

Rail Accident Report



Fatal accident at Piccadilly Gardens, Manchester, 5 June 2011

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 Piccadilly Gardens, Manchester, 5 June 2011

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Summary

At 00:16 hrs on 5 June 2011, a Manchester Metrolink tram struck and fatally injured a pedestrian.

The tram was approaching Piccadilly Gardens, from the direction of Market Street, at a speed of about 9 mph (15 km/h) when a pedestrian ran into its path. The pedestrian appeared to become aware of the tram and tried to stop before reaching the track, but fell directly in front of the tram. Although the tram had started to brake before reaching the pedestrian, it did not come to a complete stand before the pedestrian had come into contact with the under-run protector. This is a device that projects down from the underside of the tram and is designed to prevent pedestrians from being crushed under the wheels.

The RAIB has made two recommendations to UK tram operators in conjunction with UKTram (a body representing UK tram operators). These relate to improvements in the collection of pedestrian injury data in order to better understand the role of the tram front end design in minimising injury, and to research into the design of tram front ends and their potential for injuring pedestrians in collisions.

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.
- 2 The RAIB does not establish blame or liability, or carry out prosecutions.

Key definitions

- 3 All dimensions in this report are given in metric units, except speed, which is given in imperial units in accordance with the operating practice of Manchester Metrolink. In these cases, the equivalent metric value is also given.

The accident

Summary of the accident

- 4 At 00:16 hrs on 5 June 2011 a tram struck a pedestrian at Piccadilly Gardens, Manchester. The pedestrian was fatally injured.

Context

Location

- 5 Piccadilly Gardens is in Manchester city centre. The Gardens is an open space with pedestrian access.
- 6 Trams run in a paved area that is shared with pedestrians around two of the outer edges of the Gardens as shown in figure 1.

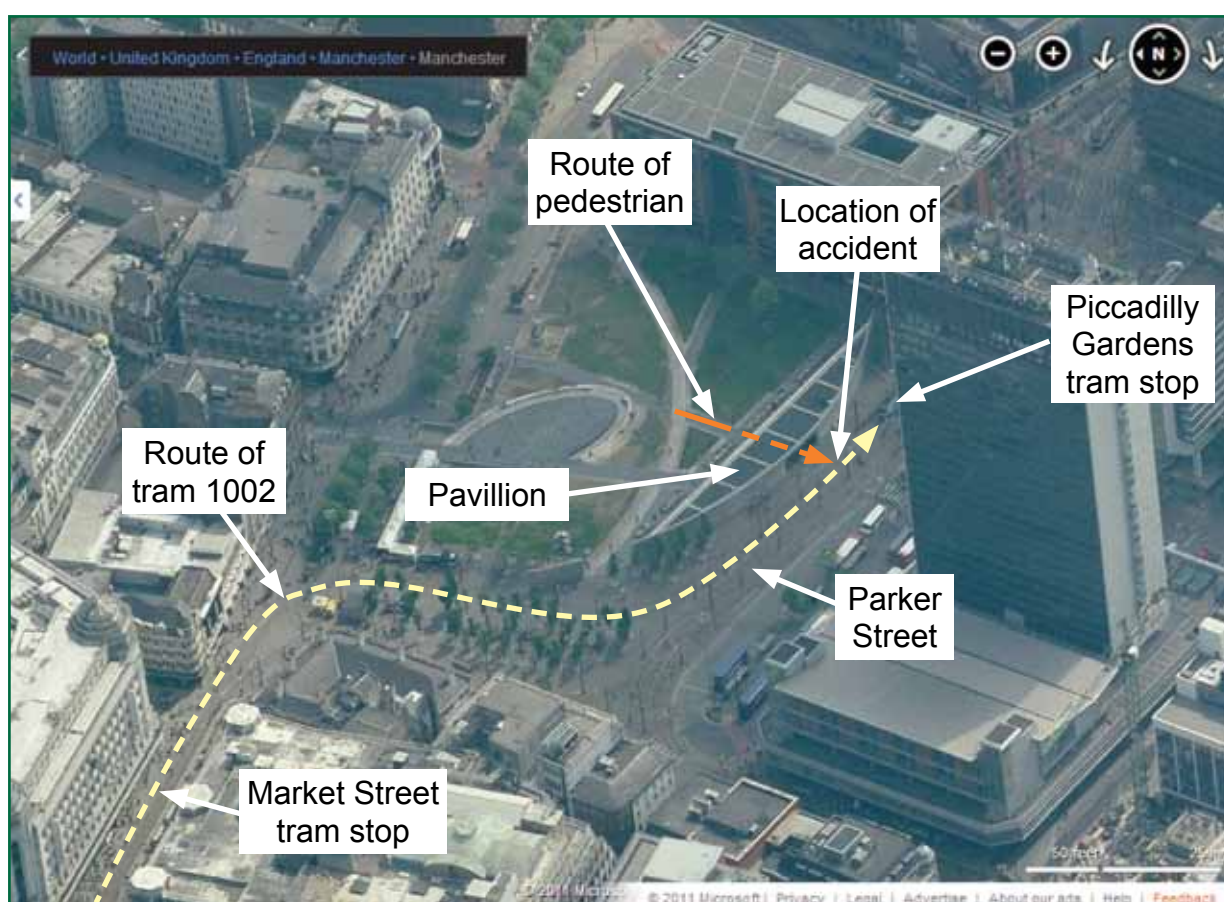


Figure 1: Location of the accident (courtesy of Bing Maps)

- 7 This section of the tramway has been operational since July 1992.
- 8 On the edge of the Gardens, is a concrete structure known as the Pavillion (figure 1). This was constructed in 2002. A large portal entrance/exit in its centre allows pedestrian access between Parker Street and the Gardens (figure 2). The passage within the portal is covered by the roof of the Pavillion for approximately 12 metres. This leads to an unsignalled pedestrian crossing on Parker Street, allowing access to the Piccadilly Gardens tram stop platform.

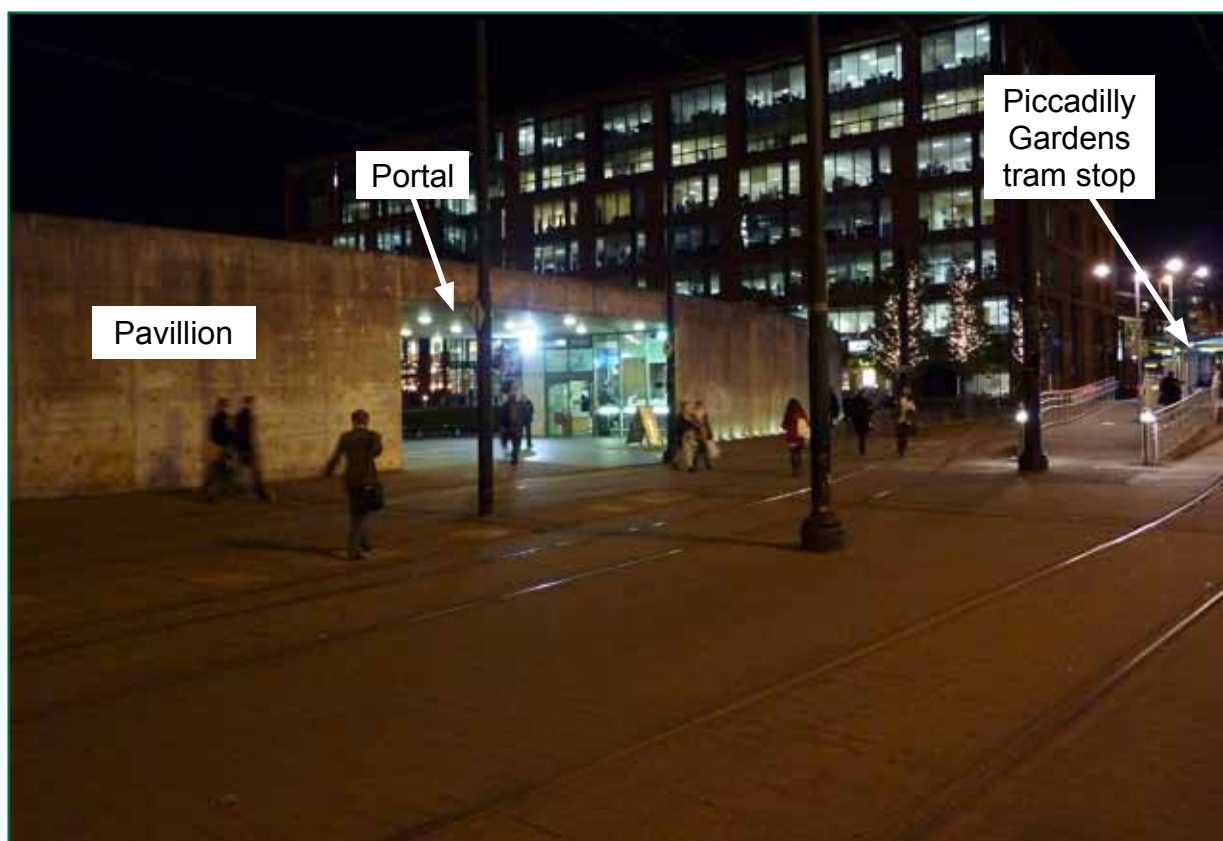


Figure 2: The Pavillion showing the portal entrance leading to/from Piccadilly Gardens

Organisations involved

- 9 The tram system is owned by Transport for Greater Manchester (TfGM). At the time of the accident the tram was operated and maintained by Stagecoach Metrolink, who was also the employer of the tram driver. Since August 2011 tram operations have been undertaken by RATP Dev UK Ltd.
- 10 RATP Dev UK Ltd and Stagecoach Metrolink freely co-operated with the investigation. TfGM had no significant involvement in the RAIB investigation.

The tram and its operation

- 11 The tram involved in the accident was a T68 type, number 1002 (figure 3). This was one of the fleet of 32 T68 trams, built by Ansaldo, Italy, first introduced in 1992. It was travelling from Bury to Piccadilly Gardens tram stop.
- 12 In Parker Street the trams operate under a speed limit of 10 mph (16 km/h). Tram operation is similar to that of road vehicles in that they are driven in accordance with a principle known as 'Line of Sight'. This means that drivers must be prepared to stop within the distance that can be seen to be clear, while taking into account the presence of other road vehicles and pedestrians on, or about, the track. For street running, trams are equipped with road vehicle type headlights, sidelights and indicators.
- 13 The driver controls the speed of the tram using a control handle which can either apply power or operate the brake depending on its position. If the handle is moved beyond the service (normal) brake position the hazard brake is applied. There is also a plunger which, if pressed, operates the hazard brake.



Figure 3: The 'A'-end of tram 1002 at the accident site

- 14 The hazard brake applies maximum service braking effort as well as deploying the electromagnetic track brakes¹ and depositing sand to improve the adhesion between the wheels and the rails.
- 15 The tram has a driver-operated horn and a street whistle. The horn is used as a warning when operating on off-street (segregated) sections and the street whistle is used for on-street running.
- 16 Tram number 1002 was fitted with a skirt around its ends and sides, together with a guard in front of the leading wheels (figure 4). The purpose of this guard, also known as an object deflector or under-run protector, is to prevent both people and objects from being run over by the tram's wheels. Figure 4 shows the tram in the depot; in Parker Street the paved surface is level with the tops of the rails.
- 17 The under-run protector on the leading end of the tram was mounted on the bogie frame (the metal frame equipped with the wheelsets), 1.4 metres back from the front of the tram. It consisted of two wooden sections fixed to metal support brackets and it spanned the full width of the bogie. On the leading end of tram 1002, the clearance between the lower edge of the wooden section and the road surface was 115 mm. Metrolink's design and maintenance instructions specify that this clearance should be 115 mm, with a tolerance of +/- 5 mm. Some clearance (ground clearance) is necessary between the underside of the protector and the paved highway to prevent contact between the protector and the rails and road surface when the tram meets changes in vertical curvature in the track.
- 18 On the lower edges of the wooden sections were 10 mm thick rubber strips. The rubber strips projected below the wooden sections giving a clearance of 80 mm between their lower edges and the road surface when on level track.

¹ A brake that consists of an electromagnetic friction brake applied directly to the rail heads and provides a high rate of retardation for use in emergency situations.



Figure 4: The under-run protector on the 'A'-end of tram 1002 (not at accident site); the notches in the rubber edge are caused by occasional contact with rail heads

Staff involved

- 19 The tram driver had joined the tramway in February 2011. Following a period of training that started on 21 February 2011 he was certified by Metrolink to be fully competent on 25 May 2011. The training involved theory sessions and a minimum of 80 hours of monitored driving.

External circumstances

- 20 The accident occurred at night and the area was illuminated by street lighting.
21 The weather was warm, dry and clear.

Events preceding the accident

- 22 The tram driver signed on for duty at 17:12 hrs on 4 June 2011. His planned shift end was at 01:31 hrs on 5 June 2011. After undertaking three return journeys between Altrincham and Bury he took a planned meal break from 21:08 hrs to 21:38 hrs. Following his break he drove a further two return journeys between the same locations. His next journey from Bury at 23:48 hrs took him again into the city centre.
- 23 All journeys including the last, from Bury to the Market Street tram stop, were uneventful.

Events during the accident

- 24 Tram 1002 departed from Market Street tram stop at 00:15 hrs. The tram data recorder shows that the street whistle was sounded before departure in the usual way.
- 25 Approximately 10 seconds after departing, the driver sounded the street whistle to warn some pedestrians in the area.
- 26 The tram data recorder shows that the maximum speed reached on its journey between Market Street and Piccadilly Gardens was 10 mph (16 km/h). This was within the speed limit (paragraph 12).
- 27 The city centre CCTV footage shows the pedestrian walking from the Gardens towards the Pavillion and Parker Street. The tram at this time was turning the corner into Parker Street and was 50 metres from the point of collision.
- 28 The pedestrian walked into the covered passage of the Pavillion 8 to 9 seconds prior to the accident. He was within the central half of the passage's width. At this time the tram had turned into Parker Street and was about 30 metres from the point of collision (figure 5).

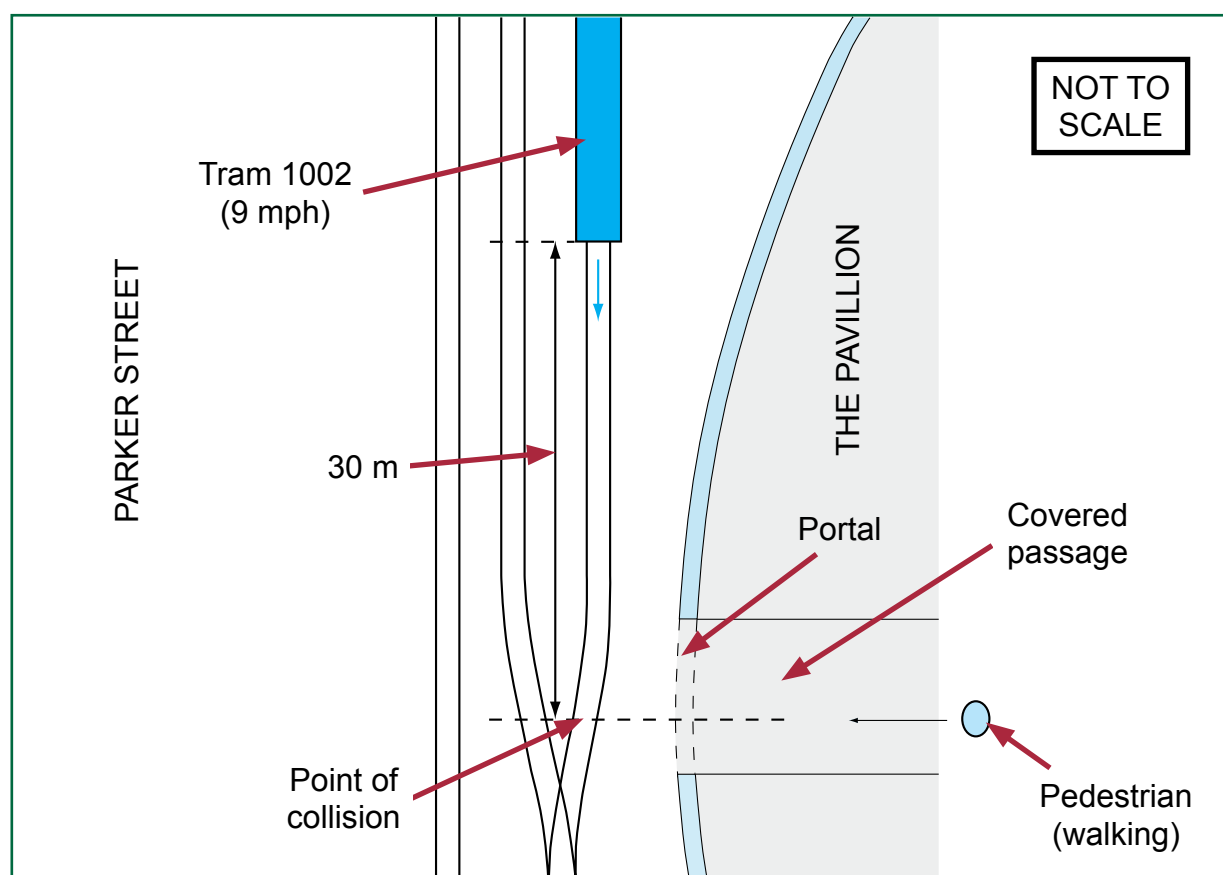


Figure 5: Positions of tram and pedestrian 8 to 9 seconds before the accident

- 29 The pedestrian became visible on the tram's forward facing CCTV around 3 seconds before the collision. This footage shows that he was running out of the passage towards Parker Street. The tram at this time was travelling at 9 mph (14.5 km/h).

- 30 The data recorder shows that the driver sounded his street whistle between 1.5 and 2 seconds before the collision, when the tram was approximately 6 metres away (figure 6).

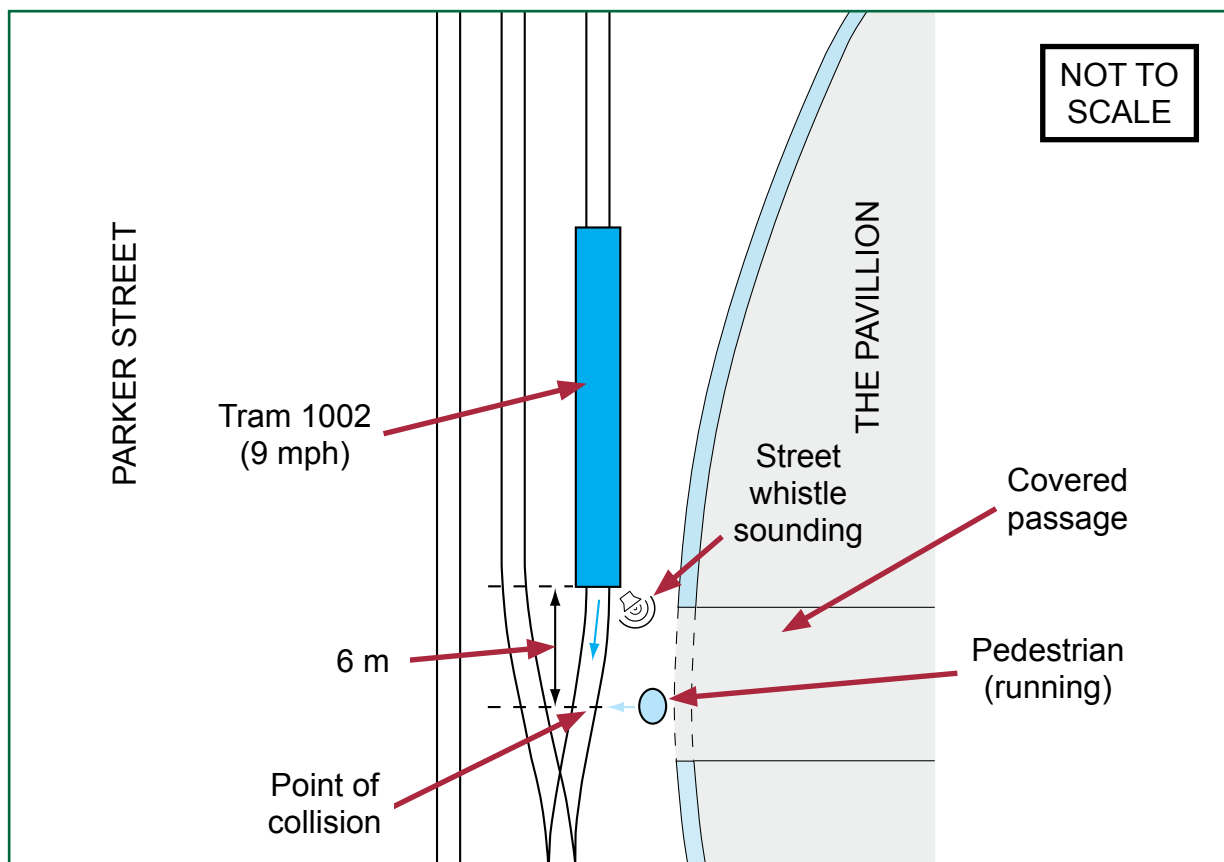


Figure 6: Positions of tram and pedestrian 1.5 to 2 seconds before the accident

- 31 The data recorder indicates that within 1 second of sounding the street whistle the driver removed power and applied the service brake. The tram street whistle was still being sounded. The pedestrian at this time was still running and was within 2 to 3 metres of the closest rail.
- 32 The CCTV footage shows the pedestrian attempting to stop immediately before crossing in front of the tram then stumbling (figure 7). The tram at this time was continuing to brake and sound its street whistle. The data recorder indicates that the speed of the tram was 8 mph (13 km/h) when the pedestrian was struck.
- 33 The driver stopped sounding the tram whistle and applied the hazard brake (figure 8). This was within 2 seconds after the collision and when the tram was travelling at 7 mph (11 km/h).
- 34 The tram stopped within a distance of 2.3 metres and a time of 1.5 seconds after the application of the hazard brake.

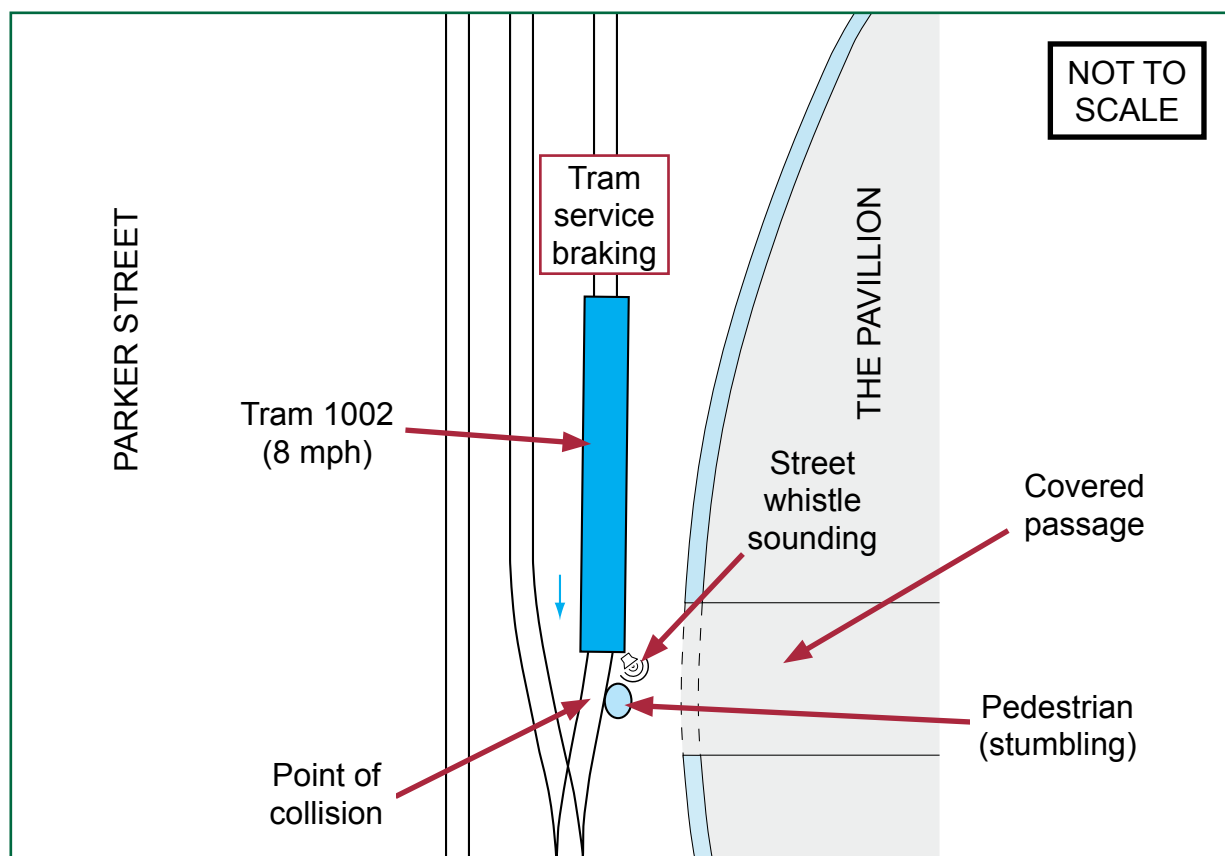


Figure 7: Positions of tram and pedestrian approximately 1 second before the accident

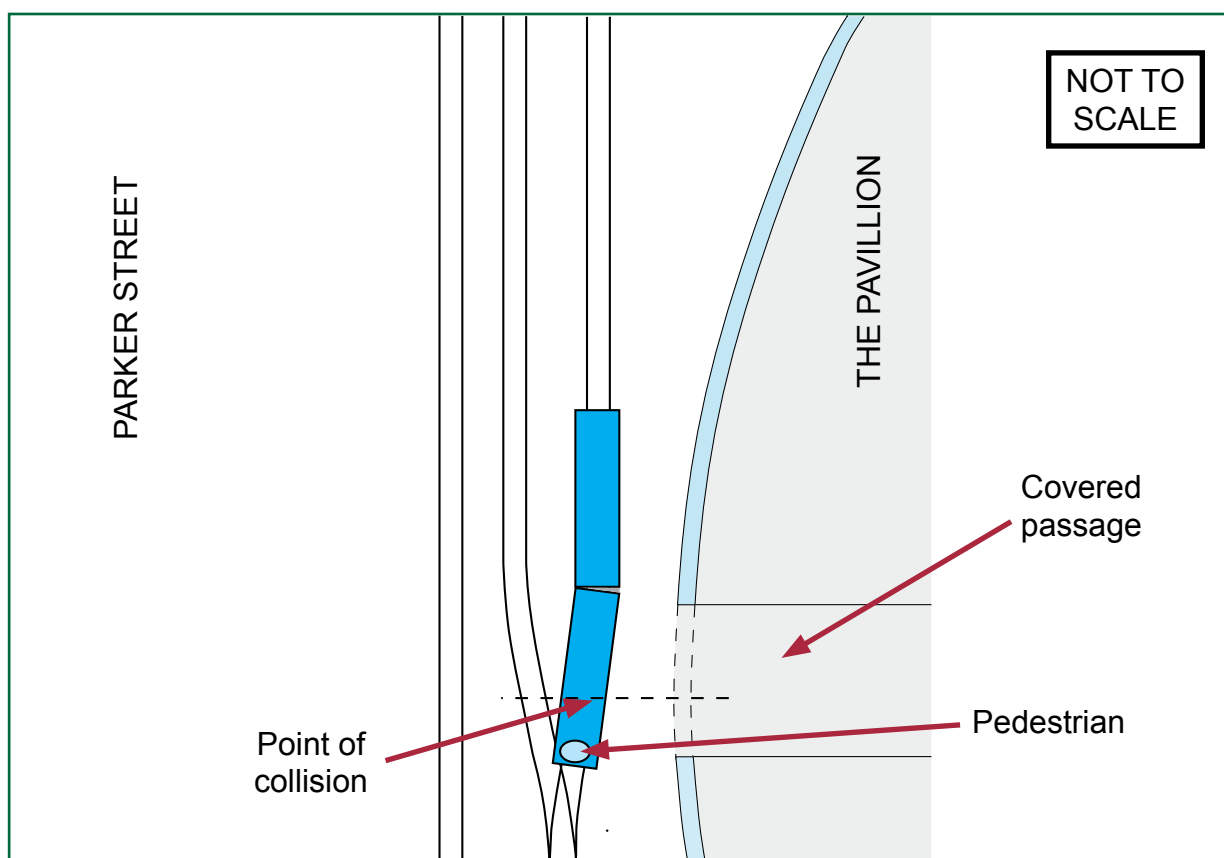


Figure 8: Positions of tram and pedestrian following the accident

Events following the accident

- 35 The driver contacted the Metrolink control room to report the accident. The control room contacted the emergency services.
- 36 The tram driver was tested for drugs and alcohol in accordance with normal procedures following an accident. He tested 'clear' for both drugs and alcohol.
- 37 The city centre CCTV footage shows that the driver of tram 3005, waiting to depart from Piccadilly Gardens tram stop, left his tram to assist the injured pedestrian. The footage also shows police in the area arriving within seconds of the accident and medical assistance arriving within 5 minutes.
- 38 The pedestrian was taken to Manchester Royal Infirmary and died in hospital on 9 June 2011.

The investigation

Sources of evidence

39 The following sources of evidence were used:

- the tram data recorder;
- CCTV recordings taken from the forward facing camera on tram number 1002;
- CCTV recordings from cameras in Piccadilly Gardens provided by Manchester City Council;
- site photographs and measurements;
- information from one of the paramedics who attended the scene of the accident;
- pathology reports;
- evidence about the tram and tram operations supplied by Stagecoach Metrolink;
- a report produced for the RAIB by biomechanical consultants in the automotive industry, and
- a review of past UK light rail pedestrian collisions.

Key facts and analysis

Background information

Railway Safety Principles and Guidance on Tramways

- 40 This report refers to industry guidance on tramways, namely Railway Safety Principles and Guidance, Part 2, Section G Guidance on Tramways, published by the Office of Rail Regulation (ORR). It was first published in 1997 and revised in 2006. The document is intended to give advice and is not mandatory. It does not apply retrospectively to existing works, plant and equipment, and therefore to the tram involved in this accident. However it reflects current British practice. Relevant extracts are shown in appendix A.

The tram and its driving

- 41 Post-accident functional testing by Metrolink did not reveal any operational faults with the tram, in particular with its braking system, street whistle and lights. Appendix A, references 1 and 2, gives guidance relating to braking systems and street whistles. These are covered in more detail in paragraphs 42 and 45. The CCTV images show that the tram's headlights were illuminated; the actual brightness levels of these are not considered critical as the area was well illuminated by the street lighting.
- 42 Analysis of the tram data recorder shows that once the hazard brake was applied, the tram came to rest from travelling at 7 mph (11 km/h) in 1.5 seconds and in a distance of between 2 metres and 2.3 metres. This represents an average deceleration rate of between 2.1 m/s^2 and 2.4 m/s^2 . Industry guidance (appendix A, reference 1) advises that the average hazard brake deceleration should be at least 2.5 m/s^2 . However, this is not directly comparable, because it relates to average deceleration rates from full speed. The difference between these rates almost certainly results from the time that the brake takes to build up to its full application force; this having a greater influence on the average deceleration rate in a low speed brake application.
- 43 The rate at which the brake builds up is known as the jerk rate; industry guidance (appendix A, reference 1) suggests that jerk rate be limited to 1 m/s^3 . This is to reduce the risk of passengers being hurt when hazard brakes are applied. The hazard brake on tram 1002 built up considerably quicker than 1 m/s^3 , indicating that its stopping time (and distance) from 7 mph (11 km/h) was relatively short. There were no reports of any passengers on the tram being injured as a result of the emergency stop.
- 44 The tram data recorder shows that the street whistle was sounded for approximately 2.5 seconds. When the tram street whistle was first sounded the distance between the tram and the pedestrian was about 6 metres; this was between 1.5 and 2 seconds before the accident. While it was sounding there was a clear line of sight between the tram and pedestrian.

- 45 Industry guidance (appendix A, reference 2) advises that trams should be fitted with an audible warning device. The RAIB took measurements of sound pressure levels of T68 trams sounding their street whistles for at least 1.5 seconds at this location with a calibrated sound pressure level meter. These measurements were conducted around 20:00 hrs on a weekday evening with road traffic and pedestrian activity broadly similar to those at the time of the accident. The measurements were taken with the meter and trams in similar positions to the pedestrian and the tram when the whistle was sounded before the accident.
- 46 The unit of sound pressure level was the decibel (A-weighted), or dB(A). This unit of sound pressure level is described by 'curve A' in the international standard EN 61672:2003. It has been widely adopted for measuring environmental noise and is a standard measure of sound pressure in many sound level meters².
- 47 These measurements showed an increase in the sound pressure level over a background level of around 60 dB(A) to 70 dB(A), of at least 20 dB(A) when measured from inside the covered passage at a distance of 3 metres from the portal entrance/exit. This represents the approximate position of the pedestrian when the tram street whistle was sounded.
- 48 The sound pressure level of the whistle on the end that was leading at the time of the accident on tram 1002 was measured from 10 metres away when it was stationary at Piccadilly Gardens tram stop. This recorded an increase from a background level of 62 dB(A) to 95 dB(A).
- 49 The post-accident testing of the street whistle of tram 1002 was a functional test rather than a quantitative measurement. It was conducted by staff at the depot relying on their experience. They did not note any abnormality with this tram whistle compared to others.

The street layout

- 50 Although the accident occurred during night hours, the CCTV images show that the scene, including the covered passage was illuminated. The tram's headlights and interior were also illuminated.
- 51 The pavement on Parker Street leading from the covered passage in the Pavillion formed the route crossing the two in-bound tram lines for pedestrians leaving the Gardens.
- 52 The demarcation between the pedestrian pavement and the tram lines was by means of different colours of paving materials (figure 9). A warning sign stating 'Tramway – look both ways' was mounted on an electrification mast in the centre of the pavement leading from the covered passage to the tram lines. The RAIB found no evidence of a tripping hazard on the pavement areas where the pedestrian crossed.

² dB(A) is a commonly used unit of measurement for measuring the loudness of sound. Because it requires about a tenfold increase in power for a sound to register twice as loud in the human ear, a logarithmic scale is used for comparing sound intensity. This means that each increase of 10 dB(A) corresponds to a tenfold increase in intensity and a doubling of loudness.



Figure 9: The approach to the tram lines from the covered passage

- 53 From analysis of the positions of the tram and the pedestrian, based upon the CCTV footage, the tram would have been visible to the pedestrian when he was 6 to 7 metres from the nearest running rail. At this point the pedestrian was 3 to 4 metres from leaving the covered passage and corresponds to a time when the tram was approximately 12 metres from the crossing. For the running pedestrian, based upon his approximate speed measured from the CCTV footage, this was about 3 seconds before reaching the tram lines (figure 10).

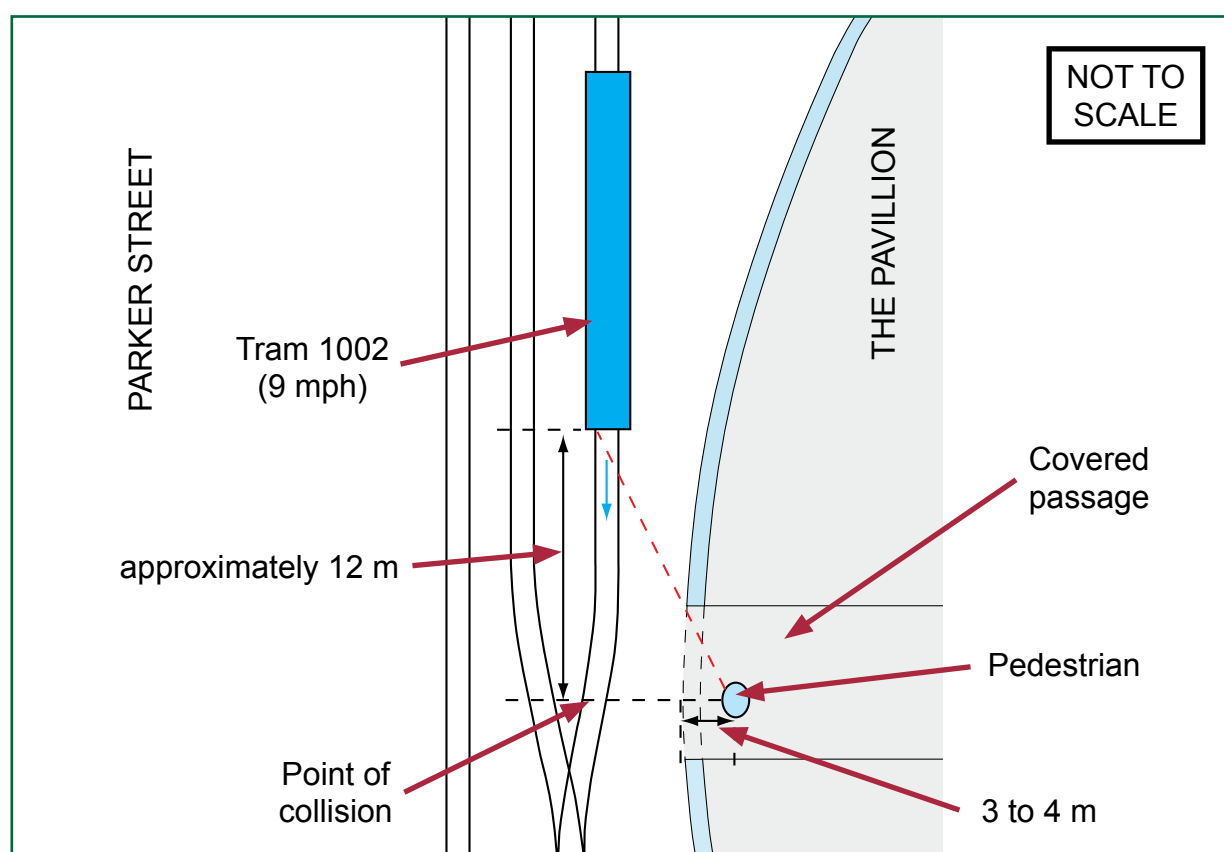


Figure 10: Relative positions of tram 1002 and pedestrian when the tram was visible

The pedestrian

- 54 The 67 year-old pedestrian lived in Salford and was likely to have been returning home.
- 55 The police have told the RAIB that the pedestrian's family reported that he was in good health and fit for his age. They also indicated that he had suffered with cataracts in both eyes and wore glasses; a pair of glasses was found close to the pedestrian following the accident. The RAIB has not investigated the level of his vision or hearing. Nothing was found at the scene of the accident that may have impeded his ability to hear.
- 56 The toxicology report indicates that there were no drugs or alcohol present in his bloodstream.
- 57 Information from one of the paramedics who attended the scene indicated that the pedestrian was lying on his back, across the width of the tram after the accident. The under-run protector was in contact with the left-hand side of his body; his left arm and left leg were behind the protector.
- 58 From the information obtained on the positions of the pedestrian during and following the accident, together with the pathology report, the RAIB, supported by commissioned specialists, has ascertained the likely way in which the injuries received led to the pedestrian fatality. These are discussed in paragraph 72.

Identification of the immediate cause³

- 59 **The pedestrian stumbled and fell immediately in front of the approaching tram.**

The actions of the pedestrian

- 60 **The pedestrian was running from the covered passage and did not observe and react to the approaching tram until it was too late to stop clear of it. This was a causal factor.**
- 61 The CCTV evidence indicates that the pedestrian was aware of the oncoming tram and attempted to stop before reaching it (paragraph 32). The pedestrian left the passage running (paragraph 29). This gave him less time to see and hear the approaching tram and react to it. Trying to stop quickly while running led to him stumbling and falling in front of the tram.
- 62 The reason for his change of pace, from walking to running, while in the covered passage is not known. A possible explanation is that he saw tram 3005 waiting on the other side of the tram stop which was due to depart for Salford, and that he wanted to catch this tram home. This may have also distracted him from looking for the approaching tram as he was leaving the passage.
- 63 The pedestrian would have been able to see tram 3005 waiting to depart, including its illuminated destination board, from halfway through the covered passage. However, at this point, he would not have been able to see the oncoming tram; tram 1002 would have only come into view when he was 3 to 4 metres from leaving the passage (paragraph 53).

³ The condition, event or behaviour that directly resulted in the occurrence.

Other possible factors

The way the tram was driven

- 64 The tram service brake was applied and the street whistle sounded within 2 seconds of the pedestrian becoming visible to the tram's forward facing CCTV camera (paragraph 29). It is not known exactly when the driver saw the pedestrian, but published research⁴ indicates that reaction times of up to 2 seconds are not unreasonable for familiar, but unexpected events.
- 65 The hazard brake was applied within 2 seconds of the subsequent collision (paragraph 33).
- 66 The RAIB has concluded that the driver actions were not incompatible with the findings from research for reaction times in similar circumstances.

The street layout

- 67 Although the covered passage of the Pavillion limits the visibility of approaching trams as compared with a fully open space, the consequences resulting from a collision between a tram and a pedestrian would normally be expected to be partially mitigated by the tram's maximum speed limit of 10 mph (16 km/h).
- 68 There are visual prompts present alerting pedestrians of the presence of the tram lines (paragraph 52). The visual prompt provided by the change of paving begins approximately 4 metres before reaching the passage exit. At this point pedestrians walking at a typical speed of 3 mph (5 km/h) have approximately 5 seconds to look for an approaching tram before reaching the first tram line. Beyond this point moving towards the tram lines, the distance visible to pedestrians increases to the full length of the Pavillion to the north of the covered passage, ie the full length of the tram lines in Parker Street. The street layout possibly contributed to the accident by reducing the available sighting, and consequent reaction times available, for both the pedestrian and the tram driver. However, in this case, these times were reduced substantially because the pedestrian was running.

The street whistle

- 69 The street whistle was sounded approximately 1 to 1.5 seconds after the pedestrian became visible to the tram's CCTV camera (paragraphs 29 and 30); this indicates the earliest possible time that the driver could have seen the pedestrian. It is likely that the pedestrian's attempt to stop himself crossing in front of the tram was a reaction to hearing the whistle. The RAIB sound pressure level measurements (paragraph 47) found an increase in the level over the background level of at least 20 dB(A). Research on the levels of auditory warnings⁵ indicates that an increase in level of 15 dB(A) above a similar ambient level is considered to be sufficiently audible to serve as a warning.
- 70 The design of the tram involved did not allow the driver to use the louder warning horn in the street (paragraph 15). Industry guidance (appendix A, reference 2) advises that the louder horn should be available for emergencies in the street. More modern trams, and some converted older trams, do have this feature.

⁴ Driver reaction times to familiar but unexpected events, version 1.3, TRL. March 2008.

⁵ Auditory warning sounds in the work environment, R.D. Patterson, Phil.Trans. R.Soc. London B327, 485-492 (1990).

- 71 It is not possible to determine whether a louder warning would have attracted the pedestrian's attention earlier. However the outcome is unlikely to have been different given the short time available to react.

Factors affecting the severity of consequences

- 72 The pedestrian died as a result of injuries received during the accident (paragraph 58). These injuries were from more than one instance of contact with the tram, all at speeds of less than 9 mph (13 km/h).
- 73 From the evidence available, together with research by biomechanical specialists commissioned by the RAIB, the following sequence of events following the pedestrian's actions of stumbling and falling in front of the tram is probable:
- the pedestrian fell to the ground with his right arm lifted towards the tram;
 - the pedestrian was rolled over and forwards onto his back by his arm contacting the lower part of the tram's skirt;
 - during these actions injuries were received that likely led to the pedestrian being concussed; and
 - while in this supine position the under-run protector passed over his left arm and leg and onto his chest.

Assessment of the injuries in relation to the design of the tram

- 74 The injuries and their severities have been considered by biomechanical specialists against injury scales developed by the automotive industry. The Abbreviated Injury Scale⁶ (AIS) coding system assesses the injury type and its likely outcome. This includes information from graphs indicating the likelihood of persons receiving a particular injury severity. Such graphs relate the chance of receiving a level of injury (AIS score) to the Head Injury Criteria (HIC)⁷ in the case of head injuries, and the degree of chest compression⁸ for chest injuries.
- 75 Injuries sustained by the pedestrian during the period before he came into contact with the under-run protector were assessed against the AIS severity scale as 'survivable'. A person's age is a factor in the consequence of injury, ie older people are generally less tolerant to injury and more likely to receive a more severe outcome than a younger person. In consideration of the pedestrian's age, it is likely that one outcome was a degree of concussion.
- 76 The chest injury sustained by the pedestrian after he came into contact with the under-run protector was rated by the AIS severity scale as 'life threatening'. The injury graphs suggest that this would almost certainly be the case irrespective of age.
- 77 For the under-run protector to make contact with the chest, the protector had to be able to pass over the arm and shoulder.

⁶ AIS - Abbreviated Injury Scale, Association for the Advancement of Automotive Medicine.

⁷ HIC – Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems, Eppinger. November 1999.

⁸ Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems – II, Eppinger, et. al., 1999.

- 78 To evaluate some of the design aspects of the protector, a model section of it was made. This recreated the ground clearance and rake angle of the tram's under-run protector. This allowed static tests with crash test dummies and a human volunteer to evaluate contact points with the chest. Both the human volunteer and one of the crash test dummies were representative in chest depth to the pedestrian involved in the accident. This showed that the smaller the ground clearance, the more likely a given size of person will be pushed forwards or rolled by the under-run protector, rather than it coming into contact with the chest region.
- 79 A comparative test was done with the rake angle removed, ie the under-run protector mounted vertically with the ground clearance maintained at 115 mm. In this case, although the protector passed up the arm, it did not override the shoulder to the same extent as when raked.
- 80 Further tests were done using a range of dummies representing different sizes of person. This comparatively evaluated the potential for chest and head regions of the body to come into contact with the protector. While this was not a comprehensive study, it indicated the potential benefit of reducing the rake angle and the ground clearance to minimise these types of injuries. Reducing the ground clearance also improves the principal reason for having an under-run protector, that of preventing persons from making contact with the tram wheels.

Proportion of similar incidents

- 81 The RAIB analysed pedestrian collision accident figures from UK light rail operators. It was found that approximately 20% of tram/pedestrian frontal collisions resulted in the pedestrian going under the front of the tram. In the remainder of the accidents, the pedestrians were either moved to one side of the tram, or, following the initial collision, the tram stopped before the pedestrian went underneath. This suggests that in a significant minority of frontal tram/pedestrian collisions, the design of the under-run protector may become a factor affecting the severity of the outcome.

Observations⁹

Data gathering

- 82 The historical data available from UK light rail operators (paragraph 81) was insufficiently detailed to be able to determine pedestrian injuries and the way in which they had likely been received. For example, it was not possible to find the instances when pedestrians had come into contact with under-run protectors and any injury received from these.

Comparison of injury outcomes between the T68 tram and a lorry

- 83 As part of the injury assessment, a comparison was made of the likely initial impact injuries that would be received by a standing pedestrian involved in a collision with the front of a T68 tram and a modern flat-fronted lorry. It was found that the injury severities from the initial impact were similar; one difference found was that the windscreen wipers on the tram were more prominent than those on the lorry and at a height which would increase the severity of a head injury.

⁹ 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.

Poor quality of tram forward facing CCTV images

- 84 The images from the tram's forward facing CCTV camera were of poor quality. It was found that the view was obscured by an anti-glare film that had been applied to the upper windscreen.

Use of the louder warning horn

- 85 Although it is considered unlikely that a louder audible warning would have prevented the accident (paragraph 71), it was observed that the design of tram 1002 did not allow the driver to use the louder warning horn in an emergency (paragraph 70).

Summary of conclusions

Immediate cause

- 86 The pedestrian stumbled and fell immediately in front of the approaching tram (**paragraph 59**).

Causal factor

- 87 The causal factor was:
- The pedestrian was running from the covered passage and did not observe and react to the approaching tram until it was too late to stop clear of it (**paragraph 60, no recommendation**).

Factors affecting the severity of consequences

- 88 Factors that exacerbated the consequences of the event were:
- a. The pedestrian's stumbling position when the initial collision occurred (**paragraph 86, no recommendation**).
 - b. The ground clearance and rake angle of the under-run protector (**paragraph 80, Recommendation 2**).
 - c. The age of the pedestrian (**paragraph 75, no recommendation**).

Additional observations

- 89 Observations are made on the quality of the historic data (**paragraph 82, Recommendation 1**), prominence of the windscreen wipers on T68 trams (**paragraph 83**), and the poor quality images from the forward facing CCTV (**paragraph 84**) and the use of the louder warning horn (**paragraph 85**).

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

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

- 90 At the time of writing this report, the industry guidance on trams (paragraph 40) is being revised. The Office of Rail Regulation has informed the RAIB that this will include guidance to minimise the risk of pedestrian injury from exposed prominent features on the fronts of trams, such as the exposed windscreen wipers (paragraph 83).
- 91 RATP Dev UK Ltd. has informed the RAIB that it has modified the windscreen anti-glare film on the windscreen of T68 trams to improve the CCTV image quality (paragraph 84).
- 92 RATP Dev UK Ltd. has informed the RAIB that it has modified all trams of the T68 fleet, including tram 1002, to allow drivers to use the louder warning horn when street running (paragraph 85).

Recommendations

93 The following recommendations are made¹⁰:

- 1 *The aim of this recommendation is to improve the detail of pedestrian injury data to better understand the role of tram front end design in minimising injury.*

UK tram operators should work together to improve the data collection on tram front end collisions with pedestrians. This is to include greater detail on the type and severity of any injury received as far as possible, and the likely points of contact with the tram (paragraph 82).

- 2 *The aim of this recommendation is to better understand the design of tram front ends and their potential for injuring pedestrians in collisions.*

UK tram operators in conjunction with UKTram (as a representative body of UK light rail operators), and in consultation with tram owners, should undertake research into the potential for the reduction of injuries to pedestrians involved in front end collisions with trams. Operators should understand the likely ways in which pedestrians can come into contact with the fronts of trams, and the severity of any consequential injuries. Should this research show that it is appropriate to implement design changes, either to existing trams or emerging new designs, these should be done (paragraph 88b).

¹⁰ 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.

Appendices

Appendix A - References

Extracts from Railway Safety Principles and Guidance, Part 2, Section G Guidance on Tramways, published by the Office of Rail Regulation (ORR). November 2006¹¹.

1. Paragraph 353 (b), Brake performance
 353. *Trams running on-street should have:*
 - (b) *a hazard brake with a maximum instantaneous retardation rate of between 3 and 4 m/s², and a retardation rate of at least 2.5 m/s² for a stop from the maximum permitted speed of operation. The control for this should be incorporated into the main brake controller (or traction/ brake controller where one is used), but should not easily be applied inadvertently. This brake application should be revocable by the driver. The application and stopping jerks should be limited so far as is reasonably practicable and should not normally exceed 1 m/s³.*
2. Paragraphs 276 and 277, Audible warnings
 276. *Trams should be fitted with an adequate audible warning device at the driving ends. The warning emitted should be in keeping with the environment in which the tram runs. The warning should be loud enough to indicate the approach of a tram without causing injury or undue alarm to those in the proximity.*
 277. *The warning device should have two levels of sound where trams run both on-street and off-street:*
 - (a) *the lesser level, for use on-street to alert people of the tram's presence, should produce a sound that is distinctive compared with that emitted by other road vehicles; and*
 - (b) *the greater sound level, for use in emergencies and off-street, should be adequate to warn staff who are working on the track that a tram is approaching.*
3. Paragraphs 278 and 279 Pedestrian protection and obstacle deflection
 278. *Collision protection should be provided for pedestrians as follows:*
 - (a) *the tram ends and sides should be continuously skirted. The bodywork and skirting should be designed to deflect people who may come into contact with the tram and stop them from passing beneath;*
 - (b) *exceptionally and with prior agreement of the Inspectorate, where the skirting at the end of a tram does not provide adequate protection due to the topography of the system, there should be a guard in front of the leading wheels designed to prevent people or objects being run over by the tram, with adequate clear space to prevent crush injuries; and*

¹¹ There are additional guidance notes available on the ORR website <http://www.rail-reg.gov.uk/server/show/nav.2003>.

- (c) the guard should be positioned as close to the highway surface and to the wheels as is reasonably practicable. It may have a deflecting lower edge of pliable material to close the gap to the surface of the highway.*
279. *Effective obstacle deflection equipment should be provided to reduce the risk of derailment. This equipment may be attached to the running gear or to the tram underframe. Such protection is in addition to that provided in relation to pedestrian collision.*

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