Hot topics in controlling risk at level crossings

Jay Heavisides[1], John Barker[1] & Michael Woods[2]
[1]Arthur D. Little, UK and [2]Rail Safety & Standards Board, UK

Abstract

This paper focuses on level crossing risk, the subject of a number of current, high-profile, industry programmes in the UK. These aim to either improve safety or better measure safety levels. The paper considers two of the ‘hot topics’ to come out of these programmes:

Topic one concerns modelling of risk at level crossings, and a concerted effort to use a common basis for assessment of all crossings.

Topic two concerns the use of obstacle detection to provide an early warning to the train driver on approaching an object on the track. Of particular interest are the benefits (and drawbacks) of some very different solutions to obstacle detection currently used within Europe.

1. Introduction

There are around 8000 level crossings on the British network contributing approximately 7% of the network risk (some 12 fatalities and weighted injuries per year[1]). Over the past decade, the British railway industry has put significant effort into understanding the causes of risk at level crossings, and in developing approaches to managing these risks. Improving technology platforms (for example use of web portals by Network Rail to manage shared access to software models) and a better understanding of the different risk drivers that are common to different level crossing types has meant that recent years have seen a shift from developing new risk assessment tools to consolidating knowledge within a fewer more sophisticated systems.

This paper presents two recent topics from this drive to understand and codify understanding of level crossing risk: the first concerns a concerted effort to use a common basis for the assessment of all level crossing types, the second concerns the challenges to be faced for the development of an obstacle detection system.

2. All Crossings Risk Model

2.1 Background

For more than a decade Network Rail has used a tool to support assessment of risk at automatic crossings. The automatic crossing model is fault tree-based, with the frequencies modified according to specific crossing features such as traffic moment (users x trains), levels of abuse, orientation, approach etc. Although the model has proven success, it has recognised limitations. The most obvious limitation is its inability to model the risks at passive crossings. Passive crossings differ significantly from automatics in several ways, for example:

- The default status of an automatic crossing is open to users, whereas for many passives such as user worked crossings or footpath crossings the default is closed and user must open a gate or cross a stile to cross the railway.
- At automatic crossings the user is informed when it not safe to cross, often passive crossings rely on the judgement of the user and their sighting along the track.
- Automatic crossings have been designed to be more visible than passive crossings as a vehicle user may approach the crossing at speed.
- The operational differences alter the opportunities for crossing abuse. For example, at an automatic half barrier crossing, a driver may choose to zigzag around the barriers when the crossing is active, whereas at a user worked crossing a user may leave the protecting gates open, which influences the risks to other users if they are not aware of the crossing.

An awareness of these limitations led to RSSB commissioning the development of a new All Crossings Risk Model (ACRM). The remit was to extend assessment to all crossing types (automatic, passive and manually controlled crossings) by considering new ways that level crossing risk could be assessed at the different crossing types.

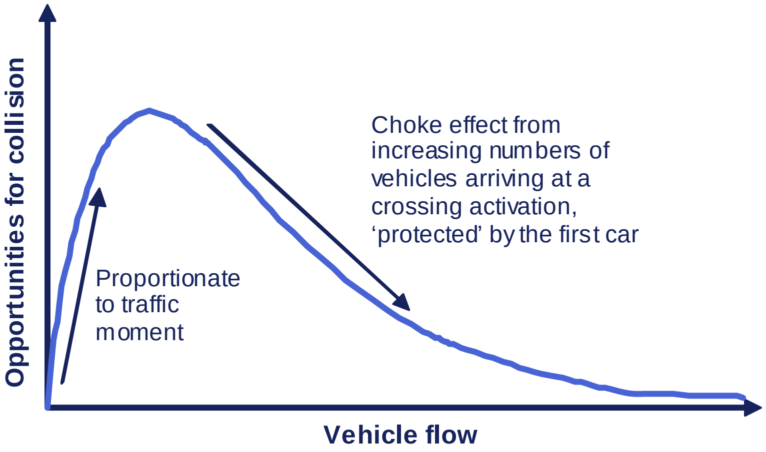
2.2 Modelling the risk

Some very different approaches were required to assess similar risks within the same model. These were tackled by adopted a modular design, with each module (such as calculating sighting time or consequences of derailment) used by one or more crossing types.

The 'Stott' effect

The ACRM introduces new ways of determining how risk is related to crossing utilisation. The automatic crossing model assumes that vehicle risk is proportional to the traffic moment (i.e. vehicles x trains). At low levels of usage this worked well. However, at high traffic levels the automatics model was likely to over predict the level of risk. The ACRM approached this problem through the use of concepts developed by Professor P. F. Stott[3] (known here as the 'Stott' effect). Professor Stott proposed that a user only has the opportunity to collide with the train if they are the first vehicle to arrive at the active crossing *and* that they do so around two seconds before the train *and* they fail to stop. Hence, there is a chain of events required for a vehicle to collide with a train or the crossing equipment. At crossings with high traffic levels, there will always be a first vehicle, and providing the first vehicle stops it forms a 'protective barrier' between any additional vehicles that arrive and the crossing. The number of opportunities for collision per user therefore rapidly decreases as the flow of vehicles increases (see Figure 1).

Figure 1: The 'Stott' effect



The ACRM has developed the 'Stott' effect from its original form (focussing on red light running at automatic open crossings) to use in modifying the frequency of a number of other events, such as red light running, late braking, rear-end shunting and collisions with equipment. At passive crossings the frequency of vehicle users is relatively low, and therefore traffic moment - and for some hazards the number of users - was found to be the more suitable modifier.

Effect of heavy goods vehicles on collision frequency

During development of the ACRM, analysis of historical data at crossings showed that heavy goods vehicles (HGVs) were more likely to be involved in certain events than smaller vehicles. Safety loss incident data revealed that a collision between a train and road user is 2.3 times more likely to involve a HGV than any other type of vehicle. Operational loss data was also analysed to understand the type of vehicles involved in user-equipment collisions (few incidents of this type result in a safety loss). This suggested that HGVs are 15 times more likely to collide with crossing equipment than other vehicles. The model incorporates these adjustment factors for the influence of heavy vehicles by weighting the calculated frequencies for each event type by the relative population of HGV traffic at the crossing versus non-HGV traffic.

Derailment consequences

The presence of HGVs and other large vehicles also increases the risk of derailment following a collision. However, following a derailment how is it possible to determine the consequences? For the ACRM we developed a probabilistic spatial model that takes into account specific features of the track and its surroundings. As part of the model inputs users are required to complete site visits to assess the features of each crossing. One assessment section is dedicated to the crossing environment, in which users record features such distances from the crossing to track and the presence or absence of points, other crossings, platforms, cuttings, bridges etc. These are used by the ACRM to modify the collision consequences, consider aspects such as what the chance of derailing is (inline and offline), how far the train may travel before coming to a stop and what obstacles it may collide with to further worsen the consequences. The collision consequences are calibrated within the model against historical derailment data. The ACRM then incorporates the additional risk of derailment into the overall risk calculation.

2.3 Constructing the model

Taking the paper description of the model (the Functional Specification) and turning it into a software-based tool was started in 2005. Jointly funded by Network Rail and the Rail Safety & Standards Board (RSSB), over the last 10 months the ACRM has been coded, tested and partially calibrated.

The ACRM is constructed of three main components:

- A database to store and manage all the level crossing data (not a small task, considering the ACRM can be used to assess all crossings on Network Rail-controlled infrastructure)
- A risk engine, which calculates the risk for a given level crossing from the user inputs
- A web-based interface, into which the user enters the assessment inputs and retrieves the results

As a web-enabled tool, the ACRM will be accessible nationally by all of those involved in Network Rail's level crossing risk management. Previously the automatics model was spreadsheet-based, with an individual file created for each crossing. The architecture of the ACRM with a single central database makes managing the considerable amount of level crossing data that will be generated from the new assessments far easier.

At the time of writing this paper, Network Rail is preparing to conduct the first level crossing assessments with the ACRM. A number of the level crossing inputs have not previously been gathered on a national basis. The data will therefore provide a valuable insight into a number of aspects of level crossing use, which eventually with help the industry better understand how these risks can be managed.

3. Obstacle detection

3.1 Background

In November 2004, a train collided with a stationary vehicle at Ufton Automatic Half-Barrier (AHB) level crossing, causing the train to derail leading to the death of six people on the train, including the train driver. The Formal Inquiry into the accident made several recommendations, including Recommendation 5 calling for research into whether or not a practical system can be developed to detect and warn train drivers of obstructions at AHBs in Great Britain. The Rail Safety & Standards Board (RSSB) therefore commissioned a research study into obstacle detection, expanding the scope to include manually controlled barrier with closed-circuit television (MCB CCTV) crossings as well as AHBs. This paper focuses on some of the obstacle detection configurations and applications at level crossings that were identified as part of the RSSB study, and the potential challenges faced when considering applying obstacle detection to AHBs.

During the study we carried out an Issues Analysis to identify key factors for consideration, which was followed by a base case risk analysis to determine the theoretical maximum safety benefit that could be achieved from implementing obstacle detection. To identify potential obstacle detection solutions and their applications at level crossings we spoke to several detection equipment suppliers within and outside the rail industry, as well as representatives of level crossing operators from other countries. The findings of the interviews were evaluated via a workshop and further assessment.

3.2 What is obstacle detection?

It is important to understand what is meant here by ‘obstacle detection’: in this context it is a means of identifying the presence of an object on a level crossing as the train approaches, providing information to guide a suitable response so that collision with the object can be avoided or the consequences minimised. Obstacle detection is not just about the type or technology of the detector; what is done with the output is also critical for an effective system. At present there are no obstacle detection systems in operation at level crossings in Great Britain. However, there is growing use of these systems in other countries (these are discussed later).

Ideally, an obstacle detection system would:

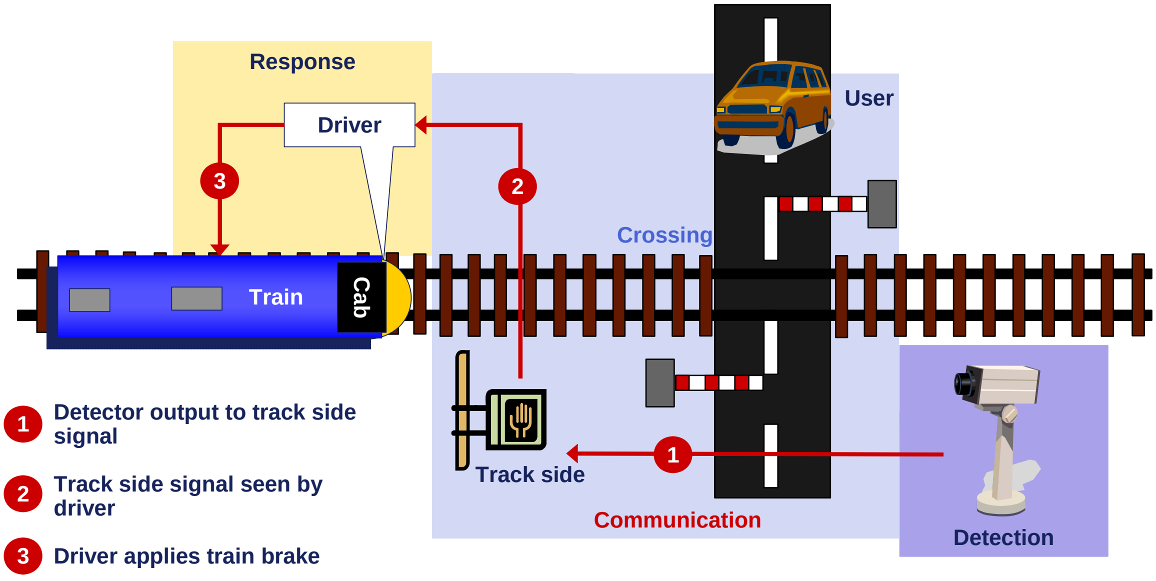
- Improve safety at level crossings for all users (road and rail)
- Cause no or minimal delays for both train and road users
- Be affordable in terms of costs to install, operate and maintain
- Be practical to use and maintain

These requirements are often in conflict. For example it might be possible for a particular system to offer good safety benefits, but only at the expense of causing significant operational disruption (which itself can introduce safety risks). Another issue is the requirement for any candidate obstacle detection system(s) to interface effectively with the existing railway infrastructure, rolling stock and operations standards.

Given the definition used at the start of this section for obstacle detection, there are three main components (see Figure 2) that can be used to describe the configuration of such a system at level crossings:

- **Detection:** determining whether or not the crossing is clear
- **Communication:** a means of informing a person or system the need to take action
- **Response:** the action taken to mitigate collision

Figure 2: Example, obstacle detection system at AHB



Detection

A ‘detector’ is required to be installed at the crossing to determine whether or not an object is present. There are several technologies that are capable of carrying out detection, such as radar, lidar, camera (stereo or infra red, with or without intelligent software), ultrasonic sensors, induction loops or strain gauges. The choice of detector can depend on several factors, e.g. environmental conditions, size of object. The application of the system will influence the outcome of a positive detection, for example: what does the system need to detect, and when in the sequence of level crossing operations does the detector need to detect an object?

Communication

Once an object has been detected a method of communication is required to convey this in a timely manner so that action may be taken to prevent or reduce the chances or consequences of an accident. There are several options for providing the communication, including use of existing line side railway signalling infrastructure, use of train protection systems, line side indicators or more novel ideas including wireless and infra red technologies connected to an in-cab alarm or alert. The design of any alarm or alert always needs to consider existing audible and visual warnings used within train cabs; any additional means of communication may degrade the efficacy of existing alarms and alerts. Fitting devices to the cab can also be costly and can increase obstacle detection implementation costs significantly, the obvious problem being inter-operability (i.e. should all rolling stock be fitted with obstacle detection systems if only a few level crossings have obstacle detectors?).

Response

The method of communication is closely linked to the intended form of response. There are a number of possible means of responding once the object has been detected; the aim of all of them is to reduce the chance or the consequences of a potential accident between the train and what has been detected. For example, the train driver may respond to some indication of the detected object, the train itself may respond without actions by the driver (automatic braking), the signaller may not clear the protecting crossing, or the response might be to influence the operation of the crossing (e.g. by raising the exit barriers allowing the trapped user to exit). The method of response has to be time-effective, especially at AHBs in Great Britain where the average time between a crossing activation and a train arriving at a crossing is around 35 seconds[2]. This means that only about half of trains would be able to stop before the crossing if the warning was given to stop the train at the current point of crossing activation (when vehicles may legitimately still be using the crossing). This figure decreases to 16% if the warning was given as soon as the barriers are lowered. Increasing the warning time is an option but other research has shown that this is likely to result in increased numbers of vehicles and pedestrians negotiating the crossing around the closed barriers (and not to say a significant cost of moving the existing train detection circuits). A decision about the point at which to start detecting would have to consider the trade off between the safety benefits and operational disruption from detecting legitimate crossing users.

3.3 Findings and discussion

There have been a number of successful installations and trials of obstacle detection at level crossings in European countries. The configurations and applications of obstacle detection for four of these countries is summarised in **Table 1**.

Two categories of detector were found to have been installed in the countries interviewed: radar and induction loops. Radar detects objects by the variation in returned signal as radio waves reflect of the object’s surfaces. Induction loops detect the presence of a metal moving object by the current induced in a metal coil placed on the crossing decking.

Making the train driver responsible for applying the brakes is the most common form of response amongst the detection systems that we reviewed, being implemented in Germany, Italy and at one trial site in the Netherlands. In these instances the need for the driver to apply the brakes is communicated either by line side indicators or traditional railway signalling. Only the Swedish system makes use of an on-board train system, ATC, which was implemented for reasons other than responding to obstacle detection.

Table 1: Application of Obstacle Detection at Level Crossings in Europe

Country	Detection, Communication & Response (D/C/R)		Application
Germany (DeutscheBahn)	D	Radar	▪ Introduced to reduce operating costs by replacing signallers responsible for operating the crossing ▪ Only used at full barrier crossings ▪ Must be able to detect objects that are 1m (height) x 0.5m (width) x 1.5m (length), i.e. unlikely to detect dogs or small children ▪ The radar carries out three consecutive consistent scans before confirming the crossing is clear or an object is present ▪ The radar commences scanning once the entry barriers are closed ▪ If object is detected, crossing is reopened and the sequence restarted ▪ Obstacle detection is installed at around 70 crossings
	C	Traditional railway signalling	
	R	Train driver applies brakes	
Italy (Rete Ferroviaria Italia)	D	Radar	▪ Used as an alternative where crossing closure is not possible and as a means to introduce full barriers without the need for CCTV ▪ Must be able to detect objects that are 0.5m x 0.5m x 0.5m, though not necessarily pedestrians ▪ Main driver is to mitigate catastrophic risk ▪ Obstacle detection is installed at around 10 crossings, with around 20 further installations planned in the next year
	C	Traditional railway signalling	
	R	Train driver applies brakes	
Netherlands (ProRail) Trial 1	D	Radar and inductive loops	▪ Trialled as a means to upgrade AHBs to full barrier crossings at inner city locations, improving safety ▪ Applied to vehicle crossings, although can detect pedestrians ▪ Radar scans the crossing during barrier closure, after closure and crossing considered clear, it turns off and detection is carried out by induction loops only ▪ Line side indicators were located to be highly visible and provide sufficient braking distance ▪ Strike-in time was increased from 25 seconds to 42 seconds
	C	Line side indicators and direct cabling to level crossing controller	
	R	Train driver applies brake and exit barriers raise	
Netherlands (ProRail) Trial 2	D	Radar and inductive loop	▪ Trialled as a means to upgrade AHBs to full barrier crossings at inner city locations, improving safety ▪ Applied to vehicle crossings, although can detect pedestrians ▪ No change in the crossing strike-in time
	C	Direct cabling to level crossing controller	
	R	Exit barriers raise	
Sweden (Banverket)	D	Inductive loops	▪ Introduced with full barrier crossings as part of the high speed line upgrade ▪ Obstacle detection is carried out during crossing closure ▪ Once barriers are closed and crossing confirmed clear, the obstacle detection is turned off ▪ If an obstacle is detected the exit barrier is only lowered to 45° to allow the vehicle to exit the crossing area ▪ Obstacle detection is fitted to around 100 level crossings
	C	Automatic train control and direct cabling to level crossing controller	
	R	Automatic application of train brakes and partial lowering of exit barrier	

All of the countries interviewed applied obstacle detection to full barrier crossings. Full barriers were introduced for two main reasons: improving safety and minimising operational disruption from detecting users nipping across. If obstacle detection were applied to AHB crossings in conjunction with stopping the train, pedestrians and vehicles could negotiate the barriers reaching the other side of the crossing without harm yet causing the train to brake rapidly. Such harsh braking could result in on-board train injuries to passengers and staff (from falling, being hit by falling luggage or scolded by split hot drinks). The strike-in time at AHB crossings means that it is unlikely that the train will be able to stop before the crossing. An increase in warning time at AHBs in order to allow sufficient braking time can also lead to an increase in abuse from vehicles zigzagging the crossing. Therefore the implementation of full barriers could provide for increased warning times whilst managing levels of abuse.

The main focus of the obstacle detection systems implemented in **Table 1** is to prevent collisions between trains and road vehicles i.e. those collisions that could result in catastrophic risk. For this reason in Germany the minimum dimensions of an object that should be detected have been set. An object exceeding any one of these dimensions should result in a positive detection. This should ensure detection of all vehicles and some pedestrians. The minimum dimensions set have been guided by historical events, for example that no small children have been involved in incidents in the past and therefore are not required to be detected. Inclusion of detecting small children would increase the chances of nuisance detections (such as foxes and dogs), which could impact operations and potentially safety.

Although pedestrians represent the user group with the highest risk (in Great Britain pedestrians account for around 60% of the overall risk attributed to level crossing use) the safety benefit from detecting them and mitigating incidents may be offset to some extent by the significant operational disruption that they cause. Two trials set up in the Netherlands have focused on detecting trapped vehicles - not pedestrians - and therefore the detection has only been applied to the road vehicle crossing area. At the first trial site an approaching train driver would be warned of the presence of an object by a flashing white line-side indicator, whilst the exit barriers for the crossing would remain open to provide opportunity for the vehicle to leave. When implementing this system the white indicator was located at a suitable distance in order to provide sufficient time for braking. This required an increase to the strike-in time of the crossing and therefore the overall crossing closure time. Although detection was aimed at road vehicles, pedestrians were found to jump over the barrier protecting the road vehicle crossing area triggering detection, therefore causing the train driver to apply the emergency brakes. This abuse by pedestrians was partly attributed to the increase in the crossing closure time. The detections led to operational delays and prompted a second trial with a slightly different crossing application.

At the second trial site in the Netherlands, the detector no longer communicates with the driver. Instead, the only output is to the level crossing controller, who has the operation of leaving the exit barrier raised. As the detector is no longer intended for stopping the train, the crossing closure times are maintained and therefore should not impact the level of pedestrian abuse and hopefully operations. This second trial had just commenced as this study was carried out.

The Swedish system of induction loops can only detect metal objects i.e. road vehicles. Therefore disruptions from pedestrians are not an issue. However, induction loops themselves can be problematic in a railway environment due to electromagnetic interference, track vibrations and crossing decking maintenance.

Once a full barrier crossing is closed, should a pedestrian be trapped there is usually sufficient space for safe refuge between the barriers and track. The same cannot be said for vehicles, hence why the Netherlands and Sweden have designed their systems to keep the barriers raised to allow additional time for a vehicle to leave the crossing area.

Although safety would seem to be the obvious driver for the installation of obstacle detection, it is not alone. The costs savings appear to be a consistent driver. For example, in Germany level crossings have been fitted with obstacle detection to obtain whole life cost savings by replacing the signaller and CCTV with an obstacle detector. In Sweden, fitting obstacle detection was means of allowing higher speed lines whereas in Netherlands it was a cost-effective upgrade path from automatic half to full barriers.

The 470 AHBs in Great Britain account for around three fatalities and weighted injuries per year. Obstacle detection if fitted to all AHBs would not be capable of preventing even one tenth of these because of the time required to stop the train and the timing of the users (involved in incidents) entering the crossing. However upgrading an AHB to an automatic full barrier crossing would have several benefits over an AHB:

- Ability to increase the warning times whilst mitigating the associated increase in abuse to maximise safety benefits from obstacle detection
- The crossing would provide full barrier protection without the need for crossing keeper/signaller operating costs, providing whole-life cost savings
- Once full barriers were closed, detection could be stopped to prevent operational disruption and potential negative safety impacts from heavy braking caused by any pedestrians determined to nip across

We have been able to develop a basic specification for a full barrier crossing with obstacle detection from the findings of this research. This specification is currently being considered for further development. Regardless of the specification detail, obstacle detection has shown its potential to be a key feature of level crossing design and renewal programmes. For example, it is possible for an AFB with obstacle detection to be combined with other technologies that are becoming available such as predictors to form a new whole-life cost effective generation of level crossings.

4. Acknowledgements

The authors would like to acknowledge the funding provided by RSSB, without which this research would not have been possible. The authors also acknowledge the following organisations for their assistance during the research:

Banverket
DeutscheBahn
GE Transportation Systems
Honeywell
ProRail
RailCert
Rete Ferroviaria Italia

References

[1] “Profile of safety risk on the UK mainline railway”, Rail Safety & Standards Board, Issue 5, (2006)

[2] Output from Network Rail’s Automatic Level Crossing Risk Model V3.1, Network Rail (2004)

[3] Stott, P. F. “Automatic Open Level Crossings A Review of Safety”, paper to the Department of Transport (1987)