IRSE INTERNATIONAL TECHNICAL COMMITTEE

INTERNATIONAL BARRIERS TO LEVEL CROSSING

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Level crossings are a significant contributor to road safety issues. They can account for about 1% of all road fatalities. Most incidents arise from incorrect pedestrian and road user behaviour. Protection systems are often not revised even when vehicle types and traffic volumes on both modes changes substantially. After each accident the press say it must not be allowed to happen again. But what really happens?

Informed by risk assessment, improvement is wanted but:

- *Legal environments may inhibit cost effective improvement*
- *Different transport policies and funding arrangements produce different safety outcomes*

Issues include

- *Level crossing elimination*
- *Extent of technical protection*
- *ALARP vs. regulation and rigid standards*
- *Incremental enhancement / Residual risk*

This article asks 'what are the trends - what could we do differently?'

Methodology

This paper is not the result of thousands of hours of intense technical research or development; rather it rests on a simple Delphi survey that asked some of those 'in the know' to provide a snapshot of trends within the industry. The questionnaire did not seek to achieve statistical significance – in each case the respondent was assumed to be in a position to give sufficiently authoritative information in relation to the railway infrastructure in his / her country. We asked some simple questions about the legal environment, the sources of investment funds, the safety, dependability, and age of technical protection systems, the crossing 'population', trends evident nationally, and how research and development might help. This source material was supplemented by www-based desk-research, and by peer review of the draft article. The underpinning safety statistics do not apply universally shared definitions, so we use the term 'incident' to refer to an event in the statistics – usually, but not always, an accident.

Crossing Knowledge

Knowledge about crossing systems can be generated by collection of operational information, by collection of accident statistical data, and by incident investigations that suggest possibilities for safety improvement. Most level crossing data is held in association with accident statistics. While many crossings have data recording for juridical purposes, there is surprisingly little routine data collection, or analysis of operational information. Information capture systems are generally there to support or protect the owner in court rather than to help work out how to do things better.

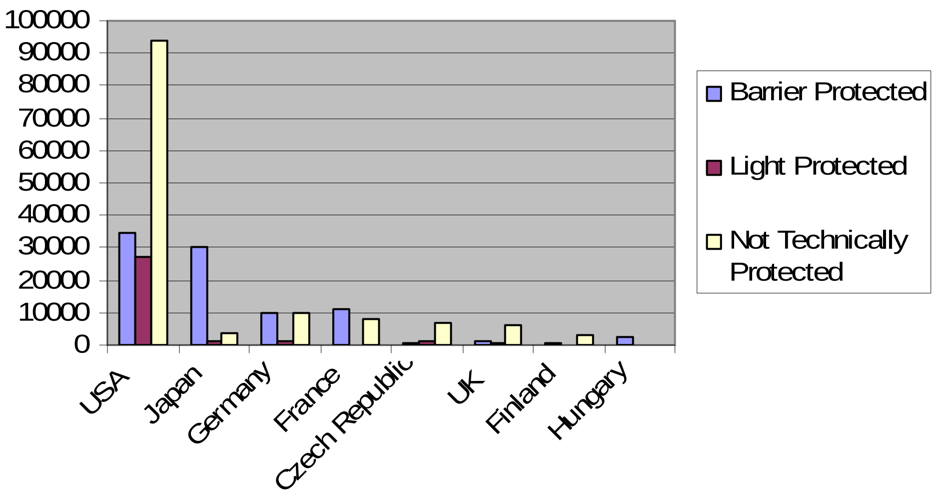
Knowledge of crossings tends to be linked to their legal status – for example station and 'barrow' crossings in the UK – of which there are about 200 (2.5% of the UK crossing population) – have been under-documented until recent human factor research work by RSSB[1]. This may simply be because some have not been subject to approval of the safety regulatory bodies. Statistical treatment of footpaths crossing railways is an equally grey area.

Missing information examples from individual respondents to our survey included ‘average age of assets’, and ‘asset dependability’. Even at the requirements level, the necessary level of safety at crossings was not explicit for a number of administrations. To efficiently manage any asset and its associated risks, it is generally desirable to have good knowledge of key asset statistics and performance data.

Crossing Populations

Europe is not the centre of the crossing universe. Some simple statistics for crossings protected by active warning devices (here generally called ‘technical protection’) point to sector dominance (within the market economies) by the US and Japanese rail systems. In the USA the FRA annual report[4] for 2000 lists 155370 at-grade crossings of which 34296 have gate protection, and 27100 have flashing light warning systems. In Japan, the level of technical protection exceeds 85% of crossings, so that in 2004, for a total population of 35612 crossings, 30488 had barrier protection and a further 1117 had flashing light protection. By comparison the number of protected crossings in France, UK and Germany combined is about 24000. This is illustrated in Figure 1 below.

Figure 1
Crossing Populations



Legal Environments

In the UK the crossing engineer needs to be aware of 13 separate and weighty pieces of directly applicable legislation and their interpretation. As in France and Germany, applicable law requires extensive user consultation regarding any change to crossing availability or functions. Requirements for risk assessment tend to be satisfied by significant volumes of ‘unique-to-site’ engineering effort with engineering re-use often limited to component and design fragment level.

Transport Policy and Safety Outcomes

Where transport policy strongly invests in crossing safety, the outcomes can be seen in the accident statistics. In the USA, sustained policies of state investment in predictor based technical protection systems that give consistent warning times, coupled with investment in enhanced crossing visibility and public education, have contributed to a halving of crossing fatality rates over the past 20 years[4]. Investment in Japan has seen crossing incidents fall to

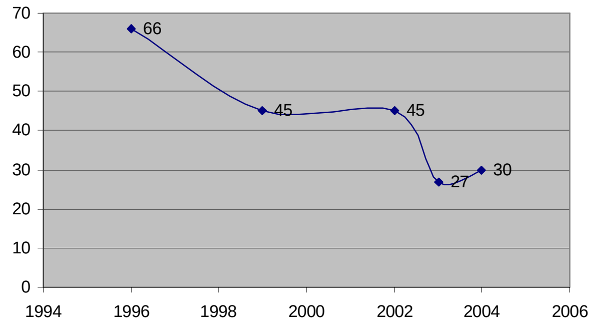
37% of their former level over the same period. In Europe the smaller absolute volumes make analysis less certain – outcomes in Germany are similar to those in Japan.

Crossing Closures

While our survey showed a general wish or requirement to avoid or remove crossing systems, the costs of closure mean that crossing population decline is generally very limited, in some cases principally reflecting change over time to network route-km. To quote one respondent, “closing a crossing isn’t easy under present legislation”.

More analytic approaches to closures[8] simply act to underline that closure investments are a low political priority. In France closure expenditure is around 15million Euro p.a. A further 6m Euro p.a. is spent on enhancements so that only about 50 open ‘light protected’ crossings remain.

Figure 2
Crossing closures per annum in (e.g.) France:



The Netherlands has a similar emphasis on the removal of open crossings protected only by lights, with replacement by automatic half barrier systems. In Finland with just under 800 barrier crossings the closure fund is high pro-rata at around 7 million Euro p.a., but still only impacts about 10 of this type of crossing. While Germany has eliminated 25% of its crossings in just 12 years, elimination is typically a 50 -100 year programme!

So crossings will be with us for the foreseeable future, importing major risks to rail operation.

Crossing Safety Requirements and Performance

SIL levels are generally not used in crossing specifications as the technical protection systems in use typically pre-date the applicable standards. While most respondents expected crossings to satisfy current European Standards and to provide SIL 4 technical protection, some administrations (e.g. Finland) take the view that SIL 2 installations equally meet their needs. While the UK requires obstacle detection to achieve SIL 3 or better, respondents generally did not distinguish whether the SIL level could or should be different for the various parts of a single installation.

Safety performance at Level Crossings is impacted by multiple complex factors, but some simple statistics serve to illustrate the difference in incident levels that may arise. In Japan and Germany the reported accident rate is about one per year per 100 crossings, while the USA incident rate is above six per year per 100 crossings. Typically this might be assumed to be due to the much lower use of active warning devices at crossings in the US – but perhaps surprisingly the US incidence rate is slightly higher at gated crossings than at those without such protection.

U.S. government statistics show that vehicle-train collisions at highway-rail intersections have been cut in half over the past 20 years despite obvious growth in road traffic volumes (source: – Operation Lifesaver[7]). At this rate of improvement it could still take half a century for the US to reach today’s safety levels in Japan.

Fatalities at US grade crossings totalled 425 in 2000. With total road deaths around 42500 per annum, this means that grade crossings account for 1% of all road fatalities. In Europe crossings can typically account for 0.5 to 1% of all road fatalities. For example in both France and Germany the crossing toll has ranged between 0.7% and 1.1% of total road fatalities over the last few years.

The national differences show limited correlation with general road safety, where the rates (expressed in terms of fatalities per 100,000 of population)[6] include:

Country	General Road Safety Fatalities per 100000 of population	Crossing fatalities as % of General Road Safety Fatalities
France	12.9	0.7% to 1.1%
Japan	7.5	1.3%
USA	14.9	1%
Germany	6.5	0.7% to 1.08%

Figure 3. Crossing Safety in Relation to General Road Usage Safety

Causes of Crossing Incidents

Crossing incidents are almost universally attributed to the fault of the road user. US statistics[4] are typical of causal analysis:

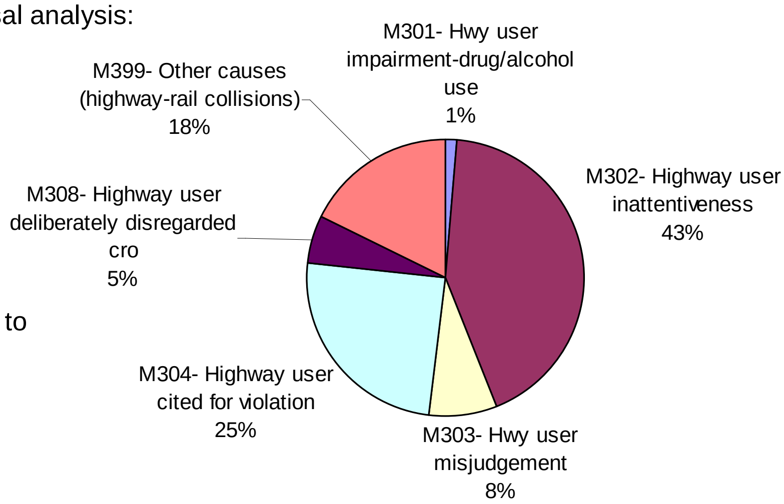


Figure 4
Reason attributed to "Obstacle Arrival At Crossing"

With one of the most technically protected rail networks, timing analysis of crossing incidents in Japan shows the following picture[11]:

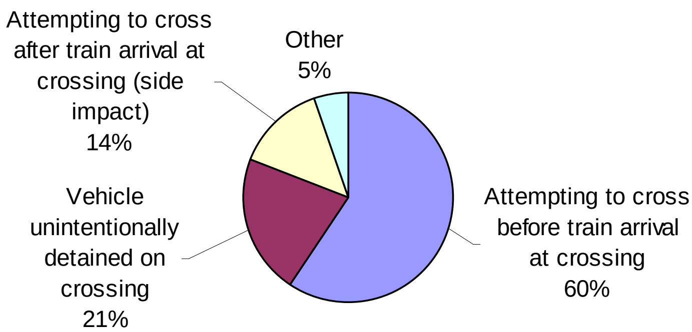


Figure 5
Timing of Obstacle Arrival At Crossing

Information from Incident Investigations

Investigations of major crossing incidents can prove a rich source for crossing enhancement ideas and initiatives. The Ufton (UK 2005) incident report[13] highlighted 23 action headings for safety improvement. Of these, three related to achievement of crossing closure, one added new considerations to existing crossing risk assessment process, one provided for design effort on obstacle detection and indication to the train driver, one provided for a crossing telephone optimised to its 'signaller emergency contact' purpose, and one proposed changes to roadway materials to mitigate derailment risks. The last two in particular would have been unlikely to emerge as issues had no accident occurred.

Incremental Enhancement and Residual Risk

Given that closure and replacement in most instances remain unlikely, a principal emphasis of research has been on the incremental enhancement of technical protection to mitigate residual risk. In the UK action is required on residual risk where the estimated risk of fatality per year to a regular crossing user (making > 250 journeys across the crossing) exceeds 1 in 10,000 and is deemed 'intolerable' – a criteria applied equally by highway authorities to a road intersection. While in theory ALARP based approaches should encourage flexible matching of investment to risk, adapting rigid construction and other standards to adequately reflect this remains a challenge and standards adherence continues to drive renewal cost.

High technology approaches in Japan and Germany are now targeting the automated detection of people as well as vehicular obstacles on the line by use of ultrasonic overhead sensors, stereo cameras, and laser radar. At the other end of the technology spectrum RSSB

(UK)[12] is researching the effectiveness of median strips in reduction of intentional crossing violation by road users.

Impact of Technical Safety Systems
It is often implicitly assumed that technical protection systems will make a crossing safer for all users. This assumption may be in the same category as the assumption that road markings always make roads safer to use (where research is now ongoing on the removal of road markings as one means to reduce average vehicle speed and thus risk). Research in the UK by RSSB[2] on user worked crossings with Miniature Warning Lights (Red / Green) has shown that *"the primary source of risk at Miniature Warning Light crossings was found not to be related to visibility or comprehension of the lights and instructions, but instead to deliberate crossing violations. An underestimation of time taken to cross combined with an overestimation of the time between the onset of the warning system and the arrival of a train was identified as a major cause of these violations"*.

Crossing Dependability
Despite the wall of statistics associated with crossing safety, it is difficult to draw any international comparisons that consider the impact of crossing system dependability on incident probability. I.e. – is malfunction of crossing technical protection systems a significant factor in the incident rates?

The US DOT Level Crossing inventory form (circa 150 fields) does not provide fields to record technical protection system dependability. The Federal Accident Notification form does not explicitly question the status of the protection equipment at the time of an accident. The equivalent UK form for written notification of serious incidents to the safety regulator does not appear to be web-accessible.

A brief www search for research on the dependability of crossing systems highlighted just one study[9] on application of condition monitoring systems to crossings. Reliability has generally been low-profile as an issue at applicable conferences. It is an issue being surfaced by increasing crossing related litigation that is driving investment in monitoring.

Safety Requirements
How can it be that in some countries plc systems offering SIL2 safety protection are considered satisfactory whereas in others the rail signal systems for crossings are required to operate at SIL 4? Is it logical, where risk is principally introduced by road vehicle driver and pedestrian behaviours, infrastructure managers can be required to use SIL 4 systems to respond to train movements while systems controlling road movement at the crossing may have lesser integrity?

Common Safety Targets (CST) in Europe
In Europe there is an expectation that the European Rail Agency (ERA) will set out high-level safety targets for railway companies. It is responding to an EC mandate (04/49-MA01 of 16.12.05) that includes a requirement for CSTs to define minimum safety levels for level crossing users in terms of risk acceptance criteria.

The CSTs use risk acceptance criteria rather than specification of solutions, though consideration will be given to European Standards that give a presumption of conformity. This means that Infrastructure Managers may seek to satisfy these targets by emphasis on dependability rather than on absolute safety. In doing so they may point to the % of accidents that are associated with malfunction of technical protection systems that may nominally employ SIL 4 components.

Targets inevitably demand some form of classification of the targeted objects. Here Europe has yet to align its means of crossing classification. As example, in Germany a relatively complex matrix (table 1 below) is used to relate rail line speed (>80kmh-1), number of tracks, type of road, and road traffic density, to technical protection required and non-technical protection by other measures which may include rail speed restrictions. In France a rather simpler structure was established by government regulation in 1991 (Arrêté du 18 mars 1991 [3]).

This provided for four basic crossing types – two for road use with rail speeds limited to 160kmh-1 or 140kmh-1 respectively, pedestrian only crossings, and private crossings. Application of consistent targets to 25 sets of inconsistent crossing classification systems is just one of the challenges facing the ERA.

Density and kind of road traffic	Main lines and secondary lines with v > 80 km/h (railway)	Secondary lines with v ≤ 80 km/h (railway)	
		More than one track	One track
	Kind of safety protection		
High traffic density	Technical protection	Technical protection	
Moderate traffic density (field and forest ways are excluded)	Technical protection	Technical protection	View on the railway line and acoustic signals from the railway; *otherwise* acoustic signals from the railway and speed restriction (20 km/h) for the railway
Moderate traffic density on field and forest ways	Technical protection	Technical protection	View on the railway line and acoustic signals from the railway; *otherwise* acoustic signals from the railway and speed restriction (60 km/h) for the railway
Low traffic density (field and forest ways are excluded)	Technical protection	View on the railway line	View on the railway line; *otherwise* acoustic signals from the railway and speed restriction (20 km/h) for the railway
Low traffic density on field and forest ways	Technical protection	View on the railway line	View on the railway line; *otherwise* acoustic signals from the railway and speed restriction (60 km/h) for the railway
Foot and bike ways	View on the railway line and passable obstacles (see Fig. 2) *or* acoustic signals from the railway and passable obstacles (see Fig. 2)	View on the railway line *or* acoustic signals from the railway	
Private level crossings without public traffic	If v > 140 km/h: technical protection If v ≤ 140 km/h: acoustic signals from the railway and locked gates, barriers etc. *or* locked gates, barriers etc. and telephone	View on the railway line *or* acoustic signals from the railway and speed restriction (60 km/h) for the railway *or* locked gates, barriers etc. and telephone *or* locked gates, barriers etc.	

Private level crossings with public traffic in harbour and industrial areas with moderate and low traffic density	**Technical protection**	**View on the railway line** ***or*** **locked gates, barriers etc. and speed restriction (20 km/h) for the railway**

Figure 6. Classification of Crossing Types and Protection Requirements – Germany[5].

The ERA process is likely to have little early practical impact as the initial efforts are intended to document pre-existing targets. The ERA approach is described below:

> "Following the requirement of Article 7(3) of the Safety Directive, *the first set of CSTs (Common Safety Targets) shall be based on an examination of existing targets and safety performance in the Member State*. Therefore a survey will be launched at the beginning of the work to identify and collect the necessary information from the Member States and from railway sector organisations, concerning existing safety targets and associated methods for setting targets."

In reality the first CSTs to be adopted by the European Union by 30.04.09 may well not be initially unbundled to the level of system features such as level crossings. As methodologies for CST apportionment have yet to be validated, and as our survey suggests key data to underpin this may simply not be available, it appears that CSTs for level crossings may not emerge until the second set of CSTs is adopted some time after 2010.

Funding for Crossing Investment

The sources and volumes of funding vary substantially between nations. Typical of several environments, funding in Hungary is the responsibility of the party introducing change to the infrastructure. In many states the costs are shared between Infrastructure Manager, highway authorities, and other state or regional government sources, however both extremes are also present. The rail Infrastructure Manager in the USA is 90-100% funded by others while in Sweden and the UK the cost has historically been totally with the Infrastructure Manager.

Cost Benefit Analysis of Investment Options

Various models have been created to assist incremental investment decision-making. RSSB (UK) has focused on international comparison of best practice[13]. In Korea a Bayesian approach to analysis[10] has identified that the top three performing countermeasures there for reducing crashes are in-vehicle warning systems, obstacle detection systems, and constant warning time systems.

Specific analysis has been made[14] of conversion of a UK Automatic Half Barrier crossing to CCTV supervised manually controlled barrier status. This would increase crossing safety for trains as train movement is not signalled until the crossing is proven clear by inspection of CCTV by the signal operator. "The results showed that an expenditure of some £1 million would be required to achieve a safety benefit with an equivalent value of £65,000." The analysis showed that the investment was not justified. Differing analysis may apply when the installation is at end of technical life as differential system installed cost is minimal.

Technical Developments

Several survey respondents felt that research and development on 'cheap bridges' would be the most appropriate use of crossing related funds. Crossing technology was subject to a significant change about 50 years ago with the introduction of automated technical protection systems. Since then the protection systems have been subject to tinkering rather than substantive change. Questions on development that should be pursued indicated this trend would continue – a focus on improved crossing visibility impact on the road approach (USA / Japan), LED replacements for filament lamps (Hungary), electronics to replace relays in control logic (general), more capable forms of obstacle detection (Japan), improvements to supervision and monitoring arrangements (general), use of ERTMS to reduce warning time and to improve safety in the event of crossing system failure (Czech Republic), and even the use of barriers dimensioned to physically prevent violations by determined road users

(Finland) – but no conceptual improvements. Several respondents were specific that further research would be of limited value as the real issue was funding for closure.

The Need for Change
Rail users, particularly at automatic and user worked crossings, are at direct risk on account of the behaviours of road users. It is suggested that 'local users' are most at risk as through frequent usage they form a belief that they can judge the risk to themselves in violating the crossing warnings. Accepted thinking, supported by hard evidence, is that road users are less likely to violate the crossing if closure time is minimised - with times as short as 25s being reported. It is a corollary that in event of actual violation the train generally cannot be protected – which is not a desirable outcome from the view of rail users. In other words we reject the use of 'technically safer' solutions because of the increased risk of deliberate misuse. Could this be an area ripe for general attitudinal change?

Change will come soonest if the 'need for change' is strongly perceived by those who can influence the adoption of the change. A recent UK survey[15] of public attitudes to safety on the railways has shown that concern about level crossings is similar to concern about risk from vandalism and is much lower than concern about infrastructure maintenance / track defects. If the public perceive crossing risk at all, they do so quite differently from how they perceive the risk of terrorism, though in many countries it is of similar statistical significance for public safety. Even major accidents have not produced the level of public concern needed to trigger significant investment in change.

So What Could We Do Differently / What Will Trigger Change?

Today's legal environment acts as a barrier to change both through cumbersome planning / permission processes, and high compensation payments in the case private crossings.

Legislation could play a different role. Legislation could tilt the playing field in a different direction – for example it could require that crossing equipment is not renewed at the end of its life – but that the crossing should be closed, with any replacement bridges funded by the mechanisms used to fund road building. This would set something like a 30 year timescale for removal of all road crossings – with a 'special case' process to resolve the way forward for the most difficult urban centre crossings.

The rapidly escalating costs, to the Infrastructure Manager, of response to 'no win no fee' litigation and to the associated 'compensation culture', present another force for change. Quite simply this cost improves the 'business case' for investment in closure.

Where, for whatever reason, crossings are not to be closed, then it is a task for the rail signalling community to devise technical protection that combines reduced cost and improved protection. Rail investment in communications based train control solutions can be seen as one possible driver of such change.

(1) Potential Impact of ERTMS at Automatic Crossings
Application of ERTMS to the 'Conventional Network' in Europe could be an enabler for new thinking on crossing protection. There is no specific provision of functionality within ERTMS/ETCS at Level 1/2 in relation to level crossing closure times – automatic crossings are substantially independent of the signalling of train movements. However necessary change to those signalling arrangements as a whole to implement the system at level 2 does offer the possibility of requiring train position reporting to the control centre during crossing approach. Movement authority across the crossing could be withheld in the event the crossing is not proven clear – a condition that is not applied at automatic crossings today. An event sequence for an automatic crossing could be:

> *Predicted train arrival time at crossing triggers crossing closure / warning sequence (using non-vital information from control centre), non-vital obstacle detection is activated upon crossing closure, detection of an obstacle or a not closed / safe level crossing prevents release of movement authority across crossing (or causes existing*

movement authority to be revoked). A rail speed-restriction is automatically imposed and enforced in event of relevant detected failure in the technical protection systems

This sequence would increase closure time to that necessary for rail vehicle safety – with the increased time being linked with four quadrant gate arrangements and digital camera enforcement of crossing violations by road users. Penalties pitched far above 'speeding fines' could present one mechanism to increase public sensitivity to the applicable risks.
The increase in delay time may equally act to increase public support for those crossing closures where bridge replacement could be reasonably considered – a potential win / win situation for user safety.
It has to be emphasised that increase of closure times is not 'conventional wisdom' as levels of crossing violation increase with increased closure time and to date have forced adoption of the shortest possible crossing closure times. Here the question being posed is whether this is something that should be accepted despite the risk to rail traffic or is it an area where the industry and safety regulators are prepared to challenge user attitudes to achieve change?

(2) Potential impact of CBTC / PTC at Automatic Crossings
Where long/heavy trains are the norm, as in the USA, there is no expectation of being able to "Protect" the public from an approaching train. The carefully chosen term is to "Warn" of an approaching train. No specific train signals govern the train's approach to the level crossing. Due to the very long stopping distances of the trains this is seen as impractical. Highway users are expected to comply with warning systems. In this environment where a constant warning time is seen as critical, at best CBTC / PTC can mitigate the consequences of crossing misuse. This is recognised in the applicable standard which provides, at the selection of the relevant authorities, for the system to "interface to grade-crossing warning devices to permit control of such devices based on (train) location reports and to co-ordinate movement authorities through the crossing based on the status from such devices".

(3) Potential impact of ERTMS or PTC at User Worked Crossings
Considered from the viewpoint of the railway technical systems, there is little difference between protection of a crossing movement at a user-worked crossing, and protection of a work-gang at a railway work site during service operational hours. In each case a 'possession' of the line is needed to assure safe separation from train movements.

So the question to be asked is "*why cannot a work gang 'Mobile Protection Terminal' be adapted to use in crossing protection?*" The principal challenge is the production of an intuitive and minimalist user interface not dissimilar from that at pedestrian road crossings such that user familiarisation requirements are minimised.

The material components of such a system are relatively inexpensive so implementation would substantially depend upon avoidance / minimisation of site-specific attributes in the overall system design.

Conclusions
Crossing incidents continue to present a treatable risk to dependable and safe rail system operation. In essence our systems are adequately safe as long as there are no users to improperly use them, but generally detection rates for misuse are very low and penalties an exception not a norm.

This suggests a three-track approach to delivery of change.

- Use of ERTMS/PTC introduction as the trigger to enhance technical protection of the train (and road users) against detected crossing malfunction or violation.

- Extended closure times associated with full barrier crossings and/or application of an efficient misuse detection/deterrent penalty regime acting to reinforce both public awareness of the importance of the issue for public safety, and public arguments for permanent closures.

- o A co-ordinated technical/information campaign to establish 'a presumption of closure instead of renewal' as both best practice and the legal norm in each country.

Is the industry ready to campaign?

Abbreviations

ALARP	As Low As Reasonably Practical (in relation to risk)
CBTC / PTC	Communications Based Train Control / Positive Train Control – Both terms are used in the US market place with the term CBTC being commonly associated with metro applications.
CCTV	Closed Circuit Television
CST	Common Safety Targets
ERA	European Rail Agency
ERTMS	European Rail Traffic Management System (This term is used generally including in places where the term ETCS – European Train Control System – could be technically appropriate)
FRA	Federal Railroad Authority
LED	Light Emitting Diode
PTC	Positive Train Control
RSSB	Rail Safety & Standards Board (UK)
SIL	Safety Integrity Level
US DOT	United States Department of Transportation

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