



# International Railway Safety Conference 2007 Goa, India

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**Emerging trends on mitigation of Third party Hazards**

Title of Paper:

**Traffic moment at level crossings: when busy crossings can be safer**

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## DEVELOPMENT OF THE CONTRIBUTION

### Abstract

*A major new level crossing risk model (the All Level Crossing Risk Model or ALCRM) funded jointly by Network Rail and the Rail Safety and Standards Board was launched earlier in 2007. The ALCRM, the functional specification for which was written by Arthur D. Little, incorporates a number of new concepts that had not been previously considered during the assessment of level crossing risk in Great Britain (GB), including consideration of how traffic density influences vehicle driver behaviour and the opportunities for collision with the train that may result.*

*The overall principle – building on that first introduced by Professor P F Stott in his work reviewing the safety of automatic open crossings<sup>[1]</sup> – is that likelihood of an accident increases with traffic flow. However, as traffic flow reaches high levels, driver behaviour is conditioned less by the level crossing protection, and more by the vehicle ahead. This means that at busy crossings relatively few motorists actually respond to the crossing equipment and the majority stop behind the vehicle ahead, as in normal driving. The opportunity for a collision with a train may therefore actually decrease at higher traffic flows.*

*Use of this theory within the ALCRM has caused a significant re-appraisal of which are the 'highest-risk' level crossings in GB. Some crossings are now shown by the ALCRM to be relatively higher risk than previously thought, while other more busy crossings may actually be safer - changes that appear to agree with anecdotal evidence on the pattern of fatalities and serious injuries at these crossings.*

*Once validated, these changes will have important implications for future spending on level crossing safety in GB.*



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### Summary

This paper concentrates on level crossing utilisation, an important factor that influences the opportunity for collisions between trains and level crossing users, and considers some new approaches to calculating traffic moment from level crossing utilisation that are likely to have a significant effect on the overall risk at a given crossing.

The paper begins by introducing the hierarchy of level crossing protection in Great Britain (GB), from small passive crossings on private land to manually-operated public crossings operated on the busiest public roads that provide full separation of the railway from the road. The paper then gives a brief history of level crossing modernisation in GB over the last 50 years and discusses the introduction of automatic crossings. Whilst this programme has significantly reduced the disruption to road users (given the shorter operational cycle of automatic crossings) and reduced operating costs, it is generally acknowledged that their use can introduce different hazards to the user interactions that occur at level crossings.

The paper continues by discussing briefly the distribution of level crossing risk amongst the different level crossing types, and explains how risk tends to be concentrated at a relatively small number of level crossings rather than be evenly dispersed. Traffic moment (the product of the number of trains and number of level crossing users) has an important role to play in this distribution of total network risk.

The paper then provides an overview of a linear relationship between traffic moment and collision frequency that has been used by a number of level crossing risk models within Europe to predict the opportunity for collisions at a given crossing.

The approach is contrasted with a non-linear approach that has been adopted in recent work to determine traffic moment at busy crossings. This new approach considers the more complex interactions between users and level crossings as the level of traffic reaches high levels and users begin to queue to use the crossing. This approach is used in the new All Level Crossing Risk Model (ALCRM), commissioned by the Rail Safety and Standards Board and implemented by Network Rail. Anecdotal evidence from the ALCRM suggests that this non-linear approach will strongly influence the overall risk at some level crossings, and the paper concludes by illustrating these differences with some example data.

### Introduction

There are around 8,300 level crossings on the British network. The risks to users (and those onboard the train) are mitigated by different levels of protection from passive crossings on private land with warning signs only to manually-operated public crossings operated on the busiest public roads that provide full separation of the railway from the road.

This hierarchy, illustrated in Figure 1 below, is broadly split (in order of increasing protection) into passive crossings, automatic crossings and manually-controlled crossings.

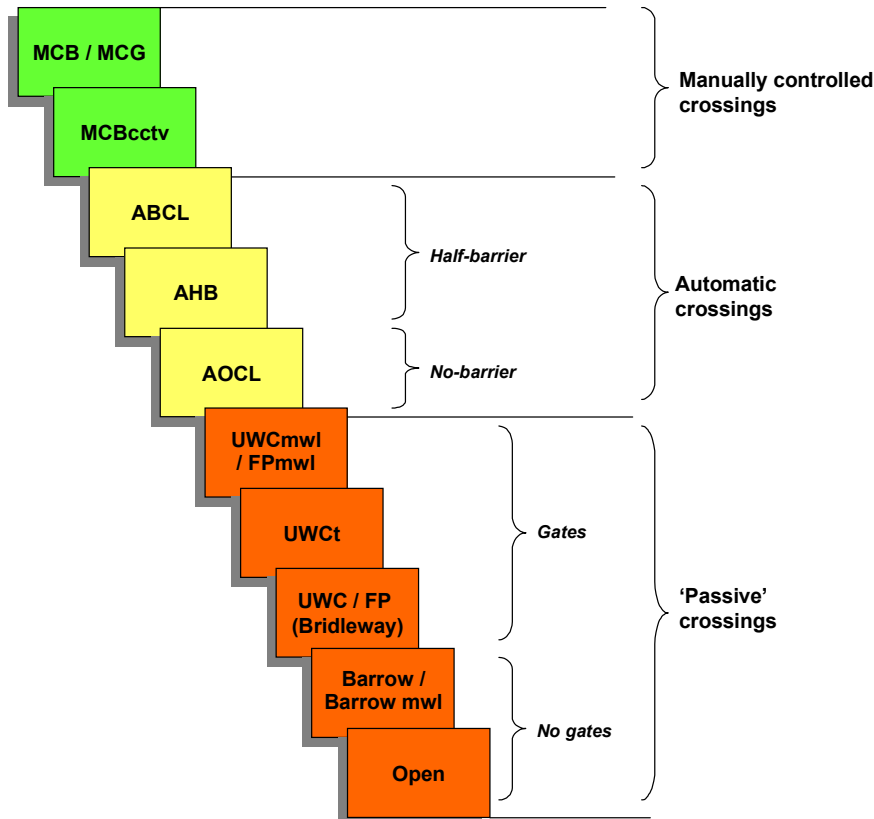


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Figure 1. Hierarchy of level crossing protection



Source: Arthur D. Little

**Passive level crossings** (shown above in orange) provide the lowest level of protection of all crossing types, with the user making a decision on whether or not it is safe to cross. Where miniature warning lights (UWCmwl) are installed, these indicate the approach of a train, or where a telephone is provided (UWCt) the signaller advises the user if a train is approaching. Gates or barriers are generally provided, except at open crossings at which train speeds are very low.

**Automatic crossings** (shown above in yellow) provide the next highest level of protection, with warning of train approach provided automatically either by lights or lights and barriers activated as the train 'strikes-in'. Lights and half-barriers are provided at AHBs and ABCLs, but not at AOCLs which have only lights. At level crossings wig-wag lights are used comprising a single yellow flashing light followed by double flashing reds. Half barriers ensure that an exit route is always available (provided that the exit is not blocked by a queue of road vehicles).

**Manually controlled crossings** (shown above in green) provide the highest form of protection of all crossings, with full barriers separating road users from the railway. The road traffic is stopped by phased lowering of one



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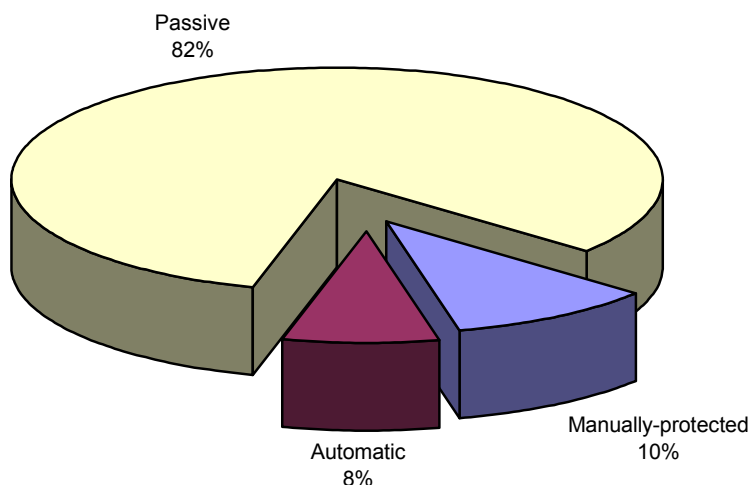
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set of barriers with a delay before the second set is lowered, which allows vehicles to safely exit. Before the protecting signals are cleared, the signaller verifies that the crossing is free of vehicles and pedestrians by visual check (which may be via CCTV). Interlocks prevent the train signals being cleared unless the crossing activation sequence is complete.

The vast majority of level crossings in GB are passive (>80%), with the remaining split between automatic and manually-protected crossings (illustrated in Figure 2).

**Figure 2. Level crossing distribution by type**



Source: Arthur D. Little

Over the past 50 years there has been an ongoing programme of level crossing modernisation that began with the conversion of manually-operated level crossings into the first automatic crossings during the 1960s. Automatic crossings appeared to provide a solution that balanced both the cost of operation and the disruption to increasing traffic volume with safety. However, the reliance at these crossings on the user to understand and heed the warnings provided that indicated when it was not safe to cross introduced a number of new hazards not previously associated with level crossing use. This was highlighted by the accident in January 1968 at the Hixon level crossing – amongst the first of the then new automatic half barrier (AHB) type – which led to extensive revision of the technology and operation of AHB level crossings<sup>[3]</sup>. This work was not completed until 1973 and caused some delay to the further introduction of this type of crossing. Since then, the modernisation programme has seen a gradual fall in the total number of public road crossings in GB, but with various changes in the relative proportions of the different level crossing types in use (illustrated in Figure 3).

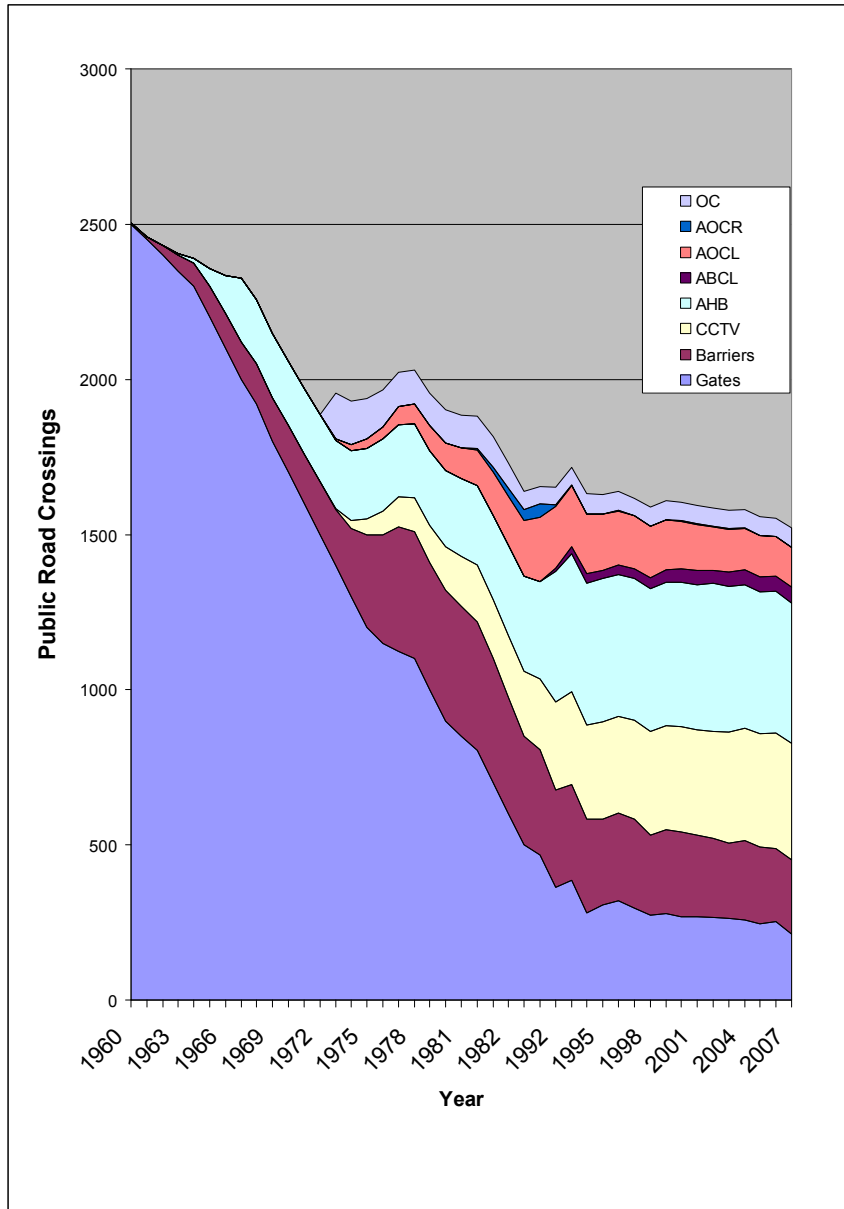


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Figure 3. Public road level crossing modernisation in Great Britain 1960 – 2007



Source: [5]

Of note from the figure is the replacement of a proportion of manually-protected crossings with automatic crossings. In these instances it becomes very important to understand how total risk is redistributed and the impact on this risk of changes in the various site-specific factors. This is especially true for the 'middle tier' of



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crossings within the hierarchy shown in Figure 1, where the differences in collective risk for different crossing types might be quite small.

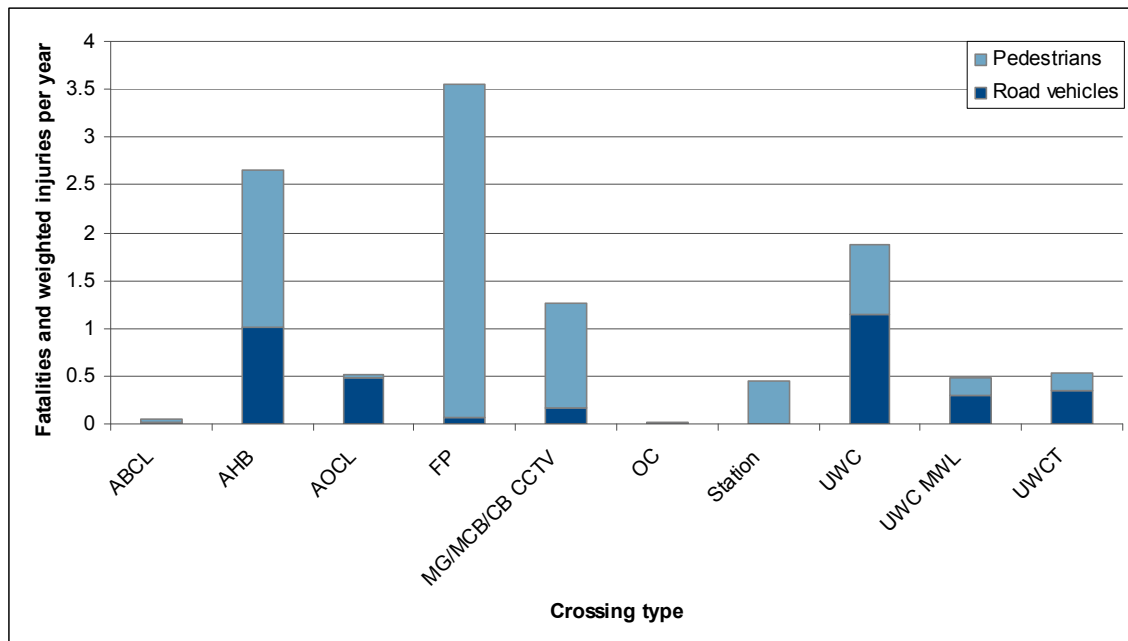
## Distribution of risk

In Great Britain level crossings are generally recognised as a contributor to catastrophic risk on the railways<sup>[3]</sup>. This was highlighted by the major accident that occurred during 2004 involving a car driver who stopped his car on a level crossing and caused the death of the train driver and five passengers in the subsequent derailment (Ufton Nervet). Since then there have been a number of high profile incidents involving collisions between trains and users at level crossings.

Notwithstanding catastrophic risk, level crossing fatalities contribute some 7% of the total network risk (some 12 fatalities and weighted injuries (FWI) per year<sup>[1]</sup>). Approximately 60% of this loss occurs at passive crossings, with the remainder occurring at manual and automatic crossings. It is important to note that this figure excludes deaths that result from other causes such as railway trespass and suicide (as was suspected at Ufton Nervet).

Figure 4 shows the distribution of this risk by level crossing type<sup>[1]</sup>.

**Figure 4. Collective risk by level crossing type (expressed as FWI / year)**



Source: <sup>[1]</sup>



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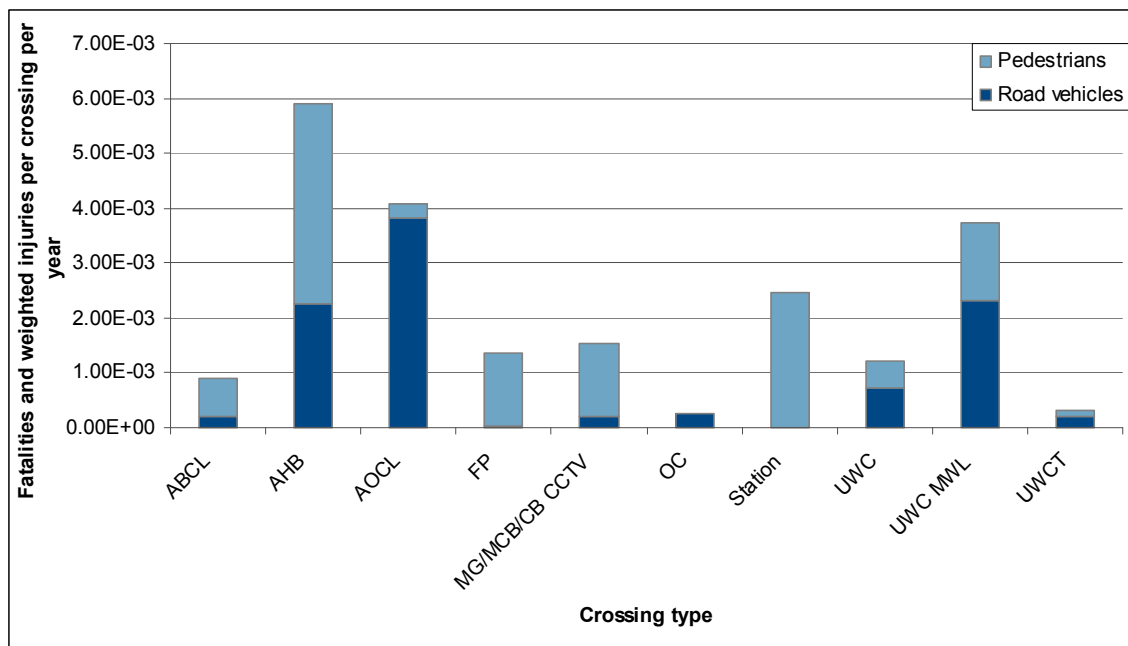
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Whilst the histogram shows that the collective risk for some populations of passive crossings (particularly user-worked crossings) is comparable to automatic and manually-protected crossings, the very low levels of utilisation usually found at passive crossings means that the individual risk to which a typical crossing user is exposed is very different. This can be highest at passive crossings, contrasting with the relatively low levels of individual risk found at manually-protected crossings and automatic crossings. These latter crossing types can experience very high levels of utilisation, sometimes many thousands of traverses a day for the busiest crossings. In other words, the differences in individual risk and crossing utilisation tend to produce collective risk of similar order for the majority of level crossing types.

A second point to consider is the number of crossings over which the collective risk is distributed. The large numbers of passive crossings act to produce a very dispersed collective risk (especially for footpath crossings), whereas the relatively small number of automatic crossings produce the opposite: a concentration of risk amongst relative few 'high risk' level crossings. This is illustrated in Figure 5.

Figure 5. Collective risk normalised by crossing population (expressed as FWI / year)



Source: Arthur D. Little

This uneven distribution of collective risk is further accentuated by the good levels of safety found at manually-protected crossings, achieved through the full separation of users from the railway, the manual check by the signaller that the crossing is clear of users and the relatively long strike-in times needed to complete closure of the crossing prior to arrival of the train.



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Total network risk can therefore be found dispersed amongst the many passive crossings (each of which may have a high individual but low collective risk), with the remainder concentrated largely within the automatic crossing population (that may have a lower individual risk but higher collective risk by virtue of their utilisation).

## **Assessment of collision frequency**

Assessment of risk at level crossings has tended to separate the collision frequency and consequences by user type: typically pedestrians and users in vehicles. The vehicle component has been of particular interest, given the more complex interaction between the vehicle and the level crossing (the driver has to observe and react in time to the warnings displayed to them) and the potentially more serious consequences of a collision between a train and a vehicle (particularly the catastrophic consequences that can result from a derailment).

## ***Linear traffic moment***

A linear relationship between traffic moment and collision frequency has previously been used in a number of European level crossing risk assessment models. The relationship assumes that the collision frequency increases with traffic moment, so that the busiest crossings have the highest number of collisions. Hence for two crossings with similar train speeds (i.e. assuming similar consequences of those collisions with the train), the overall risk at the busier crossing would be higher.



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Figure 6. Linear traffic moment increases the risk at busy crossings



Source: Arthur D. Little

It is important not to confuse the *consequences* of a collision with the collision frequency itself. Risk assessments that predict collisions linearly with respect to traffic moment may still show a significant *non-linear* variation in overall risk once the consequences of those collisions are taken into account (the consequences may be proportional to the kinetic energy imparted by the train during the collision or the square of its speed). However, the underlying linear relationship with traffic moment remains unchanged.

### **Opportunities for collision**

Work proposed by P F Stott <sup>[1]</sup> at AOCLs suggested that the opportunity for collision with a train is not always linear with respect to the crossing utilisation. Stott argued that a user only has the opportunity to collide with the train if they are the first vehicle to arrive at the active crossing, that they do so around two seconds before the train traverses the crossing and that they fail to stop. Hence, there is a chain of events required for a vehicle to collide with a train or the crossing equipment. For a particular train arrival at a crossing, the result is:



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- For **lower traffic levels**, as the traffic flow increases so does the opportunity for collision (i.e. the relationship is approximately linear). This relationship is similar to that for linear traffic moment; the greater the number of vehicles the more likely one is to arrive two seconds before the train. This relationship continues up to the point where the traffic levels increase and arriving vehicles start to encounter a vehicle already stopped safely at the level crossing (which forms a 'protective barrier' between the arriving vehicle and the crossing). At this point the proportion of vehicles that do not have the opportunity to collide with the train (i.e. arrive outside the two second window or are 'protected' by another vehicle in front) starts to increase, therefore decreasing the overall impact of greater utilisation. At this point therefore the non-linear relationship with utilisation peaks.
- For **higher traffic levels** there will always be a first vehicle, and again providing the first vehicle stops safely this produces a 'protective barrier' for any additional vehicles that arrives at the crossing. For this level of utilisation the effect of the additional vehicles queuing starts to dominate, and the overall number of opportunities for collision decreases (i.e. those that would have arrive two second before the train are now protected by a car or several cars already queuing at the crossing).

This effect is illustrated in Figure 7.

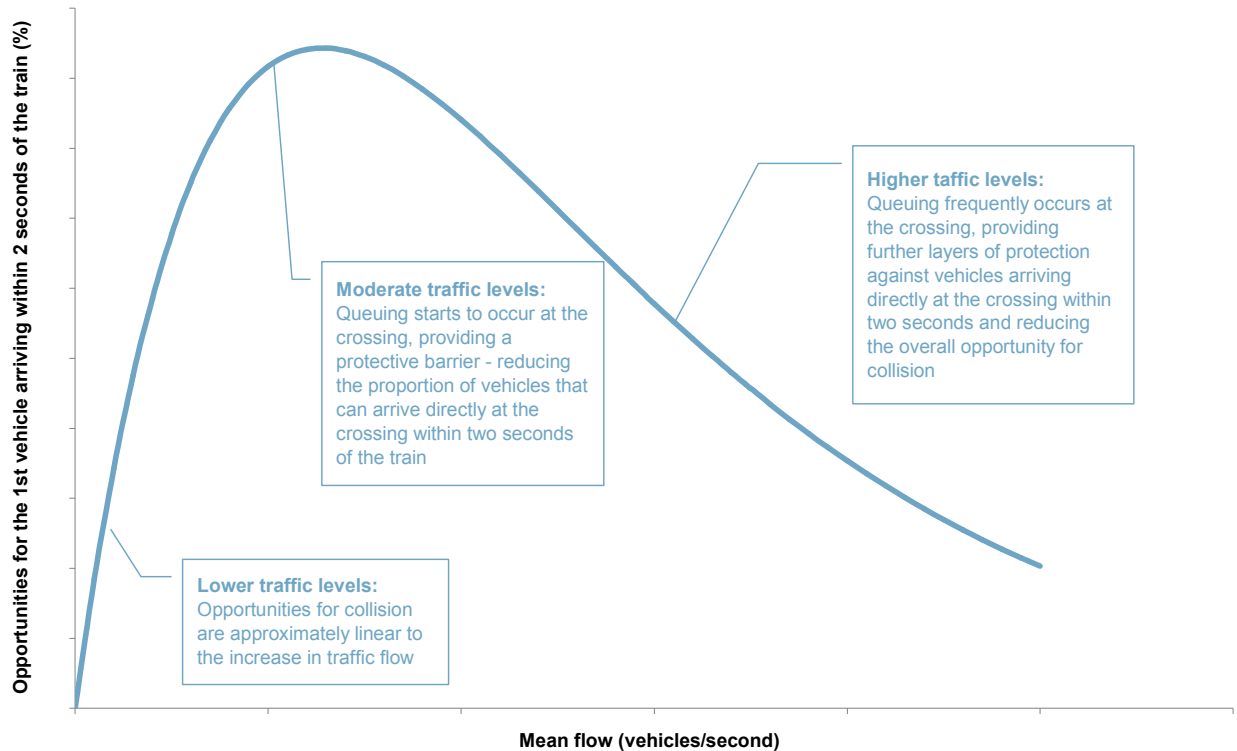


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Figure 7. The influence of non-linear traffic moment on the opportunities for collision



Source: Arthur D. Little

The theory therefore implies that those crossings with the greatest risk of collision have a traffic moment that peaks at a moderate mean traffic flow. Very busy crossings may actually have a much lower predicted traffic moment because of the high incidence of stationary vehicles waiting at the crossing.

Stott's work focused on 'red light running' at AOCLs, but his theory can also be applied to other automatic crossings in the form of barrier 'zig zag' (a user deliberately driving a vehicle around the level crossing barriers once these have descended) as the principles are the same. However, it is important to note that not all vehicle-train collisions are associated with these forms of deliberate abuse. Analysis of GB accident data shows that late braking, road surface conditions (such as ice or mud) and visibility conditions (such as low sun or fog) are also significant contributors to collisions, and therefore remain important factors to be taken into account alongside traffic moment.



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## **The ALCRM and implications for using non-linear traffic moment**

The ALCRM, which has been in use since January 2007, uses elements of non-linear traffic moment based on the work completed by Stott <sup>[1]</sup>. This is an important change to the risk assessment methodology adopted by Network Rail, who have already been using computer-based models to support their risk assessment of automatic crossings for over 10 years. The ALCRM, the functional specification for which was written by Arthur D. Little, is currently being used by Network Rail to support risk assessments of all level crossings on Network Rail Managed Infrastructure (NRM). As part of this work, existing assessments of automatic crossings are being revisited to determine how the new risk assessment methodology used by the ALCRM has altered the predicted risk.

Anecdotal evidence suggests that the non-linear traffic moment calculations included within the ALCRM will alter the list of those crossings thought to be 'highest-risk' within GB. Some crossings are now shown by the ALCRM to be relatively higher risk than previously thought, while other more busy crossings may actually be safer.

These changes are most apparent at busy AHB crossings; the high traffic densities experienced on Britain's trunk roads means that census counts at around 20 of the 450 or so AHB crossings in GB will exceed 10,000 vehicles per day (illustrated in Figure 6).



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Figure 8. A busy AHB crossing on a trunk road in GB



Source: Arthur D. Little

These high traffic densities rapidly lead to queues as soon as the level crossing is activated (shown in Figure 9).



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Figure 9. Traffic queuing at the same AHB crossing after activation



Source: Arthur D. Little

The theories proposed by Stott<sup>[1]</sup> argue that, in these cases, the lead vehicle stopping safely at the crossing then acts as a 'safety barrier' for the vehicles that arrive at the crossing after it (illustrated in Figure 10). In this case and assuming that the first vehicle had an opportunity for collision as it arrived within 2 seconds of the train, the non-linear traffic moment would be 25 percent of that predicted from a model based on a linear traffic moment for this instance of queuing (as the remaining three vehicles are prevented from colliding with the train by the safety barrier).



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Figure 10. First car that arrives acts as the 'safety barrier'



Source: Arthur D. Little

The effect of a non-linear traffic moment on crossing risk is further illustrated in Figure 11. Sample crossing data were used for automatic level crossings in GB and the crossing risk (calculated as FWI / year) first calculated using a linear traffic moment. The results are ranked in the figure, with the five crossings with the highest risk shown in red and the next fifteen shown in blue. The predicted risk for the same 20 crossings – designated 'LX A to T' – were then recalculated using a non-linear traffic moment. Those that remained within the previous 20 retain their colour codes; the change in order was found to be significant. Only two of the five crossings previously predicted to have the greatest risk remained in the top five when risk was calculated using a non-linear traffic moment.



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Figure 11: Level crossings ranked by total risk using linear and non-linear traffic moment

Designation	Linear	Non-linear
LX A	1	21
LX B	2	2
LX C	3	5
LX D	4	101
LX E	5	54
LX F	6	1
LX G	7	7
LX H	8	85
LX I	9	90
LX J	10	37
LX K	11	6
LX L	12	282
LX M	13	186
LX N	14	4
LX O	15	3
LX P	16	61
LX Q	17	77
LX R	18	8
LX S	19	207
LX T	20	60

Source: Arthur D. Little

Further comparison of the data showed that the greatest changes in ranking were at crossings with very high utilisation, showing the importance of the 'protective barrier' in reducing the opportunities for collision at these crossings. Those that remained within the top 20 tended to have lower utilisation. Most interestingly of all, those whose risk rank increased (such as LX F, N and O) were found to have a moderate utilisation that translated into a traffic moment somewhere near the peak value illustrated in Figure 7, therefore resulting in a high number of opportunities for collision.

This trend of highest risk during moderate level crossing utilisation is supported by anecdotal evidence gathered on train-user collisions at these crossings. The data (from 2001 to 2006) showed train-user collisions at those crossings with a moderate traffic moment, but none during the same period for the busiest crossings. Although the data sample were by no means statistically significant, this apparent coincidence was interesting to note.

## Conclusions

Until results from the ALCRM are published and peer-reviewed by industry, it will be difficult to determine precisely how non-linear traffic moment will affect the distribution of total network risk amongst those crossings on NRM. The ALCRM, in common with other national risk models, also takes into account many other factors influencing level crossing risk, and therefore the effect of traffic moment will by no means be uniform.



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However, the concentration of total network risk at a relatively small number of level crossings in GB and the high utilisation that tends to be found at those crossings means that the relationship between collision frequency and traffic moment remains a key factor determining how those risks are predicted.

## **Acknowledgements**

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## **References**

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