LRSSB - LRG - 2.0

LIGHT RAIL
Safety and Standards Board

Guidance on Tramway Crossings for Non-Motorised Users

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DESCRIPTION:					
THIS DOCUMENT PROVIDES GUIDANCE ON THE DESIGN AND ASSESSMENT OF TRAMWAY CROSSINGS FOR NON-MOTORISED USERS					
EXPLANATORY NOTE:					
LRSSB is not a regulatory body and compliance with this guidance document is not mandatory. This document reflects good practice and is advisory only. Users are recommended to evaluate this guidance against their own arrangements in a structured and systematic way, noting that parts of this guidance may not be appropriate to their operations. It is recommended that this process of evaluation and any subsequent decision to adopt (or not adopt) elements of this guidance should be documented. Compliance with any or all of the contents herein, is entirely at an organisation's own discretion.					
SOURCE / RELATED DOCUMENTS:					
LRG 1.0 Tramway Principles and Guidance (TPG) (LRSSB) LRG 4.0 Signage and Marking of Tramways and Highway Interface (LRSSB) LRG 5.0 Tramway Audible Warning Acoustic Test Guidance (LRSSB) LRG 8.0 Guidance in the Management of Vulnerable Persons (LRSSB) LRG 17.0 Driver Inattention Systems Guidance (LRSSB) LRG 18.0 Speed Management Systems Guidance (LRSSB) LRG 19.0 Cycle Tramway Interface Guidance (LRSSB) LRG 24.0 Pedestrian Safety Guidance (LRSSB) LRG 28.0 Guidance on the Provision of Accessibility in Light Rail Systems (LRSSB) Traffic Signs Manual Chapter 6: Traffic Control, 2019 (DfT) The Design Manual for Roads and Bridges Volume 6 Section 3 Highway Feature, Part 5, TA 90/05 The Geometric Design of Pedestrian, Cycle and Equestrian Routes (National Highways) BS 5489-1:2020 Design of Road Lighting Part 1: Lighting of Roads and Public Amenity Areas - Code of Practice BS EN 15153-2:2020 Railway Applications - External visible and audible warning devices. Part 2: Warning horns for heavy rail BS EN 15153-4:2020 Railway Applications - External visible and audible warning devices. Part 4: Audible warning devices for urban rail GG 119 Road Safety Audit Version 2 Jan 2020 (Highways England, Transport Scotland, Welsh Government and Department for Infrastructure)					
RELATED TRAINING COURSES:				**RELATED LEGISLATION:**	
Defensive Driving Techniques Emergency Track Brake Operation				Health and Safety at Work Act etc. 1974 Railways and Other Guided Transport Systems (Safety) Regulations 2006 (as amended) (ROGS) 2006 SI 1996/362: The Private Crossings (Signs and Barriers) Regulations 1996 Traffic Signs Regulations and General Directions 2016	

	The Electricity Safety, Quality and Continuity Regulations 2002

CHANGE NOTES:

Date of Issue	Issue No.	Revision No.	Reviewer	Details of Revision
20/05/2019	01	01	D Keay	Amendments to text / format
02/08/2019	01	02	D Keay	Amendments to text / format
01/09/2019	01	03	D Keay	Amendments to text / format
16/11/2020	02	00	D Keay	Amendments to text / format
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14/03/2023	02	02	LRSSB	Underrun appendix added, amendments to text / format
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GUIDANCE ON TRAMWAY CROSSINGS FOR NON MOTORISED USERS

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Figures

Tables

Revisions from Previous Issue:

Replacement of term ‘Locked out’ with ‘zoned out’ throughout the document.

Numerous minor text amendments.

TERMS AND ABBREVIATIONS

Table A: Terms

Term	Definition
Active Warnings and Controls	A feature or system that actively provides a warning.
Electromagnetic	A type of force that occurs between electrically charged particles.
Hazard Zone	The area of a crossing that extends between 600 mm from the swept envelope of the tram on one side to 600 mm from the swept envelope on the other side of the crossing.
Infrastructure Manager	Person who is responsible for developing and maintaining that infrastructure or manages and uses that infrastructure or station, or permits it to be used, for the operation of a vehicle.
Line of Sight	Operating mode where a tram should be able to stop before a reasonably visible stationary obstruction ahead, from the intended speed of operation using the service brake.
Passive Warnings and Controls	A feature or system that does not actively provide a warning.
Second Generation Trams / Tramways	UK tramways and Light Rail systems that have been in operation from the 1990's.
Swept Envelope	The kinematic envelope that has been enlarged to allow for the effects of vertical and horizontal curvature, speed etc.
Tramway Operator	The operator of the tramway / Light Rail system.
Transport and Works Act (TWA) Order (or Transport and Works (Scotland) Act (TAWS) Order	Statutory process for attaining Powers to build operate and maintain a tramway / Light Rail system.
Underrun Protection	Infrastructure measures to provide protection to pedestrians and other users of non-motorised crossings such as those described in Appendix 2.
Zoned Out	A person / non-motorised user (NMU) who is distracted and not generally aware of their surroundings, for example, being focused on their hand-held device.

Table B: Abbreviations

Abbreviation	Definition
APROSYS	Advanced Protection Systems
ASP	Audible Sounding Point
AWD	Audible Warning Device
BS EN	British (BS) adoption of a European (EN) standard
dB	Decibel
dB (A)	A Weighted Decibel
DfT	Department for Transport
DMRB	Design Manual for Roads and Bridges
EU	European Union
Km/h	Kilometres per Hour
LED	Light Emitting Diode
LRSSB	Light Rail Standards and Safety Board
m	Metres
m/s	Metres per Second
mph	Miles per Hour
NMU	Non-Motorised User
ORR	Office and Rail and Road
OS	Ordnance Survey
ROGS	Railways and Other Guided Transport Systems (Safety) Regulations 2006 (as amended)
SE	Swept Envelope
sec	Second
TPG	Tramway Principles and Guidance
TSM	Traffic Signs Manual
UK	United Kingdom

1. Introduction

1.1. This guidance supports the high level principles set out in LRG 1.0 Tramway Principles and Guidance (TPG) published by the Light Rail Safety Standards Board (LRSSB).

1.2. This document provides high level guidance in relation to Tramway Crossings for Non-Motorised Users (NMUs) those delegated this responsibility in relation to UK tramways (Light Rail systems) based on 'line-of-sight' operations only. As with all guidance, this document is not prescriptive and is intended to give advice not to set a mandatory standard for the sector, and it is based upon goal setting principles as good practice. Much of this guidance is based on the experience gained from existing UK tramways and from published documents.

1.3. This guidance is not intended to be applied retrospectively to existing tramways. However, owners and operators should consider and assess any implementation of this guidance and / or any subsequent revision, to ensure continual improvement, so far as is reasonably practicable.

2. Scope

2.1. This guidance is for the design and ongoing assessment of all formalised crossings of tramways at grade which will be utilised by crossing users (NMUs). For the purpose of this guidance document, a crossing user includes the following (not exclusively):

- Pedestrians;
- Those with mobility impairment (including persons using non-motorised wheelchairs or accompanied by perambulators or pushchairs);
- Riders on horseback (herein referred to as equestrian users);
- Pedal cyclists; and
- Person using motorised wheelchairs or electrically assisted scooters, pedal cycles or skateboards.

2.2. Refer to LRG 8.0 Guidance in the Management of Vulnerable Persons in relation to vulnerable persons and LRG 28.0 Guidance on the Provision of Accessibility in Light Rail Systems for guidance relating to specific accessibility.

2.3. This guidance is only for tramway crossings having passive warnings and controls, for example signs, markings, chicanes etc.

2.4. In instances where statutory powers within an Act or Order make special provision governing the design or operation of a particular NMU crossing, if there is any inconsistency between that provision and this guidance, the special provision is to prevail.

2.5. Where, in conformity with this guidance it is considered advisable to install signs or barriers relating to a crossing on the property of an adjacent landowner, a tramway operator may, in default or in the absence of an agreement with the landowner, seek authorisation to carry out that installation[1] by applying for statutory powers conferred by a Transport and Works Act Order or Transport and Works (Scotland) Act (TAWS) Order.

2.6. Where the principles in this guidance cannot be met by a passive crossing, then active warnings and controls should be considered or grade separation.

2.7. This guidance is intended for tramways driven on line of sight principles. The primary mitigation on any line of sight tramway relies upon the tram driver being able to brake in sufficient time to avoid hitting a person or object on the crossing. The tramway promoter / operator should ensure that line speeds are established that will allow a tram to stop safely from line speed using the full service brake when a stationary obstruction is seen on the track ahead.

2.8. Further mitigation includes the training and supervision of tram drivers to use defensive driving techniques.

2.9. In addition, trams are fitted with electromagnetic track brakes that can be applied to prevent or mitigate collisions with crossing users in the event they have continued to

[1] The Private Crossings (Signs and Barriers) Regulations 1996 SI 1996/362: https://www.legislation.gov.uk/uksi/1996/1786/made/data.pdf

cross within the time that the tram driver is able to stop before the crossing using the service brake. Tram drivers should therefore be trained and prepared to use the emergency track brake.

3. Overarching Principles of Tramway Crossings for Non-Motorised Users

3.1. The overarching principles of crossings for NMUs are listed below:

- Eliminate crossings where possible;
- Crossings shall be subject to quantified risk assessment to ensure that risks are suitably controlled. In some cases, this may well lead to the elimination of the crossing or grade separation;
- Crossings shall be safe, accessible and practical for use by all users;
- Designs should consider the general standards and principles adopted for highway design;
- Crossings should have treatments appropriate to the level of risk; and
- Crossing layouts should maximise awareness and encourage crossing users to stop and wait when necessary.

4. Risk Assessment

4.1. Every crossing for NMUs shall be subject to a quantified risk assessment. The assessment itself should be reviewed on a cyclical basis or whenever there is a change to the use or the local environment. A suggested risk assessment template (NMC1) is contained in Appendix 1 to this document and is also available to download from the LRSSB website[2].

4.2. The risk assessment should be undertaken both during the design and the operation of the tramway / crossing, and should consider the following (not exclusively):

- The various patterns of tram operation over the crossing including approach line speed and speed over the crossing;
- The crossing user types, including any local facilities that may bring infrequent / unusual user numbers;
- Local conditions in the vicinity of the crossing, including visibility of the crossing from approaches, vegetation, lighting, ambient noise etc.;
- The characteristics of the trams operating on the system, including performance of brakes, audible warning device and lighting; and
- The nature of the crossing, including surfacing, chicanes, signage, etc.

4.3. The output of any risk assessment, undertaken by a suitably competent person, should produce a series of mitigations to ensure that that the risks are reduced so far as is reasonably practicable and to an acceptable level.

4.4. The risks of a crossing should be balanced against the factors (including cost) of providing alternatives such as a bridge or underpass, which at some locations may be an appropriate alternative to an at-grade crossing.

4.5. Records should be kept of all risk assessments and reviews, and any cost benefit analysis conducted on any alternatives considered.

4.6. Further information on the site assessment of crossings is contained in Section 12 below.

2 https://lrssb.org/

5. Design and Maintenance of Crossings for Maximum Awareness by NMUs

5.1. The direction of NMUs' travel over the crossing should be perpendicular (90 degrees) to the track as the flange gap can be a hazard to users, which increases when the crossing is at a different angle to the track.

5.2. Gradient changes are a hazard for pushchairs and mobility devices in particular, and should be avoided if possible.

5.3. Crossing users should be made aware that it is a tramway crossing and therefore the possibility of any trams approaching. This is particularly important, for example, when any of the following conditions apply (not exclusively):

- Crossing users are distracted by personal devices, headphones, mobile telephones etc. that might affect perception and concentration i.e. they are 'zoned out';
- The crossing is obscured on approach or the tramway is obscured for the crossing user by vegetation, fencing, or buildings;
- Approaching trams are obscured by mobile physical obstructions or nearby distractions such as traffic movements, traffic noise, or the track is curved such that it reduces the sighting time of the approach of the tram;
- Trams approach a crossing from each or multiple directions at about the same time;
- An NMU approaches the crossing at speed, requiring time to react and stop; and
- NMU crossings that are in close proximity to major railway stations or other locations where there could be a large number of people who may not be familiar with the area and layout.

5.4. Further to the third bullet point above, as the majority of collisions between trams and pedestrians result in the casualty being thrown clear, at new or altered crossings, the cess and six-foot areas should be kept clear of obstructions such as equipment cabinets and poles where practicable. This will also assist with intervisibility between tram drivers and pedestrians near crossings.

5.5. The design of NMU crossings should reflect the general standards adopted for highway design as stated in Section TA 90/05 of the Design Manual for Roads and Bridges (DMRB)[3]. This guidance document sets out good practice that demonstrates uniformity to crossings for NMUs.

5.6. As TA 90/05 of the DMRB is focussed on highway conditions and not written to take any account of a fixed track tramway, it should only be used as a reference guide. The tramway designer / Infrastructure Manager should determine both the suitability and means of applying this document on a case by case basis.

5.7. Guidance is also provided in LRG 24.0 Pedestrian Safety Guidance and LRG 28.0 Accessibility Guidance.

3 The Design Manual for Roads and Bridges. Volume 6, Section 3 Highway Features, Part 5, TA 90/05 The geometric design of pedestrian, cycle and equestrian routes: https://www.standardsforhighways.co.uk/dmrb/

5.8. In addition, there is DfT guidance in Chapter 6 'Traffic Control' of the TSM[4] covering the design and assessment of pedestrian crossings.

5.9. Consistency of signs, markings and barriers etc. should be achieved to reduce uncertainty for tramway staff, passengers and non-users as to which parts of the crossing are a place of safety and what is the hazard zone within the Swept Envelope (SE) of the trams. For further advice and detail, refer to LRG 1.0 TPG.

4 Traffic Signs Manual Chapter 6 Traffic Control, 2019: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/851465/dft-traffic-signs-manual-chapter-6.pdf

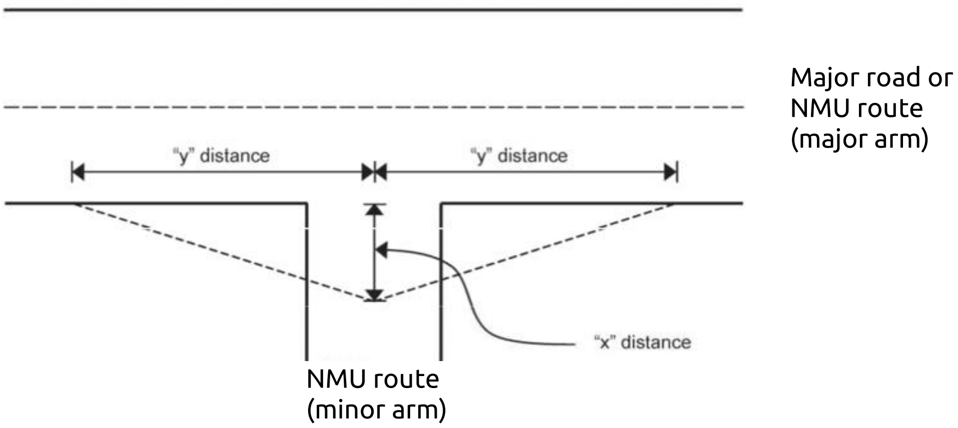
6. Intervisibility Sighting Distances

6.1. The visibility parameters set out in TA 90/05 of the DMRB are recommended as a starting point for the design of NMU crossings and as such, are referred to below on this basis.

6.2. Chapter 3 of TA 90/05 refers to the visibility at junctions or crossings which enables both the crossing user to see approaching traffic, and other users on the highway to see NMUs about to cross.

6.3. A visibility splay should be provided for crossing users approaching crossings where they have to stop or give way as illustrated in Figure 6.1 below.

Figure 6.1: Visibility Splay Diagram for Highways



6.4. The distances referred to as "x" and "y" from TA 90/05 represent the following:

- "x" - the 'perpendicular sighting distance', is the distance back along the NMU approach route which is measured perpendicularly to the edge of the major route, known as the 'highway minor arm'; and
- "y", the 'sighting distance', being the distance left and right at the crossing threshold along the highway major arm.

7. Determination of Perpendicular Sighting Distance ("x")

7.1. For tramways, the application of the perpendicular sighting distance "x" is calculated from the outside edge of the SE as illustrated above in Figure 6.1.

7.2. For a tram vehicle that is 2.65 m wide, the distance from nearest running rail to the outside of the SE on straight track would be calculated to be 750 mm.

7.3. For this measurement, it is assumed that both pedestrians and cyclists have come to a stop at the crossing, or at least their travel speed is likely to be less than 10 km/h at the start of the "x" distance.

7.4. For pedestrians, the preferred "x" distance stated in TA 90/05 is a minimum of 2.0 m, but to allow for the needs of the mobility impaired a distance of 1.5 m is generally accepted as good practice in UK tramway systems.

7.5. However, when taking into account cyclists, a longer "x" distance than the minimum is more appropriate, and therefore 2.5 m would provide a more practical distance to allow cyclists to slow down and observe the full "y" distance.

Speed of Approach and Barriers

7.6. Speed affects the distance available to react and respond to the presence of a crossing, in terms of both the tram driver and the crossing user to the presence of a tram. Crossing approaches with poor sighting distance may require faster crossing users to slow down and should therefore be designed accordingly, i.e. by the use of chicanes.

7.7. The design of crossings on non-highway sections of tramway system that are remote from tram stops should start with the assumption that chicane barriers will be fitted unless a risk assessment demonstrates that the risks can be controlled without the use of these barriers.

7.8. In some circumstances, advance warning signs and markings may be required in order to alert higher-speed users as they approach the crossing and also if there are obstructions / distractions as detailed in Section 5.

7.9. Other suggested crossing approach speeds to consider (as stated in the DMRB) are as listed below:

- Mobility impaired pedestrian: 3 - 4 km/h (0.8 - 1.1 m/s);
- Able-bodied pedestrian: 4 - 6 km/h (1.1 - 1.7 m/s);
- Mobility scooter user: 6 - 16 km/h (1.7 - 4.4 m/s);
- Skateboard / scooter user: 10 - 15 km/h (2.8 - 4.2 m/s) (electric devices may be faster);
- Child cyclist: 12 - 18 km/h (3.3 - 5.0 m/s);
- Adult commuter cyclist: 20 - 25 km/h (5.6 - 6.9 m/s); and
- Racing cyclist (or electric-assisted bike user): 30 - 35 km/h (8.3 - 9.7 m/s).

7.10. However, for tramway crossings, pedestrian approach speeds are important to consider when assessing the visibility splays and the length of time that a tram driver will have a good sighting of an approaching pedestrian.

7.11. As the majority of tramway crossings are shared between cyclists and pedestrians, a lower design speed of 10 km/h (as a walking speed) may be considered appropriate. This would be qualified by a site based assessment that has demonstrated that sufficient controls are in place to reduce the approach speed of cyclists or to ensure that all crossing users could be treated as pedestrians (for example, cyclists shall dismount).

7.12. Due to the width of chicanes required to allow for the mobility impaired, it is possible for a cyclist to ride around or otherwise avoid the features of a crossing where it has been designed to slow the approach speed. This should be considered in both the design and assessment of the crossing.

7.13. As well as their role in controlling the speed of a crossing user, barriers also have a key role in ensuring that users are turned to face along the track which increases the likelihood of them looking to see an approaching tram.

7.14. Chicane arrangements that turn users to look in both directions should be used where practicable for double track and / or bi-directional tramway sections.

Application to Equestrian Crossings

7.15. When designing or assessing a crossing for equestrian use, the tram approach speeds to the crossing should be risk-assessed, taking into account the crossing speed and the potential unpredictability of horses.

7.16. TA 90/05 recognises that equestrians will generally slow down to a walking speed (10 km/h) on the approach to a junction. Therefore, physical controls should always be provided to make the presence of the tramway clear to ensure that the equestrian slows their speed. An equestrian chicane should be provided as illustrated in TA 90/05.

7.17. It should be noted that the sight line for the rider of a horse is significantly different to that of a pedestrian or cyclist, with the rider being both higher and further back from the crossing point. Guidance on addressing this issue is given in TA 90/05.

7.18. Due to the additional height of a horse rider (and the potential for vehicles to also use an equestrian route), overhead line electrification shall have a minimum height of 5.8 m above rail level at equestrian crossings (refer to The Electricity Safety, Quality and Continuity Regulations 2002[5]).

7.19. Where the crossing is designed to accommodate cyclists and pedestrians as well as equestrian users, the risk assessment should recognise that this type of crossing should always be treated as a higher risk location, as it is not possible to put in place the same arrangements that would be used for a pedestrian / cycle crossing.

7.20. As a consequence, there is a high probability that cyclists in particular will approach equestrian crossings without reducing speed or being fully turned to face approaching trams.

7.21. Where reasonably practicable, it is recommended that equestrian crossings of tramways should be removed or avoided where possible.

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5 The Electricity Safety, Quality and Continuity Regulations 2002:
https://www.legislation.gov.uk/uksi/2002/2665/contents/made

7.22. Further guidance in relation to cyclists is provided in LRG 19.0 Cycle Tramway Interface Guidance and in relation to pedestrians LRG 24.0, as well as LRG 28.0 Guidance on the Provision of Accessibility.

8. Recommended Perpendicular Sighting ("x") Distances

8.1. For the purposes of assessment of NMU tramway crossings, the perpendicular distances as specified in the DMRB and shown below in Tables 8.1 and 8.2 should be utilised.

Table 8.1: Recommended "x" Distances for Pedestrian / Cycle Crossings

Measured From	Acceptable in TA 90/05	Acceptable Minimum	Absolute Minimum in TA 90/05
SE	2.5 m	2.0 m	1.0 m
Nearest running rail	3.25 m	2.75 m	1.75 m

Table 8.2: Recommended 'x' Distances for Equestrian Crossings

Measured From	Acceptable in TA 90/05	Acceptable Minimum	Absolute Minimum in TA 90/05
SE	5.0 m	4.0 m	3.0 m
Nearest running rail	5.75 m	4.75 m	3.75 m

9. Determination of Sighting Distance ("y")

9.1. The 'y' sighting distances in Tables 10.1 and 10.2 below have been calculated using a tram service brake rate of 1.3 m/s-2 which includes a 2 second thinking and reaction time. These figures are considered by the Light Rail sector to be reasonable for a tram driven on line-of-sight principles with dry railhead conditions.

9.2. Therefore, on this basis, this guidance sets out recommended 'y' distances for tram speeds between 20 km/h and 75 km/h.

9.3. For all speeds below 20 km/h, it is recommended that the minimum 'y' value is 30 m which provides a reasonable factor of safety when considering the stopping distances in terms of sight lines. General experience shows that crossing users will believe that they can still cross safely at most speeds, which takes approximately 5 seconds at average walking pace.

9.4. Tram drivers will generally not begin braking unless a crossing user has encroached within the 'x' distance.

10. Recommended Sighting ("y") Distances

10.1. For the purposes of assessment of tramway crossings, the sighting distances in Tables 10.1 and 10.2 below should be utilised.

Table 10.1: Recommended "y" Distances for Pedestrian / Cycle Crossings

Tram Speed (km/h)	Recommended Sighting Distance ("y") (m)
20	30
25	35
30	40
35	50
40	60
45	75
50	90
55	100
60	120
65	135
70	155
75	170

Table 10.2: Recommended "y" Distances for Equestrian Crossings

Tram Speed (km/h)	'y' Distance Recommended (m)
20	40
25	55
30	70
35	85
40	100

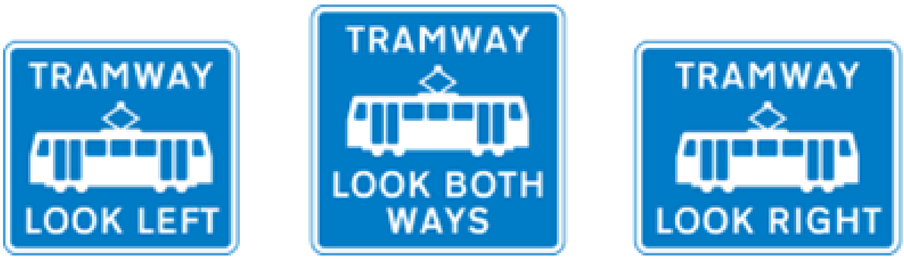
10.2. An appropriately responsible person (for example, an infrastructure manager and / or operator) should undertake sighting and braking tests to ensure that a tram can stop within the sighting distance of the crossing using the service brake.

11. Mitigation Measures and Warnings

Signage

11.1. For signage at all formalised tramway crossings, Diagram 963.3 of the Traffic Signs Regulations and General Directions 2016[6] should be used as illustrated in Figure 11.1 below, with the character height being between 40 and 50 mm. All signs should be clearly visible to users on all sides of the crossing when approaching.

Figure 11.1: Diagram 963.3



40 mm
- 50 mm

11.2. The sign in the centre of those in Figure 11.1 above is used for bi-directional tram lines. The two variants on the right and left are those used for uni-directional only tram lines.

11.3. For further guidance relating to signage for tramway systems, refer to LRSSB document LRG 4.0: Signing and Marking of Tramways Guidance.

Crossing Surface Treatments and Markings

11.4. The crossing surface should be low slip potential with a minimum width of 2.4 m. The surface should be adequately drained to minimise the effects of water and ice.

11.5. Rather than marking a notional decision point for users, it is recommended to clearly mark the hazard zone which is the space between the outside of the two SEs for double track or the one SE for single track. It is good practice to colour the hazard zone surface yellow and extend the colouring 600 mm beyond the SE.

11.6. For crossings in unlit or rural environments, consideration should also be given to marking the outer edge of the hazard zone with Light Emitting Diode (LED) lighting during the hours of darkness.

11.7. Where tactile ground surface warnings are used, they should be consistent with highway treatment and should be installed at the edges of the of the hazard zone to alert the visually impaired or distracted user. The tactile warning should be of a contrasting colour (but not red) and should extend for 800 mm from the hazard zone for the full width of the footway.

11.8. For crossings of ballasted track, there should be a suitably flush surface between the rails along the distance of travel at either side of the main crossing surface to ensure underrun protection is maintained. It is recommended that the surfacing be asphalt or infill panels.

6 Diagram 963.3 of the Traffic Signs Regulations and General Directions 2016: https://www.legislation.gov.uk/uksi/2016/362/made/data.pdf

11.9. At higher speeds, for example 60 km/h, extended underrun protection is not effective. However, it is assumed that emergency braking would be activated, and the tram will be able to reduce its speed to 30 km/h when it arrives at the crossing.

11.10. Further guidance in relation to track bed underrun protection can be found in Appendix 2 of this document.

Lighting

11.11. As crossings are used at night, tram drivers may not be able to see crossing users waiting to cross, so it is essential that the crossing can be adequately seen in the hours of darkness including against the background of other lights and signs in its vicinity.

11.12. As all crossings are different, the provision of lighting for any crossing should be based upon an assessment of the risks for that particular crossing including, for example, visibility, vulnerable users, adjacent schools etc. For guidance in relation to vulnerable persons, refer to LRG 8.0 Guidance in the Management of Vulnerable Persons.

11.13. Lighting levels should be to the levels recommended in the appropriate section of BS 5489[7].

LED Lighting

11.14. LED based light sources should be considered as they have a number of advantages such as the following (not exclusively):

- Small, lightweight;
- Robust have a long life (usually 15 to 25 years) so lower maintenance cost;
- Unaffected by frequent switching;
- Easily dimmed;
- Very low current requirement;
- Compatible with solar panel power supplies in locations where a mains electricity supply is not readily available; and
- Do not contain mercury or lead and do not emit any poisonous gases so have an environmental and also cost benefit.

11.15. In addition, LED marker lights can be embedded in surfaces to provide additional warning to crossing users. These could be constantly lit or triggered by approaching trams or crossing users.

Additional Mitigation Measures

11.16. There are some additional measures that may need to be considered depending on their appropriateness to the tramway system and the risks assessed.

11.17. In terms of the driver of a vehicle, technological approaches can be taken to driver inattention and also speed management; for further guidance refer to LRG 17.0 Driver Inattention Systems Guidance and LRG 18.0 Speed Management Systems Guidance.

7 BS 5489 Part 1: Code of practice for the design of road lighting. Lighting of roads and public amenity areas

11.18. Some crossing users focused on their hand-held devices have a tendency to move whilst looking down, only occasionally glancing up at their surroundings (described as being zoned out). It is therefore recommended to consider the following (not exclusively):

- Additional warnings on / at ground level to catch their attention, for example, yellow surfacing and active in-ground LEDs; and
- Approach treatments involving chicane barriers can force crossing users to look up to assess their forward progress.

11.19. For new or altered crossings, a Stage 1 and 2 Road Safety Audit (RSA) should be undertaken during the design of the crossing to assess and evaluate any measures being proposed. Guidance on RSAs is given in GG 119 Road Safety Audit, a section of the DMRB[8].

11.20. Where sighting distances of approaching trams are adequate for crossing users and corresponding sighting distances for tram drivers of crossing users approaching crossings are also adequate, principle audible warnings from approaching trams should not be routinely necessary.

Audible Warnings

11.21. Where sighting distances are limited, or there are concerns about users of crossings being distracted tram promoters / operators should consider consistent use of audible warnings by the approaching trams.

11.22. Audible levels for any warnings should be meet the recommendations set out in BS EN 15153-2[9] and BS EN 15153-4[10]. Further guidance on test procedures for audible warning devices is given in LRG 5.0: Tramway Audible Warning Acoustic Test Guidance.

11.23. The sound pressure of any Audible Warning Device (AWD) should be discernible above the background noise at the crossing by between 10 - 15 dB (A).

11.24. Audibility of AWDs will be dependent on the site specific conditions of the crossing. If audible warnings are to be used, practical tests should be undertaken to ensure that any AWD for an approaching tram is adequately audible at the crossing.

11.25. Measurements should take account of wind direction which can potentially further reduce audibility. This might require a reduced tram approach speed to deliver effective warning times.

11.26. There is a calculation for the sound pressure level at the crossing that can be applied on the basis of the standard sound pressure decay over distance formula as shown below:

$$SP_d = SP_7 - [20.\log(7/d)]$$

---

8 GG 119 Road Safety Audit, a section of the Design Manual for Roads and Bridges: https://www.standardsforhighways.co.uk/dmrb/search/710d4c33-0032-4dfb-8303-17aff1ce804b

9 BN EN 15153-2 2020 Railway Applications. External visible and audible warning devices. Warning horns for heavy rail

10 BS EN 15153-4:2020 Railway Applications. External visible and audible warning devices. Audible warning devices for urban rail

Where:

SP is Sound Pressure (dB)

SP_d is the calculated sound pressure reading 'd' metres from the NMU crossing

SP_7 is the sound pressure measured at a distance of 7 metres from the NMU crossing

7 is the distance for first sound pressure measurement (m); here this is the first distance from the point of measurement (i.e. 7 metres from the NMU crossing)

d is the distance of measurement (m); here this is the second distance from the point of measurement (i.e. 'd' metres from the NMU crossing)

Log is the base 10 logarithm

Audible Sounding Point (ASP)

11.27. The ASP is the point from the crossing at which a zoned out pedestrian has not clearly acknowledged the presence of the tram but still has enough time to see the tram and reach a place of safety. The ASP is NOT the point at which a tram can come to a complete stop. A place of safety is at a point 1 m from the nearest running rail which is calculated as:

The SE 0.75 m plus 0.25 m for additional clearance

11.28. The calculation of the distance required for a person to reach this place of safety when using an NMU crossing is:

2 SE outside of running rail + Rail Gauge + additional clearance

11.29. Therefore, for a 2.65 m wide tram vehicle, the calculation of the distance required for a person to reach this place safety on an NMU crossing would be 3.435 m.

11.30. Using the above calculation and using a worst case and assuming a mobility impaired person walks at 0.8 m/s^{-1} the time required to walk between places of safety would be 5 seconds (inclusive of 0.67 seconds reaction time from hearing the horn of an approaching tram). This is calculated as:

Time = 3.435/0.8 = 5 seconds

11.31. Therefore, the ASP for a tram driver should be this calculated time plus an additional safety factor of 25% to allow, for example, a person pushing a wheelchair, thus a value of 6.2 seconds.

11.32. Trams braking from higher speeds will have slowed sufficiently for other safety measures such as underrun protection to be effective (see Appendix 2 for further details). A tram braking from 60 km/h at the ASP in emergency brake mode on wet rails is calculated to take 6.2 seconds.

11.33. A risk assessment should be conducted to determine if a standard tram sound horn sign should be installed in advance of an NMU crossing at the ASP.

12. Site Assessment of Crossings

12.1. Following on from Section 4 above relating to risk assessment, this section looks at undertaking an assessment on site.

12.2. Personal safety in respect of tram and road vehicle movements is paramount when carrying out any crossing assessment. Only persons holding appropriate tramway and highway safety competences should undertake the assessments, and tramway track safety rules and normal highway safety procedures should be observed.

Records of Crossings

12.3. The crossing details should be recorded including the following (not exclusively):

- Crossing name;
- Asset number;
- Crossing type;
- OS grid reference;
- Design chainage; and
- Section of route.

12.4. Due to the above, care should be taken when naming crossings to ensure there will be no confusion or ambiguity between them.

12.5. The operator's asset management systems should retain information on the infrastructure at each crossing including inspection records and maintenance records. Risk assessment details may be held in this system or separately, but a common unambiguous crossing reference should be used to clearly link records where there are separate record systems.

Photographs

12.6. At construction, maintenance and each inspection of the crossing, photographs should be taken of the following (not exclusively):

- The crossing approaches, including signage and other markings to record the user's view;
- The view across the crossing from the "x" point on each side;
- The crossing surface and the surface of approach routes;
- Signage provided for tram drivers, for example, advice of crossing approach and any speed restrictions;
- Chicanes, barriers and other measures to warn and manage the users of the crossing;
- Any equipment associated with the crossing, for example, telephones and gates where provided;
- Views from the edge of the hazard zone on both sides looking up and down the line (if safe to do so, these can be taken with a tram approaching), to record anything which might limit sighting;
- Any problems identified, for example, missing or confusing signage, signs of abuse or defects and any other matters requiring attention etc.; and

- Evidence of change of use or change in the local environment including the creation of new desire lines.

Sound

12.7. Sound level meter readings should be taken and recorded at each crossing in both directions for tram horn warnings at each audible sounding point.

Estimating Crossing Use

12.8. To assess the likely risk at a crossing, it is essential to obtain good estimates of the number of users and types of users.

12.9. A census of usage of the crossing by numbers and types of users should be carried out as part of each initial site assessment. It is recommended that the census is then repeated at every third assessment review, when a significant change being made to the crossing, when a change is made to the local environment, or the use of the crossing has been identified.

12.10. The census should consist of at least three, two-hour blocks and include a morning and evening peak periods (for example, school runs, commuting etc.). The census should take place at the same times of day and roughly the same time of year as the previous census, choosing dates where heaviest use is likely (for example, during school term etc.).

12.11. The content of the census should comprise and especially identify a count of the following (not exclusively):

- Child pedestrians;
- Adult pedestrians;
- Pedestrians with prams or pushchairs;
- Wheelchair users;
- Pedestrians with visible limited mobility;
- Horses and riders; and
- Cyclists and motorised vehicles for example mobility scooters.

12.12. At particular locations where there have been numbers of reported near misses and measures have been put in place as a response, a video camera could be mounted at the crossing for a period of time (for example, 1 month), and then the resulting footage analysed to identify any changes to user behaviour and actions.

12.13. Where crossings may be associated with locations with infrequent abnormal use patterns, for example, crossings adjacent to sports grounds, then the census should still include this. If the data is consciously excluded, the operator should still take account of these periods and provide alternative measures to manage these crossings at times of unusual use.

Record of Tram Movements

12.14. The number of trams per day passing over the crossing should be recorded for a normal operational daily service.

Measuring Sighting Distance

12.15. Further to the guidance above relating to the intervisibility sighting distances and Figure 6.1, the sighting distance of the crossing in both directions, looking up and down the track should be measured from the perpendicular distance ("x") point.

12.16. The sighting distance ("y") should be measured from the point at the crossing where a tram comes into sight. The method of measurement should be recorded together with the point of sighting, the distance and any limits on continuous visibility of the tram due to elements of the infrastructure.

12.17. The point of sighting should be identified with an appropriate marker between the rails, which can be used for successive assessments and provide a reference for the removal of foliage or any modification to the infrastructure.

Additional Risk for Crossing Users

12.18. Tramway operators should consider and document other factors that may increase risks for crossing users using the crossing, for example, the following (not exclusively):

- Adjacent tram stops;
- Use by higher than usual numbers of vulnerable people (schools, care homes, hospitals etc.);
- Seasonal events and sporting fixtures;
- Sources of ambient noise that might reduce effectiveness of tram audible warnings i.e. adjacent roads, business premises; and
- Other desire lines to cross the tracks in the proximity of the crossing.

12.19. Further guidance relating to pedestrian movements is contained in LRG 1.0 TPG, LRG 24.0 Pedestrian Safety Guidance and LRG 28.0 Accessibility Guidance and LRG 28.0 Guidance on the Provision of Accessibility in Light Rail Systems.

Condition of the Crossing

12.20. The physical condition of all elements of the crossing should be noted and time-bound actions produced for any deficiencies, for example, the following (not exclusively):

- Poor crossing surface;
- Damaged or missing signage; and
- Foliage impairing sighting.

Recording the Assessment

12.21. Information collected during the assessment should be recorded in a report along with any mitigations proposed and timescales for implementation. To assist with prioritising any further action, relative risks at each crossing can be assessed using a qualitative approach to aid the assessment, but this is not a substitute for a full risk assessment of each crossing.

13. Post Site Assessment Review

13.1. Where the acceptable “x” and “y” distances have been achieved, the crossing may be considered acceptable from an intervisibility perspective and no further action is required at this time.

13.2. Where it proves difficult to achieve acceptable “x” and “y” distances, further engineering design and risk assessment will be required.

13.3. A Stage 4 RSA should be undertaken on any crossing that does not meet acceptable “x” or “y” distances.

14. New Crossings

14.1. All new crossings should be subject to a formal RSA audit and an NMU site assessment.

14.2. The RSA audit is not a technical design check, it is an audit carried out from the user's perspective and offers an opportunity to assess the value of the current / proposed crossing arrangements to the user.

Appendix 1 – Risk Assessment Template (NMC1)

LRSSB	Example Non-Motorised User Crossing Risk Assessment Template	RA Ref		Form NMC1
		Issue Date		
		Review Date		

Part (A) Assessment Details:				
Name of Assessor/s				
Date				
Assessment Start Time/s		Assessment End Time/s		
Associated Bowtie Assessment Reference (if applicable)				
Crossing Asset Reference				
Location				
Number of Lines Crossed				
Track Geometry	Horizontal Curvature		Vertical Curvature	
Speed Limit km/h	Inbound Line		Outbound Line	

Crossing Usage:	Map or Satellite Image Indicating Position of Crossing:	
	Insert Image	
	OS Grid Reference	
	Design Chainage	
	Section	

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Part (C) Crossing Approaches and Environment (insert photographs as titled size = 4.7 cm H by 8.0 cm W):			
	In Bound View (towards)	Centralised View	Outbound View (towards)
In Bound Side	*Insert Image*	*Insert Image*	*Insert Image*
Out Bound Side	*Insert Image*	*Insert Image*	*Insert Image*

Part (D) Sighting Distance (from 3.2m of nearest running rail):

All distances in (metres)	Minimum sighting distance required (insert NMCU table value vs line speed)	Measured sighting distance in (m)	Point sighting distance is measured to (e.g. OHLE pole umber)	Is sighting distance compliant Y/N?				If sighting distance is not compliant is it mitigated Y/N?				Sighting time mitigations (Mandatory sounding of horn/bell on approach etc.)
Inbound side looking Inbound				Y		N		Y		N		
Inbound side looking Outbound				Y		N		Y		N		
Outbound side looking Inbound				Y		N		Y		N		
Outbound side looking Outbound				Y		N		Y		N		

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LRSSB	Example Non-Motorised User Crossing Risk Assessment Template	RA Ref		Form NMC1
		Issue Date		
		Review Date		

Part (E) Sighting Restrictions:	Inbound Direction Y/N				Out-bound Direction Y/N			
Nothing: Vanishing point	Y		N		Y		N	
Track curvature	Y		N		Y		N	
Permanent structure (building, bridge, wall etc.)	Y		N		Y		N	
Signage or crossing equipment	Y		N		Y		N	
Vegetation	Y		N		Y		N	
Bad weather on day of assessment	Y		N		Y		N	
Other – Please provide details below:	Y		N		Y		N	
	Y		N		Y		N	

Part (F) Census Data:	Census data taken on day (number per hour)	Average traverse time (in min / sec)	Lowest traverse time (in min / sec)
Child pedestrians			
Adult pedestrians			
Pedestrian with pushchair			
Wheelchair users			
Pedestrian with visible limited mobility			
Cyclists			
Motorised vehicles e.g. Mobility scooter			
Equestrian users			
Other			

Part (G) OHLE Wire Height at Crossing: (Note: a minimum of 6.8m above rail height at equestrian crossing should be observed)	Specified	Actual

Part (H) Lux Level:	Specified	Actual

Notes:

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LRSSB	Example Non-Motorised User Crossing Risk Assessment Template	RA Ref		Form NMC1
		Issue Date		
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Part (I) Risk Assessment: (refer to part (K) for risk matrix)

No	Issues	Observations	Existing Controls	Freq + Like	Pso + Sev	Ex Risk	Additional Controls	Freq + Like	Pso + Sev	Res Risk
1	Sighting Hazards - **Pedestrians** (Infrastructure/Trees/Track Alignment) Seasonal effects (fog)		**Example Calculations** ➡	4 (2+2)	7 (1+6)	28		3 (1+2)	7 (1+6)	21
2	Sighting Hazards - **Tram Drivers** (Infrastructure/Trees/Track Alignment) Seasonal effects (fog)			6 (2+4)	8 (4+4)	48		3 (1+2)	3 (1+2)	9
3	Underrun considerations (i.e. Ballasted track/Paved alignment)			4 (2+2)	5 (2+3)	20		4 (1+3)	4 (1+3)	16
4	Pedestrian Clearances			6 (2+4)	4 (2+2)	24		3 (1+2)	3 (1+2)	9
5	Local Amenities impacting/potential to impact on crossing usage			4 (2+2)	4 (2+2)	16		2 (1+1)	7 (1+6)	14
6	Signage, Defined Walkways, Disability Issues			4 (2+2)	4 (2+2)	16		3 (1+2)	4 (1+3)	12
7	Fenced barrier (chicane)			9 (4+5)	6 (2+4)	54		3 (1+2)	7 (1+6)	21
8	Pedestrian 'Transition to High Risk Area' Markings, Indication or Physical controls			5 (2+3)	6 (2+4)	30		3 (1+2)	6 (1+5)	18
9	Impact on pedestrian position (anything that may affect pedestrian approach)			4 (2+2)	7 (1+6)	28		2 (1+1)	7 (1+6)	14
10	Temporary works in proximity to crossing			5 (2+3)	7 (1+6)	35		3 (1+2)	7 (1+6)	21
11	Crossing lighting			5 (2+3)	7 (1+6)	35		3 (1+2)	3 (1+2)	9
12	Transition from light to dark, proximity to trams stops and other sources of light			3 (1+2)	4 (2+2)	12		3 (1+2)	3 (1+2)	9
13	Desire lines			5 (3+2)	6 (3+3)	30		3 (1+2)	4 (1+3)	12
14	Other			4 (2+2)	4 (2+2)	16		3 (1+2)	7 (1+6)	21
	Total average of existing risk					28	Total average of residual risk			15

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		Issue Date		
		Review Date		

Notes:

Part (J) Incident History:

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		Review Date		

Note:

An editable word version of this risk assessment template can be downloaded from the LRSSB website under the forms section

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Appendix 2 – Guidance on Track Bed Underrun Protection

Background

1) Evidence from tramway accidents shows that casualties are more likely to be thrown clear and to one side. However, a significant minority of casualties are over-run by the tram. In addition, proportionally, collisions with pedestrians and cyclists remain the greatest cause of death and serious injury on tramways. Therefore, it is important to consider provision of effective underrun protection (vehicle and infrastructure) in addition to any other mitigation measures.

2) The early second-generation UK trams operating on-street were fitted with lifeguard protection on the vehicles, but this was only effective when running on-street or where embedded track was fitted. As UK Light Rail has expanded, guidance from the Office of Rail and Road (ORR)[11] was developed to provide a requirement for some form of level underrun surface to be provided immediately after pedestrian crossings. This then became typical for subsequently constructed tramways, but there was a lack of standardisation in how this requirement was interpreted and applied.

3) In addition, situations arose during the design stages of later tramways where there was an unavoidable requirement for both underrun protection and anti-pedestrian measures, usually due to proximity of a crossing to motorised points. Novel panels were developed in response to overcome this.

4) This appendix is intended to clarify these issues.

Scope of this Appendix

5) Mitigation of hazards relating to the total track bed surface between tramstop platforms is not covered here, other than immediately beyond the pedestrian crossing points. These hazards should be considered separately, in particular on low floor systems where the risk of people stepping down to cross the track is greater. However, it should be remembered that a balance needs to be struck between reducing the risk of underrun injury and the possibility that a level surface might tempt pedestrians onto it between platforms, thus increasing the risk of collision.

6) This appendix does not offer guidance on recommended speed of approach to crossings. This is for operators to risk assess, in particular on approach to crossings when entering tramstops.

Principle

7) The term 'underrun protection' is used here to refer to the infrastructure measures described below. Other publications may use the same term to refer to the on-vehicle features designed to minimise underrun, generally referred to here as the 'lifeguard'.

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11 RSPG–2G–Tramways, superseded by RSP2, later by LRSSB document LRG 1.0 Tramway Principles and Guidance (TPG)

8) Although reference is made throughout this appendix to pedestrians, these measures also relate to other users of non-motorised crossings as described in Section 2.1.

9) Pedestrian crossings associated with road crossings of segregated tram tracks should be considered in the same way as other pedestrian crossings of tramways.

10) Second generation trams are designed to minimise the risk of injury to pedestrians should they be struck by the tram. This is usually achieved by providing bodywork and skirting to minimise the risk of pedestrians passing under the tram and a lifeguard extending as close as practicable to rail level and located immediately ahead of the leading wheels, with a relatively safe survival space ahead of it where the casualty can be captured. However, the design detail may vary, for example, on trams without conventional bogies.

11) Should a pedestrian be knocked over at a relatively low speed in the street and not pushed aside, they should be pushed along the road surface rather than passing underneath the wheels and underframe. However, off-street track-forms typically comprise a slab or sleeper base significantly below the railhead and therefore there is a much deeper gap beneath the tram's lifeguard, and a likelihood of greater injuries if the tram knocks a person down.

12) Infrastructure underrun protection on off-street sections should comprise of a built-up section between the rails, designed to bring the surface of the track-form up to the level of the top of the rails and thereby reduce the injury risk to a level similar to that of an on-street tram collision at the same speed.

13) The design principle is that in credible collision scenarios where the collision speed is low enough for a casualty to survive the initial impact, the tram should be able to stop before reaching the end of the underrun protection.

14) Any alternative track form such as grass-track that is close to railhead height should not be assumed to provide equivalent underrun protection unless this has been demonstrated.

Maximum Effective Speed of Underrun Protection

15) Underrun protection should be provided to ensure that a person struck by a tram at 20 mph (32.2 km/h) or less, where the hazard brake has already been applied, will not be pushed beyond the end of the panels. Justification for the choice of this speed is provided below.

16) When using data on pedestrian survival rates, differences between pedestrian collisions with road vehicles and collisions with trams shall be recognised. Casualties in a frontal collision with a car are less likely to be knocked forward and then overrun than if the collision is with a tram (or some heavy road vehicles) due to the different frontal shape. In addition, those casualties who are over-run by a tram will probably have worse outcomes than if over-run by a road vehicle due to the latter having rubber tyres and typically a greater ground clearance.

17) While detailed analysis of the relationship between speed of trams and the outcomes of pedestrian collisions is sparse, much research has been carried out for road vehicles, although analysis of such research is complex with many variables. However, the

consensus from this data is that the risk of fatality in collisions between pedestrians and road vehicles increases slowly up to 30 mph (48.3 kph), then increases rapidly above this speed. In addition, at 20 mph (32.2 kph), less than 5% of frontal collisions with a car will be fatal whereas at 30 mph (48.3 kph), this increases to about 10% and at 40 mph (64.4 kph) to about 50%[12].

18) One study[13] comparing differences in survivability of pedestrians in collision with either trams or cars suggests that the above fatality figures would be higher for trams due both to the frontal shape and the outcomes of the pedestrian being run over.

19) Tests of trams with crash test dummies indicate that underrun protection is less effective above about 30 km/h (approximately 20 mph).

20) The EU funded APROSYS project[14] relating to active pedestrian protection on heavy vehicles, implies an upper survivable speed of 40 km/h (25 mph) for pedestrians struck by trucks, which may have a similar frontal geometry to trams. This further reinforces the above rationale[15].

Underrun Infill

General

21) The extended underrun surface should typically consist of panels, flush with the railhead. These shall be securely fitted so as to minimise risk of displacement (due to damage) that might risk fouling a passing tram, whilst also being relatively easy to replace. Consideration should be given to allowing water run-off, for example, by being slightly convex. Adequate flangeway clearances shall be assured.

Surface Treatment and Friction

22) A balance needs to be struck between having a degree of non-slip surface treatment to minimise slip incidents by track workers or errant pedestrians, and permitting a prone casualty to be slid along. Whilst the former type of incident will have a higher frequency, the severity will generally be low. However, collision with a pedestrian may be less likely, but the potential severity is very high, so the underrun protection provided shall not be compromised. The panels are not intended to be walked on and therefore should have warnings on them to clearly state this. For this reason, any non-slip treatment should offer no greater friction than, for example, smooth tarmac.

23) UK trials using an adult weight test dummy on commonly used standard panels with fairly aggressive non-slip surface are illustrated in Figure Ap2.1 below. These caused significant

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12 DFT Road Safety Web Publication No. 16 'Relationship between Speed and Risk of Fatal Injury: Pedestrians and Car Occupants' - D. C. Richards Transport Research Laboratory September 2010 Department for Transport: London

13 Stanislaw Gaca and Lukasz Franek from the journal Open Engineering https://doi.org/10.1515/eng-2021-0110

14 Advanced Protection Systems (APROSYS): https://cordis.europa.eu/project/id/506503

15 Strategies for enhanced pedestrian and cyclist friendly design APROSYS project FP6-PLT-506508, report AP-SP21-0062, RWTH Aachen, 03/05/2006-issued 2009

resistance and abrasion damage after the simulated casualty had been pushed by the tram lifeguard, braking to standstill from about 20 km/h.

Figure Ap2.1: Standard Panels with Aggressive Non-slip Surface

24) Figure Ap2.2 below provides an illustration of a similar test on the half cylinder panels where no abrasion damage is evident. This is further described in the Pedestrian Deterrence section below.

Figure Ap2.2: Test on Half Cylinder Panels

Direction of Infill From Crossings

25) The infill will normally be on the run-off side of the crossing for the normal direction of travel (see Pedestrian Deterrence section below), but crossings of tracks that are operationally bi-directional should have infill in both directions.

Width of Infill

26) The intention of the infill is to provide protection between the rails, on the assumption that if a person falls to the outer side of the rails the injury risk from over-run is much less. However, if a crossing is positioned unavoidably on a sharp curve, the need for infill extending into the cess or six-foot areas should be assessed, but any such measures should not create additional risks by removing a potential survival space for a prone casualty who has been pushed aside, such as between rail and platform edge[16]. Where

16 See RAIB report 'Pedestrian struck by a tram at Sandilands tram stop, Croydon, 16 May 2012: https://www.gov.uk/raib-reports/pedestrian-struck-by-a-tram-at-sandilands-tram-stop-croydon

the required underrun length extends through point- work that is close to a crossing, good efforts should be made to fit shaped panels within this, whilst not compromising the operation or maintenance of the points.

27) As pedestrians should not walk on these panels, a slightly greater than usual flangeway gap can be provided to facilitate the inspection of track fixings without disturbing the panels. However, this should not be so great as to present a significant trapping risk to a casualty being pushed along.

28) Figure Ap2.3 below provides a rare example of underrun infill extended into the cess on a curve, following risk assessment of a very busy crossing.

Figure Ap2.3: Underrun Infill on a Curve

29) Below in Figure Ap 2.4 is an example of infill panels shaped to extend through points while retaining flangeway clearance, again a rare example after risk assessment at a very busy location. It shall be noted that after this photo was taken, the gaps before and beyond the points machine lid were closed in.

Figure Ap2.4: Infill Panels Shaped to Extend Through Points

Length of Infill

30) The length of infill required will be dependent on the following:

- Braking capability of the vehicles;
- Line speed at the crossing;
- Gradient of the track; and
- Maximum speed at which tram / pedestrian collisions are considered to be 'survivable'.

31) When considering the length of infill required, each crossing should be individually assessed and the required length calculated. For this purpose, it should be assumed that a collision could occur anywhere on the crossing, so the length of the underrun surface should be measured from the run-off edge of the crossing and not include the crossing itself. However, if a level surface already continues beyond the crossing edge, this can be included and panels fitted beyond this to achieve the required length.

32) The length of underrun provided should be at least equal to the hazard brake pure stopping distance of the vehicle from the achievable line speed in dry conditions (excluding driver reaction and brake build up time), with a cut off maximum length equal to the stopping distance at 30 km/h. As an example, the following equation can be applied:

$D = V^2 / 2a$

Where:

D is the stopping distance on level track

V is the tram speed in metres per second when the hazard brake is applied.

a is the deceleration rate in m/sec^2

33) Assuming a hazard brake rate of 2.5 m/sec^2 throughout the speed range (which may differ between vehicle types) gives a length of 13.9 m. This could be rounded up to 15 m as the 'nominal length' underrun panel for level track at 30 km/h or greater, but operators shall base the calculation of required underrun protection on their own vehicle and Light Rail system parameters.

34) The following can be used as a guide, but these figures should be confirmed using the individual Light Rail system's specific data:

- Level track where the achievable line speed is 30 km/h or greater: nominal length underrun should be fitted. This takes account of the fact that trams operate line of sight and even if the line speed is greater than 30 km/h, a driver might well brake to a survivable impact speed after recognising a developing hazard.
- Level track where the achievable line speed is below 30 km/h: the required underrun length may be reduced from the nominal length in accordance with data on the vehicle stopping distances.
- Gradients: all of the above distances should be adjusted for any gradient (uphill or downhill) through the crossing in accordance with the vehicle braking distance data or by using the appropriate formula to adjust the level braking distances in relation to gradient. Significant gradients will be fairly rare on UK tramways as crossings on gradients are to be avoided wherever possible.

- As many crossings are just after tramstops, it might be useful to calculate achievable speeds from standstill that can then be applied to crossings at a range of distances from the start position. Typically, a second generation tram can achieve 30 km/h about 30 m after setting off from the platform end. Therefore, nominal length underrun should be provided at all crossings that are 30 m or more from the platform departure end, but for crossings closer than this, the length should be calculated according to achievable speed. Consideration shall be given to the possibility of non-stopping trams on tramways where this is operationally permissible.

Reducing Risk of Secondary Collision Injuries

35) As stated above, the majority of collisions between trams and pedestrians result in the casualty being thrown clear. For this reason, at new or altered crossings, the cess and six-foot areas should be kept clear of obstructions such as equipment cabinets and poles where practicable. This will also help with intervisibility between tram drivers and pedestrians near crossings. As a guide, this should apply alongside the length of any underrun panels fitted.

Pedestrian Deterrence

36) Regardless of whether the track beyond the crossing is open access or not, underrun panels should have plates with 'No Pedestrians' symbols on them to dissuade pedestrians from walking down the panels from the crossing.

37) Where a risk assessment has resulted in pedestrian access beyond a crossing being either prohibited or dissuaded, a method should be used to provide both underrun protection and physical pedestrian deterrence. Such restrictions might be due to motorised points that can be called from distance, tunnels, viaducts etc.

38) Traditionally on tramways (and railways), either timber slatted 'shepherd boards' or rubber pyramid blocks have been used for pedestrian deterrence (see Figure Ap2.8). However, where the deterrence needs to be at or close to the crossing, some UK tramways have used half cylinder panels which effectively combine both functions. These consist of half cylinder or 'half-log' strips fitted parallel to the direction of the rails onto a flat panel, either painted or of treated timber. The top of the half cylinders should be level with the railhead.

39) Figure Ap2.5 below illustrates half cylinder panels where the vertical surface at the join between 2 types of underrun panel is sloped to minimise the edge catching against the sliding casualty.

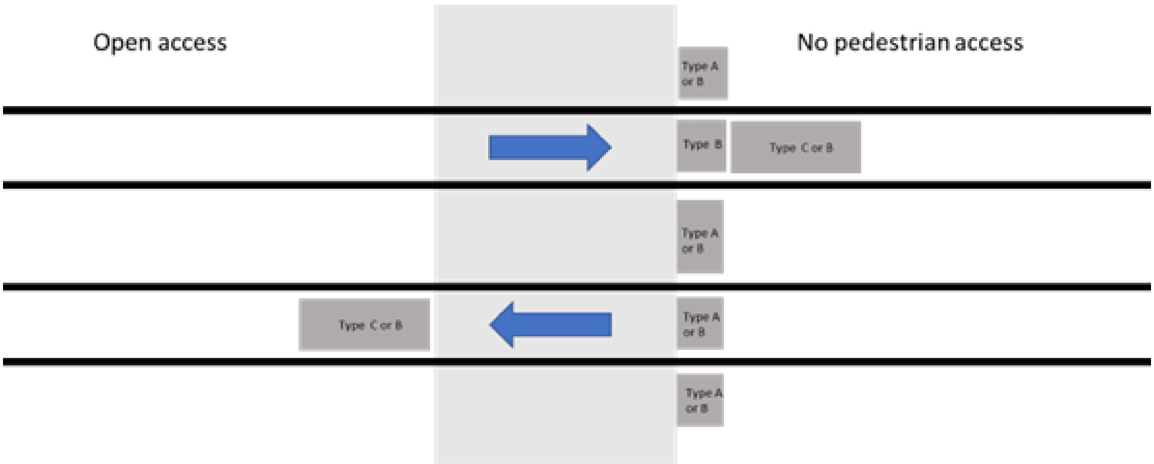
Figure Ap2.5: Half Cylinder Panels with Sloped Join

40) As illustrated in Figure Ap2.6 below, these panels are no more conducive to walking than traditional shepherd boards and offer strong visual deterrence.

Figure Ap2.6: Half Cylinder Panels

41) Trials and subsequent use of panels in the UK have shown that these provide a strong visual deterrence and are difficult to walk on, but offer the same or less resistance than standard flat panels to a prone casualty being pushed along by a tram's lifeguard. Therefore, where pedestrian deterrence is required, these half cylinder panels may be used either at the commencement of the underrun panels, with the remainder being standard panels, or for the entire length of the underrun as shown in Figure Ap2.7 below.

Figure Ap2.7 – Types of Underrun Panels Used at Crossings



Where:
Type A is a pyramid or anti pedestrian shepherd board
Type B is a half log underrun protection
Type C is flat underrun protection

42) Figure Ap2.8 below is an example of where the half-cylinder panels provide underrun protection and anti-pedestrian deterrence extending into the standard panels for the required underrun length. Timber shepherd boards provide the pedestrian deterrence in the cess. The panels are green to fit in with that particular tramstop design where grass-track is used.

Figure Ap2.8: Application of Half Cylinder Panels (note that anti-pedestrian signage had not yet been fitted in this example)

43) The other half of the same crossing is shown below in Figure Ap2.9 with the half-log panel fitted around the track crossing rail.

Figure Ap2.9: Application of Half Cylinder Panels (note that anti-pedestrian signage had not yet been fitted in this example)

44) There are instances in the UK where half-cylinder panels have been used effectively to provide all required underrun **and** all anti-pedestrian measures at crossings instead of shepherd boards or pyramid type deterrence. Figure Ap2.10 below provides an example where the half-cylinder of treated timber was used for the full underrun length and also for the anti-pedestrian panels in the cess and six-foot.

Figure Ap2.10: Application of Half Cylinder Panels (note that anti-pedestrian signage had not yet been fitted in this example)