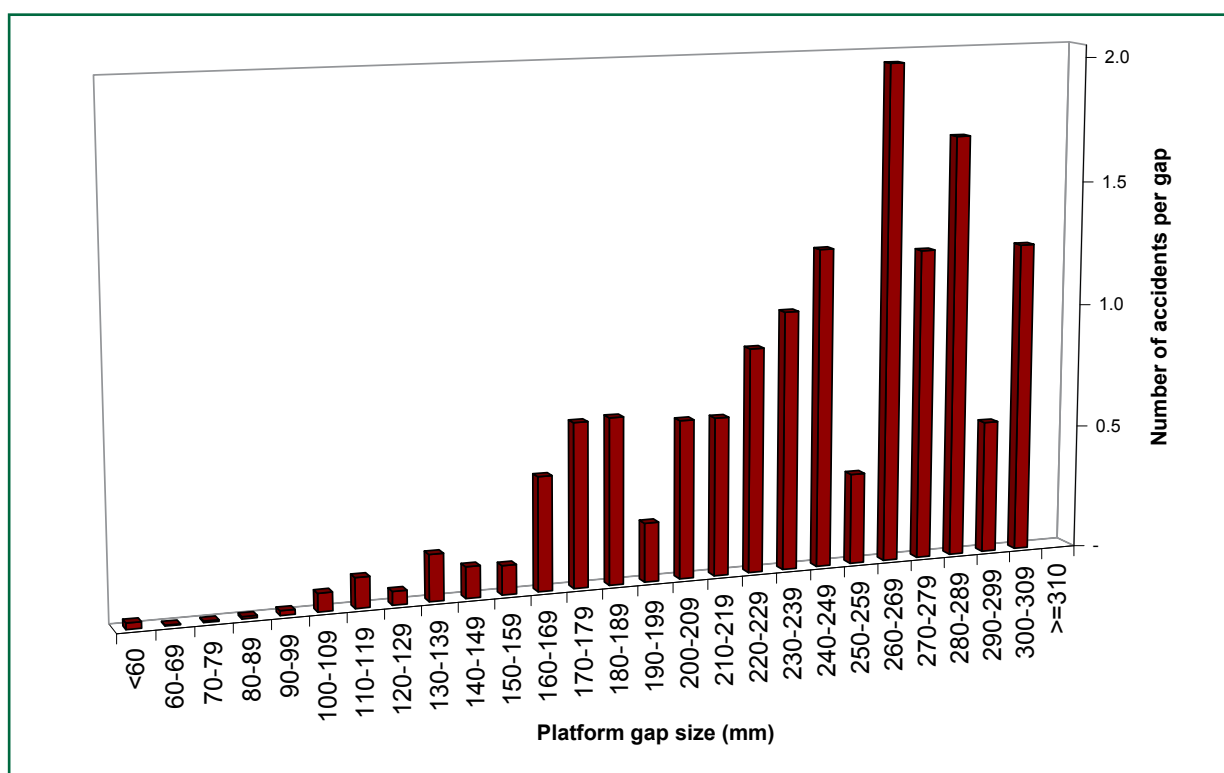


Figure 19: The number of accidents per gap vs. gap width on the Kowloon-Canton Railway between 2001 and 2006²⁸

²⁸ Managing Railway Operations and Maintenance: Best Practices from KCRC. Edited by Robin Hirsch. Published 2007. ISBN 9780952999720. Courtesy of W. Y. Fung and Robin Hirsch.



Figure 20: 1935 district line Q stock at the London Transport Museum



Figure 21: Nexus Tyne and Wear Metro



Figure 22: 508124 at Birkenhead North in 2010 (Courtesy of Neil Bradley/Railway Herald)



Figure 23: 1938 Class 503 stock at Birkenhead North in 1955 (Copyright Ray DeGroote/Online Transport Archive)



Figure 24: 1906 stock at Birkenhead North station in 1955 (Copyright Ray DeGrootte/Online Transport Archive)



Figure 25: The James Street platform edge gap, shown reduced by raising the platform



Figure 26: A platform edge (not on the Merseyrail network)



Figure 27: Gap filler bolted to the platform edge



Figure 28: The platform edge after fitting gap filler

Previous similar accidents and incidents

63 The following are examples of similar accidents and incidents that were not investigated by the RAIB:

- a. 29 July 2001 at Clapham Junction. A departing train had travelled approximately 10 metres when a man opened a passenger door, stepped onto the platform then fell through the platform edge gap and was killed. The accident summary stated that the employee on the platform responsible for dispatch was looking in the opposite direction and so did not see the man disembark. It also stated that had he seen the man disembark he could not have stopped the train in time to prevent the accident.
- b. 22 March 2003 at Wivelsfield. A man ran alongside the train he had just left until he fell through the platform edge gap and was killed. The train driver, who was responsible for dispatch, did not see the man approach and then run alongside the train as it had moved a short distance beyond the platform mirrors/monitors and he was unable to see back along his train.
- c. 11 June 2003 at Gunnersbury. A man walked alongside the train he had just left, banging on its side until he fell through the platform edge gap. A bystander tried to pull the man up but was unable to do so and as the train moved the man was struck and suffered serious injuries. The Court of Appeal upheld the ruling that both the injured man and the train operator were liable for the accident. The injured man because of his behaviour while under the influence of alcohol; the train operator because their guard did not act on the passenger's behaviour but instead boarded the train and dispatched it while the man was out of his line of sight.
- d. 2 May 2004 at Ainsdale. A man was pushed into the train he had just left, fell through the platform edge gap and was killed. The guard did not see this happen; he had followed Merseyrail's dispatch procedure and was behind his closed door with the man out of his line of sight when he sent the 'ready to start' code. He became aware of the incident soon after the train moved off because the man struck and activated a door release valve as he fell, which automatically braked the train to a stop. This incident is not included in railway industry statistics as it was judged the consequence of a criminal act.
- e. 11 January 2005 at Clapham Junction. A man approached a train and pressed a pushbutton to open the passenger doors but the doors did not open because they were closed and locked. The man turned away from the train but then fell back through the platform edge gap and was killed.
- f. 11 January 2007 at Gidea Park. A man ran alongside a train until he fell through the platform edge gap. He was found on the track almost an hour later and subsequently died from his injuries. The railway employee that dispatched the train from the platform did not see the man approach and run alongside the train because he had returned to his cabin almost a minute before the train left the station.

- g. 1 December 2007 at Alresford on the Mid Hants heritage railway. A man ran to board a train as it pulled out of the station as the guard and people on the platform shouted for him to stand clear. He operated the door handle and was able to open the door because central door locking is not required of heritage trains that operate at low speed. He then fell through the platform edge gap and was killed.
 - h. 25 February 2008 at Hilsea. A man ran alongside a train, banging on its side until he fell through the platform edge gap and was killed. The guard had seen the man banging on the side of the train while it was stationary.
 - i. 21 November 2009 at Angmering. A sixteen year-old person ran alongside the train she had just left, banging on its side until she fell through the platform edge gap and was killed. The young person was found to have a blood alcohol concentration that was approximately three times the UK legal drink drive limit and she was wearing high heeled shoes at the time of the accident. The guard had seen the young person banging on the side of the train while it was stationary and thought that once the train started to move she would move away, which she did before running alongside it.
 - j. 3 August 2011 at Clapham Junction. A man fell into the side of a train as it arrived at the station, fell through the platform edge gap and was killed.
- 64 The RAIB has investigated and reported on several similar accidents, including the following:
- a. 15 February 2006 at Huntingdon. A train driver, who was responsible for dispatch, drove away from the station immediately after observing a man with his hands on the train. He did not realise that the man's coat was trapped in the passenger doors or that the train dragged the man along the platform before he fell through the platform edge gap. The man sustained serious injuries as a consequence. See RAIB report 11/2007.
 - b. 1 November 2007 at Tooting Broadway on the London Underground. A train driver, who was responsible for dispatch, drove out of the station without seeing a woman, visible on his in-cab monitor, who was trapped in the doors as he pulled away. The woman freed herself and sustained minor injuries as a consequence. See RAIB report 17/2008.
 - c. 28 January 2011 at Brentwood. A train driver, who was responsible for dispatch, drove out of the station without seeing a woman held upside down in the platform edge gap by a man attempting to stop her from falling further. The man and woman were visible on the driver's platform monitor although it is possible they were partially concealed by another person on the platform. The woman sustained minor injuries as a consequence. See RAIB report 19/2011.
 - d. 10 October 2011 at King's Cross. A member of staff dispatched a train from the platform and then could only watch as a woman, trapped in the passenger doors, was dragged along the platform. The woman was able to free her hand before the train left the station and sustained minor injuries as a consequence. See RAIB report 09/2012.

- 65 The causal factors of the accident at James Street were that the guard sent the driver the 'ready to start' code and no subsequent 'stop' code while the young person was leaning against the train. He did this possibly because he expected her to move away or possibly because he had not seen her. When she did not move away but instead fell through the platform edge gap, he was unable to stop the train directly and quickly. The accidents described in paragraphs 63 and 64 are similar to the accident at James Street because:
- a. the employee responsible for train dispatch did not see the person at the platform/train interface at Clapham Junction in 2001, Wivelsfield, Gunnersbury, Ainsdale, Gidea Park, Tooting Broadway, Brentwood and King's Cross;
 - b. the employee responsible for train dispatch saw the person at the platform/train interface but expected them to move away at Clapham in 2005, Hilsea, Angmering and Huntingdon;
 - c. the employee responsible for train dispatch could not stop the train directly and quickly in an emergency at Clapham Junction in 2001, Angmering and King's Cross; and
 - d. the person involved in the accident fell through the platform edge gap and onto the track at Clapham Junction in 2001, 2005 and 2011, Wivelsfield, Gunnersbury, Ainsdale, Gidea Park, Alresford, Angmering, Huntingdon and Brentwood.

Summary of conclusions

The immediate cause

- 66 The young person fell through the platform edge gap and onto the track as the train began to move out of the station (**paragraph 28**).

The causal factors²⁹

- 67 The causal factors were that:
- a. The guard sent the driver the 'ready to start' code, and no subsequent 'stop' code, while the young person was leaning against the train. He did this possibly because he expected her to move away or possibly because he had not seen her (**paragraph 30, Recommendation 1a**).
 - b. The young person fell as the train was moving out of the station (**paragraph 35**).
 - c. When the young person fell, the platform edge gap was wide enough for her to fall through and onto the track (**paragraph 37, Recommendation 2**).
 - d. By the time the guard warned the young person to stand back she had been leaning against the train for approximately eleven seconds. It is not known when the guard saw her during this time or, if he saw her, whether he delayed taking action in the expectation that she would move away. Platform video camera footage shows him warning her to stand back in the moments before the train departs and it is likely he did this because he thought that it would be immediately effective and because he had no direct and immediate way to stop the train (**paragraph 39, Recommendation 1b**).

Observations

- 68 The increasing rate of accidents at the platform/train interface indicates that there is a need to provide guidance to industry on technical solutions to reduce platform/train interface risk (**paragraph 56, Recommendation 3**).

²⁹ Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

Actions reported as already taken or in progress relevant to this report

Merseyrail

- 69 After the accident, Merseyrail added an alternative process to their dispatch procedure. The alternative process allows guards, at their discretion, to send a driver the 'ready to start' code before their door has fully closed, which reduces the dispatch time.

RSSB

- 70 RSSB informed the RAIB that it established the Station Safety Improvement Project in June 2011 after monitoring of safety risk across the railway system identified issues with the platform/train interface. The project is supported by the Association of Train Operating Companies (ATOC), train operators, Network Rail and the Office of Rail Regulation. RSSB advised that to date the project has delivered:
- a. increased awareness across all operators and Network Rail through one to one interviews, surveys, conferences, workshops and newsletters;
 - b. a network of Station Safety Improvement Champions in each of the supporting companies;
 - c. an improved understanding of the risk with publication of the special topic report and other analysis;
 - d. new tools and guides to improve risk assessment and competence; and
 - e. a new Station Safety Resource Centre on OPSWEB to provide operators with easy access to all project outputs and other relevant information.
- 71 RSSB informed the RAIB that the project continues with the objective of developing a holistic approach to the assessment of all types of station risk, specialist research into potential engineering and asset solutions. Recognising the future challenges of passenger growth, ageing population and station investment opportunities, the project is now to develop a longer term strategy for the co-ordinated improvement of station safety across the rail network.

Previous RAIB recommendations relevant to this investigation

- 72 The following recommendation was made by the RAIB because of a previous investigation:

[Passenger accident at Brentwood, 28 January 2011, RAIB report 19/2011 published November 2011](#)

Recommendation 2

RSSB should consider the inclusion of guidance in RIS-3703-TOM so those responsible for train dispatch should, so far as is reasonably practicable, observe the closing of the train's doors and be alert for any dangerous occurrence while this is taking place.

RSSB advised that RIS-3703-TOM is to be reworded to read '...consideration should be given to the level of monitoring required...during the door close process.'

Recommendations

73 The following recommendations are made³⁰:

- 1 *The objective of this recommendation is to reduce train dispatch accident risk by improving the way in which trains are operated.*

Merseyrail should evaluate equipment and operational arrangements that allow the person responsible for train dispatch to:

- a. observe the platform and train without interruption for as long as possible, ideally until the train has left the platform; and
- b. stop the train directly and quickly in an emergency.

Equipment and operational arrangements should be evaluated for existing trains and platforms, and for planned changes and upgrades. The outcome of the evaluation should be a plan to implement appropriate measures to improve safety at the platform/train interface.

- 2 *The objective of this recommendation is to reduce the likelihood of falls through the platform edge gap.*

Merseyrail, in consultation with Merseytravel, Network Rail and other relevant industry bodies, should evaluate equipment and methods that reduce the likelihood of a person falling through the platform edge gap. Platform edge gap fillers and vehicle body side panels should be included in the evaluation, the outcome of which should be a plan to implement measures when appropriate to do so, for example when trains or the infrastructure are changed, improved or replaced.

continued

³⁰ Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation to enable it to carry out its duties under regulation 12(2) to:

- (a) ensure that recommendations are duly considered and where appropriate acted upon; and
- (b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 167 to 171) can be found on RAIB's website www.raib.gov.uk.

- 3 *The objective of this recommendation is for the rail industry to be provided with guidance on reducing risk at the platform/train interface.*

The Office of Rail Regulation should, in conjunction with railway industry parties, ensure that the findings of this report are taken into account in published guidance on the types of measures that promote the safe movement of trains from platforms through the adequate control of risk.

The areas that should be the subject of particular consideration in such guidance are:

- a. equipment and methods which enable the person responsible for dispatch to observe the platform/train interface without interruption for as long as possible, ideally until the train has left the platform;
- b. equipment and methods which enable the person responsible for dispatch to stop a train quickly in an emergency; and
- c. adaptation of trains and infrastructure to reduce the size of the platform edge gap when this is possible and appropriate, for example in connection with investment in new trains and infrastructure.

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