Review of Criteria to Prioritise Level Crossings

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30 June 2004

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Introduction

There are approximately 1400 level crossings over the New Zealand railway network. Between 2001 and 2003 there was an average of 6 fatal, 5 serious injury and 4 minor injury crashes per year at these level crossings. Thus improving safety at level crossings is a key to improving railway safety in New Zealand.

The appropriate allocation of safety improvements to level crossings to reduce the incidence of accidents is a difficult task. Accident experience alone fails to provide a good appreciation of future expected accidents at level crossings (Saccomanno & Xiaoming, 2004). This is because accidents at crossings are rare, random events, which vary considerably over time and space. The expectation of accidents can only be obtained from accurate and reliable collision prediction models. The development of such models allows the appropriate prioritisation of safety improvements.

Aim & Terms of Reference

The aim of this report is to review the criteria used to prioritise level crossings in New Zealand where safety improvements should be made, based on international ‘best practice’.

Outline

The report begins with a summary of the New Zealand criteria for prioritising level crossings for safety improvements. This is followed by summaries of international criteria, beginning with Australia. At the end of the summary of each international criteria there is a discussion of the applicability of that criteria to New Zealand. The paper concludes with recommendations for prioritising level crossings in New Zealand for safety improvements.

New Zealand’s Criteria

In New Zealand two different models have been developed to predict future accident involvement at level crossings and thus prioritise crossings for safety improvements. These are Toll Rail’s Product Assessment System and Transfund’s Accident Prediction Model.

Product Assessment System

The Product Assessment of a level crossing is one of the principal factors used to determine the priority for installation or upgrading of automatic warning devices in New Zealand today. It uses a level crossing risk assessment formula based on various level crossing characteristics to give a risk exposure score, known as the “Product Assessment”, which is then adjusted for the number of accidents at the crossing to give a “Product Number”. These characteristics relate to:

- train volumes
- vehicle volumes
- view factors
- number of tracks

It is unclear how the Product Assessment system was developed. Percival (2002) reported that it has been in place for at least 20 years and is largely accepted by the level crossing improvement funding bodies (Toll Rail and Transfund NZ). It is used by other railways, particularly in the USA, which suggests it was probably developed in the USA.

Belz (1992) conducted a study in the early 1980s on the correlation between the formula and actual collision data. For the study he used the results of a level crossing survey completed in 1978 and 15 years accident data. The crossings were classified into 20 bands based on the type of protection. The number of accidents within each band was calculated and normalised by dividing by the number of crossings within each band.

Belz found that the mean accident rate (number accidents / number crossings) increased consistently with the Product Number. There was a significant correlation between the mean 15 year accident rate and the Product Number for passive signed crossings, as well as for crossings with either flashing lights and bells or half-arm barriers.

Below a brief description of the Product Assessment formula is outlined.

Product Assessment Formula:

The following is cited from Percival & Neilson (1997).

$$\boxed{\text{Product} = (2\,TD + TN) \times RV \times VF \times HF}$$

Where,

TD = Number of trains/day (0700-1800 hours)

TN = Number of trains/day (1800 – 0700 hours)

(Note: for both TD and TN, shunts and train movements at 25 km/h or less are divided by a factor of 2).

RV = Average number of vehicles per week day

VF = View factor = 1 + A1 + A2 + A3 + A4

Where A1…A4 = 0 when automatic warning devices are already installed
= 0.5 at a road crossing for each quadrant where the view along the track at 55 m from track centre line is less than distance S2 in Table 1 below

HF = Hazard factor = 1.0 for single track
= 1.25 where there is one or more sidings in addition to a main line track
= 2.0 where there is a second main line or loop track or where a crossing loop terminates near the level crossing.

Table 1. Minimum View Lines

Train Speed V2	Restart View		Road Approach View S2
	Minimum S3M	Desirable S3D	
25 km/h	56 m	140 m	41 m
40 km/h	89 m	225 m	65 m
55 km/h	122 m	309 m	90 m
70 km/h	156 m	393 m	114 m
80 km/h	178 m	449 m	131 m
100 km/h	222 m	561 m	163 m
110 km/h	244 m	617 m	180 m

Source: Percival & Neilson (1997)

Notes for Table 1:
V2 = the highest authorised train approach speed in the direction concerned.
S3M = the minimum view along the track at 5.0 m from track centre line for all road level crossings including those fitted with automatic warning devices and private road crossings. (Based on the time take for a 12 m road vehicle to restart and clear the railway).
S3D = the desirable view along the track at 5.0 m from track centre line for all road level crossings. (Based on the time taken for a 20 m road vehicle to restart then clear the railway plus a 10 second safety margin)
S2 = the minimum view along the track at 30 m from track centre line for all public road level crossings unless automatic warning devices or “stop” signs have been installed.

Alarm Upgrading Policy

For road crossings with a Product Assessment greater than or equal to 10,000 the crossing is placed on the list to be upgraded to flashing lights and bells. When it is greater than or equal to 50,000 (with a View Factor equal to 1) the crossing is placed on the list to be upgraded to half arm barriers. Note though, that when the rail speed is restricted to 10 km/h (i.e. shunting movements only) no automatic warning devices will be installed.

Alarm Priority List

Further priority for provision or upgrading of automatic warning devices at a road level crossing is determined using the Product Number. This is the Product Assessment suffixed with a letter of the alphabet to indicate the number of accidents (if any) recorded at the crossing in the previous 10 years, whereby:
A = 0 accidents
B = 1 accident
C = 2 accidents
Etc

Downgrading policy

Where the rail or road count means the Product Assessment falls to half the values given in above for upgrading (i.e. to 5,000 for crossings with flashing lights and bells and to 25,000 for crossing with half arm barriers) and is unlikely to rise again and where the removal of the protection results in substantial savings, then automatic warning devices may be downgraded or replaced by passive protection after consultation with the local road authority.

The Product Assessment is not used to determine crossing closure. This is determined by agreement between Toll Rail, the Roading Authority, the public and other interested parties.

Summary

The Product Assessment system uses a level crossing risk assessment formula based on level crossing characteristics (train and vehicle volumes, view factors, number of tracks) to give a risk exposure score, known as the Product Assessment. The value of the Product Assessment determines whether the crossing should be upgraded with flashing lights and bells or half arm barriers. Crossings with higher numbers of accidents get higher priority for upgrade than other crossings. An early study found the Product Assessment system was significantly correlated with collision data.

Accident Prediction Model

Transfund’s Project Evaluation Manual contains an Accident Prediction Model for use in prioritising level crossings for upgrade (Transfund, 2002). The Accident Prediction Model was developed by Shane Turner and Mike Jackett by modelling data from a database that contained accident data as well as road and traffic volume data for all level crossings in New Zealand (Shane Turner, personal communication). Currently the model combines urban and rural crossings, but Shane indicated that in the future they would like to model urban and rural separately.

Accident Prediction Model

$$\boxed{A_T = b_0 * T^{b1} * Q_T^{b2}}$$

Where,

A_T = typical accident rate (reported injury accidents per year), where accidents include:

- vehicle hit train
- rear-end

T = the number of trains per day

Q_T = the daily two-way traffic volume (AADT)

The values of the parameters ($b_{0,}$ b_1 and b_2) vary depending on the control type (see Table 2).

Table 2. Railway Crossing Accident Prediction Model Parameters.

Control Type	b_0	b_1	b_2
Half Arm Barriers	5.25 E-04	0.27	0.33
Flashing Lamps and Bells	7.82 E-0.4	0.61	0.32
No Control	1.81 E-03	0.31	0.36

Source: Transfund (2000) Table A6.8(a), page A6-35

The accident prediction model only applies within specific ranges of traffic and train volumes (see table 3). The accident rate can also be weighted by the type of control (see Table 3).

Table 3. Railway Crossing Accident Prediction Model Flow Ranges and k Values

Control Type	Flow Range		k
	Q_T AADT	T AADT	
Half Arm Barriers	<13,000	<40	1.8
Flashing Lamps and Bells	<6,000	<30	0.7

No Control	<1,000	<20	2.7

Source: Transfund (2000) Table A6.8(b), page A6-35

If a level crossing is located in close proximity to a low design speed curve then a separate accident rate is predicted using the curves in Figure A6.2 of Transfund's Project Evaluation Manual (Transfund, 2002, page A6-33). This problem is reasonably common since the low design speed approach curves are often caused by the route having to deviate sharply when crossing the railway line.

Summary of New Zealand Models

In New Zealand two models are available to prioritise level crossings: Tranz Rail's Product Assessment System and Transfund's Accident Prediction Model. Both models take into account the daily train and traffic volumes at a crossing, although the Product Assessment doubles the value of trains during the day. The models differ on several other factors. The Product Assessment takes into account the view at the crossing and the number of tracks. It also takes into account the number of accidents at the crossing in determining priority for upgrade. In comparison the accident prediction model takes into account the type of control at the crossing as well as the crossing's accident history. Below the advantages and disadvantages of the two models are outlined.

Accident Prediction Model

Advantages

- takes into account train and vehicle volumes;
- has been developed based on the accident history of the crossing using statistical modelling;
- takes into account the control type at the crossing;
- specifies the train and vehicle volume ranges for which the model applies.

Disadvantages

- does not account for the difference in risk between day and night;
- relies on past accident history data to determine the risk scores, thus it is more reactive than proactive;
- does not take into account a number of other crossing factors that are likely to influence accidents, although it does take into account low design speed curves on the crossing approach. (Shane Turner indicated that there may be the possibility of developing the model further based on other factors, if other factors are available in the level crossing database);
- does not provide any guidelines on when an upgrade is needed or what treatments should be conducted;
- does not allow for accident prediction outside specified flow ranges for each category type. Thus if a crossing has an abnormal flow for its control type and hence its flow is outside the specified ranges then the model cannot be used.

Product Assessment

Advantages

- takes into account train and vehicle volumes;
- takes into account the time of the train volumes, with a higher rate for volumes during the day than at night;
- takes into account two important influential factors: the view at the crossing and the number of tracks;
- correlates with collision data;
- provides clear guidelines as to what values are needed to upgrade a crossing.

Disadvantages

- it is unclear whether it has been developed based on the accident situation in New Zealand (although it reportedly correlates well with actual collision data);
- does not take into account a number of other crossing factors that are likely to influence accidents;
- treatments are limited to active control measures.

Conclusion

The Product Assessment system is likely to be more effective in prioritising level crossings than the Accident Prediction model as it takes into account more level crossing characteristics and specifies treatments. However it could be improved with the addition of other crossing factors that influence accidents and the specification of other treatments.

Despite the advantage of the Product Assessment system the Accident Prediction model should not be dismissed, since it could be improved with the addition of other crossing factors. Moreover it is likely to be the model roading authorities use since it is in Transfund's Project Evaluation Manual. Thus it would be beneficial to continue to improve this model, based on best practice.

Australia's Criteria

In Australia a large amount of work on level crossing prioritisation models has been conducted in Queensland. Below some of the Queensland models are outlined, culminating with the most recent Queensland model.

Other Australian states are likely to have prioritisation models, but these have not been examined in time for this report.

Department of Main Roads, Queensland – Traffic Engineering Manual

The Traffic Engineering Manual prepared by the Department of Main Roads provides a process for scoring level crossings to prioritise them in terms of safety (reported in Queensland Transport, 1999). A score is calculated based on:

- sight distances
- train volume
- vehicle volume
- accident history

Queensland Transport (1999) reported that there is some suggestion that the scoring system is very complex to use fully. Thus it is not used widely.

The Traffic Engineering Manual also provides guidelines on selecting level crossing control devices. Specifically devices are selected based on sight distances at the level crossing with respect to road and rail characteristics. This list of devices is limited to give way signs, stop signs or active control. Guidelines are also provided on when flashing lights and boom gates would be appropriate.

Queensland Rail – Guidance for Assessment

Queensland Transport (1999) reported that Queensland Rail have developed a scoring system for prioritising level crossings in terms of safety. The system uses elements similar to those in both the Warren Henry formula (see USA section) and the Department of Main Roads Traffic Engineering Manual (see above). It undertakes detailed measurements of the sight distances and identifies scores for level crossing parameters such as:

- vehicle and train speed and volume
- crossing angle
- multiple train movements
- adjacent land uses
- special road features
- weather effects
- accident history

A total score is produced by combining the relative scores on the above. Queensland Transport (1999) indicated that one of the key deficiencies of the system is that it uses past accident history in determining the risk score. Thus to some degree the system is reactive, not proactive.

Department of Main Roads, Queensland – Risk Management Assessment

Queensland Transport (1999) reported another system developed by the Department of Main Roads in Queensland that calculates a value of relative risk for a high consequence event on the urban CityTrain network. It identifies the relative risk value at the level crossing by scoring each of a number of parameters including:

- crossing control measure
- vehicle (including bus and truck) volume
- train volume
- queuing from adjacent intersection
- vehicle and train speed
- driver information load

- number of road lanes
- number of rail tracks

The system has only been used in the context of urban level crossings. Thus the system cannot be applied to New Zealand's railway network.

Risk Based Scoring System (RBSS)

In February 1999 a Level Crossing Safety Project Team was established in Queensland Australia (Hughes, 2002). One of the main objectives for the project team was to develop technical guidelines that would assess the level of risk at level crossings and determine appropriate treatments to reduce this risk to an acceptable level. The Project Team reviewed a number of existing risk assessment systems for level crossings, but could not find any that as a whole would achieve their objective. Thus they took the best features of the existing systems (including those discussed above) and developed them into a single system, titled "Risk Based Scoring System (RBSS)".

Unlike existing systems, the RBSS is based on the idea that there is not a single, universal cause of accidents at level crossings. Specifically the system specifies 19 different causes of accidents at crossings. For each cause the system allocates risk points based on characteristics of the crossing under 29 different headings. These risk points are combined to give a "total risk score" for a level crossing and then multiplied by an exposure index to give a "risk exposure score".

The RBSS is described in more detail below (Hughes, 2002).

Accident Mechanisms

The RBSS contains 19 different generic ways in which accidents can occur at level crossings. These are referred to as "accident mechanisms" and can be categorised into three groups:

1. unaware of the level crossing,
2. unable to stop,
3. unwilling to stop.

An example of an accident mechanism in the 'unaware of the level crossing' group is the road user being distracted by many other competing stimuli on the approach to the level crossing.

Crossing Characteristics

The RBSS then considers how the characteristics of a level crossing can combine to increase the risk of accidents occurring by each of the different accident mechanisms. These characteristics include details of:

- the existing controls at the level crossing;
- the road geometry;
- the road traffic control;
- the road vehicles using the level crossing;

- the rail vehicles using the level crossing;
- the geometry of the level crossing; and
- the visibility at the level crossing.

Using these characteristics enables the RBSS to determine why a level crossing is high risk as well as assess whether a level crossing presents a high risk. For example, where a level crossing is adjacent to other road intersections, pedestrian crossings, or advertising billboards then there is an increased risk of accidents occurring because road users are distracted and not concentrating fully on the level crossing.

The details of the characteristics are scored and entered as ‘risk points’ to the RBSS. For example, the risk points assigned for the distance from an intersection to a level crossing are:

- more than 200 metres = zero risk points.
- Between 50 and 200 metres = 1 risk point.
- Between 20 and 50 metres: = 3 risk points.
- Less than 20 metres = 5 risk points.

Risk points are assigned for each of the 19 accident mechanisms. These were developed by the Project Team using a process of assumptions, workshops and calibration to match recorded data. Thus an overall risk score for a level crossing can be calculated, but it is also possible to see what is creating the risk (i.e. which of the accident mechanisms is giving the largest contribution to the risk score).

Treatments

Once the risk score is determined as well as what accident mechanisms are contributing to the risk the RBSS can then be used to determine what treatments are appropriate to reduce the risk. The RBSS considers 38 different treatments that can be applied to level crossings and the situations where each treatment would be effective at reducing the risk. For example, where a level crossing has a high risk of accidents because road users are unable to stop in time, suitable treatments for the level crossing include:

- reducing the road speed on the approach to the level crossing;
- improving the advance warning of the level crossing;
- and improving the quality of the road surface on the approach to the level crossing.

There are three main categories of risk reduction strategies at level crossings:

- installing new treatments at the level crossing e.g. improved signage,
- changing the characteristics of the level crossing e.g. changing the road speed or improving sighting distances, or
- by changing road and rail vehicle volumes at the level crossing e.g. by diverting road traffic to a nearby bridge over the railway line.

By selecting treatments that are appropriate to the risk at a particular level crossing it is possible to implement a relatively low-cost package of treatments that has a very large impact in reducing the risk.

Maximum Risk Limits

The total risk score for a level crossing is compared with fixed limits for maximum allowable risk scores to determine whether treatment is required. There are two risk limits used by the RBSS:

1. Intervention limit – the maximum risk score that a level crossing is allowed before intervention is required to reduce their risk.
2. Installation limit– the maximum risk score that is allowable for a new level crossing installation.

The installation limit is lower than the intervention limit. That is the RBSS demands a lower level of risk at any new level crossing installation than is tolerable at existing level crossings.

The intervention and installation limits used in the RBSS were calculated by considering the level of risk that is currently experienced at railway level crossings and determining a target improvement for the entire road system.

The intervention and installation limits are not the same for all level crossings.
Specifically, the intervention limit = V × T
where,
V= the daily number of road vehicle crossings
T= daily number of train crossings

The higher the VT product the lower the intervention level. Thus the RBSS is used to get the greatest increase in safety over the entire rail / road network, and this is achieved by reducing the number of accidents at all level crossings rather than reducing the risk at rarely used level crossings.

The intervention limit (VT) is then multiplied by the risk score for the crossing to give the risk exposure score. The risk exposure score needs to be minimised over the road / rail network.

Minimum Standards

Before the RBSS can be applied a crossing must meet minimum standards. These standards relate to the minimum amount of time a road user has between first becoming aware of a train approaching a level crossing and when the train arrives at the level crossing. The amount of time is determined by considering the amount of approach visibility a road user has of a train and the speed of the train and the road vehicles.

Success of the RBSS

During the development of the RBSS the system was reviewed by a group of expert engineers from road and rail authorities within Queensland. The results of the RBSS were found to agree very closely with accident history and the opinions of expert staff who are familiar with level crossing safety. Furthermore an independent review of the RBSS conducted by the Australian Road Research Board (ARRB) concluded that, with the appropriate data, the system is ‘a very powerful tool’.

Cairney et al (2002) reported that attendees at a workshop of representatives from stakeholder organisations across Australia and New Zealand unanimously supported using the RBSS to assess risk and select treatments. The workshop participants anticipated that there would be scope to fine-tune the system as experience with its use accumulated, and that there may be a need to modify the weightings applied to some risk factors and treatments to suit conditions in different jurisdictions. It may also be necessary to adapt the system to suit local circumstances. Overall the participants considered that using a risk management programme, such as the RBSS, is good practice in managing risk at passive railway crossings.

Summary

In the past a number of models have been available in Queensland to prioritise level crossings. However recently a new model has been developed, the RBSS, that supersedes previous models. The RBSS provides a system that identifies the characteristics of a level crossing that are contributing to accidents and targets treatments to reduce these accidents. Specifically it allocates risk points based on the characteristics of the crossing and the relationship between these characteristics and different causes of accidents. The combined total of these risk points is multiplied by vehicle and train volume data to give a risk exposure score.

Other International Criteria

A wide range of criteria for prioritising level crossings exist internationally. Below the criteria accessed in time for this report are reviewed and their applicability to New Zealand discussed.

Canada

In Canada it has been recognised that many current collision prediction models fail to represent the full range of factors explaining variation in collision frequency at individual crossings over a given period of time (Saccomanno & Xiaoming, 2004). However Saccomanno and Xiaoming (2004) have reported that the reliability of collision prediction models can be improved significantly by first aggregating crossings into clusters with similar attributes and then developing separate cluster-specific prediction expressions. These models can then be used to assess the safety merits of selected counter-measures applied to crossings.

The specific steps to achieve the models are:

1. Obtain a complete list of geometric and traffic attributes assumed to affect level crossing crashes from the crossing inventory and occurrence database.
2. From the list extract a reduced number of orthogonal (not correlated) factors that reflect underlying attributes in the crossing data. (Varimax Factor Analysis with rotation)
3. For the factors obtained in step (2) estimate “factor scores” for each crossing and factor in the database. These scores are used in a cluster analysis to identify

individual clusters of crossings with similar attributes. All crossings in a given cluster are assumed to behave in a like manner in explaining the expected number of collisions.

4. Where there is variation in the number of collisions for individual crossings within the same cluster then it is accounted for statistically by developing cluster-specific collision prediction models that reflect individual crossing attributes that were not considered in the clustering exercise.
5. The accuracy of these prediction models is validated using a split sample of crossings from each cluster and comparing these to predictions based on the combined national crossing data.
6. Demonstrate the usefulness of the model by evaluating the collision reduction effects of selected countermeasures. These countermeasures affect crossing attributes in two ways:
    - attributes that are included in the collision prediction model (step 4)
    - attributes not in the prediction models but included in the clustering exercise

Applying the Prediction Models to Analyse Selected Counter-Measures

The collision prediction models obtained from the above six steps can then be used to estimate the effect of selected counter-measures at individual crossings. The procedure involves four basic steps:

1. obtain crossing attributes before and after the counter-measure
2. estimate the factor scores for each crossing and determine its parent cluster
3. if the counter-measure results in changes in either cluster membership or variable found to be significant in the prediction model, estimate the expected number of collisions before and after the counter-measure. Changes in cluster membership are determined by comparing Euclidean distances for each factor score.
4. If the crossing does not change cluster membership and the counter-measure is not reflected in the prediction model then the changes in the number of collisions would not be expected to be significant.

Example

The above approach was used to develop a collision prediction model based on inventory and collision history data from 10,449 level crossings in Canada between 1993 and 2001 (Saccomanno & Xiaoming, 2004). The inventory data consisted of:

- warning devices, e.g. presence of a sign
- geometric attributes, e.g. track angle
- traffic characteristics e.g. vehicle and train volumes and speeds
- collision occurrence, e.g. collision causes

Five clusters were developed as summarised below:
Clusters 1 & 5

- mostly urban
- high AADT and road speed

Cluster 2 & 3

- spread out throughout the S. Ontario region

- mainly along major highways in rural areas
- low volumes
- infrequent train service

Cluster 4
- rural or suburban rural
- medium AADT and train volumes
- medium train and high road speeds
- equipped with a mix or active and passive controls

To develop the models the member crossings in each cluster were split into two random samples on a 50-50 basis, with one sample to calibrate the model and the other to validate the model within each cluster. Five Negative Binomial models were developed. Each model was validated by comparing the expected number of collisions with the actual number of collisions observed. The validation indicated that all the models provided a good explanation of the observed collision frequency for all clusters in the data.

The models were used to assess changes in the expected number of collisions that follow the upgrading of warning devices. The model indicated that upgrading of signs to either flashing lights or gates results in a significant reduction in the expected number of collisions.

Saccomanno and Xiaoming (2004) warn that the model is currently preliminary in nature but the results to date indicate it is useful for evaluating different counter-measures applied to grade crossings.

Applying the Prediction Model to New Zealand

Below the advantages and disadvantages of applying the prediction model to New Zealand are outlined.

Advantages
- the models would be New Zealand specific since they would be developed based on New Zealand data
- the models can take into account a wide range of crossing factors
- level crossings of similar type will be grouped together
- an assessment of the effect of different treatments on accidents can be made

Disadvantages
- a comprehensive list of inventory data for each crossing would need to be developed
- would need to consider what variables are needed in the analysis (e.g. variables not specifically in the railway corridor)
- would involve a large amount of time to develop the models
- the models do not prioritise crossings
- the approach does not specify what treatments are necessary

Conclusion

The Canadian approach would allow New Zealand specific models to be developed with as many crossing characteristics as desired. It would also allow an assessment of the benefits of treatments. However the approach does not prioritise crossings or specify what treatments are necessary. It could also involve a considerable amount of time and resources to develop. Thus at this stage this approach is not recommended for use in New Zealand as prioritisation method, but it could be used in the future to estimate the effect of various treatments for benefit-cost analyses.

Iran

Iranian Railways have set a target to reduce 20% of accidents at crossings (Zakeri, 2004). This has involved 3 strategies:

1. Removing level crossings with high accidents & traffic (122 crossing are under removal operation);
2. Upgrading track superstructure in crossing zones and equipping them comprehensively;
3. Applying intelligent barriers.

Formulae to prioritise crossings for the above three strategies has not been developed. However several variables are considered for each strategy.

1. Crossing elimination:
In selecting which crossing to eliminate the following variables are taken into account:

- number of trains per day
- number of road vehicles per day
- accidents at the level crossing
- the importance of the road
- maximum train speed and vehicle speed.

2. Upgrading track superstructure
to upgrade the track superstructure the following are considered important factors:

- road vehicle entrance and exit to and from railway zone
- providing an even surface for rapid and convenient crossing of road vehicles
- signal boards
- speed reducing
- barriers
- warning systems
- communication systems

3. Intelligent barriers
In selecting crossing for intelligent barrier systems the following will increase the chance of getting such a system:

- level crossings with great disturbances like existing oil, gas and water pipes
- complexes near level crossings

Summary

Iranian railways does not have a specific level crossing prioritisation formula. However they consider several crossing factors in deciding to eliminate a crossing, upgrade the track superstructure or apply intelligent barriers. Some of these factors could be incorporated into a New Zealand model for prioritising crossings, such as train and vehicle speed.

Netherlands

In the Netherlands there are four main categories of level crossings:

1. Level crossing without technical protection measures
2. Level crossings with road traffic light signals
3. Level crossings with half barrier
4. Level crossings with full barrier

The protection required for a level crossing is based on (Steininger, Schäll & Weidl, 2004):

- the accident risk (see below)
- warning time (the optimal warning time is 15 seconds)
- the financial risk

Whereby,
Risk = annual crash frequency over a 12 year period × equivalent fatalities per crash

and 1 fatality =

  - 10 seriously injured
  - 100 lightly wounded

If a more detailed examination is required the following factors are considered:

- urban or rural area
- characteristic of the street
- maintenance and operational costs per year
- traffic density

Summary

Overall it appears that the Netherlands does not have a specific level crossing prioritisation formula. However to assess the protection required at a level crossing it takes into account accident and injury risk, economics and warning time. Other crossing factors are considered if a more detailed examination is required.

The Netherlands approach relies heavily on accident risk. In New Zealand accidents are rare and random events. Thus if the Netherlands approach was applied to New Zealand it is likely that crossings with an accident history would be given treatment priority. However there are likely to be many other crossings who would miss out on treatment despite having a high potential for an accident due to their characteristics. The Netherlands approach does take into account other factors, such as warning time, but there is no specific formula. Thus the current New Zealand approach of the Product Number is preferable as it provides a clear and objective measurement and does not rely on accident risk.

Spain

Currently in Spain three general aspects are considered in making a decision about elimination or improved protection of a railway level crossing (Ubalde, Bachiller & Casas, 2004). These are:

- railway speed, V_m (level crossings are not allowed when top speed is higher than 160 km/h);
- traffic momentum, A.T (daily average number of road vehicles, A × Daily average number of trains, T); and
- visibility at the level crossing.

Level Crossings are then classified based on the three aspects into six types (see Table 1). For example, a level crossing is classified as type C if the train speed is less than 160 km/h, the traffic momentum is between 1000 and 1500 and the daily average number of road vehicles is greater than 100.

Table 1. Classification of level crossing according to Spanish regulations depending on traffic characteristics.

Type	Brief description	Location	Traffic characteristics
A	Fixed signaling	Out of stations	V_m<160 km/h A.T<1000 real visibility>techincal visibility
		At stations	Provisional
B	Traffic lights and fixed signaling	Out of stations	V_m <160 km/h 1000<A.T<1500 A<100
		At stations	No
C	Crossing gates, traffic lights and fixed signaling	Out of stations	V_m <160 km/h 1000<A.T<1500 A>100
		At stations	V_m <160 km/h
D	Train can only run if it has permission given by railway personnel	Out of stations	V_m <40 km/h 1000<A.T<1500
		At stations	V_m <40 km/h 1000<A.T<1500
E	Crossing gate and railway personnel at level crossing	Provisional	
F	Level crossing for pedestrians and livestock		

New Method of Risk Evaluation

More recently Spain has considered a specific method of risk evaluation: FMEA ("Failure Mode and Effect Analysis"). FMEA applications involve evaluating three issues in order to get a representative risk factor (K):

- probability of failure i (Ai)
- detection facilities (Bi)
- severity of failure consequence (Ci)

Risk K is then defined as traffic momentum (AT) multiplied by the sum of ABC for each risk.

$$K=AT \sum_{\text{risks } i} Ai\ Bi\ Ci$$

Applying FMEA brainstorming indicates that the factors in Table 2 should be considered in a safety assessment of level crossings.

Table 2. Some factors that should be considered in a safety assessment of a level crossing.

Railway		Speed Number of trains per day Turnouts at level crossing Location near stations Signaling
Road	Vehicles	Speed Number of vehicles per day Classification of vehicles Signaling (for vehicles and for pedestrians)
	Pedestrians	Traffic Handicapped people access
Crossing geometry		Visibility Protection system Alternative ways for pedestrians Number of tracks Number of road lanes Road layout Track layout Nearby intersections Background distractions

Summary

In Spain the treatment for a level crossing is decided based on railway speed, traffic momentum and visibility at the crossing. More recently a specific method of risk evaluation: FMEA ("Failure Mode and Effect Analysis") has been considered. This method considers the probability of failure, detection facilities and severity of failure consequence for a large number of railway, road and crossing geometry factors.

Application to New Zealand

The current system in Spain is not fully applicable to New Zealand because it is based on higher train speeds and different protection factors to those used in New Zealand. In comparison the risk evaluation system currently being considered has greater applicability for New Zealand. It considers a large variety of road, rail and crossing geometry factors in defining risk. However further details of the system are needed to assess how it could be applied. Furthermore it does not specify treatments for different levels of risk. Thus it would require a large amount of time and resources to develop. It is likely to be easier to use a system that has already been developed, such as Queensland’s RBSS.

USA

Warren Henry Formula

Queensland Transport (1999) reported that the Warren Henry formula was developed in the USA to calculate an Index of Hazard based on a numeric equation using such parameters as:

- vehicle volume
- train volume
- sight distances
- number of tracks
- road grade/curvature
- adjacent intersections
- sun glare
- pedestrians
- manner of use

The exact formula was not described. However Queensland Transport reported that it does not identify the specific cause of the hazard.

US Department of Transport

The US Department of Transport use the following formula to predict the number of accidents that can be expected to occur at a given level crossing (Saccomanno et al, 2002; cited in Watson & Schmid, 2004).

$$A = K \times EI \times MT \times DT \times HP \times MS \times HL$$

where,

a = un-normalised accident prediction (accidents/year at the crossing)
K = constant for initialisation of factor values at 1.00
EI = factor for exposure index based on product of highway and train traffic
MT = factor for number of main tracks
DT = factor for number of through trains per day during daylight
HP = highway paved factor

MS = factor for maximum timetable speed
HL = factor for number of highway lanes

The variables for the equation are quantified according to three crossing categories (see Watson & Schmid, 2004, page 8):

1. passive crossings
2. crossing with flashing lights
3. crossings with gates

Watson and Schmid (2004) pointed out the following problems with the formula (which would also apply if the formula was used in New Zealand):

- the formulae fail to address the changing pattern of both road and rail traffic throughout the day;
- there are only three categories of warning systems and no distinction between half and full barrier gates;
- the angle of the crossing with the road is not considered; and
- vegetation in the vicinity of the crossing is not considered.

Comparison Between The RBSS and New Zealand Product Assessment System

Both the RBSS and New Zealand Product Assessment system take into account vehicle and train volumes. However the RBSS differs from the Product Assessment system in that it determines a risk score for a large number of crossing characteristics and variety of accident causes. In comparison the Product Assessment system only consider a very small number of crossing characteristics (number of tracks and view). Moreover the crossing characteristics in the RBSS focus wider than the immediate crossing environment to include factors related to the road environment near the crossing. For example, a risk score is calculated for the proximity to road intersections since nearby intersections may influence traffic flow and queuing at the crossing.

The RBSS then identifies risk reduction treatments based on the causes of accidents at the crossing. A wide variety of treatments are listed, from treatments based specifically at the crossing to treatments in the road environment. In comparison the Product Assessment system focuses only on the installation of active controls.

Overall the RBSS takes a more holistic approach by calculating risk based on a wide variety of factors and then treating a wide variety of factors than just at the crossing. It takes into account traffic and train volumes in prioritising the crossing for treatment. The Product Assessment system places a greater emphasis on train and traffic volumes so that crossings with higher volumes are given higher priority for upgraded automatic alarm treatment. Hence the RBSS is likely to be useful in considering possible alternative treatments for level crossings that do not have sufficient traffic to justify an increase in automatic alarm protection.

Application of RBSS to New Zealand

Percival (1997) examined the feasibility of using the RBSS in New Zealand, discussing the advantages and disadvantages of using it over the Product Assessment system.

Advantages of the RBSS over the Product Assessment System:

- It considers a wider range of level crossing characteristics
- It considers a wider range of alternative treatments rather than the traditional ones of automatic alarms, grade separation or completely closing a crossing, thus it can be used for minor upgrades.
- It identifies safety improvements outside the railway corridor
- It could improve overall safety at level crossings over a whole railway network without increasing the rate of installation of new or upgraded automatic alarms
- It attempts to give a more objective quantifiable assessment of many level crossing risk promoting characteristics that are currently considered only subjectively by Tranz Rail
- It has many features in common with the Product Assessment System and thus could be easily adjusted for New Zealand.
- It contains a minimum risk score necessary before any intervention to improve safety need to be taken
- The intervention and installation limits in the RBSS are calculated by considering the level of risk that is currently experienced at railway level crossings and determining a target improvement for the entire road system. Thus in New Zealand limits could be set that align with road and rail target reductions.

Disadvantages of the RBSS over the Product Assessment System:

- It does not include crossing characteristics that have been shown to influence level crossing collision risks on other railways such as:
    - number of trains during daylight hours (NZ and USA)
    - number of road lanes (USA)
- it would be much more complex and expensive to maintain
- it requires a large amount of data for each crossing (29 characteristics)
- its complexity could lead to less transparency when dealing with requests for improved protection from the public and their elected representatives
- it may not be politically acceptable if it caused “collision black spot” level crossings to be removed from the existing upgrading list
- some alternative treatments would not be as clearly visible to members of the public as the installation of upgraded automatic alarms
- the system needs to have wide acceptance by local roading authorities to enforce adoption of treatments outside the railway corridor. It may also need government administration and regulations to enforce adoption of treatments outside the railway corridor.
- many of the RBSS additional level crossing treatments already require treatment by Tranz Rail’s safety code of practice or are recommended in the LTSA Manual of Traffic Signs and Markings, e.g.
    - prohibition of conflicting intersections close to HAB crossings
    - yellow cross-hatching if intersection close

  - additional advance warning signs if visibility of crossing limited
  - prohibition of right turns at intersections near level crossings

Percival also noted some disadvantages of both the RBSS and the Product Number. These were:

- Both do not include crossing characteristics that have been shown to influence level crossing collision risks on other railways such as:
  - road type (USA uses 6 categories from interstate highway to local road)
  - type of passive control currently installed (i.e. Stop or Giveway)
- both do not include the treatment of removing view obstructions.

Despite the disadvantages outlined above with the RBSS Percival concluded that it could have positive benefits for New Zealand, particularly for those crossings that do not have sufficient traffic to justify the installation of upgraded automatic alarms. However the system would need to be tested by applying it to a sample of level crossings in New Zealand including the 70 crossings that have had two or more collisions in the last 10 years. It would also need to be modified to take into account some important New Zealand factors, such as the number of trains during daylight. Furthermore the costs of the RBSS would need to be assessed. This would include surveying all level crossings in New Zealand to assess the 29 characteristics in the RBSS and maintaining a database of the survey results.

Allan Neilson of Toll Rail (personal communication, 2004) noted that the RBSS is likely to be effective in detecting minor upgrades to level crossings, but not at detecting major upgrades. He suggested retaining the Product Assessment but adding on some of the factors included in the RBSS.

Conclusions & Recommendations

Conclusions

In New Zealand the Product Assessment system is primarily used to determine the priority for installation or upgrading of automatic warning devices by Toll Rail. This system takes into account the following factors:

- train volumes
- vehicle volumes
- view factors
- number of tracks

Research in the early 1980s indicates that the Product Assessment system is significantly correlated with the mean annual accident rate. However more recent research has not been conducted to assess whether this is still the case.

There are a number of other systems used internationally to prioritise level crossings. A lot of these systems take into account a wider variety of factors than the Product Assessment system. These include:

- train and vehicle speeds

- road grade/curvature
- adjacent intersections and land use
- crossing control measures
- queuing from adjacent intersections
- driver information load
- number of road lanes

There does not appear to have been any evaluations of the effectiveness of most of these international systems at predicting which crossings have the highest accident risk, or whether the treatments are effective. The only exception was the recently developed Queensland RBSS. A trial of the RBSS indicated that it correlated well with accident history. Furthermore its ability to assess risk and select treatments was judged to be of a high standard by a group of expert engineers from road and rail authorities within Queensland and representatives from stakeholder organisations across Australia and New Zealand.

Due to time constraints further information on international criteria and the Queensland RBSS have not been investigated for this report. It would be useful for this to be conducted in the future before making any changes in New Zealand. Thus it is suggested as a recommendation below.

Recommendations

1. Monitor any further developments with the Queensland RBSS, particularly any evaluations of effectiveness.

2. Investigate other international criteria for prioritising level crossings that have not been included in this report and assess whether there have been any evaluations of such criteria.

3. Assess whether the Product Assessment system is significantly correlated with recent accident data.

4. If there is a very good correlation between the Product Assessment system and accident data then continue to use this system for prioritising crossings for upgrading to active controls, but assess the feasibility of introducing the RBSS for minor treatments.

5. If there is not a good correlation between the Product Assessment system and accident data then conduct a study to assess whether it would be feasible to introduce the Queensland RBSS or a modified version into New Zealand. This study would need to assess the resources required to introduce such a system as well as whether it is likely to be effective in the New Zealand environment.

6. Investigate whether integration of either the Product Assessment system or RBSS system with New Zealand's Crash Analysis System (CAS) is feasible and if so estimate the likely costs, benefits, advantages and disadvantages of an independent system.

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