The Institution of Railway Signal Engineers Inc

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Human Factors at Level Crossings

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SUMMARY

Today's railway fatalities are arguably more likely to occur at level crossings than in the train collisions we tend to focus most attention on controlling. Designing for level crossing safety can be messy and grey, especially when the dependence on the behaviour of people, members of the general public, is taken into account.

AS 7658 provides guidance on the minimum warning time applicable for a crossing. It also provides guidance on the maximum warning time applicable unless no practicable means exists to reduce it.

In my experience, the guidance on maximum warning time appears less well understood by designers than that concerning minimum warning times. Some would like to ignore it.

This paper will briefly review the behaviours model which forms the basis for the minimum warning time requirement. It will then look at how excessive warning times (based on AS 7658 threshold) can lead to unsafe outcomes.

Two illustrative level crossing cases will be presented (one for pedestrians and one for road vehicles) demonstrating the reality of reduced safety from excessive operation.

The importance of context and the crossing user's expectations in determining safe outcomes is discussed. An illustrative example from the world of cricket will be provided.

An historic case will be looked at where a number of fatalities occurred at a particular crossing at a rate of around 1 every 3 years up till when it was finally grade separated. An additional incident happened at an adjacent crossing. Both crossings have since been grade separated, but there are too many level crossings to grade separate all of them within the lifetime of even the youngest of our members.

Design associated with level crossings (to allow for all operations and behaviours at each location) can be quite complex when the need to avoid excessive ring times is included as a requirement; but worthwhile. Safety requires warning times to be optimised, not maximised.

1 Introduction

Travelling by train has long been recognised as one of the safest forms of travel available for the traveller. Even better, as knowledge and technology has improved, we have seen continual reductions in accident rates over the years. RTC Rolt writing in 1955 makes much of the contribution of "Lock and Block" to delivering those safe outcomes, but no railway would be accepted as adequately safe today based just on that technology.

Travel by car is not as safe.

However, if we look at road safety by itself we see similar downward trends in fatality rates at intersections over the same time span of years. Improved technologies and implementation of design changes (often evidence based human factors improvements) to both road intersections and road vehicle designs have made that possible.

But there is one part of our railway system where that continual downwards trend seems to be absent and fatality rates remain stubbornly high. That area is level crossings. Railway level crossings (including pedestrian crossings, on a per crossing/intersection basis) are today arguably some of the least safe parts of our road or rail network.

In our toolbox we identify "grade separation" as the preferred treatment to reduce that risk. But there are too many crossings and the cost is too high to grade separate them all within the lifetime of even today's youngest signal engineer.

Projects to activate level crossing protection at passive crossings or modify the protection at currently activated level crossings remain important scopes in current railway signalling projects. Evidence based designs are required ensure the risk to road vehicles and pedestrians at each of those crossings is minimised by those projects.

This paper is provided to contribute to safe crossing designs.

In particular, the issue of excessive warning time is looked at. The data presented suggests that a crossing suffering from excessive warning may be around 8 times less safe compared with the average risk for the average crossing. This increase in risk can be explained by observing the Human Factors aspects of people using the level crossings involved.

The Standards, based on work carried out in the 1960's, deliver safe crossings to a base level. The more recent trend to design crossings with substantially increased warning times does not appear to be sufficiently evidence based. The evidence appears to suggest that increasing warning time to the extent that it can be categorised as excessive can increase risk rather than reducing it.

The crossings I have typically observed which could be termed "excessive" routinely provide 90 - 120s warning before the train arrives at the crossing. Signal designs which provide such outcomes seem quite common, in spite of our Signalling Standards warning against them.

2 The Standards

Through the course of recent years the comment has been made to me by some influential signal designers that whilst the Signal standards specify a minimum warning time for a Level Crossing they do not specify a maximum warning time. As such the "safe" option is always, when there is any element of doubt, to add seconds to the design approach times.

As it turns out, the evidence does not appear to support that approach. Design of Level Crossing warning for optimum safety often requires multiple potentially conflicting factors to be weighed and appropriately taken into account.

The following provisions may be found in AS7658:

Clause B.1 states:

> "The design of an active level crossing shall use a calculated minimum warning time that evaluates the following timing factors at the particular level crossing:"

Subclause (a) then goes on to state:

> "The minimum warning time between the commencement of the level or pedestrian crossing activation and arrival at the level or pedestrian crossing of the fastest train shall be 20 seconds."

Clause B.1 then further goes on to state:

> "Where reasonably practicable, the design warning time should not exceed 50 seconds."

Whilst it is true that the standards set out minimum warning times, these "minimums" can be seen to be "calculated" design minimums based on a set of design assumptions.

It is also not true that no maximum warning time is specified – AS7658 does provide that.

For actual level crossing designs the provisions of this National Standard are then overlaid with State based standards which generally specify a minimum warning time around 25s.

Thus the requirement in accordance with the Standard is that the design warning time is constrained with both minimum and maximum values. It should be said that although the current version of AS7658 is dated 2020 this dual requirement is not new to our profession. When I commenced design as an Engineer in the Level Crossing Section in the Victorian Railways in 1981 (in the days before our standards were written down) I was made aware very early on of the requirement to respect the equivalent of a 50s design maximum warning threshold.

This was the reason, I was told, for the inclusion of Express Stopper selection in new designs for suburban level crossings. It was also one of the reasons why, around 3 years later, the first constant warning time Level Crossing controllers (aka Predictors) were introduced onto our country network.

Since that time it appears that respect has been lost for the specified upper threshold of the design warning time. This has occurred to such an extent that it has been put to me recently by some quite senior design staff that Engineering Compliance is achieved just by looking at the lower required band. The upper required limit is a mere "nice to have", I was told, which the Rail Operator can safely agree to forego.

There has been expressed a view that there are no safety risks worth considering associated with exceeding this maximum; that any such risks can be effectively controlled by simply enforcing compliance. If the bells and lights are operating, any accident is the road (or footpath) user's fault. We need look no further.

The purpose of this paper is to provide some balance to that view.

I will show how "excessive operation" can be seen as a causal factor contributing to fatalities seen on our rail networks today. Since level crossing fatalities comprise the highest number of fatalities seen on our network, these are matters which should be taken more seriously by the Signal Engineering Profession than currently seems to be the case.

3 Human Factors

Human Factors issues are important to the safety of level crossings. However the number of accidents available to study in this regard remains low.

In order to establish a framework for understanding the contribution by Human Factors, we will look first at an analogous endeavour where similar issues can be seen, but where "accident" rates are much higher. We will look at Cricket.

3.1 Cricket

There are few things which raise levels of excitement higher than the first day of a Boxing Day test in Melbourne. Yet are those too who find it boring, describing as no more than practical exercise in applied statistics (this from a colleague from years ago), slightly ahead of watching paint dry.

I recall attending one match some years ago against India with Australia bowling. Australia took 3 wickets in the opening session, the peak of excitement. Of those 3, I actually only saw 2 with my own eyes (being before the days of big screens and instant replays) due to some social distraction in the moment.

The similarities with rail safety are many, and in sport human factors are paramount. No batsman faces the ball with the expectation of going out. And at test cricket level, regardless of the circumstances, the batsman is right in that expectation the majority of the time. It is much more likely that runs will be made from a ball than that the batsman will go out. Sometimes (as I saw Bob Simpson and Bill Lawrie do once on opening for Victoria) a partnership can stay intact for just about the whole day. But then there will be just one ball where something unintended (from the batsman's point of view) happens and a batsman will be out.

Thinking of the analogy with the rail context and that unintended occurrence would be the accident.

Now we can imagine the risk based investigation into the batsman’s dismissal. The ball delivery and pitch will be analysed in detail together with the batsman’s response. What were the slips and errors? Was there any departure from standard (“No ball” was not called, the weather was sunny)? Batsman error (“he didn’t get properly to the pitch of the ball”) will be the likely finding if the scope of the study is limited to just the dismissal delivery.

We can imagine the equivalent rail investigation for a level crossing accident. The logs of the actual incident with train are dissected and analysed in detail, the replays viewed when available. The bells and booms were operating to standard when the train reached the crossing, nothing about that to report. Road user error is commonly the cause found.

But such an analysis only gives half the story. Both investigations would be inadequate in identifying the root cause for the same reason.

To see why that is we need to look at the other end of the pitch and observe the bowler. We will consider Shane Warne (perhaps the greatest bowler of his generation), who set out his thoughts on his own contribution to all of the above in his autobiography[1]. He describes his process:

> “The art of leg-spin is creating something that is not really there. It is a magic trick, surrounded by mystery, aura and fear. [The batsman must think about] what is coming and how will it get there? At what speed, trajectory and with what sound, because when correctly released, the ball fizzes like electricity on a wire! How much flight, swerve, dip and spin and which way? Where will it land and what will happen?
>
> “... Leg-spinners cannot create physical fear, in the way fast bowlers can, so they look to confuse and deceive. The intimidation factor in spin bowling comes from a batsman's ignorance and consequent fear of embarrassment.”

Shane then goes on to talk about the need for patience.

> “Richie Benaud taught me something interesting that I've passed on to a lot of the young kids who tell me they struggle to take wickets regularly. 'Hey, Warney, I bowled 15 overs the other day and only got one wicket,' they say. I ask them if they think I was any good and they say, 'Yeah, you're the best!' Nice. Okay, how many balls do you reckon it took me to get a wicket? 'Oh I don't know, you probably got one every two or three overs.' No, I got one every nine to 10 overs - every 57.4 balls to be exact. Murali and all the other guys are around the same, nine to 10 overs to get a wicket. The message is that patience is very, very important to spinners.”

And then after all that preparation and patience we get the case study, a single ball:

> “The Gatting ball is a rare thing because usually it takes time to nail a good player, especially if he's already settled when you first come on to bowl. You kind of have to stalk him and then set him up. If a guy is a good sweeper, your line has to be outside off-stump, spinning away, with six fielders on the off-side, and your length has to be fullish so he feels compelled to cover drive instead. By starving him of an easy ball to sweep, you challenge him to fetch it from dangerously wide of his go-to zone, and then, when you sense the frustration is eating away at him, you bowl faster and straighter, saying, 'There's the line you're looking for, mate, go for it.' I've hit the stumps and the pads more than a few times with a straightforward plan like that.”

The point here is that the actual ball which gets the bowler out, Shane says, is often pretty ordinary in its pace, pitch and spin. Sometimes there will be no spin. Your average weekend Pennant player could happily bowl the same all afternoon and never get anyone out. It is only when Shane Warne does it that it as part of his strategy that it becomes truly dangerous.

To fully understand the accident event (the batsman going out), the analysis needs to take in more than just the dismissal ball in isolation. You need to look at Shane’s strategy in the lead up, the mind games of concealment and surprise (the “Gatting ball” left as a topic for research). The “human factors” analysis would look beyond the bland facts of the ball itself to consider the batsman’s expectations of that ball created by the bowler’s mind games which played out in the preceding overs. Only then will the bowler be identified as an important contributing factor to the dismissal in spite of the fact of that pedestrian ball that finally got him out.

Consider now the level crossing accident. The now deceased person did not enter the crossing with the expectation of being hit by the train. What were his/her expectations and what was the basis of them? We can quickly establish that the bells and lights were operating and the minimum warning time was provided. But what about Shane Warne’s contribution?

To understand why the accident happened the Human Factors need to be analysed as well. The context of the incident investigation needs to include more than just the single accident event itself. What did the public expect from this particular level crossing? What was its reputation? How long did the train usually take to arrive? How did its typical performance over time measure up not just against the requirement for minimum warning time, but also against standards associated with excessive operation?

For a Level Crossing to have minimum risk, we ideally don’t want Shane Warne to be there (in spirit) at all. The crossing is safest when we have that weekend social player who’s just going to send the same ball down every time without ever taking a wicket. Our safest crossing would be one providing consistent minimum standard warning time for every train.

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[1] Shane Warne (2018). “No Spin”

3.2 Rail Cases

In the above section we saw that Shane Warne was able to articulate a couple of the mechanisms (referred to as "bowling strategies") that he was able to use to raise the risk of a bowler going out from a base of perhaps one in 30 overs up to around one in 10. An increase by a factor of around 3.

Similarly for a level crossing we can articulate a couple of the mechanisms which enable the observed increase in risk at level crossings based on consistently excessive warning times (where that is what is provided by the designer). Evidence will be shown that a risk increase from a base of perhaps one fatality in 25 years up to a risk of around one in 3 can occur (based on our historic case).

3.3 Case 1: Road vehicle operating across level crossing - the case of the ambulance

I do not get out much when in Adelaide, but I do remember one occasion not long ago when I observed an ambulance running around some lowered boom barriers with its lights flashing and its sirens going. That I was able to observe this occurring establishes that the risk is more than just theoretical; and suggests it is probably quite common.

What is the perceived risk equation for the ambulance driver in driving around the booms?

There are a number of situations where ambulances are called to attend to situations where the emergency is time critical. At the top of this list is perhaps where the patient is having difficulty breathing. My wife suffered an incident of this type many years ago. The window to take action is very small compared to the operating time for a level crossing. CPR and defribulators are of no assistance and a delay of a couple of minutes in the ambulance arriving can be the difference between life and death.

Whilst it is quite unlikely that a signalling engineer will ever be held responsible for any contribution in an individual case of this type, in the larger sense of controlling society's risk, cases like this are legitimate to consider when determining measures which improve safety.

One day it may be your own wife or loved one on the wrong side of that level crossing.

A quantified scenario

To determine the impact of excessive operation for this scenario it is useful to use a parameter used by the Roads Department for this purpose – the level crossing percentage operation time. This is a parameter which can be readily measured. For the Victorian case a level crossing in peak hour may be expected to have a percentage operation around 30%. When the crossing is impacted by excessive operation issues, that figure becomes closer to 50%.

Considering now the case of an ambulance needing to cross at a level crossing to attend an emergency, in 20% of cases (50% minus 30% - taking the above proportions in the absence of specific data we'd be able to obtain for each crossing in Adelaide) the ambulance will find itself stopped at the crossing in a case where it would not have been stopped had the design avoided having the outcome of excessive operation.

We may estimate that in one case per month (again better data would be available using historic records for each crossing and case) the ambulance will need to cross the crossing to attend a case which is time critical in the terms discussed above.

Based on these numbers on average on 1 occasion each 5 months an ambulance will find itself stopped due to the operation of a level crossing in a situation where the crossing would not be operating if the alternate approach to design had been taken.

The ambulance driver must make a choice between 2 ways forward:.

Option 1: Wait for the booms to lift

> For the incident scenario described here the expected outcome would be that the patient would die. The delay of (say) "couple of minutes" would likely cause the lack of oxygen to become fatal.
>
> Converting this to an overall fatality rate, the outcome would be that there would be approximately 2 additional fatalities per year associated with the excessive operation.
>
> It should be noted that this is an addition to a situation where there is already a couple of unavoidable such fatalities per year associated with operation of level crossings, even with optimised operation (grade separation could correct that).

Option 2: Run around the booms against the flashing light warnings

> For the incident scenario the expected outcome would be that the patient would be reached in time and likely survive.
>
> However there is also a risk that a train will collide with the ambulance as it attempts to cross at the level crossing.
>
> In Victoria this general scenario (collision between train and emergency vehicle) caused the death of 2 policemen at North Rd some years ago. Emergency vehicles no longer run around boom barriers in Victoria.
>
> I know of no similar incidents in South Australia. But it is in the nature of risk that, with the policy settings in place (that emergency vehicle run around boom barriers) this is just a matter of time.

This is just one safety risk scenario. It can be seen that the outcome is around 2 deaths per year. More precise figures can be obtained by extracting suitable historic data from relevant authorities, but the risk described is a valid safety risk.

Neither of these options is desirable. However, at design stage there exists a third option in line with the standards.

Option 3: Design the crossing operation to avoid excessive operation

> For the incident scenario the lights and booms will not have commenced operation yet when the ambulance arrives at the crossing (since the ambulance arrives less than 2 minutes prior

> to the train arriving, but prior to half a minute prior).
>
> In this case the ambulance will cross at the level crossing without incident and without risk.

Option 3 is clearly the minimum risk scenario. It should be adopted.

Case 2: Pedestrians utilising level crossing

To catch the up train at a station with side platforms adjacent to a level crossing, some school children are required to use the down end pedestrian crossing to cross both tracks.

Up trains can on occasion be held for some time at the previous station (which the designer has unnecessarily included as part of the holding section). Typical reasons for a long station stop can include (a) in peak period station stops can be longer than those allowed in the standard due to the volume of passengers, (b) the need for wheelchair passengers to board or exit the train (both can be required at the same station stop, and the pattern can be regular for regular passengers), (c) the train arrived a little early at the station and must wait a minute or two for the scheduled departure time.

A pattern can be created where the school children wait at the pedestrian crossing for a down train to depart then, because the up train they are planning to board is stopped at the previous station inside the designer's calculated (unnecessarily long) holding section performing one or more of the duties set out above, the gates remain closed. In this situation the gates can be closed for a number of minutes with no train approaching. The schoolchildren can become habituated to this fact. The outcome is that they will miss their train because the gates will not open again until after the up train has passed the crossing.

Being habituated to the situation where the up train takes a number of minutes to arrive, the schoolchildren will have an incentive to try to bypass the closed gates. Being inventive they will likely succeed and, 999 times out of 1000 catch their train (even in the face of measures such as gate locks).

On that 1 time in 1000, the up train will not be waiting at Noarlunga platform but on the approach to the crossing (obscured from view temporarily by the down train which has just passed). A child will cross the tracks in the habitual way and be hit by the up train.

The alternative scenario

Where the holding section "recommended" by standards is used, the holding section is shorter, not stretching back as far as the previous station's platform.

In this case, the gates (following sequence of events set out in the risk scenario) will open after the down train and whilst the up train is performing its duties in the previous station's platform. They will be waiting safely on the up platform of their own station when the up train arrives.

In the cases where the gates do not open after the down train has passed, they will be habituated to the fact that the up train is then upon them almost immediately and there is no chance to attempt to cross safely. The cases will be far fewer and the habituation will match the danger of the situation.

This scenario is safer than that provided by extending the holding section back into the approach station's platform.

Case 3: Centre Rd, Bentleigh

Bentleigh is a suburban station in Melbourne. It was converted to a 3 track configuration in 1987 with pedestrian access between platforms by a pedestrian underpass or by a gate protected at grade crossing (2 tracks maximum protected by each gate pair connecting platforms).

The crossings in this section were known for their long operating times. I was Engineering Maintenance Manager in the early 1990's and conducted/oversaw more than one review. Findings included:

- Slow running trains due to congestion in the 3 track section on approach to junctions at each end;
- An intermittent/recurring fault which had the effect of causing large numbers of scheduled stopping trains to be signalled as express trains for the purpose of crossing operation.

It is expected that both of these factors remained present at various times right up to the time when grade separation finally occurred.

In late 1990's the pedestrian underpass was closed due to because of concerns about safety and flooding.

Over the next period there followed a number of accidents, including the following, involving deaths of pedestrians[2] :

23 March 1998

> During the morning peak an 18 year old lad ran across the boom gates to get a train, and didn't realise there was a train (8:01 a.m. up City Loop) coming in the opposite direction. He was hit and killed by this train. This case mirrors the scenario presented in case 2 above.

18 November 2004

> Alana Nobbs, a 15-year-old who attended a local high school got off the train and was crossing the tracks at Bentleigh Railway Station when she was hit by the city-bound express.
>
> The girl died at the scene.
>
> Police say the boom gates were down.
>
> AAP reported she was one of three people killed on the crossing in six years
>
> A 2006 inquest into her death heard she had been walking to meet friends on the station platform before school when she pushed through a pedestrian safety barrier at the level crossing and was struck by a train.

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[2] These reports are compiled from contemporary Newspaper and other public reports.

10 February 2011

> A woman hit by a city-bound express train at Bentleigh was reported to be the fourth pedestrian to be killed at that level crossing since 1998.
>
> The woman, aged between 40 and 50, was crossing the tracks at Centre Road around 8:45am when she was struck by the city-bound train. Police believe she was killed instantly.
>
> A man believed to be her husband witnessed the collision, which onlookers said happened as the pair attempted to cross the tracks while the boom gates were down and warning lights were flashing. It was reported that the woman's husband had already crossed the train line and was waiting for her on the other side.

1 April 2014

> POLICE appealed for witnesses after a man was hit and killed by a train.
>
> He was struck by a city-bound train near Bentleigh Railway Station at around 7.15pm.
>
> It appeared he was attempting to cross at the level crossing on Centre Road when he was hit, police reported.

In 1990s there was an additional nearby case involving a vehicle accident at North Rd level crossing Ormond (same line section as Bentleigh). This involved a police car attending a crime (sirens operating) which attempted to run around the boom barriers at North Rd and collided with a train. 2 Police Officers were killed. This instance mirrored Case 1 above.

There are no more recent reports of level crossing fatalities at these level crossings since they were grade separated in early 2016.

In this extract of actual fatalities at a particular crossing it can be seen that the specific risks raised in cases 1 & 2 are more than just theoretical. They are cited as having actually occurred in the historic incidents.

The level of increased risk caused by the crossing configuration and operation can also be estimated. A report presented by ARRB in 1990 presents level crossing accident statistics for the period since 1975. That data shows an average pedestrian fatality rate at level crossings protected by boom barriers as approximately 1 per crossing per 25 years.

Based on the accident record for Centre Rd Bentleigh, its pedestrian fatality rate through that period was around 1 per 3 years. This is evidence of an 8 fold increase in risk of fatality for this crossing compared with the average for the network. Whilst there may be multiple contributing factors to the risk profile for an individual level crossing, long warning times (per AS7658 B.1) was one which was present at Bentleigh through this period.

3.4 Why are long warning times accepted?

Our approach to implementing safety is required to be evidence based. We can see in the previous sections the evidence that excessive warning times increase risk. We can see that there are Human Factors mechanisms which explain how excessive warning times cause that increased risk. We see that some of those specific mechanisms were observed happening in actual fatality events at Bentleigh. We have a statement in our Australian Standards (AS7658 B.1) which states that designs must avoid providing excessive warning times to the extent reasonably practicable.

Yet in my experience the dangers of excessive warning are not well understood by our suppliers or our rail authorities. The standards designed to avoid excessive warning are treated as optional extras which can be ignored based on a risk assessment process involving just a meeting. Then in the risk assessment process the risks are routinely excluded or downplayed. Why are the standards designed to avoid excessive warning times treated as optional? Why are the risks associated with excessive warning times downplayed or denied?

One reason given by suppliers is that it is the minimum warning times clauses in the standards are the only ones which are important. They need to be treated as mandatory and a comfortable extra margin is routinely added “to be safe”. Provision of the comfortable margin is said to take absolute precedence over any standards related to avoiding excessive warning times.

> What does the evidence say about this?

We have reviewed the evidence showing how excessive warning can cause increased risk. What is the evidence in that same space concerning designed minimum warning times?

4 Minimum Warning Time

Work to establish design parameters for minimum warning occurred in the 1960s.

Level Crossing required warning times were defined based on a physical model of track and vehicle dimensions together with vehicle behaviours. The road vehicle can stop quickly from that speed, within around 1s and 2m.

The standard road vehicle has maximum length of 20m (66 ft or 1 chain) and can sustain a minimum speed of 3m/s. This is approximately 10kph or 6mph.

The standard crossing is taken to have width of 10m.

If the vehicle is just entering the crossing when warnings commence, the vehicle will be clear of the entry zone (where the booms will descend) within 7s. This parameter is important since it determines when in the cycle the booms can commence descending without fouling the space occupied by the vehicle and sustaining damage. The minimum pre-warning time is thus established.

Note that the adequacy of his dimension and the assumptions around it are tested on a daily basis in the form of boom damage rates.

Having fully entered the crossing the vehicle is fully clear of the crossing in a further 4s.

Thus the total minimum warning time for the vehicle to be clear of the crossing is 12s. In determining this base it can be further noted that the vehicle covers 12m (rather than 10m) in the 4s, or 15m if it is recognised that there were actually 5s available (after the initial 7s prewarning) available for the final crossing (of the rear of the vehicle) to occur.

Having established the minimum 12s, an engineering margin was added for safety.

In the US (AREMA) this margin was set at 2/3 (67%) to give a required minimum design warning time of 20s. This same number is seen in AS7658.

In the UK there was an additional consideration to be included. Relevant legislation requires that the railway be fenced. For level crossings a fence obviously be placed across the road all the time, but it can be so placed for the approach of a train.

In the case of interlocked manual gates there are 4 quadrants which fully enclose the railway when open for rail traffic (closed to road traffic).

Automatic half barriers were always considered a compromise against this requirement, so provision was provided in the operational sequence for additional barriers to close across the exit portion of the roadway before the train arrives.

Roughly the required sequence became 8s prewarning followed by 8s entry barriers descending followed by 8s exit side barriers descending (all road vehicles required to be fully clear of the crossing area within 16s of warnings commencing – again tested on a daily basis by rates of boom damage). A total 24s was thus required with 1s for calculation to give 25s.

This 25s translates to a 100% engineering margin for safety. In Australia there is no similar legislative requirement to fence the railway, so we are free of this additional English constraint.

Over the more than 50 years since the standards were developed there has been ample opportunity to evaluate and ask whether there is a difference in safety outcomes from adopting the 20s minimum warning vs adopting the 25s minimum warning.

I have been unable to find any study which concludes that safety outcomes are improved by requiring 25s minimum warning rather than the 20s alternative. Comparing level crossing risk between jurisdictions (US vs Australia for instance) does not appear to provide that evidence. We would expect to find increased accident and fatality rates for the US and we do not seem to. Rather the trend in the US has been towards providing Constant Warning (crossing predictors) which put emphasis on consistent warning times at the 20s level rather than longer warning times.

If there were a material difference in risk for a crossing providing 20s warning compared with one providing 25s warning we would expect to be able to identify some safety scenario mechanism which explains the difference (as the human factors argument presented earlier explains the increased risk for the 50s case).

For the standard vehicle slowly crossing the standard crossing the crossing is safe of collision risk after 12s. The additional time provided above that level represents margin provided by the standards.

Looking at the record of historic accidents it is possible to see other behaviours (eg car stalling of traffic banking up) and make a judgement whether the 13s margin provides better safety outcomes compared to the 8s margin. A US study[3] occurred which in effect did this, made various recommendations, but did not suggest that increased warning times would provide safer outcomes.

The study did look at practical precursors to accidents (eg vehicle stalled on line for extended time) and recommended various mitigating measures. These included elimination of the legislative requirement for vehicles to stop at every level crossing before crossing regardless of whether the warning devices are operating, but no recommendation to increase minimum warning time.

In the UK following the accident at Hixon[4] in 1968 there was an increase in the safety margin from 100% to 167% (32s minimum warning time) but this change was subsequently reversed following a study[5] in 1978 which concluded that the resultant minimum warning time was too large.

The picture we are left with from the studies is that achieving an optimum consistent warning time is the objective for lowest risk outcomes.

5 Conclusion – The Balance of Risks

Providing optimum warning involves balancing the risks of inadequate warning times against the risk of the warning time being excessive. Practical design warning times must fit in the window between those two levels.

Downplaying or simply ignoring the importance of the upper threshold has never been the right approach.

Human factors issues have always been considered important to the design of level crossings. In the evidence provided to the Hixon enquiry BR Engineers stated reasons for avoiding excessive operation. In practice in Melbourne in 1970s and 1980s it was a requirement of the design office to avoid providing designs where the design warning time was more than double the required minimum warning time (50s for boom barrier protected locations).

This design requirement at that time drove the need for express/stopper selection, selective approaches based on approach route speed, and later the adoption of constant warning crossing predictors for operation of warning times.

Thus can be seen the engineering bases for various of the design requirements now found in AS7658.

Practical level crossings which have failed to adequately account for the need to avoid excessive warning times can be observed in service on our railways today. These routinely have calculated minimum warnings for the affected train pattern in the 90s – 120s range. When measurements are taken of their in-service performance,

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[3] National Cooperative Highway Research Program (1968). Report 50. Factors Influencing Safety At Highway-Rail Grade Crossings

[4] Ministry of Transport (1968). Report of the Public Inquiry into the Accident at Hixon Level crossing on January 6th 1960

[5] Department of Transport (1978). Report on Level Crossing Protection

outcomes are often even worse. 180s operating time is not uncommon and 240s routinely reached.

The data suggests that the accident risk for such crossings can be around 8 times higher compared with crossings providing standard consistent warning times.

At the other end of the scale minimum warning times for the fastest train are rarely measured less than 20% above that calculated required by the standard. The standard itself provides an engineered margin for safety determined to be adequate by the framers of the standard. When the designer then adds an extra margin on top, that decision should be based on evidence that the extra warning time reduces risk at the crossing. This evidence does not appear to be available, although the evidence concerning the increased risk is.

The current trend for ever increasing design warning times does not appear to be evidence based. The risks associated with excessive warning times are not being adequately controlled.

6 Afterword

Between completion of this paper and preparation of the slide pack, I obtained a copy of Mark Aldrich's most recent book[6] (a follow up to "Death Rode the Rails" which brings his study of US rail safety into the modern era) and, following up his references, encountered a rich vein of NTSB LX accident reports produced in the US through the 1960s and 1970s. Mark points out that the rail industry and its suppliers have strong economic incentives to blame the victims of accidents. The independent professions (represented by the NTSB in this case) do not legitimately have those same incentives, and so the discussions in the NTSB reports are refreshing.

The LX accident at Plant City, Florida on 2 October 1977[7] killed 10 people. This compared with the 11 people killed at the more studied Hixon LX accident 3 months later.

Prior to this accident there had been 4 previous accidents (2 killed and 2 injured in total) at the same crossing over a 6 year period. It was identified as a classic "Shane Warne" crossing. Passenger trains travelling at 70mph (warning time 27.4s) were mixed with much more common but much slower freight trains (typical warning time 1.5 minutes). But this Plant City LX accident was not thought of as an isolated event and the report quotes a study from California from 10 years earlier:

> "There are many grade crossings where railroad operating conditions cause wide variation in signal warning times, false warnings, and unclear and misleading warnings. This results in motorists becoming excessively familiar with low-risk conditions that may change quickly, creating a 'booby-trap' situation."

The report goes on to analyse the accident performance of level crossings (standard protection was via provision of flashing lights) in Florida, comparing the "Shane Warne" types with those with consistent warning times. It found that accident numbers were 12 times higher for the "Shane Warne" types compared with the others.

The report then went on to evaluate the benefits of upgrading crossings to Boom Barrier protection (based on the program in place for doing that). It found that accident risk (based on actual accident rates) was reduced by 35% by this provision.

Boom Barriers were thus found to be an effective control, but not nearly effective enough to offset the risks imposed by the "Shane Warne" crossings. Hence the relevant NTSB recommendation:

> "Insure that the improvement plans for upgrading the Turkey Creek Road railroad/highway grade crossing, as well as all crossings on the 240 miles of track between Jacksonville and Tampa, Florida, include provisions for uniform warning times for various train speeds in conformity with the American Association of Railroads and the Federal Highway Administration guidelines."

This accident and its report represent just one data point in a decade filled with similar accidents and NTSB reports across the US. Subsequently, constant warning technology was developed and rolled out starting in the 1980s; Express Stopper selection standards and methods from the 1970s.

Since then Shane Warne has come and gone, whilst this important part of the history of rail safety and its lessons have apparently been almost entirely forgotten by the current generation of Australian Signal Engineers.

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[6] Aldrich, Mark (2018). "Back on Track: American Railroad Accidents and Safety, 1965-2015."

[7] National Transportation Safety Board (1978). Report NTSB-RHR-78-2 Seaboard Coast Line/Amtrack Passenger Train/Pickup Truck Collision Plant City, Florida, October 2, 1977.

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