Research Programme

Operations and Management

Research into the causes of pedestrian accidents at level crossings and potential solutions

Revision 1

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Written by:
John Barker, Arthur D. Little

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Executive summary

Introduction

This report, *T984 Research into the causes of pedestrian accidents at level crossings and potential solutions*, has been commissioned by RSSB to document a wide-ranging review of the causes of pedestrian accidents at level crossings. It provides a statement of the importance that the rail industry places on level crossing risk in general, and specifically with the aim to reduce harm to pedestrians using level crossings. There are around eight pedestrians struck by trains at level crossings annually. Whilst there have been significant improvements made to the safety of level crossings in recent years, the residual pedestrian risk has become very diffuse over the several thousand lightly-used pedestrian crossings that include footpaths and bridleways – alongside more heavily used road crossings protected by barriers. The business case for crossing closure is often therefore very hard to make, despite this being the clear highest priority risk control. Therefore, this research explores those measures that are demonstrably cost-effective in specific situations (for example for particular user types and specific level crossing configurations) to form a credible basis for improving safety.

Objectives and scope

The objectives of this research were to:

- Establish the causes of pedestrian accidents at level crossings
- Improve or promote any existing, and identify any new mitigations that offer cost-effective solutions to reduce pedestrian risk

To meet these objectives the industry required this research to consider all possible causes of accidents such as distraction (from portable music players, mobile phones, groups, dogs) and all possible mitigation measures. However, mitigation measures that involve closure or upgrades to different types of crossing were outside the scope of this research.

The scope of work also included consideration of decision points. RAIB recommendations from recent (at the time of the research) fatal accidents at passive crossings (at Tackley, Oxfordshire and Fairfield, Berkshire) generated four separate objectives for this research:

- Examine the case for having decision points at footpath and user worked crossings used by pedestrians.
- Explain clearly under what circumstances, if any, decision points should be used at footpath and user worked crossings used by pedestrians.
- Describe how the optimum decision point should be identified.
- Describe the method(s) in which the decision point should be marked. If more than one method is identified, advise under which circumstances each method should be used.

In recognition that no single approach could provide a robust response to the project objectives, a number of complementary methods were applied during the research. These methods comprised literature review; quantitative analysis of safety data; site visits; eye tracking studies and human error analysis of plausible user errors and violations. The research started in

August 2012, with the interim reports completed some 11 months later and the final report drafted for industry review some 18 months after the research first commenced.

Conclusions

The research reached the following general conclusions about pedestrian risk at level crossings:

- There is a strong link between the occurrence of pedestrian accidents and pedestrian moment. Whilst this is not a new conclusion (it has been demonstrated in several previous research studies) this research reconfirms this strong relationship.
- Accidents are also more common at station crossings and for male users, and increase with age above 30.
- There is poor or no evidence that overall, other user, crossing and environment factors can be associated with higher rates of accidents. This lack of evidence is a useful conclusion as it suggests that there should not be a strategic focus on such factors.
- Therefore, the current risk assessment approach (ALCRM), which is focused primarily on pedestrian moment, is robust.
- However, at specific locations, combinations of characteristics of users, trains, the crossing layout and equipment, and other factors may 'add up' to cause users to have particular difficulties in crossing safely. This supports the idea that an improved site specific hazard assessment should be carried out alongside the quantitative risk assessment. Such ideas are currently being discussed with industry at the time of the research (T936 *and* related discussions). Inclusion of such improved hazard identification would also help to satisfy requirements for a 'suitable and sufficient' risk assessment.

This research has identified and ranked a number of mitigation options which are either new, or have already been considered to some degree but are not currently standard solutions. Many of these would not be applicable to a wide range of crossings, due to practical difficulties in installation, or because they would be of benefit to address specific hazards that do not exist at all crossings. Indicative cost benefit analysis has been used to highlight in broad terms whether each candidate option is likely to be affordable at all crossings, or the top 10 / 20% of highest risk.

Amongst the most promising options assessed for this research are:

- 'Danger zone' demarcated with a single block of yellow colour (passive crossings).
- MWLs – back to back lights, or repeater LED lights on gates.
- Improved auditory alarms at active crossings.
- Anti-climbing rollers at full barrier crossings.
- Improved crossing surfaces (at all crossings – particularly passive crossings) - in combination with demarcation of the 'danger zone' as noted above.

Overall, we conclude that the greatest gains in reducing accidents are likely to come from a focus on fewer specific actions:

- Establishing reliable, low cost active warnings to upgrade passive crossings – where existing methods for warning cannot be justified because of high cost. The research has reviewed three alternative means of providing such lower cost active warnings, but notes that in all cases a final conclusion on their adoption has not been reached. We consider that establishing workable designs for low cost active warnings solutions is a high priority given the potential benefits to be gained by increasing the number of passive crossings that could be upgraded.
- Providing good surfaces at all crossings (non-slip, demarcated zones of colour at FP and UWC). This should not be constrained by having to seek 'business cases' for improving crossing surfaces, but prioritise improvements based on the current level of risk - from highest to lowest or whenever existing surfaces are due for renewal.
- Busy station crossings should be specifically prioritised for risk reduction due to evidence of higher accident rates than crossings located away from stations.
- At passive crossings, 'design principles' should be followed when upgrades / maintenance work is carried out – documented by Turner et al (2013).

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Glossary of terms

AHB	Automatic half barrier crossing
ALCRM	All Level Crossing Risk Model
BCR	Benefit to cost ratio
BTP	British Transport Police
CCTV	Closed-circuit television
CCTV	Closed circuit television
FP	Footpath crossing
FWI/yr	Fatalities and Weighted injuries per year
HEA	Human error analysis/analyses
HFI	Human factors issue
LXRMTK	Level Crossing Risk Management Toolkit
MCBCCTV	Manual crossing with barriers and closed circuit television
MCX	Manually controlled crossing with either barriers, gates or CCTV
MWL	Miniature stop lights
NR	Network Rail
ORR	Office of Rail Regulation
POGO	Power operated gate opener
POS	Position of safety
RAIB	Rail Accident Investigation Branch
SHERPA	Systematic Human Error Reduction and Prediction Approach
SIDB	Safety Management Incident Intelligence Database
SLL	Stop, look and listen sign
SMIS	Safety Management Information System
SRM	Safety Risk Model
T000	Research project: User worked footpath level crossing research
T524	Research project: Use of risk models and risk assessments for level crossings by other railways
T668	Research into the safety benefits of train horn use at level crossings
T730	Research project: Understanding human factors and developing risk reduction solutions for pedestrian crossings at railway stations
T936	Research project: Enhancing the accuracy and functionality of the All Level Crossing Risk Model (ALCRM)
T9835	Research project: Research into signs at private level crossings
T984	This research project: Research into the causes of pedestrian accidents at level crossings and potential solutions
UWC	User worked crossing
UWCT	User worked crossing with telephone
VUPM	Vehicle user in pedestrian mode
WP	Work package

1. Introduction

Background

Level crossings have been, and continue to be, a key component of the research programme run by RSSB. Many topics within the level crossing area have been covered by research since RSSB's very first project T000, and this has added to the understanding of risk and human factors at level crossings, and to the development of a number of improvements in management – including most notably the Level Crossing Risk Management Toolkit (LXRMTK) and the All Level Crossings Risk Model (ALCRM). In the absence of such risk management activity the annual trend in pedestrian fatality and injury rates would be at best flat and at worst increase, for example due to increasing rail traffic and the emergence of new risk factors (such as potential distraction caused by the prevalence of smart phones).

This report documents a wide-ranging review of the causes of pedestrian accidents at level crossings commissioned by RSSB: T984 *Research into the causes of pedestrian accidents at level crossings and potential solutions* (herein just referred to as T984). It provides a statement of the industry's appreciation of the importance of pedestrian risk and the criticality of addressing these issues systematically. The overriding purpose of T984 is to identify cost-effective mitigations that could be used by industry to reduce pedestrian risk at level crossings. RSSB (2013) calculates that there are around eight pedestrian/train strikes that occur each year. Whilst there have been significant improvements made to the safety of level crossings in recent decades, residual risk has become very diffuse over the several thousand lightly-used pedestrian crossings that include footpaths and bridleways – alongside more heavily used road crossings protected by barriers and audible warnings. The business case for crossing closure is therefore often very hard to make. Therefore from the outset T984 has considered measures that are demonstrably cost-effective in specific situations (for example for particular user types and specific level crossing configurations).

A key aspect of the approach for T984 has been considering both behaviour of pedestrian users (human factors) and the evidence linking that behaviour to historical trends in safety risk. Historically, few level crossing accidents are attributed to technical failure of either the train or line side equipment; the immediate cause of such accidents is usually clear. This leaves the majority of accidents where the user believes their specific behaviours are 'safe', but where ultimately they have been struck by a train. The industry's duty of care to the user is to mitigate unsafe behaviours that may lead to accidents; the better the understanding of evidence for these behaviours the greater the opportunity for effective mitigation.

The causes of certain types of behaviour and the consequences of that behaviour can be linked to determine the value of a given risk mitigation. This is important given that the underlying factors – or root causes – of pedestrian accidents are often unclear. Analysis of data within the Safety Risk Model (SRM) by RSSB (2013) included later in this report shows the prominence of 'cause unclear' compared to other (known) causes. Better understanding of the related human factors shows which behaviours are leading to collisions and therefore precisely how an installed mitigation should be designed to protect the level crossing.

Research objectives

The objectives of this research were to:

- Establish the causes of pedestrian accidents at level crossings.
- Improve or promote any existing, and identify any new mitigations that offer cost-effective solutions to reduce pedestrian risk.

In order to meet these objectives the industry required T984 to consider all possible causes of accidents such as distraction (from portable music players, mobile phones, groups, dogs) and all possible mitigation measures. However, mitigation measures that involve closure or upgrades to different types of crossing were outside the scope of T984.

Decision points

The scope of work also included explicit consideration of decision points. Already an *implicit* aspect of understanding level crossing risk (*at which point should the user decide it is safe to cross?*), RAIB recommendations from recent fatal accidents at passive crossings (at Tackley, Oxfordshire and Fairfield, Berkshire) generated four separate objectives for T984:

- Examine the case for having decision points at footpath and user worked crossings used by pedestrians.
- Explain clearly under what circumstances, if any, decision points should be used at footpath and user worked crossings used by pedestrians.
- Describe how the optimum decision point should be identified.
- Describe the method(s) in which the decision point should be marked. If more than one method is identified, advise under which circumstances each method should be used.

The industry requested an early report against these objectives. This was delivered mid-way through the research (see Chapter 2. Approach) and has been published by RSSB. All findings from this separate report of relevance to the wider T984 research project are reported in the chapters that follow.

Pedestrian user types

For the purposes of this research, the term ‘pedestrian’ encompasses a broad range of user types (and not just limited to users on foot). These are:

- User type, such as dog walker or horse rider.
- Age group, such as elderly or adult.
- Grouping, such as alone or accompanied.

Outputs

The research has outputs informing existing level crossing risk management tools (notably ALCRM and the LXRMTK); on-going research streams (eg T983, T936-01) and Network Rail policy and procedure.

2. Approach

Introduction

In recognition that no single approach could provide a robust response to the project objectives, a number of complementary methods were applied during the research. These methods comprised:

- Literature review to establish the known causes of pedestrian risk.
- Quantitative analysis of safety data to establish the historical evidence for patterns of risk.
- Site visits to understand how user behaviour translates into level crossing risk.
- User observations and interviews, to record how users interact with level crossings.
- Cognitive walk-throughs for a wide range of users including adults, children, horse riders, wheelchair users and animal herders to support human error analysis (HEA).
- Eye tracking studies to identify exactly what users are looking at as they cross.
- HEA review of plausible user errors and violations.

These methods are described in more detail in Appendix I. Research methods.

Research plan and schedule

T984 was completed over nine work packages (WPs), illustrated in the figure overleaf. **WP 1-3** concerned the review of the available literature and data on pedestrian train collisions. This review was used to inform a site visit programme (**WP 4**) using both conventional tools (eg user observation and interview) and an eye tracker; a novel technique for recording eye movement and relating this movement to observable features at the level crossing that may influence user behaviour. The eye tracker was deployed principally to explore the issues around decision points at passive crossings (published as a separate report – see Appendix C. Project documents). Eye tracker findings applicable to the wider T984 research are reported where relevant in this current report.

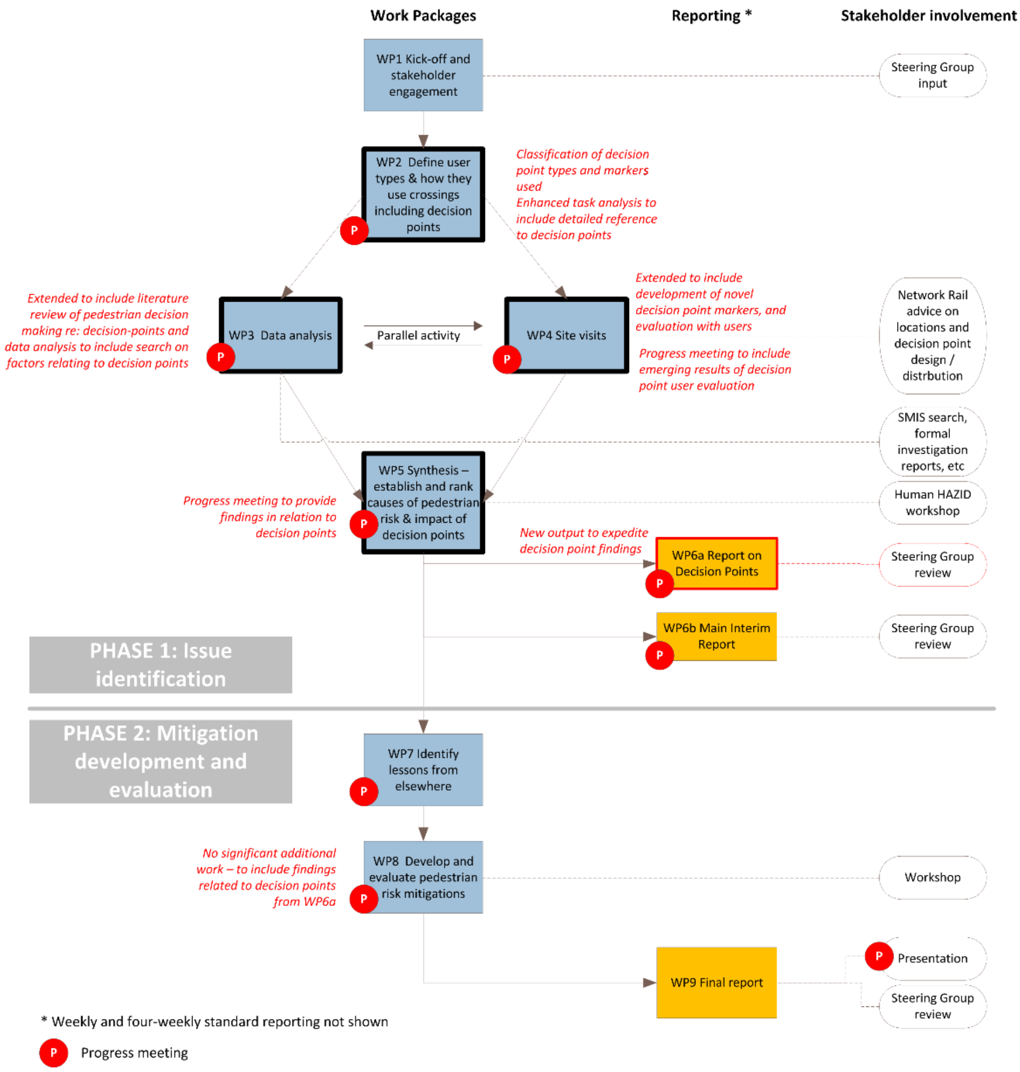
The synthesis of conclusions from **WP 1-4** were completed in **WP 5**, which established the known causes of pedestrian accidents at level crossings, and identified the most prominent factors considered to influence that risk.

The industry had requested that decision points be given early consideration within the scope of T984. **WP 6** therefore included the separate report on decision points, as well as a main interim report providing a summary of progress from the first 12 months and five completed work packages.

WP 7 began with a review of known risk mitigations in order to identify the lessons learnt elsewhere. Risk mitigations selected from the review were scored and presented at a workshop to which an external audience was invited to review the completed scores – the purpose of **WP 8**. All of this work was written up in a research report (**WP 9**) – this document.

An overview of the approach taken is illustrated in Figure 1.

Figure 1 – Approach overview



Source: Arthur D. Little / ERM

The research started in August 2012, with the interim reports for **WP 6** completed some 11 months later and the final report drafted for industry review some 18 months after the research first commenced – illustrated in Table 1 overleaf.

Table 1 – Project schedule

Work Package	Description	Q2-2012	Q3-2012	Q1-2013	Q2-2013	Q3-2013	Q4-2013	Q1-2014
WP 1	Project kick-off	■						
WP 2	Define user types	■						
WP 3	Data analysis	■						
WP 4	Site visit programme		■	■	■			
WP 5	Project synthesis				■			
WP 6	Interim reporting				■			
WP 7	Identify lessons from elsewhere					■		
WP 8	Developing risk mitigations						■	
WP 9	Project reporting						■	■

Regular contact was retained throughout the research with a steering group that included representatives from the Office of Rail Regulation (ORR), Network Rail and RSSB. **WP 6** was also presented to the Rail Accident Investigation Branch (RAIB).

The remainder of this report is divided into the following sections:

- **Chapter 3. Factors influencing risk** at level crossings discusses the evidence from both the analysis of historical risk and human behaviour that influences risk.
- **Chapter 4. Options for further risk control** describes the risk mitigations that appear best placed to mitigate the risk of pedestrian-train strikes from occurring.
- **Chapter 5. Overall assessment of mitigation options** reports the results of the overall assessment of options taking into account user behaviour, cost benefit, wider implications and safety.
- **Chapter 6.** Conclusions present the overall conclusions from the study.

Given the duration and scope of this study there have been several separate documents and reports produced to support the research. These have not been included in this report for brevity, but are referenced where applicable in the text.

3. Factors influencing risk at level crossings

Introduction

This research has reviewed a significant body of evidence documented in Appendix A. Causes of pedestrian accidents at level crossings and Appendix B. Identification of user errors and violations. This report aims to bring the various areas of research together, to confirm whether there appears to be positive influenced for a given factor or, equally importantly, a lack of evidence for the same factor.

It is the absence of compelling evidence for a particular risk factor that is most revealing within the profiles of recorded train strikes and near misses; whilst site-specific factors may play a significant role in the hazards present at a given crossing, there appear to be few factors systemic to all crossings beyond those already identified by quantified risk assessment (ALCRM) and qualitative local assessment. In particular:

- No additional compelling evidence has emerged that short sighting is a dominant risk factor at passive crossings; analysis of sighting time for FP crossings (where short sighting is – potentially – of greatest concern in the absence of other forms of level crossing protection) indicates that train strikes and near misses seem no more common where sighting times are short. However, in combination with other risk factors (such as impaired mobility or pedestrians accompanied by dogs) marginal sighting may pose an additional risk.
- In isolation, neither train speed nor number of tracks appear to act as additional risk factors, but low train frequency does appear to influence risk, where a proportional sense of risk is only maintained where train services are relatively frequent.
- Train strikes and near misses occurring at crossings at stations are relatively more common when moment is accounted for. This confirms previous intelligence about the additional risks for these crossing types that are less common at other crossings.

Proving this evidential link between risk profiles, level crossing features and user behaviour is an important basis for risk reduction. Subtle and site-specific differences in the level crossing environment may influence user behaviour in different ways not intuitively picked up within risk assessment. Hence, in order to move the debate forward beyond acknowledging that risk profiles and user behaviours are complex, this link must be proven.

During WP 7 (see Chapter 2. Approach) all the possible risk factors were recorded from research team discussion and grouped into three categories:

- **Factors associated with crossing users**, and otherwise independent of influence from any crossing features.
- **Factors associated with a given crossing feature**, and otherwise independent of influence from the crossing user.
- **Factors associated with the railway**, and therefore applying equally to any number of crossings and users where that factor is present.

Each category of risk factor is discussed in the following sections. The table at the start of each section gives a summary of the factors and whether they are positively supported by the available evidence (⊕) or, where there is no or little evidence for them being a risk factor (×).

Factors associated with crossing users

This section concerns factors that are independent from either influence by the railway (for example, number or speed of trains) and by the level crossing (for example, type of level crossing). The identified factors are listed in the table below. T984 found evidence for all of the factors with the exception of the influence of familiar and unfamiliar users on risk. The evidence for each is discussed in the following sections.

Table 2 – Factors associated with crossing users

Feature	Comments	Indication
User encumbrance	User encumbrance (especially dog walkers) is a reoccurring theme, suggesting users cope poorly with crossing safely under these circumstances.	⊕
Checking for trains	A small but significant minority of users fail to check for trains in either direction, and some users check for trains when not in a position of safety.	⊕
User age	The risk of being struck by a train at level crossings increases steadily with age for adult users. Males are more commonly struck by trains at level crossings than females.	⊕
Familiar and unfamiliar users	Familiar and unfamiliar users appear to show some differences in behaviour, but there is no overall evidence for either being more at risk.	×

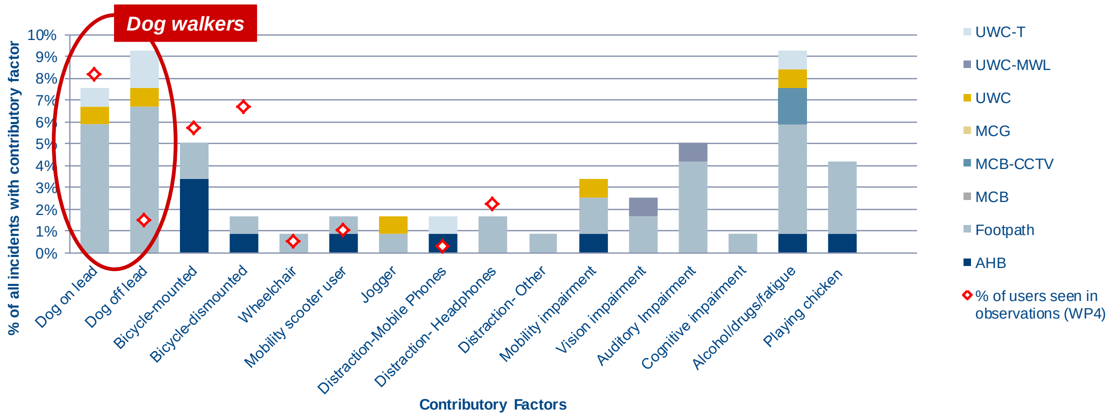
User encumbrance

Within the context of this research, an encumbered user means someone who is crossing with something that reduces their agility and can cause distraction. Encumbered users include those with pushbikes, or who are carrying objects (eg bags, cases and inflatables to the beach), and especially dogs either on or off the lead.

Accidents involving dogs especially are a reoccurring theme, suggesting users cope poorly with crossing safely under these circumstances. It is notable that in 17% of train strikes, the pedestrian was walking a dog – usually off the lead but sometimes on the lead.

During the site visits only 8% of observed users had dogs on the lead, and 1% had dogs off the lead (the red dots on the graph below). Although only a sample (and may not be representative of the population as a whole), this suggests significant *over-representation of dog walkers* in train strikes where the *dog is off the lead*. However, there are examples (such as Fairfield) that are the exception – in this case the dogs were noted as on the lead.

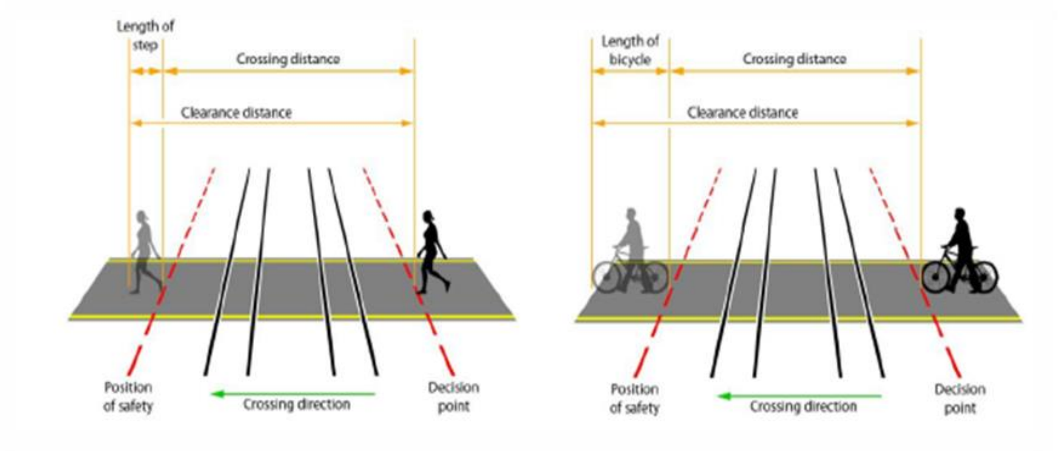
Figure 2 – Incident contributory factors



Source: Arthur D. Little

It was also observed during site visits that users with pushchairs and bicycles sometimes had difficulty in opening and closing the crossing gate. In some cases, where the gate is located within 3m of the running rails, the longer forward footprint of these users can mean that they are in a position of danger before checking it is safe to cross.

Figure 3 – Encumbrances can affect position of safety



Source: LR Scandpower, 2013

T984 therefore considered there to be sufficient evidence proving the influence of user encumbrance on the risk of pedestrian-train collisions.

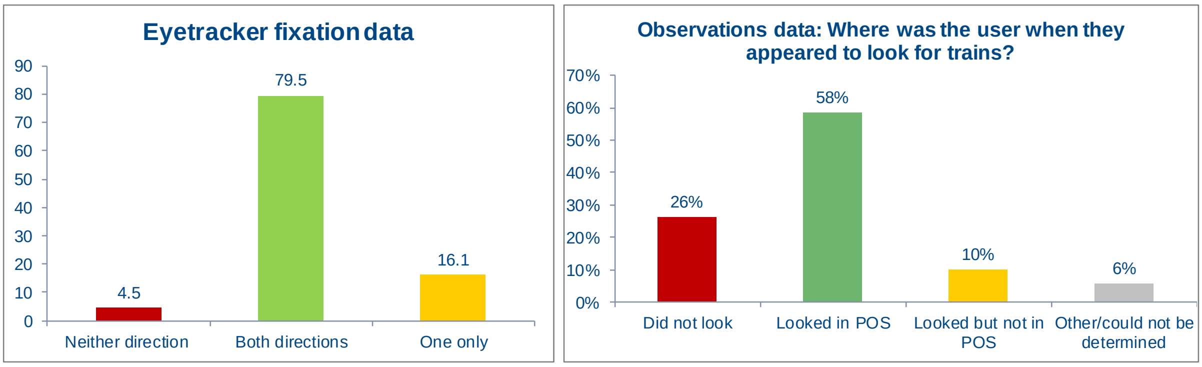
Failing to check for trains

The site visit observations using eye tracker fixation data ascertained that a small but significant minority of users (around 5%) fail to check for trains in either direction. A further 16% only looked in one direction anywhere on the approach or traverse.

Although these figures are a minority, it reveals that some users are placing themselves at greater potential risk, presumably relying on peripheral vision, hearing or an expectation that no train is coming.

These data were supported by user observations completed separately from the eye tracker studies that indicated around 10% of all users did look but not in a position of safety (POS) (ie only looked when they were on or near the line).

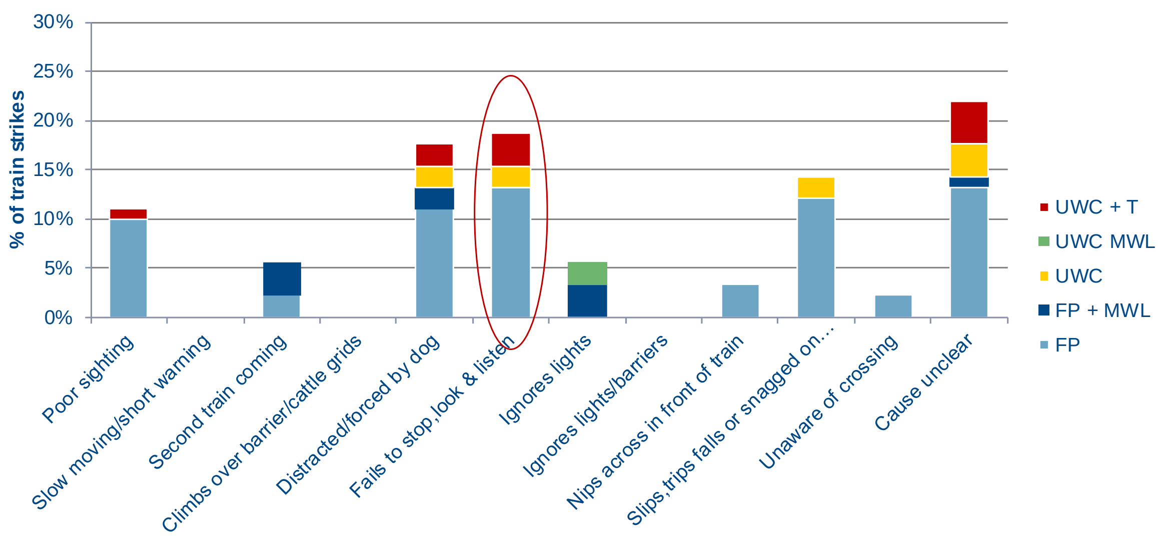
Figure 4 – Eyetracker fixation data



Source: ERM analysis of site visit data

When the causes of train strikes with pedestrians are examined, a large proportion are attributed to 'fails to stop/look/listen', suggesting that no other cause could be found other than a failure of the user to take reasonable care. The following graph indicates the relative contribution of SRM causes to train strikes, indicating the 'fails to stop/look/listen' is second only to 'cause unclear' its contribution. Given the prominence of the former, it is likely (though unproven) that the latter also includes a proportion of users whose accident cause is 'fails to stop/look/listen'.

Figure 5 – SRM precursors for pedestrian train strikes at passive crossings



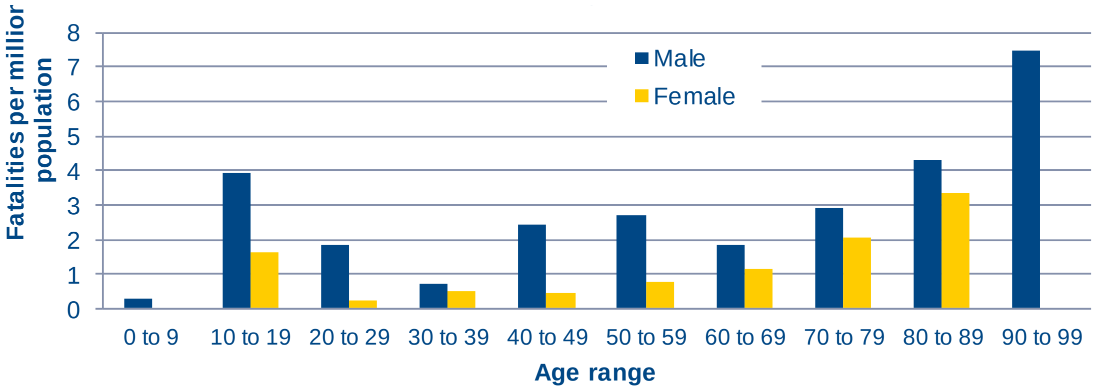
Source: Arthur D. Little analysis of SIDB data

It was therefore considered to be sufficient evidence proving the influence of the user to failing to stop look and listen on the risk of pedestrian-train collisions.

User gender and age

Males are more commonly struck by trains at level crossings than females, and the risk of being struck by a train increases steadily with age for adult users. Male pedestrians dominate accidents at level crossings, associated with 70% of all train strikes. Given that males represent approximately 50% of the population as a whole (UK government statistics), this would suggest male pedestrians are more at risk at level crossings than female pedestrians.

Figure 6 – Fatalities by age and sex



Source: Arthur D. Little analysis of SIDB data

It was therefore considered to be sufficient evidence proving the influence of gender on the risk from pedestrian-train collisions.

User familiarity

Interviews with users suggest that level crossing users that live or work in close proximity to a crossing can become familiar with the crossing attributes and procedures required for crossing (eg MWL activation durations). Their behaviour can become habitual, resulting in a failure to look for unexpected information, leaving them susceptible errors of judgment. However, the same is true of unfamiliar users who can fail to cross safely due to knowledge-based errors about correct operation.

Over three quarters of users interviewed at crossings were familiar with that crossing, being frequent users (at least once per week). Some differences in behaviour were noted between familiar and unfamiliar users, but these were sometimes counterintuitive. For example, eye tracker data revealed that first time users were less likely to look at the stop, look, and listen (SLL) sign than more frequent users. This might relate to their requirement for processing the complex crossing environment for first time, whereas more frequent users are able to prioritise key crossing information/cues, such as SLL sign. In fact, familiar crossing users were more likely to look at all signs at a crossing (perhaps suggesting that signs help users to recognise that they are at a level crossing, even if their content is not read).

Regular users were more likely than infrequent users to perceive crossing risk to be low and could therefore be more likely to commit a violation of safe crossing procedure. This is supported by research investigating vehicle driver behaviour at crossings which revealed that 53% of red light runners (at a range of testing locations) used the crossing at least once a day.

So whilst familiarity with a crossing seems to impact user behaviour, there is no overall evidence for either group being more at risk.

Factors associated with crossing features

This section concerns factors that are independent from either influence by the user (for example, age or encumbrance) and by the railway (for example, number or speed of trains). The identified factors are listed in the table below. The report authors found no evidence supporting the mitigation of risk by SLL signs, but found evidence linking risk with gates and the recurrent theme of slips and trips. The evidence for each is discussed in the following sections.

Table 3 – Factors associated with crossing features

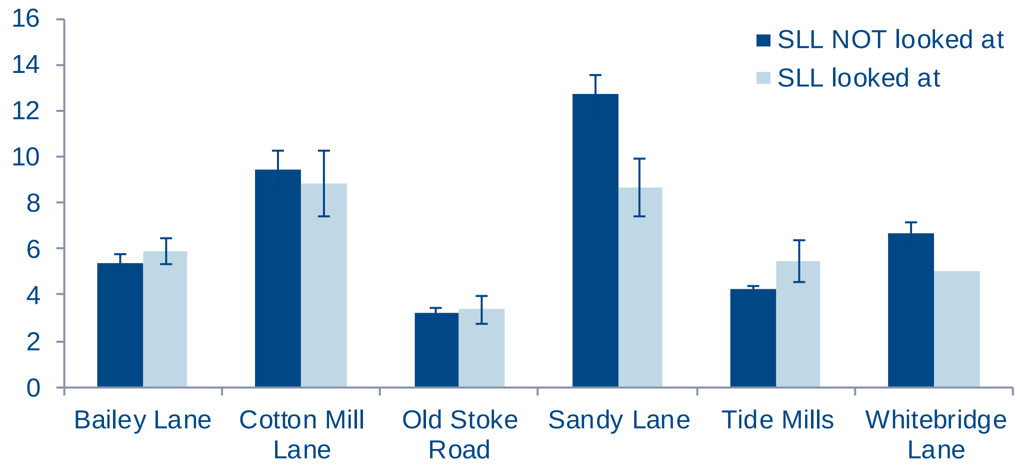
Feature	Comments	Indication
SLL signs	Stop, look and listen signs are not commonly viewed by users, and there is little if any evidence that users who do observe this sign are more likely to look for trains	×
Gates	Gates are generally a good design principle, but may complicate safe crossing use in certain specific circumstances	⊕
Crossing surface - slips and trips	Slips and trips are a recurrent theme reported as the cause of users being struck by trains; the crossing surface therefore has a key influence on risk	⊕

Stop, look and listen (SLL) sign

The most prominent crossing feature at passive level crossings is typically the SLL sign – this provides a warning to the user that they are approaching a level crossing, provides an indication of where the user might be best placed to observe an approaching train and – if read – gives instructions on how to cross safely.

Observations at site visits indicated that SLL signs are not commonly viewed by users, and there is little evidence that users who do observe this sign are more likely to look for trains. Users looking at the SLL sign are, on average, very marginally more likely to subsequently look for trains. It can therefore only be concluded that the sign is having at best a weak positive influence on encouraging users to take care to look for trains - perhaps because the sign is having a small positive impact, or simply reflecting the behaviour of some users who are more predisposed to looking. What is not clear is the extent to which the presence of a sign provides a sub conscious cue for users to look for trains (compared to having no sign at all), this latter point illustrated in the graph below which compares the average numbers of times a user looked for a train per traverse where the user looked at the SLL sign and where the user did not. Overall, there was very little difference in the frequency of looks where users did and did not look at the SLL sign.

Figure 7 – Observation of SLL signs



Source: ERM analysis of site visit data

The prominence of the SLL sign did itself seem to influence whether or not it was looked at by the user; where the sign was more conspicuous, more users looked at it on approach. Note, however, that sign prominence did not influence subsequent frequency of looks for trains.

Overall T984 therefore concluded that there was no evidence positively linking observation of SLL signs with increased care taken by the user in stopping, looking and listening.

Gates

Gates are a second prominent feature commonly found at FP crossings. Well positioned, a gate can serve to cause the user to pause on approach to the crossing. Intuitively, this may increase the chance that the user then has time to look for a train – provided that this can be done adequately from the gate location. In addition, gates act as a barrier for those crossing with small children or dogs not on a lead.

The site visit work, however, did not produce evidence for an increase in the rate of looking for trains where gates are present. This is likely due to the very large number of variables that influence when and where people look for trains.

Several potential drawbacks associated with the use of gates were also noted:

- Gates can be difficult to use in high winds (especially if encumbered).
- Users with 'large footprints' such as those with bikes / pushchairs / horses seems to rarely be taken into account in gate positioning relative to the line, and as such it can be difficult to exit the tracks unimpeded, or make a decision to cross in a position of safety.

•	At locations with interlocked gates some users, such as wheelchair users and those with pushchairs, are unable to use these gates as the locking mechanism prevents them opening fully. As such, they are forced to use the vehicle gates, potentially placing them at greater risk from accidents with a road vehicle.

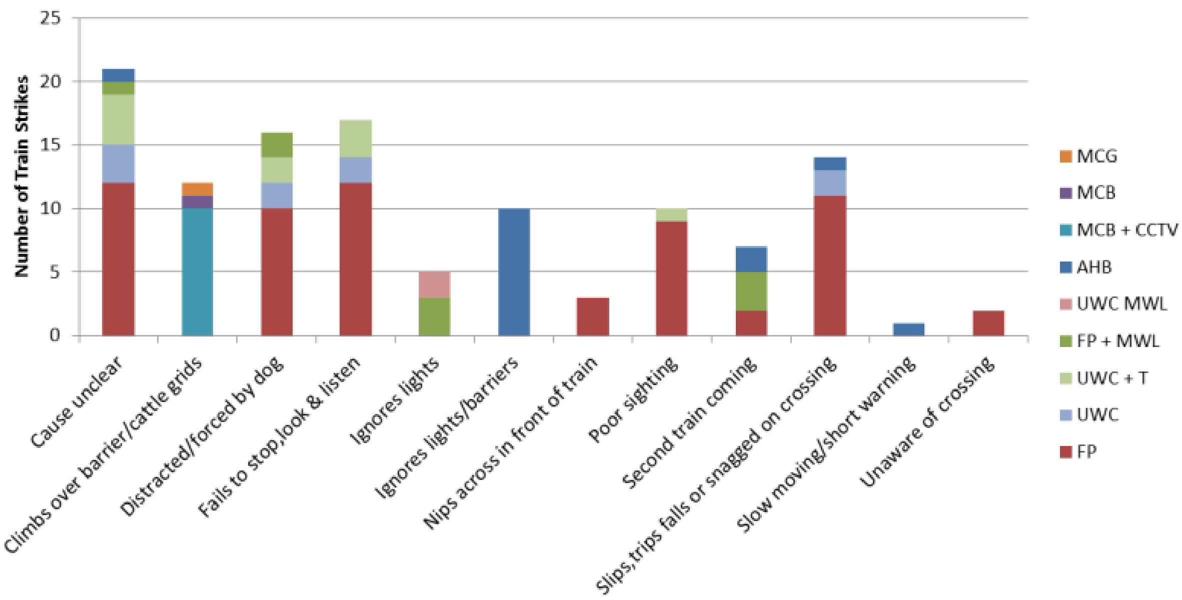
Therefore whilst gates are generally a good design principle, they may complicate safe crossing use in certain specific circumstances, further described by Turner et al (2013).

Crossing surface - slips and trips

Slips and trips are a recurrent theme reported as the cause of users being struck by trains; there are numerous mentions of this hazard within the various sources of industry data compiled on accidents. For example 14% of train strikes at level crossings (based on SRM precursors) have been attributed to slips, trips or becoming snagged on the crossing. As previously noted, a slip or trip is a single point of failure that may lead to a train strike, independent of whether the user complied with instructions for safe use. The crossing surface can therefore be regarded as having a key influence on risk.

The graph below shows total number of train strikes over the period for which data were collected, classified by crossing type and accident cause. Slips and trips are prominent amongst the different causes, after “user distraction, failing to stop look and listen and cause unclear”. Slips and trips are also prominent for FP crossings (where pedestrian crossing surface is the most variable of all crossing types).

Figure 8 – SRM precursors for pedestrian train strikes



Source: Arthur D. Little analysis of SIDB data

Eye tracker data revealed that a surprisingly high proportion of users’ time while crossing is spent looking down at the crossing surface (referred to as ‘head down time’). ‘Head down’ time is expected as pedestrians look at the ground to see where they are going and to prevent slips, trips and falls. However, the amount of time users spent looking down varied between crossings. More head down time proportionally was recorded where:

- Crossing surface was poor (uneven with worn markings).
- There were slippery conditions underfoot (snow/ice).

Improvements to crossing surface might therefore reduce the requirement for 'head down' time and afford greater opportunity for users to check for trains.

Factors associated with railway features

This section concerns factors that are independent from either influence by the user (for example, age or encumbrance) and by the crossing (for example, type of level crossing). The identified factors are listed in the table below. Amongst these risk factors, the report authors only found evidence linking risk with the colocation of crossings with stations. The evidence for each is discussed in the following sections.

Table 4 – Factors associated with crossing features

Feature	Comments	Indication
Train frequency	Risk does not appear to be proportional to number of trains; more accidents than expected occur where train frequencies are low.	×
Sighting time	There is no evidence that accidents are more common at passive crossings with short sight times.	×
Crossings at stations	Risk is higher at crossings at stations.	⊕
Train speed	Train strikes and near misses do not appear to be influenced by train speed.	×
Double track	There is no evidence for double-track crossings being a risk factor at unprotected crossings.	×

Train frequency

Data analysis shows that the occurrence of accidents does not appear to be proportional to the number of trains; in fact more accidents than expected occur where train frequencies are low. Analysis shows that two times more accidents per moment have occurred at crossings with <100 trains/day than crossings with > 100 trains/day.

In summary, whilst moment does have a strong relationship with risk (as previously reported) the component of moment that is train frequency appears to be non-linear. T000 showed that users perceived a lower level of risk where there was a low frequency of trains passing over the crossing – suggesting that risk homeostasis might be influencing the evidence. This effect is considered in ALCRM for passive crossings; specifically the likelihood of users failing to stop, look and listen is increased for crossings with low train frequencies (this was based on the work in T000 as noted above).

Sighting time

There is a lack of strong evidence that accidents are more common at passive crossings with short sight times. Although this counters a traditionally held view that maintaining good sight times is the single most important risk control at passive crossings, this finding is not new, having been previously presented in project T000. This suggested that risk homeostasis explained the lack of a relationship between risk and sight times (shorter sight times lead to more cautious behaviour). The analysis conducted for this research therefore appears to confirm that of T000.

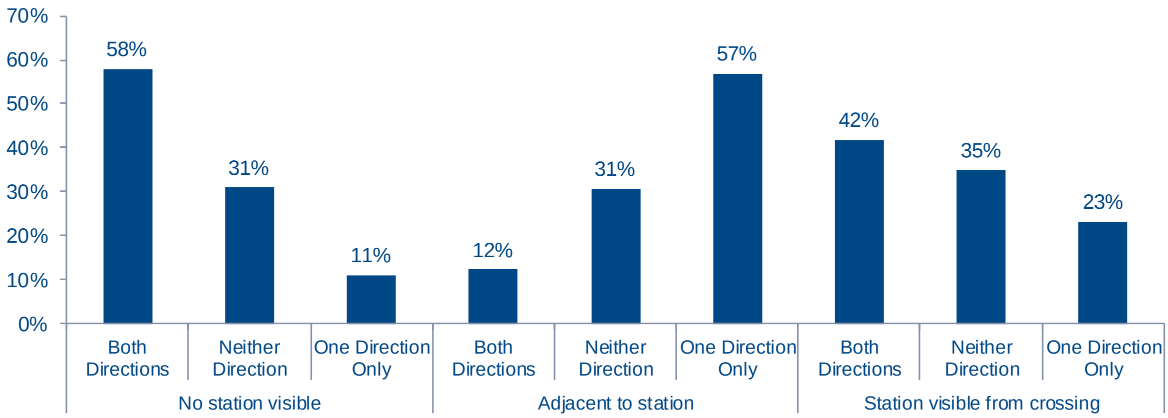
Overall, there is a lack of strong evidence for sight time having a significant impact on the rate of accidents.

Stations

Train strikes and near misses are relatively more common at station crossings when moment is accounted for (this is most clear for MCB-CCTV crossings, and evident – but less compelling at AHB crossings). This is unsurprising, as it is well understood in the industry that there are additional risk factors for level crossings at stations. There is a greater motivation for the user to violate instructions for safe use (personally optimising). Users are more likely to encounter a train (use of crossing intentionally coincides with stopping services).

Observations from site visits provide some further support for this analysis - where stations are adjacent to the crossing people are more likely to look in only one direction potentially placing them at greater risk. This may be because users tend to look more at the station (expectation of trains, distractors, more visually stimulating). Where a station was visible from, but not adjacent to, the crossing, or where there was no station in sight, people were more inclined to look in both directions.

Figure 9 – Impact of station visibility on the direction of user looks



Source: ERM analysis of site visit data

Train speed

Data analysis shows that the occurrence of accidents does not change with train speed. Therefore, there is no evidence that train speed by itself is a risk factor.

Double-track crossings

There is no evidence for double-tracks being a risk factor at unprotected crossings. In fact, for AHBs the data suggests that pedestrian train strikes are more common at single track crossings than at double track, but this is likely due to small data sets producing random variation.

The overall conclusion is that there is no evidence to suggest that pedestrians are at more risk on double track railways once moment has been accounted for.

4. Options for further risk control

Introduction

The rail industry has an active programme of technical review of emerging mitigations, supplemented by periodic local and national level education campaigns. Whilst it is *technically* possible to present information to pedestrian users in novel ways, the feasibility of implementing such depends largely on cost benefit analysis, which itself demands good knowledge of the likely risk reduction that will be achieved so as to build a business case. A review of feasibility can therefore raise more questions than it answers – unless the underlying hazards and their level of risk *specific to the crossings targeted by the mitigation* are understood.

This chapter attempts to answer such questions by stepping through the identification of risk mitigation options; the behavioural impact assessment of each option and finally a cost-benefit analysis of the options in order to provide sufficient data for their ranking (which is completed in the following chapter).

Recent (at time of this research) innovations that have been implemented at level crossings include:

- AOCL+B, 'stubby barriers' at former AOCL crossings which are primarily a risk control for vehicles.
- Lower LIDAR at new MCB-OD crossings; a mitigation to detect pedestrians who might fall on the crossing.
- Various very localised mitigations including solar edge lighting and pavement transfers.

Chronologically, this chapter is based on WP 8 (see Chapter 2. Approach), completed after some 15 months of literature review; a programme of site visits; qualitative assessment of user errors and violations and quantitative assessment of pedestrian-train collisions. This substantial body of work recorded in the various research outputs – as well as this report – provides evidence indicating those risk factors that are important, and those where a lack of evidence indicates that they are not important focuses for risk management effort.

This context is important in reminding the research that:

- There are relative few risk factors identified as systemic to risk, ie acting to change the number of pedestrian-train collisions irrespective of other site-specific factors such as user profile and sighting distance.
- Other site-specific factors are typically present in a large number of permutations, making it difficult to study any given local factor in isolation.

Such observations may be seen as counter to the active and on-going efforts to mitigate risk at level crossings. However, they are in fact a helpful reminder that there is neither a pressing need for more complicated assessment of many new risks, nor that there is a 'silver bullet' for mitigating existing risks.

The remainder of this chapter presents the risk mitigation options identified from this research and their evaluation, with the following Chapter **5. Overall assessment of mitigation options** concluding the risk mitigation assessment.

Option Assessment

The research identified 31 options for mitigating pedestrian risk at level crossings based on three main sources:

- Review of literature (research, overseas rail practices, and from the highways sector).
- Analysis of the plausible critical user errors and violations (identified through the HEA, see Chapter 4) for which there are currently only weak barriers or controls specified in standards and guidance.
- From ideas generated in an industry workshop conducted for this project, in which options were identified and systematically assessed for their impact.

The detailed assessment of all options is described within Appendix G. Option assessment. The table references within this chapter therefore cross-refer with this appendix. Each of the steps completed for option assessment is described in the following sections.

Option categories and screening

Options were first assigned to one of six categories in order to support evaluation of options with similar types of risk mitigation. The categories were:

- Improve awareness by enhanced visual information (V).
- Alert user of approaching train (T).
- Prevent access when train approaching (P).
- Improve awareness by enhanced information (E).
- Improve surface (S).
- Other (O).

Options were then screened to determine the applicable level crossing types for each option. Appendix H. Assessment approach and results give the results from the screening.

Error and violation assessment

Options were next assessed against the 26 key errors and seven key violations identified in the HEA (see Appendix F. Critical errors and violations). This was conducted independently of the risk assessment and cost-benefit analysis. A semi-quantitative approach was taken, using a four-point scale to score the options against each error/violation (Table 5 below).

Table 5 – Behavioural impact assessment – key

Impact on behaviour	Score
Eliminates error / violation	2
Reduces error / violation	1
No change	0
Increases error / violation	-1

For example, the likelihood that a pedestrian will slip, trip or fall on a crossing might be reduced with the introduction of an improved non-slip crossing surface (score '1'), but would not be affected by replacing an MWL with a 'push button and wait' type device (score '0').

The appendix presents a summary of the error / violation impact assessment, indicating the proportion of key errors and violations that each option would target. The options are presented in rank order: those that are likely to impact the greatest number of key errors and violations are ranked higher than those that might impact only a few (none in some cases). Note that this is different from the overall safety assessment of options which takes into account the relative risk at the types of crossings impacted

Unsurprisingly, those options that prevent user access to the railway are ranked highest since they target both errors and violations. Predictors+MWL and Wavetrain also score highly since they provide an active warning of approaching trains where currently there is none, thereby improving information provision to users.

Improved crossing surfaces (including tactile paving, high contrast delineation and straightened crossing surface) are in the top ten. Slips, trips and falls are a significant precursor for pedestrians being struck by trains. Improving the crossing surface not only minimises the potential for slips and trips, but can also reduce users' 'head down' time on the crossing, improving their opportunity to look for trains.

The lowest ranked options are the provision of alarms on UWC gates when gates are left open and an active 'close gates' sign, both all of which target misuse of the crossing, but are unlikely to provide any wider benefit on the key user errors considered. The low score for retro-reflective tape can be explained by the fact that it only targets one key error: failure to recognise crossing and no user violations.

Power-operated gate openers (POGOs) are also ranked low due to their potential negative impacts on user error (eg the assumption that they are interlocked with the railway leading users to cross when a train is approaching).

Cost benefit analysis methodology

Evaluating the safety benefits of mitigation options at crossings is challenging, due to the high uncertainty as to the net impact of the measure on the likelihood of accidents. While the behavioural impact assessment evaluates the relative impact of each mitigation option on specific errors and violations, 'weighing up' these individual impacts into an overall assessment is difficult because how these combine is highly complex and hard to predict in general, and this will also vary considerably by location.

Therefore, instead of trying to estimate safety benefit of a measure, we have considered the risk reduction required (in % terms) that would justify the cost of each measure. If it is judged that the risk reduction would be comfortably above this level, this would mean that the option could be 'justified' on the basis of the benefit to cost ratio (BCR). For example, if, for a mitigation measure, the cost of a measure would be matched by a risk reduction of 2%, then this mitigation would be viable if it was believed that a 2% risk reduction should be achievable. Conversely, it might be clear that a required risk reduction of 50% could not realistically be achieved, so such an option would be deemed not viable on a cost – benefit basis.

Note that this target risk reduction level is *indicative* for the groups of crossings targeted by each mitigation option; options for reducing risk would need to be assessed by Network Rail for individual crossings in their on-going programmes of risk assessment and managing risk So Far As Is Reasonably Practicable (SFAIRP). For example, the authors have not quantitatively considered the lifetime of each option within the analysis. However, the authors *have* considered implicitly considered this with the 'robustness' of each option – evaluating the likely durability of each option (and therefore its in-service lifetime).

The analysis assumes that:

- The cost is the best estimate of the total cost of the option (although this may not cover the full costs associated with approvals and research and development for the more novel options).
- The average risk (in FWI/yr) at target crossings represents the typical average risk at each crossing that is targeted for mitigation. This varies according to the target crossing type(s). If more than one type is targeted, then a weighted average level of risk is used.
- The 'risk reduction required' is then the % safety improvement that would match the estimated cost of the option.

The cost-benefit analysis is completed in Appendix G. Option assessment. The final two columns on each of the tables in the appendix repeat the analysis but examine how the mitigation options can be targeted at higher risk crossings. Two cases are considered: 'risk reduction required' if the measure were applied to the top 20% of all crossings; and also to the top 10% of highest risk crossings. This has been derived from ALCRM data (ie the risk in FWI/yr for the top 20% and top 10% of crossings, calculated from ALCRM assessments).

Cost benefit analysis results

The results show considerable variation in the risk reduction required to satisfy the costs.

Those with higher costs (such as providing warning of trains T3, T4 and T5, and preventing access when a train is coming P1, P2, P3) require significant benefits to be realised to be justifiable. Indeed, such options would not be justified at all crossings of the target type (shown by the fact that the risk reduction would need to be '>100%').

In contrast, a number of relatively inexpensive options require very small benefits to justify the costs of implementation. Examples include pavement transfers (V2), mesh on gate (O1), 'eyes signs' (O2), anti-climbing rollers (P5). However, by their very nature many of these options would have a smaller impact in user behaviour (and consequent risk) and care needs to be taken to make sure that no adverse impacts on behaviour or risk are created which could offset any foreseen benefits.

The right hand columns in the tables above show the impact of targeting higher risk crossings, rather than a 'blanket approach' of all crossings. For example, solar edge marking (S2) requires a 36% safety benefit to be justified everywhere. This seems very unlikely to be achievable when it is considered that train strikes resulting from pedestrians falling from the edge of the crossing are very rare events. However, targeting higher risk crossings (and those for example which are used heavily in hours of darkness) would make more sense – supported by the cost-benefit analysis which shows that a risk reduction of some 4% would be required to justify the expenditure at the 'top 10%' highest risk crossings.

Similarly, some of the higher cost options could have a larger impact of risk reduction – but not be affordable at all crossings. Targeting these costlier measures at the highest risk crossings makes sense, and is supported by the analysis above. Providing novel active warning of train approaches (T2, T3, T4) will range from £100k - £200k, and could not be justified at all crossings, or even the top 20% as more than 100% of risk reduction would be required. However, targeting such measures at the highest risk crossings may be justifiable – the analysis shows risk reductions of 13-69% would be required at the top 10% highest risk crossings (depending on the technology).

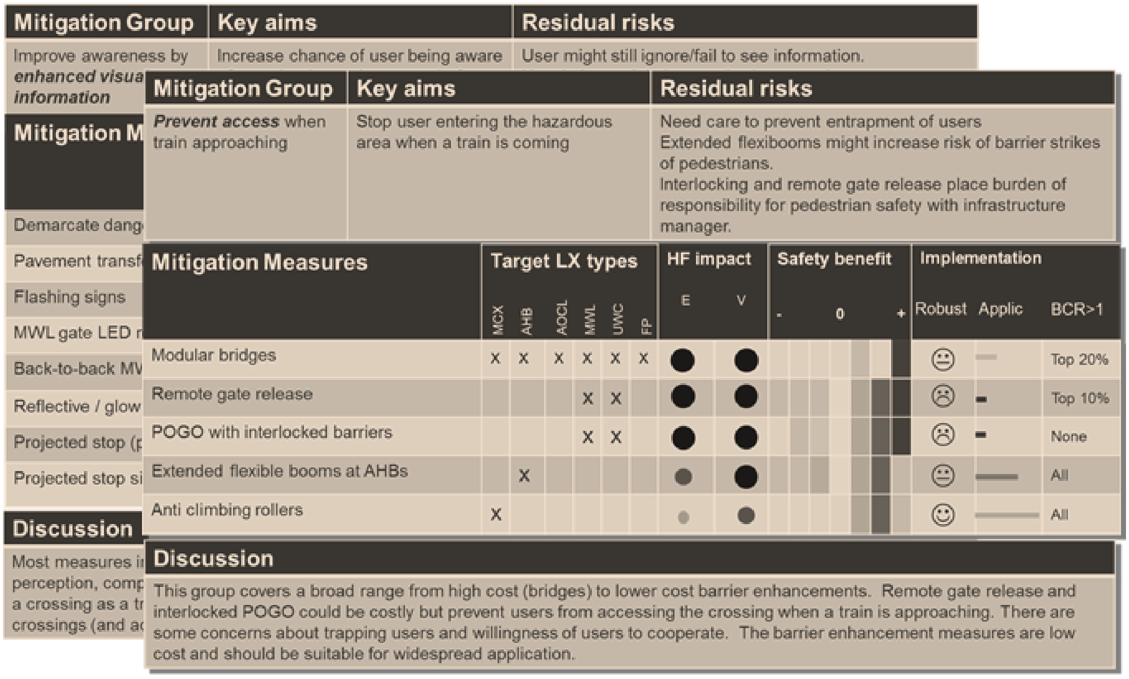
The option evaluation has to this point not considered any of the practical considerations associated with each mitigation; this is discussed in the overall evaluation of options in the next chapter.

5. Overall assessment of mitigation options

Introduction

This research included a workshop conducted as part of WP 8, to which a number of external level crossing experts were invited (see Appendix D. Risk mitigation workshop attendees). The research developed a series of risk mitigation scorecards (based on the evaluation in Chapter **5. Overall assessment of mitigation options**) and illustrated in the figure below.

Figure 10 – Mitigation assessment



Source: Arthur D. Little

The results from the scorecard review were written up in a workshop report that was re-issued to participants (see Appendix H. Assessment approach and results). The result of the overall assessment is that 21 options emerge as potential candidates for consideration to reduce risk, and 10 are not recommended for further consideration. Of the 21 potentially viable options, 12 are expected to be applicable only to specific locations, with the remaining seven applicable either to all or most crossings of the target type(s).

The evaluation of each mitigation option is described further in the following sections. Within the context of this project "potentially widespread consideration" means strong safety benefit and few site-specific factors for consideration so that the mitigation option is likely to be applicable to many sites, and "limited consideration" means mitigation options with safety benefit but only within specific circumstances or when noted technical limitations have been overcome.

The authors note that the effectiveness of many of the mitigation options is contingent on good education campaigns – for example demarcating the 'danger zone' with colour. The cost of such campaigns has not been included in the cost benefit analysis, but equally no assumptions have been made as to whether (or not) a given campaign would be effective. As such education remains a 'cost neutral' element of the option evaluation.

Options for potentially widespread consideration

V1 – demarcate 'danger zone' with the colour yellow.

The option to demarcate the crossing surface with a single block of colour emerged from the specific workstream on decision points (see decision point report, RSSB, 2013). The idea is to provide a clear distinction between the zone in which there is a risk of being struck by a train, from the crossing approach and exit areas in which there is no such risk.

The railway (Network Rail and its predecessors) have provided such demarcation at selected FP crossings in the past, so although this mitigation is not novel, the research concludes that it should be extended much more widely, and also include user-worked crossings.

A key success factor for this mitigation will be sourcing surface materials which are coloured throughout (rather than being only on the surface which could wear out) and which also provide a non-slip surface (thus encompassing mitigation option S1). Provided that such materials can be sourced at reasonable cost, then no dis-benefits have been identified either in terms of adverse safety impacts or wider implications. The safety benefits are likely to be comparatively small, suggesting that as an *additional* risk mitigation measure the 'top 10%' of FP and UWC should be targeted. However, if the surface can be provided at little or no incremental cost over standard surfaces then coloured surfaces could be used to replace traditional surfaces when they are life expired.

V4 – Augment gates at MWLs with LED repeater lights

Providing repeater lights on the gate of MWL crossings is a novel idea (as far as this research has been able to determine) so some further design work and validation would be required if this option is to be taken forward. The idea is to increase the chance that a user acknowledges the status of the MWL before entering onto the crossing.

This option has been identified as potentially viable at a wide range of MWL crossings. Potential difficulties are not likely to be significant, although a standard design is likely to require detailed review and eventual approval. In particular, the additional lights will need to have a proven robustness and to make them practical and cost effective they would not require additional power requirements over the existing MWLs. A design aspect that would need attention is whether or not the repeater lights are visible from both 'entry' and 'exit' to the crossing. Care would also need to be taken to ensure that when showing a green aspect this cannot be seen by train drivers.

Provided that the costs can be kept low (we have modelled based on a cost of £5,000 per crossing) then cost benefit analysis would indicate that the 'top 20%' of MWL crossings should be targeted.

V5 – Back to back MWLs

Back to back MWLs are an established but relatively new mitigation measure in Great Britain. They are installed currently at one trial site (Farnborough North station pedestrian crossing) to mitigate the risks associated with the large groups of users who cross there simultaneously, where the original single set of lights was often obscured from members of the group located behind others. A second trial is imminent at Rushton No.2 crossing in Dorset.

Back to back lights provide additional warning to users of the crossing status and on that basis are potentially viable at any MWL crossing where light obscuration by users from other users is problematic.

In order to be practical and cost effective, the additional lights should run off the power source of the existing MWLs. As with repeater lights (above), care should be taken to ensure that train drivers are unable to see the red aspect.

The cost benefit analysis indicates that the 'top 20%' of MWL crossings should be targeted.

T1 – Smarter auditory alarm

This option emerged as a strong candidate for consideration – effectively replacing standard auditory alarms with ones which automatically adjust to background noise levels to improve audibility. For the purposes of cost benefit modelling, we have assumed an additional cost of £10,000 per crossing above traditional alarms costs but note that if the design were established then the incremental costs could be negligible. Even based on this incremental costs, consideration should be given to widespread fitment of 'smart' alarms at all relevant crossing types at such time that equipment is due for replacement.

Care would need to be taken to calibrate effectively at each location, to cater for lowest and highest noise levels, and to manage the impact of the noise of the alarms on railway neighbours. Reliability of the alarms would need to be proven to be no lower than that of existing alarms.

P5 – Anti-climbing rollers

As far as the research has been able to determine, this is a novel option applied to railway level crossings. The purpose would be to prevent deliberate misuse at full-barrier crossings involving pedestrians climbing barriers to cross after the crossing has been closed. The safety benefits have been modelled as potentially quite high since the option could mitigate a significant proportion of the current pedestrian risk at full barrier crossings. Applicability should be widespread, but maybe less effective where there are unlocked pedestrian wicket gates (since pedestrians can still freely enter the crossing when the main barriers are closed).

If this option is to be further considered work will need to be carried out to explore different designs, and to validate their effectiveness – and ultimately to secure a design at reasonable cost. We have modelled the BCR analysis assuming an incremental cost of £1,000 per crossing over and above traditional booms (this assumes that this would not be a retrofit but only carried out where barriers are replaced). On this basis, the safety benefits are likely to exceed the costs at all full barrier crossings.

The safety benefits have, however, been modelled as potentially uncertain due to the possibility of increasing the chance that pedestrians are trapped on the crossing. To clarify the balance of safety benefits / dis-benefits (and also the potential for injury should someone attempt to climb over when the rollers are fitted), the safety case for anti-climbing barriers should include a detailed review of incidents in which pedestrians have been trapped at full barrier crossings, and the proportion of times that pedestrians escaped by climbing the barriers as opposed to simply moving out of a position of harm but still inside the barriers.

P6 – Higher barriers to prevent climbing

This option aims to have a similar benefit as anti-climbing rollers (P5) discussed 5 above – ie to stop pedestrians deliberately climbing full barriers when they have been closed to users. As such, these two options could be further researched in parallel to evaluate which one is more feasible, and could deliver the benefit at a reasonable cost.

The potential safety benefits and uncertainties with respect to trapping are similar to those discussed for option P5. A possible additional difficulty with 'higher barrier to prevent climbing' is the additional weight and wind loading which may place additional load requirements on barrier machines.

S1 – Improved crossing surfaces

The research has shown that the quality of a crossing surface can have a significant impact on user ability to traverse safely. A good even, non-slip surface not only reduces the chance of a slip or trip, but also means that their 'head down' time could be reduced, leaving more time to focus on looking for trains or on a change of status of the crossing.

Although providing good crossing surfaces applies of course to all types of crossings, we have focussed this as a mitigation measure specifically at user-worked and footpath type crossings, as it is these where there is a wider variation in crossing surface standards quality, and where most benefit could therefore be gained.

Provided that the surfaces are slip resistant and introduce no additional trip hazards due to the surface breaking up with use, there are no foreseen negative impacts. Assuming a cost of £10,000 to provide good surfaces, this could potentially be extended to all passive crossings. Practically, the best approach would be to target proactively crossings with heavy footfall (and high risk) and improve surfaces more widely at such time that existing crossing surfaces need replacement of significant maintenance. This should be combined with mitigation option V1 to demarcate the crossing with a single block of colour (ie a material to provide a level and non-slip surface, with colour).

Options for limited consideration

S3 – veloSTRAIL

A number of accidents have occurred in which users have fallen on the flange gap (including both wheelchair users, cyclists and general pedestrians). Flange gap fillers aim to mitigate this risk – such as veloSTRAIL, an inner panel system that eliminates the flange grooves, which has been in use on other European railways since 2006.

Network Rail granted full product acceptance on 30 April 2014 to the veloSTRAIL filled flangeway system following a 12 month trial at Network Rail's Innovation Development Centre (RIDC) in Tuxford. The acceptance certification has caveats that address hazard identification conducted by Network Rail during the trial. Network Rail was satisfied on trialling the technology that, when used within the defined tolerances, the technology does not import risk to the network (i.e. create new hazards that may offset the risk reduction achieved by the technology).

In correspondence with Network Rail for this research, the costs have been noted as approximately £45K per crossing fitted with the veloSTRAIL system. On this basis the indicative cost benefit analysis completed for this report suggests that use of veloSTRAIL could be justified at higher risk crossings only, or more specifically where pedestrian / cycle / wheelchair risk associated with falls at the flange gap is particularly high.

T2– Wayside horns

Although we have included wayside horns in the 'limited consideration' category, we note that there a number of potential safety concerns that would have to be overcome for them to be a viable mitigation option. We have scored the safety benefits as positive, however, this is on the basis that design and implementation avoids creating potential hazards:

- Wayside horns are not 'fail safe' – unlike a MWL the user cannot detect their failed status. It is important therefore to make the warning as reliable as possible, recognising this.
- During the research, the workshop debated what should be the sound relayed by the wayside horn; there was one view that it should not mimic an actual train horn as this might be confused with an actual train horn but signifies a different warning.
- Care needs to be taken on double track and bi-directional sections to make sure that a train leaving the section does not sound the warning. This could lead to a hazard whereby an approaching train is ignored by a user who assumes that the sound is being triggered by a train leaving the section.

Wayside horns have been retained for consideration, despite the above, since they may at very selected locations provide an improved means of alerting users to an approaching train at a lower cost (and therefore justified on the basis of cost benefit analysis) that other more costly active warnings. However, in general we consider that warnings which include visual active warning are preferable.

The method for train detection will have a significant impact on the cost – it was assumed a cost of £50,000 on average since costs much in excess of this will mean that visual warnings should be sought in preference (see options T3, T4 and T5). On this basis, wayside horns could be justified on a cost benefit basis at the highest 20% passive crossings; however as noted above, their application is likely to be very limited according to local site specific factors.

T3, T4, T5 – 'Novel' warnings – MWL dark mode, predictors, Wavetrain®

The standard MWL provides an active warning at passive crossings and as such reduces the risk to users associated with a failure to either look for, or to see an approaching train. However, traditional means of providing MWLs have very high cost which means they can generally only be justified at the very highest risk footpath and user-worked crossings. There are therefore significant potential gains in lower cost options to provide active warning as a more widely applicable upgrade path from footpath and user-worked crossings. Whilst typically active warning is targeted at crossings with sub-standard sight times, active warnings provide more general safety benefit even where sight times are acceptable.

The three options (T3, T4 and T5) are alternative methods for providing active visual warnings to users at lower cost than traditional MWLs. At the time of publication of this report, Network Rail had carried out research and trials on each of these technologies and had granted product approval for WaveTrain® as of 23 December 2013. However, Network Rail has not indicated which technologies (if any) would be further carried forward. The research has identified a number of issues concerned with reliability and applicability according to factors such as bi-directionality, double track and electrification. Clearly, further work is required to reach firm conclusions as to which technologies could provide a cost effective reliable active warning. At the conclusion of further research, some form of safety approval will be required to provide the assurance that a target level of safety improvement can be delivered.

Indicative cost estimates suggest targeting the top 10% or top 20% of crossings with lower cost active warnings. In comparison, providing traditional MWL warnings would only be justified at a much smaller number of crossings – those with particularly high levels of use and associated risk.

T6, T7 - Alternative arrangements for calling the signaller

Telephones provide a current form of risk mitigation against short sight times at UWCT- typically where the railway has established that sight times are insufficient for the user to decide whether or not it is safe to traverse when taking a vehicle over the crossing. At a very small number of crossings, telephones are provided for pedestrian users or those on horseback.

The idea of mitigation T6 is to explore whether there are specific UWCT where pedestrian users should be asked to phone the signaller. Although this would be a deviation from standard practice, there are some crossings where the sight times are short not only for vehicle users but also for pedestrians. This is considered for very limited locations only which satisfy criteria such as:

- The signaller has good information on the position of the train so can give accurate information to the caller.
- The user(s) are willing to comply with the new requirements.
- The signaller workload is not adversely impacted by additional calls from pedestrians which could increase the risk of errors in other signalling duties.

Costs of implementation would be very low – but in summary this is an option for consideration at only very specific locations.

The second option (T7) is for users to call the signaller on a mobile phone, where there is currently no user-worked fixed telephone provided. We are aware that this is a local practice that has been established at very specific locations where the caller and signaller have established a good relationship. The conditions required for this to be viable option would be similar to those above for option T6, and in addition good mobile phone signal coverage would be required. Option T7 could be used either routinely at specific locations, or during periods of seasonal activity such as harvest or when large vehicles are taken over the crossing.

P1 - Modular bridge

Network Rail's highest priority to reduce risk at level crossings is closure – either by locking out an existing passive crossing, or providing grade separation. The second of these options is typically high cost, meaning that only the very highest risk crossings can be justified for replacement with a bridge.

So-called 'modular' bridges aim to reduce the unit cost of grade separation, and although still the highest cost option considered in this research, do achieve risk elimination (assuming that users are completely prevented from crossing the tracks at grade).

We have assessed that on the best available unit cost of £400,000; modular bridges would be justified at the top 10% of highest risk crossings of all types. This only considers the benefit to pedestrians – modular bridges which also include vehicular traffic would of course also remove the vehicle risk at the level crossing, and so the business case will be easier to achieve.

Aside from the financial considerations, the practicality of bridges is often constrained by local surroundings including the space available – so for this reason we have indicated that although highly desirable, it is likely that bridges will only be viable at a limited number of locations.

P2, P3 - Remote gate release with interlocked barriers

The research identified some concerns with both options P2 and P3 – which both aim to restrict the physical access that a user has to a crossing, based on it being locked out either automatically by the signalling, or manually by a signaller. The potential concerns include:

- The difficulty in achieving reliable locking / interlocking. This would be location specific, and would need to be reliable so that users do not experience a failed state in which they are erroneously allowed to open gates, or open the POGO when a train is coming. Note that these concerns are not specific to POGO, which is evaluated separately under mitigation O3
- The uncertainty over the safety benefit that would be achievable (shown by the wide range indicated in the table below), owing to the variations in the exact specification for train detection, means of communicating with the signaller in the case of remote gate release, the behaviour of users involved, and the design of user controls and communications.

Potentially, however, these options could provide a significant positive risk reduction at passive crossings – if the above concerns could be overcome. We therefore include these options for further consideration, but note that this would be subject to rigorous hazard identification and safety approval at specific locations.

P4 – Extended flexi-booms

Flexi-booms aim to restrict physical access to the crossing on train strike-in, in effect creating full separation of the road from the railway in the same manner as other full barrier crossings.

The boom extension is designed to be flexible to prevent entrapment – for example so that vehicles can still move clear of the crossing through the barrier in the event of blocking back.

Whilst this mitigation is principally aimed at vehicle users, it may have some benefit in discouraging pedestrians from walking around the barriers after they have lowered.

The research felt that it was possible to for flexi-booms to achieve a positive risk reduction. However, there were some concerns with the option that made a business case for its implementation less straightforward. In particular:

- The lightweight boom construction was felt to make them prone to damage (for example, if a vehicle pushed pass them as they were lowered) and therefore require more regular maintenance.
- The barrier does not provide significant disincentive to prevent pedestrian violations; it does not have, for example, a skirt in the same way as a MCB.

It was also noted that the barrier may increase the risk of entrapment – for example for horse riders and cyclists caught between the barriers. This would be a new risk for AHB and may offset other (positive) safety benefits. The mitigation would therefore need rigorous hazard identification and safety approval at specific locations for it to be adopted.

E2 – Active sign 'close gates' when gates left open at UWC

This option arose from discussions on option E1 (audible alarms when gates left open), but is preferred as it could provide a warning without potentially masking the sound of an approaching train. Best estimates of the cost suggest that it could be targeted amongst the top 10% of riskiest UWC type crossings, but practically application would be quite limited for example, it could be targeted where:

- Gate misuse is known to be common.
- Other measures to prevent gate misuse have failed (for example threats to fine the offenders).
- The user would welcome the active sign to be installed.

S2 - Solar way marking

This option is proposed for further consideration given the low cost, and low potential safety benefit. The impact on user behaviour is noted to be very marginal, but it could be provided at very specific locations where there is a high level of use in hours of darkness, and where the edge of the crossing surface presents a particular hazard (for example crossings which are narrow or do not traverse the tracks orthogonally).

O2 - Official looking 'eyes' sign

This option is a very low cost measure that might be beneficial at locations which are subject to high levels of misuse or horseplay. The idea is to dissuade people from behaviour on or near the line that could result in a train strike.

Although the safety impact is likely to be relatively low, in combination with other measures (such as CCTV or visits by BTP or rail staff) it could be used at those sights which are known or suspected to have high levels of misuse.

Options not for further consideration

V2 – Pavement transfers

Although we have included this option as 'not for further consideration', Network Rail may consider very specific use of pavement transfers as part of local campaigns. The main reason this option has been rejected, is that safety benefits are thought to be very small (they rank poorly in behaviour impact), and there are some concerns / experience of wear. The research concludes that it would be preferable to prioritise option V1 – demarcating crossing surfaces with single blocks of colour.

V3 - Flashing signs

Although it is possible that flashing signs may provide some safety benefits, there is some concern that they might distract users when using a crossing and actually therefore lead potentially to a failure to look for trains. They rank poorly in terms of behaviour impact. Because the flashing sign is not 'intelligent' – ie it is not linked to the arrival of a train, it is likely that any initial positive impact would wear off quickly to users who become familiar with the warning.

V6 - Retro-reflective tape on pedestrian gates

The behavioural impact and safety benefit of this measure is considered to be very low, and as such – despite low costs – not be worthwhile. The authors also note that a light source is needed for the mitigation to function (which makes the tape of limited value to pedestrian users unless they have a torch)

V7 - Projected stop sign – no warning of train provided

This option has been rejected for similar reasons to option V3 – namely that the sign would not specifically warn of an approaching train and could be distracting rather than helpful. In addition, there are likely practical difficulties with projecting a stop sign onto the ground given the variation in lighting conditions and surfaces.

V8 - Projected stop sign at active crossing

This option has been assessed to have a stronger behavioural impact than option V7, because it would be used at active crossings and as such be able to provide a warning specifically when a train was detected. Effectively it would therefore provide a supplementary warning to the traditional lights / alarms / barriers.

Practical difficulties with projecting a sign on the ground in different lighting conditions is the main reason that this option is not suggested for further consideration.

T8 - App for alert user to approaching train

This option has been rejected from further consideration due to a number of reasons:

- It is not clear what information the app would provide to a smart phone user, and at what time in the crossing sequence.
- It is not clear that it would be possible to provide a suitably timed warning to a user when approaching a crossing.
- There is a concern that a message sent to a user when approaching a crossing may be a distraction and actually a cause of accidents as much as a mitigation.
- The penetration (in terms of people who would download and use the app) is likely to be limited.
- The costs of developing, deploying and maintaining such an app are likely to be high.

E1 - Alarms on gates at UWC – when gates are left open

On balance, this option was rejected from further consideration due primarily because there of a concern that the alarm may be a distraction to users, or mask the sound of approaching trains (ie increase risk). There is also a concern that such an alarm would not be robust in the environment typical of many UWC (farms, etc), and it could be vandalised by users who found it an irritation.

Review of this option at the industry workshop led to the development of option E2 (active sign reminding users to close the gates at UWC) which is suggested for further consideration.

E3 - Alarms on gates at UWC – when gates are opened

This option has been rejected for similar reasons as option E1; ie the concern of masking the sound of an approaching train, and robustness.

O1 - Mesh front to gate

Adding a mesh front to pedestrian gates to stop users swinging on the gates has not been put forward for further consideration primarily due to the negligible behavioural impact and safety benefit.

O3 - POGO

On balance, the research concludes that there is insufficient evidence that POGO crossings provide a net safety benefit compared with more traditional UWC. The correct use of POGOs by users could reduce the level of risk exposure – particularly due to the removal of the need for pedestrian traverse. However, misuse (leaving the gates open) and the fact that staying in the vehicle affords an impaired view of approaching trains compared to that possible on foot leads us to this conclusion.

For this reason, the research does not recommend them for further consideration, but would support further research to examine the net safety benefits / dis-benefits.

6. Conclusions

Pedestrian accidents at level crossings

- RSSB (2013) calculates that approximately eight pedestrians are struck by trains per year at level crossings on Network Rail managed infrastructure, resulting approximately seven fatalities.
- Just under half of these occur at footpath crossings, and most of the remainder occur at user-worked crossings, automatic half-barriers and manually controlled barriers with CCTV.
- The level of protection provided clearly has a very strong impact on the occurrence of accidents when normalised by traffic moment; normalised by moment, pedestrian train strikes at the least well protected crossings – passives - occur 50 more often than at the best protected – manually controlled full-barrier crossings.
- A model developed for this research for footpath crossings suggests that users are failing to protect themselves from trains strikes approximately once in 50,000 traverses on average. This is a very good level of human performance considering the myriad distractions that many users face, poor weather conditions, and the risk taking behaviour that is frequently observed.

Causes of accidents

- Overall, the research concludes that there is a strong link between the occurrence of pedestrian accidents and pedestrian moment.
- Accidents are also more common at station crossings and for male users, and increase with age above 30.
- There is poor or no evidence that *overall*, other user, crossing and environment factors can be associated with higher rates of accidents.
- Therefore, the current risk assessment approach (ALCRM), which is focused primarily on pedestrian moment, is robust.
- However, at specific locations, combinations of characteristics of users, trains, the crossing layout and equipment, and other factors may 'add up' to cause users to have particular difficulties in crossing safely. This supports the idea that improved site specific hazard assessment should be carried out alongside quantitative risk assessment. Such ideas are currently being discussed with industry at the time of the research (T936 *and* related discussions). Inclusion of such improved hazard identification would also help to satisfy requirements for a 'suitable and sufficient' risk assessment.

Risk mitigation options

- This research has identified and ranked a number of mitigation options which are either new, or have already been considered to some degree but are not currently standard solutions. Many of these would not be applicable to a wide range of crossings, due to practical difficulties in installation, or because they would be of benefit to address specific hazards that do not exist at all crossings. Indicative cost benefit analysis has been used to highlight in broad terms whether each candidate option is likely to be affordable at all crossings, or the top 10 / 20% of highest risk.

- Amongst the most promising options assessed for this research are:
  - 'Danger zone' demarcated with a single block of yellow colour (passive crossings).
  - MWLs – back to back lights, or repeater LED lights on gates.
  - Improved auditory alarms at active crossings.
  - Anti-climbing rollers at full barrier crossings.
  - Improved crossing surfaces (at all crossings – particularly passive crossings) - in combination with demarcation of the 'danger zone' as noted above.
- Overall, we conclude that the greatest gains in reducing accidents are likely to come from a focus on fewer specific actions:
  - Establishing reliable, low cost active warnings to upgrade passive crossings – where existing methods for warning cannot be justified because of high cost. The research has reviewed three alternative means of providing such lower cost active warnings, but notes that in all cases a final conclusion on their adoption has not been reached. We consider that establishing workable designs for low cost active warnings solutions is a high priority given the potential benefits to be gained by increasing the number of passive crossings that could be upgraded.
  - Providing good surfaces at all crossings (non-slip, demarcated zones of colour at FP and UWC). This should not be constrained by having to seek 'business cases' for improving crossing surfaces, but prioritise improvements based on the current level of risk - from highest to lowest or whenever existing surfaces are due for renewal.
  - Busy stations crossings should be specifically prioritised for risk reduction due to evidence of higher accident rates than crossings located away from stations.
  - At passive crossings, 'design principles' should be followed when upgrades / maintenance work is carried out – documented by Turner et al (2013).

References

This report refers to the following publications external to RSSB's own research programme; abbreviations to relevant RSSB research referred to in this report are given in the Glossary.

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RSSB R&D Programme
Floor 4, The Helicon
1 South Street
London
EC2M 2RB

enquirydesk@rssb.co.uk

http://www.rssb.co.uk/research-development-innovation/research-and-development