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ROAD SAFETY RESEARCH REPORT
CR 217

Prospects for improving the conspicuity of trains at passive railway crossings

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Title

Prospects for improving the conspicuity of trains at passive railway crossings

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Abstract

Collisions at railway crossings are the most serious safety issue faced by the rail system in Australia, although the number of deaths and injuries is small compared to other road safety issues.

The purpose of the report is to advise on the need for, the feasibility of, and the potential benefits from further research into train lighting and conspicuity, and its potential to deliver significant reduction in road trauma.

In the period 1996-2000, it is estimated that approximately 36 crashes per year occurred at passive crossings throughout Australia. These crashes resulted in an average of four deaths and six serious injuries per year. The average annual cost of collisions at railway level crossings was estimated to be at least $24.8 million for all crossings, including $16.3 million for active crossings and $8.3 million for passive crossings.

Since there are fewer locomotives (approximately 2300) than passive crossings (approximately 6000), and since locomotive lighting treatments are likely to cost less than even the low-budget active warning systems currently being trialed, treating locomotives appears to be an attractive option. However, there is presently insufficient research evidence to estimate the proportion of collisions at passive crossings that would be prevented by such treatments.

Empirical studies of the effectiveness of auxiliary lighting treatments are reviewed. There is evidence to suggest that all auxiliary lighting treatments are effective and increase detectability or improve estimations of time to arrival compared to headlights alone. A study for the US Federal Railroad Administration showed that crossing lights were the most effective treatment. Studies have also shown that strobe lights can improve detection when added to locomotives previously equipped with headlights alone. However, a recent study for Western Australian Government Railways indicated that a single strobe light did not improve detection when added to locomotives already fitted with both headlights and crossing lights.

If further research into improving locomotive conspicuity is judged to be worth pursuing, it is recommended that it should commence with careful modelling of the photometric properties of proposed conspicuity-enhancing treatments. Since field trials are very expensive and difficult to organise, they should only proceed once a solid case has been established that a treatment has a high probability of

succeeding. The photometric modelling will probably have to be supplemented by photometric measurements and some tests with subjects using real-life visibility aids on a static locomotive to provide data for the modelling process, and to investigate issues which cannot be resolved theoretically, and to confirm the predictions of the models.

Evaluation of the effectiveness of conspicuity treatments in terms of crash reductions will not be practical, due to the small number of crashes available for comparison, unless the proportion of crashes prevented by the treatment is exceptionally high.

Keywords

train conspicuity, train lighting, railway level crossing safety, passive level crossings.

NOTES:

(1) ATSB Research reports are disseminated in the interests of information exchange.

(2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government.

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The problem of collisions at railway crossings is an on-going one for rail operators, track providers and regulators and road authorities in Australia. While the number of deaths and injuries is small in comparison to other road casualties and has been reduced considerably in recent years, they are the most serious safety issue faced by the rail system in Australia.

The genesis of the present project was at a special meeting of the Australian Transport Council (ATC) on 8 August 2002 that considered the outcome of recent tests of locomotive auxiliary lighting. It was agreed at that meeting that the SCOT Rail Group, in consultation with the rail industry, develop a strategic approach to managing the full range of level crossing issues. It was further agreed that Austroads and Rail Group were to review available research on train lighting and visibility and report back to ATC at its meeting on 8 November 2002 on the need for any further research. The Australian Transport Safety Bureau was required to produce this review on behalf of Austroads and Rail Group, and has commissioned ARRB Transport Research Ltd to undertake the work.

The essential purpose of the present report is therefore to advise on the need for, the feasibility of, and the potential benefits of, further research into train lighting and conspicuity that will deliver significant reduction in road safety trauma.

Number of collisions and their associated costs

In the period 1996-2000, it is estimated that approximately 36 crashes per year occurred at passive crossings throughout Australia. These crashes resulted in an average of four deaths and six serious injuries per year. The average annual cost of collisions at railway level crossings was estimated to be at least $24.8 million for all crossings, including $16.3 million for active crossings and $8.3 million for passive crossings. As fatality data for NSW were not available, these estimates were based on the assumption that the distribution of injury outcomes for NSW is similar to that in other states. The estimates are regarded as minimums, since the data for South Australia, Western Australia and the Northern Territory were incomplete. They are based on personal injuries recorded in the road crash system and do not reflect the major losses to the rail system that can occur as a result of a collision with a road vehicle. Rail system loss data are not kept in a systematic manner by all rail operators. Data that were obtained indicated very high losses associated with some incidents. The fatality rate at level crossings per 100,000 population is considerably lower in Australia than in the United States and Finland.

Case for improving train conspicuity

Since there are fewer locomotives (approximately 2300) than passive crossings (approximately 6000), and since locomotive lighting treatments are likely to cost less than even the low-budget active warning systems currently being trialled, treating locomotives appears to be an attractive option. Increasing the conspicuity of locomotives would cost far less than providing active treatments at all passive crossings. However, there is presently insufficient research evidence to estimate the proportion of collisions at passive crossings that would be prevented by such treatments. While available data suggests that active warnings would reduce crashes by more than 60 per cent (Schulte 1976), it is not possible to say by how much increased conspicuity would reduce collisions.

Vehicle/train collisions

Under Australian conditions, approximately 70% of collisions occur during daylight and 30% occur at night. Daytime collisions also predominate in the US, but the difference between daytime and night-time crash occurrence is less marked than in Australia.

In Australia, approximately 65% of crashes involve trains running into road vehicles and 35% involve road vehicles running into the side of trains.

Seven contributing factors related to the driver of the road vehicle have been identified:

- Not detecting the crossing
- Stalling
- Not detecting the train
- Being distracted
- Inaccurate expectancies
- Deliberate risk taking
- Misjudging train speed.

There are very few cases of stalled vehicles on the tracks, and deliberate risk taking is not possible unless the driver has already seen the train. The important contributing factors are, on the one hand, not detecting the train, to which distraction and inaccurate expectancies regarding the presence of a train may contribute; and on the other hand, misjudging the speed of the train. It is not known to what extent each of these factors contributes to collisions at railway level crossings. It seems inherently unlikely that adding more lights to the train would result in more accurate (or at least more cautious) perceptions of train speed. This leaves cases which involve not detecting the train, distraction and expectations that a train will not be present as events where adverse outcomes could be avoided by better train conspicuity. Unfortunately, it is not possible to say what proportion of cases this involves, or by how much increased conspicuity (assuming effective increases in conspicuity were possible) is likely to reduce this.

Lighting standards

The Australian Rail Operations Unit, in consultation with the rail industry, is in the process of developing a draft Code of Practice for the Defined Interstate Rail Network to provide uniform guidance for the design and construction of rolling stock. The relevant volume of the Code includes provisions for lighting and reflectorised material on trains. The draft code has mandatory provisions for headlights and ‘road visibility lights’, which are similar to crossing lights. Reflectors are optional, but where provided the reflective sheeting must be to Class 1A standard and there are mandatory provisions for minimum dimension, placement and colour.

The present report discusses characteristics of different lighting systems and puts forward an outline for the development of photometric models to predict the relative visibility of different lighting treatments.

Empirical studies of the effectiveness of auxiliary lighting treatments are reviewed. There is evidence to suggest that all auxiliary lighting treatments are effective and increase detectability or improve estimations of time to arrival compared to headlights alone. A study for the US Federal Railroad Administration showed that crossing lights were the most effective treatment. Studies have also shown that strobe lights can improve detection when added to locomotives previously equipped with headlights alone. However, a recent study for Western Australian

Government Railways indicated that a single strobe light did not improve detection when added to locomotives already fitted with both headlights and crossing lights.

Possible means of improving train conspicuity

It is possible that daytime crashes might be reduced by adding coloured strobe lights or by selection of colour schemes which better contrast with the background against which locomotives on particular lines are viewed.

Although reflectorised panels may be effective in improving conspicuity, they may not be effective at crossings where the road does not cross the rail track at right angles. Self-illuminated devices, similar to those currently available as road delineators (also known as cat's eyes), may be a viable alternative.

Conduct of future research

If it is decided that the scale of the problem and the potential benefits warrant further research, then it is recommended that the following procedure be followed. Future research should proceed first by careful modelling of the photometric properties of proposed conspicuity-enhancing treatments. Only once there is a solid case established that a treatment has a high probability of succeeding should any field work be undertaken. The photometric modelling will probably have to be supplemented by photometric measurements and some tests with subjects using real-life visibility aids on a static locomotive to provide data for the modelling process, resolve issues which cannot be resolved theoretically and confirm the predictions of the models. The cost of the photometric modelling exercise is estimated at $75,000 and the supplementary program of measurements and tests at $15,000 to $45,000. A study of the safety margins allowed by drivers when crossing in front of a train would cost approximately $105,000, including equipment and a pilot study to confirm the feasibility of the method. The total program of recommended research would cost up to $225,000.

Evaluation of the effectiveness of conspicuity treatments in terms of crash reductions will not be practical, due to the small number of crashes available for comparison, unless the proportion of crashes prevented by the treatment is exceptionally high.

1 INTRODUCTION

1.1 Background

The problem of collisions at railway crossings is an on-going one for rail operators, track providers and regulators and road authorities in Australia. While the number of deaths and injuries is small in comparison to other road casualties and has been reduced considerably in recent years, they are the most serious safety issue faced by the rail system in Australia, resulting in more than 40 per cent of the rail-related deaths in Australia. Because they are relatively rare events and have large impacts on smaller rural communities when they do occur, coronial inquests tend to attract wide media coverage. Unlike many road crashes, there is someone other than the road users themselves to blame for the collision, so that there are often vigorous attempts to exonerate the victim by attempting to identify shortcomings in railway crossing treatments, visibility of trains or railway procedures.

The form of traffic control implemented at a railway level crossing greatly affects the decision that has to be made by the driver of the road vehicle and the safety of the crossing. A distinction is generally made between crossings with active control, which have flashing lights activated by the train to warn road users of the approach of the train, and passive crossings, which depend on static signs to identify the crossing and inform drivers of appropriate procedures at that particular crossing.

Collisions at passive crossings are often particularly controversial since, on the one hand, there is no direct signal that the driver of the road vehicle has disobeyed and, on the other, it is always open to question whether, had some aspect of the signing been different or had the train been more clearly visible, the collision would not have occurred.

In the period 1996–2000, it is estimated that approximately 36 crashes per year occurred at passive crossings throughout Australia. These crashes resulted in an average of four deaths and six serious injuries per year.

There has recently been an increased focus of attention in Australia on accidents at passive railway crossings. This has been influenced by:

- the 2001 report of the Western Australian Coroner into a triple fatality crash at a passive crossing, which recommended the fitting of additional auxiliary lights on locomotives,
- the Austroads project ‘Reducing collision risk at passive railway level crossings’,
- the 7th International Symposium on Railroad-Highway Grade Crossing Research and Safety, held at Monash University in February 2002 (the Monash Symposium) and
- a Western Australian field trial of additional auxiliary lighting following the Coroner’s recommendation.

The genesis of the present project was at a special meeting of the Australian Transport Council (ATC) on 8 August 2002 which considered an Austroads report ‘Reducing collisions at passive railway level crossings in Australia’. It was agreed at that meeting that the SCOT Rail Group, in consultation with the rail industry, develop a strategic approach to managing the full range of level crossing issues. It was further agreed that Austroads and Rail Group were to review available research on train lighting and visibility and report back to ATC at its meeting on 8 November 2002 on the need for any further research. The Australian Transport Safety Bureau was required to produce this review on behalf of Austroads and Rail Group, and has commissioned ARRB Transport Research Ltd to undertake the work.

The Austroads report, relying largely on a recent report on a trial of train lighting carried out for the Western Australian Government (Cairney, Cornwell and Mabbott, 2002), concluded that further lighting in addition to crossing or ditch lights was not effective in increasing the conspicuity of locomotives or the accuracy with which their time to arrival could be judged. One of the report's recommendations was that reflective strips applied to the side of rolling stock may be considered where there is a risk of road vehicles running into trains on crossings at night. However, the report notes that the strips might not be effective when crossings are skewed, as the efficiency of retroreflective materials in returning light to its source decreases with increasing entry angle.

1.2 Purpose

The purpose of the present report is to advise on the need for, the feasibility of, and the potential benefits of, conducting further research into train lighting and conspicuity that will deliver a significant reduction in road safety trauma.

The brief for this study specifically required the review to address the following issues:

- number and estimated economic costs of passive level crossing crashes in Australia;
- relevant research on train lighting and conspicuity in relation to passive level crossing crashes;
- an estimate, based on the best available information, of the proportion of passive level crossing crashes in which conspicuity might be an important factor;
- the range of conspicuity enhancement options that might have potential;
- estimates of option implementation costs, so far as this is possible;
- additional research information that would be needed to provide a clear basis for decisions about the implementation of conspicuity measures, and the limitations which apply to this information;
- the feasibility, including limitations and barriers, and likely cost and timeframe of conducting such research; and
- the potential benefit of such measures relative to other safety research options and an assessment of the likelihood that there would be clear answers about the benefits.

2 NUMBER OF COLLISIONS AT PASSIVE LEVEL CROSSINGS AND THEIR ASSOCIATED COSTS

2.1 Number of collisions

At the Monash Symposium, Ford and Matthews (2002) presented a review of safety at railway level crossings in Australia over the period 1996-2000. Included with their paper in the conference proceedings was a series of spreadsheets on which the analysis in their paper was based. These spreadsheets have been reanalysed to produce the tables and diagrams on which this section is based.

It should be emphasised that these data have serious limitations. Ford and Matthews attempted to count the number of deaths at each type of protection, but this proved difficult since they received no fatality data at all from New South Wales, whilst the data for South Australia, Western Australia and the Northern Territory were also incomplete. These omissions limit the general application of the data from this ambitious project. Moreover, the authors emphasise that the number of minor injuries is of limited reliability because this detail is not accurately recorded by some authorities.

Figure 1 shows the number of collisions at different types of level crossing from 1996 to 2000. The total number of collisions has remained at around 100 per year, with the exception of 1999 when the number of collisions was substantially lower. Over the period, 37 per cent of collisions occurred at passive crossings, nearly all of them at crossings with Give Way control. Collisions have changed little at passive crossings over the period, but have reduced considerably at crossings with active control. Very few collisions occur at crossings with other types of control (traffic signals or manually-operated gates).

FIGURE 1:
Estimated number of collisions at railway level crossings with different types of control, Australia 1996–2000

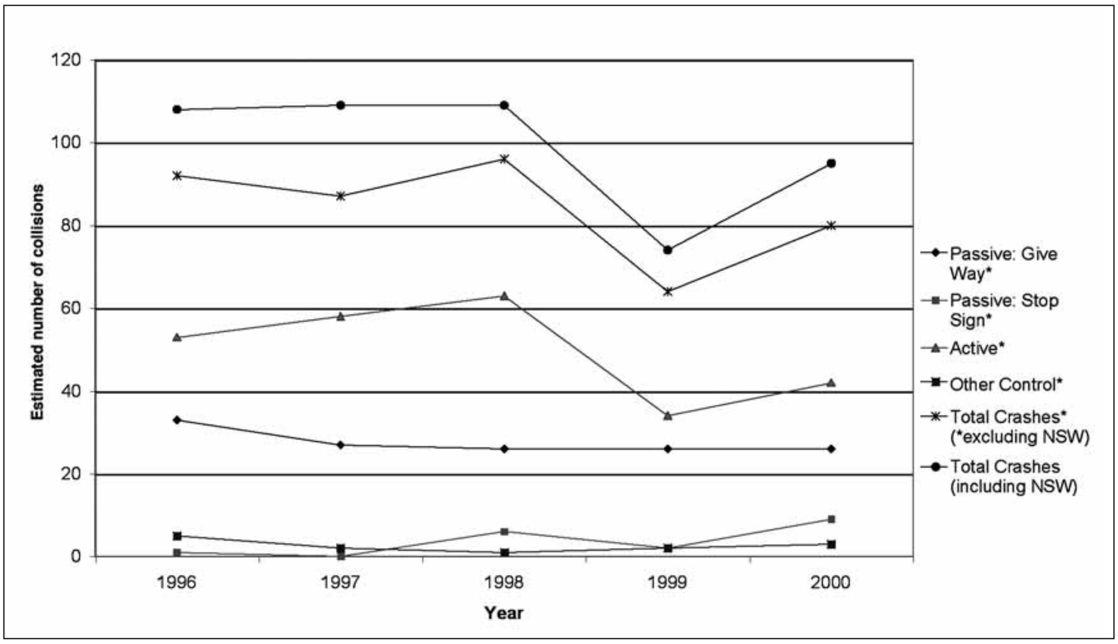


Figure 2 shows the number of people killed or injured at different crossing types over the study period. Thirty-four per cent of the deaths and injuries occurred at passive crossings. Over the same period, casualties at active crossings have reduced by almost 50 per cent, and casualties at passive crossings with Give Way control have reduced by 66 per cent.

FIGURE 2:
Estimated number of people killed or injured at railway level crossings with different types of control, Australia 1996–2000

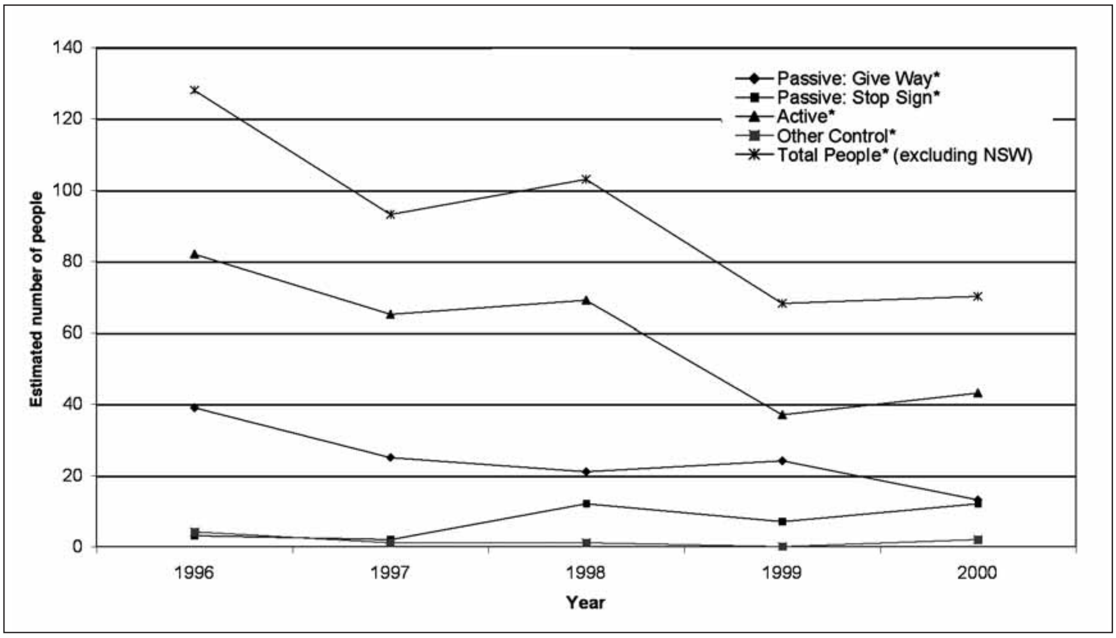
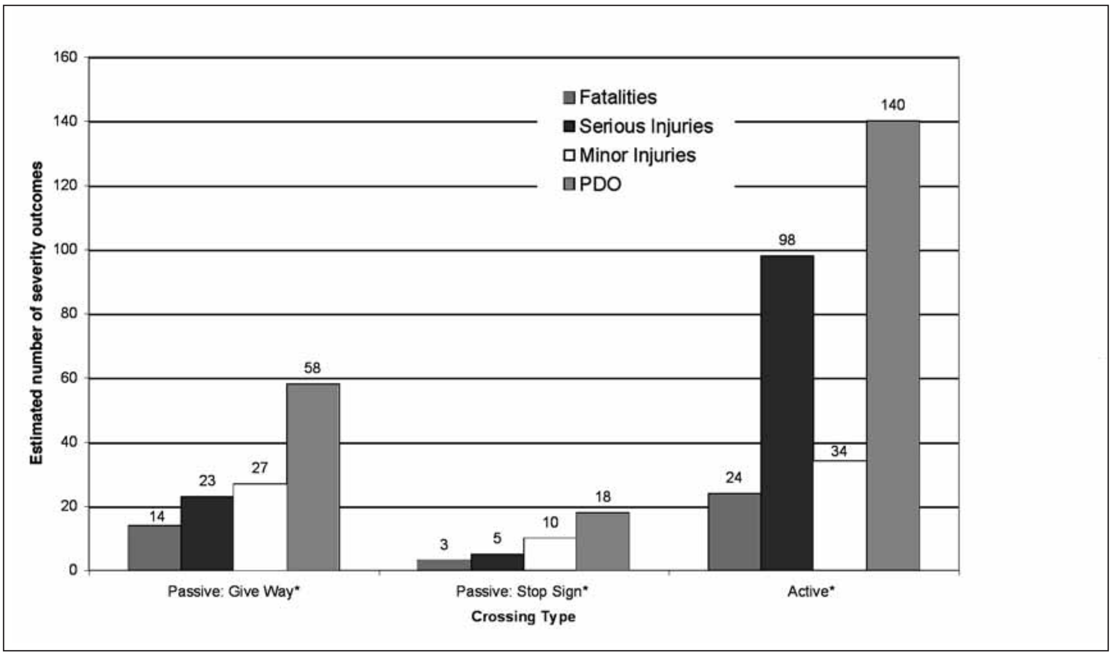


Figure 3 shows the number of different collision outcomes with different crossing controls. The most obvious feature is the high frequency of serious injuries and low frequency of minor injuries occurring at active crossings.

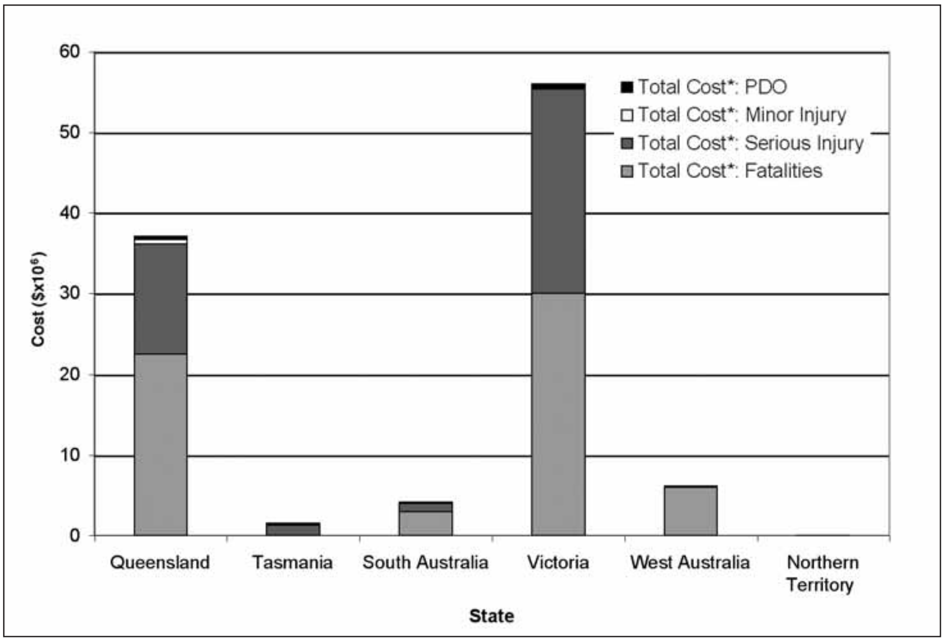
FIGURE 3:
Estimated frequency of different severity outcomes by type of crossing control at railway crossings, Australia



* *Excluding NSW 1996-2000*

2.2 Estimated costs

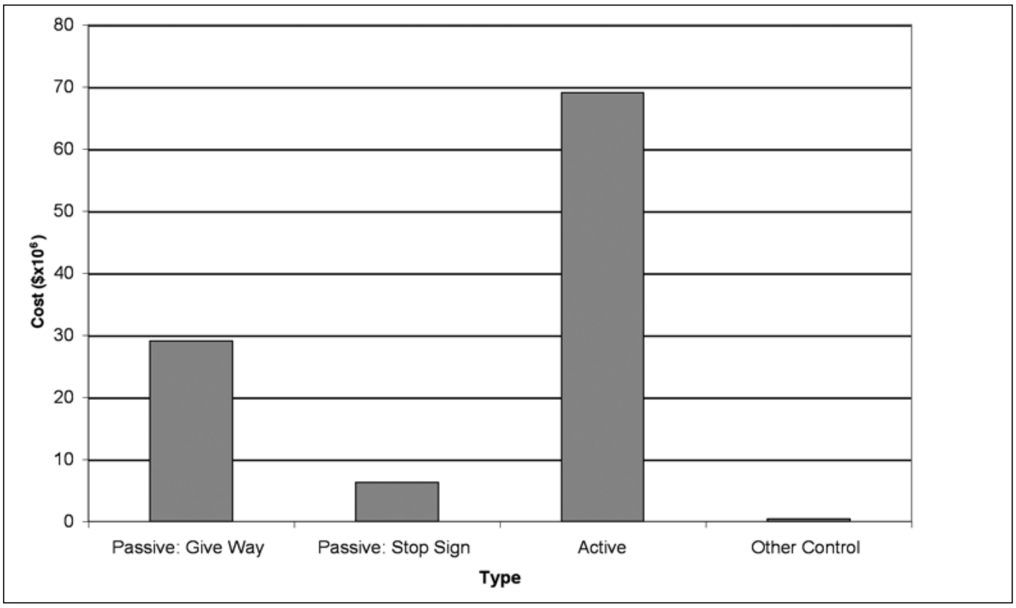
FIGURE 4:
Estimated cost of crashes at railway level crossings in Australia, 1996–2000



The cost of crashes at level crossings was estimated using the following procedure using the casualty and crash data presented by Ford and Matthews (2002) and recent estimates of crash costs in Australia developed by the Bureau of Transport Economics (BTE 2000). Certain incompatibilities in the approaches adopted in the two documents prevent this being an exact estimate, but the team believes the estimate is sufficiently accurate for the purposes of the present discussion.

Numbers of property damage only (PDO) collisions were extracted from the spreadsheets provided by Ford and Matthews (2002), and the value of a property damage collision developed by BTE allocated to these collisions. It is not known how the distribution of costs arising from collisions with trains compares to the distribution for all traffic collisions, so this procedure must be regarded as an approximation.

FIGURE 5:
Estimated cost of crashes at railway level crossings with different types of control, Australia 1996–2000



In the case of fatal or injury crashes, the total numbers of fatalities, serious injuries and minor injuries were extracted from the Ford and Matthews spreadsheets, and the relevant BTE costs for a fatality, serious injury and minor injury applied. The sum of each of these items provides an estimate of the total person costs. These totals are shown for each jurisdiction in Figure 4 and by each class of device in Figure 5. These estimates are based on personal injuries recorded in the road crash system and they do not reflect the major losses to the rail system that can occur as result of a collision with a road vehicle.

The breakdown of costs by type of protection for each year of the study is shown in Table 1. It can be seen that 1996 was an exceptional year, with much higher costs than subsequent years. Including 1996, the average cost of collisions was $21.0 million at all crossings, comprising $13.8 million at active crossings, and $7.1 million at passive crossings.

TABLE 1:
Estimated crash costs ($ million) at crossings with different types of protection, Australia excluding NSW, 1996–2000

Type of protection	*1996*	*1997*	*1998*	*1999*	*2000*
Passive: Give Way	14.4	4.4	5.9	3.3	1.1
Passive: Stop	-	-	-	1.0	5.2
Sub-total at Passive Crossings	14.4	4.4	5.9	4.3	6.3
Active	19.0	11.5	17.5	8.6	12.5
Other control	0.3	-	-	-	-
Total	**33.9**	**16.0**	**23.5**	**12.9**	**18.7**

Note: Totals slightly exceed column entries due to rounding errors and small sums in some individual cells.

Data provided by Ford and Matthews show that the number of collisions at railway crossings in New South Wales is equivalent to 18 per cent of the total collisions occurring in all other states. If we assume these collisions have the same distribution across types of control and have the same distribution of severity outcomes, figures for Australia as a whole can be estimated by increasing the costs from the states where these distributions are known by 18 per cent. This produces estimates of the annual costs of collisions in Australia at $24.8 million for all crossings, including $16.3 million for active crossings and $8.3 million for passive crossings.

Even these figures are known to be under-estimates, since Ford and Matthews not only received no data from New South Wales but also received incomplete data from several other states (South Australia, Western Australia and the Northern Territory).

2.3 International comparisons

The US experienced 173 fatalities at level crossings in 2000 (FRA 2001), equivalent to a rate of 0.06 per 100,000 population. Pajunen (2002) reports the equivalent rate for Finland as 0.21 per 100,000 population. With an estimated average of four deaths per year at passive crossings, Australia's rate is 0.02 deaths per 100,000 population, considerably lower than either of these. These comparisons do not take account of differences in train and road traffic flow or the number of level crossings in each country.

2.4 The potential for major disaster

The costs estimated in Section 2.2 are based on personal injuries and damage to road vehicles, and are averages for recent years. They do not include the costs of any major disasters such as collisions between trains and petrol tankers or school buses, both of which have occurred in the past. In addition, these costs do not take account of damage to railway infrastructure or rolling stock. Although some collisions result in extremely large losses for the rail industry, no national statistics are available for such incidents in Australia. Approaches to rail operators and regulators produced some data which give an overview of the issue.

In New South Wales, there have been thirteen derailments as a result of collisions at railway level crossings, both active and passive, since 1992 (Ford, personal communication). Four of these were fatal crashes, one of which involved five fatalities. Three involved the XPT high-speed passenger train, placing a large number of rail passengers at risk of injury. One collision involved the release of sodium cyanide and another resulted in fuel leaks from a derailed locomotive.

Seventeen major incidents occurred at railway level crossings in Queensland over the same period (Barron-Hamilton, personal communication). This data set is particularly useful as it includes estimated costs of the incidents. Eight of the incidents involved semi-trailers and a further three involved trucks; 13 incidents resulted in a derailment. Six of the 17 incidents occurred at passive crossings, five at active crossings and the type of crossing protection was not clear from the brief narrative in the remainder of cases. The highest cost ($3.25 million) was associated with an incident where a train collided with a road train, derailing the train's two locomotives and destroying both the lead locomotive and the prime mover. Other high-cost events included the derailment of a train carrying sulphuric acid in a collision with a semi-trailer ($2 million), the collision of a train and a semi-trailer resulting in the locomotive and some wagons being derailed ($1.7 million) and another incident involving a collision between a train and a semi-trailer where the locomotive was written off ($607,000). Note that these costs apply only to the railway's direct costs and do not include the person costs used to calculate the amounts in Section 2.2.

Over ten years, New South Wales and Queensland experienced thirty major incidents, or three per year. Assuming the rest of Australia has a similar crash experience on a population basis, approximately six such incidents can be expected across the country each year. If it is assumed that a third of them occur at passive crossings, then we can expect two major incidents per year.

3 CASE FOR IMPROVING TRAIN CONSPICUITY

In principle, there are a number of possible strategies for reducing crashes at railway level crossings. These include:

1. Improving the conspicuity of the train, in order to increase the probability that the driver of the road vehicle will detect the train.
2. Providing active control at the crossing, eliminating the need for a driver to make a decision.
3. Providing some form of direct communication between the train and the road vehicle which would warn the driver of the approaching train.
4. Improving crossing signing, markings and other forms of passive warning.
5. Education, training or enforcement programs aimed at road vehicle drivers.
6. Improving sight distance or reducing the speed of trains and/or road vehicles.
7. Closing the crossing.

Only Options 1 and 2 will be examined in detail. Option 3 is not yet viable and likely to be justified only as part of an Intelligent Transport Systems package which embraces many more functions. Option 4 was recently examined in depth by SCOT and Australian practice found to be at least as good at that in other countries. Option 5 will not be helpful if drivers do not detect the train in time to react appropriately. Option 6 may be useful at some crossings but is outside the scope of the present study. Option 7 requires that either the road or the railway be closed or a grade-separated crossing ('flyover') be constructed, and is likely to be a viable option for very few crossings or in exceptional circumstances, such as dramatically increased train speeds on upgraded lines.

3.1 The number of passive crossings and the cost of upgrading to active protection

Ford and Matthews (2002) assembled data on the number of railway crossings with different types of protection in each of the Australian jurisdictions. The results are summarised in Table 2.

TABLE 2:
Number of level crossings with different types of protection

Type of protection	*Number*	*Per cent*
Passive protection	6,060	65
Active protection	2,808	30
Other	512	5
Total	**9,380**	**100**

Source: From Ford & Matthews 2002

Passive treatments are by far the most common. It has not so far proved possible to obtain 'typical' costs for installing active protection at railway level crossings since costs vary considerably from site to site and between railway systems. It has not been possible to determine to what extent these latter differences are due to work practices and to what extent they are due to accounting procedures.

An educated guess suggests that the minimum plausible cost of installing conventional active protection on mainland Australia as part of a mass action program would be in the order of $200,000 per crossing, and an upper order estimate would be in the order of $300,000. The cost of installing conventional active protection at all passive crossings would therefore be between $1.2 billion and $1.8 billion. In addition, on-going maintenance costs would be considerable in view of the remote location of many passive crossings.

At time of writing, Victoria is proceeding with trials of a new type of device which promises to deliver active warning of the approach of a train at considerably lower cost (Jordan 2002). In addition to the technical issues of reliability, issues relating to the status of the message the device is intended to convey and where and how it is to be used need to be resolved before it is available for general use. The present estimates for the cost of the device are approximately $40,000. While this represents a substantial reduction on the costs of current technology, equipping all currently passive crossings would cost approximately $240 million. Ongoing maintenance costs are not known at present.

3.2 Cost of improving the conspicuity of the locomotive fleet

According to the Australasian Railways Association Yearbook for 2001, 2381 locomotives were in service in Australia (ARA 2001). We cannot be certain what the cost of effective enhanced conspicuity treatments would be, but $5,000 per locomotive would probably buy some fairly elaborate lighting equipment. As a benchmark, a pair of rotating beacons similar to those used on emergency vehicles, can be purchased for less than $1,000. If we assume it costs $1,000 to fit the equipment, then costs would probably be in the region of $2,000 - $6,000 per locomotive, or $4.8 million - $14.4 million to equip the national fleet. However, it is not clear what impact this would have on reducing crashes. While we can be confident that fitting crossing lights to a locomotive equipped with only a headlight will have a major impact on conspicuity, adding further lighting to a locomotive already equipped with a headlight and crossing lights will inevitably have much less impact. The issue of the locomotive lighting will be examined in detail in Section 5 and the issue of a quantitative relationship between increased conspicuity and reduced collisions in Sections 4 and 6.

Increasing the conspicuity of locomotives would cost far less than providing active treatments at all passive crossings. While available data suggests that active warnings would reduce crashes by more than 60 per cent (Schulte 1976), it is not possible to say by how much increased conspicuity would reduce collisions.

Considering the net annualised costs of the treatments provides another perspective on the issue. The net annualised cost of a treatment distributes costs of the treatment over its service life, discounted at the prevailing rate. If we assume that both conspicuity treatments for locomotives and low-cost level crossing treatments have a life of twenty years, and a discount rate of 7 per cent is used, the annualised costs of treating all passive crossings would be $22.7 million and of equipping the locomotive fleet between $0.5 and $1.4 million.

In the absence of predicted benefits, it is not possible to conduct a conventional benefit-cost analysis, the usual method for comparing two proposed projects. An alternative is to consider what savings the projects would have to generate in order to justify the expenditure. This is sometimes referred to as a ‘break-even’ analysis. It is often reasonable to assume that counter-measure projects with a benefit:cost ratio less than 2 will not be funded because other project options will be available that yield a greater return for the proposed investment. In the case of providing active controls, the annualised cost is $22.7 million and the annual break-even saving would therefore be $45.4 million. In Section 2.2, the average annual cost of collisions at passive crossings was estimated at $7.4 million. The break-even saving for a comprehensive program of active controls is therefore between six and seven times the annual cost of collisions at passive crossings. For improved conspicuity treatments, the annualised cost is $0.5–1.4 million and the break-even saving is $1–2.8 million, equivalent to 14-38 per cent of the average annual cost of passive crossing collisions.

Some differences in the annualised costs and the consequent break-even points would be evident if different discount rates or different predicted lives were assumed for the treatments. In the case of the active crossing treatments, the cost of the *program* would be considerably reduced if the treatments were installed at, say, the one-third of crossings where they are most needed. In fact, it is extremely unlikely that even low-cost treatments can be justified or afforded at all passive crossings. A more limited program targeting crossings with the highest train and road traffic flows or particular risk factors is likely to deliver much of the possible benefit at lower cost.

4 VEHICLE/TRAIN COLLISIONS

The relationship between improved conspicuity, higher probability of detection and reduced crashes is complex and uncertain. In order to estimate the likely effect of improved conspicuity on collisions between trains and road vehicles, and to assess its impact in relation to other measures, it is necessary to identify the possible factors which contribute to an event of this type and to identify the extent to which each type of contributing factor might be addressed by improved conspicuity. In turn, this requires an understanding of the per centage of collisions occurring during daylight and during darkness and the nature of the collision between the road vehicle and the train. These issues are addressed in this section.

4.1 Proportion of daytime and night–time collisions

Wigglesworth presents figures for collisions at passive crossings in Victoria for 1973–1976 (Wigglesworth, 1979) and 1977–1991 (Wigglesworth, 1992). Eighty three out of 113 collisions (73 per cent) occurred between 6.00 a.m. and 6.00 p.m. A similar pattern emerges in Western Australia, with 71 per cent of collisions in the period 1990–2000 occurring during daytime and only 29 per cent at night (MRWA 2000). Cairney (1990) examined crash records for collisions between road vehicles and trains in New South Wales between 1984 and 1988. Although no crash counts are presented, it is clear from Figure 2.4 in his report that more crashes occurred during daytime. Note that these last two sets of results are for all types of crossing control.

A recent monograph examined fatal crashes at railway level crossings in Australia over some of the years in the period 1988–1998 (ATSB 2002). The predominance of daytime crashes is supported by this analysis, which identified 83 per cent of the crashes occurring during daylight.

Under Australian conditions, it would therefore seem that approximately 70 per cent of collisions occur during daylight.

Examination of the US Federal Railroad Administration (FRA) annual report on railroad safety statistics reveals that 64 per cent of collisions in the US occur between 6.00 a.m. and 6.00 p.m. (FRA 2001). This figure relates to all types of level crossing control. Breakdown by time of day and crossing control is not available in the report. These proportions of daytime and night-time crashes are supported by the results from a study of vehicle-train collisions in the US State of Ohio in the period 1989–1998, which found 60 per cent of passive crossing crashes occurred during the day and 40 per cent occurred at night (Schnell and Zwahlen, 1998). Thus although daytime collisions predominate, the difference between daytime and night-time crash occurrence is less marked than in Australia.

4.2 Pattern of impacts

The way in which conspicuity might best be improved depends upon the nature of the collision between the train and the road vehicle. In instances where the train strikes the road vehicle, conspicuity of the locomotive, viewed frontally, is the critical issue. In instances where the road vehicle hits the side of the train, conspicuity of the train viewed from the side appears to be the issue.

Cairney's (1990) examination of collisions in New South Wales mentioned in the previous section is particularly useful in that he used the diagram on the accident report form to identify the nature of the collision between the road vehicle and the train (see Table 3). This makes interesting comparison with Wigglesworth's similar examination of *fatal* vehicle train collisions in Victoria over the period 1977–1991, (Wigglesworth 1992 – see Table 4). There is a higher percentage of train-hit-vehicle impacts in the latter study, which is only to be expected since it examined only fatal collisions. Collisions where road vehicles hit trains are likely to occur at lower impact speed, since the driver of the road vehicle is likely to brake before impact. Occupants are also likely to be better protected by the vehicle's structure than in cases where trains hit road vehicles, and so the former are less likely to result in a fatality.

TABLE 3:
Number and per centage of collisions of different types at passive railway level crossings in NSW, 1984–1988

Type of collision		*Number*	*Per cent*
Road vehicle stopped or stalled on tracks		3	4
Train hit front of road vehicle	25		
Train hit middle of road vehicle	13		
Train hit rear of road vehicle	3		
Total train hit road vehicle (excluding stalled vehicles)		41	59
Road vehicle hit side of train		25	36
Road vehicle took evasive action, hit train side-on		1	1
Total		**70**	**100**

Source: Adapted from Cairney, 1990

TABLE 4:
Deaths at passive crossings in Victoria 1973–91

Type of collision	*Number*	*Per cent*
Road vehicle stopped or stalled on tracks	-	-
Train hit road vehicle	48	79
Road vehicle hit side of train	13	21
Road vehicle took evasive action, hit train side-on	-	-
Total	**61**	**100**

Source: Adapted from Wigglesworth 1992

The recent ATSB Monograph (ATSB 2002) examined 87 fatal level crossing crashes and found that the impact point was the front of the train in 66 per cent of cases, the side of the train in 16 per cent of cases and was unknown in 18 per cent of cases.

Glennon and Loumiet (1992) showed that during daylight hours 75 per cent of vehicle-train accidents involved a motor vehicle being struck by a train, while at night almost 50 per cent of accidents involved the motor vehicle running into the side of the train.

The current FRA report does not permit analysis by light conditions, but it does reveal the pattern shown in Table 5. At passively controlled crossings, the locomotive striking the road vehicle is by far the most frequent type of event (FRA 2001).

TABLE 5:
Pattern of impacts between locomotives and road vehicles at railway level crossings in the USA, 2000

Type of control	*Per cent collisions in which locamative struck road train*	*Per cent collisions in which road vehicle struck locomotive*
Gates	82	18
Flashing lights	69	31
Give Way, crossbucks	86	14
Stop, crossbucks	76	24

Source: *Extracted from Federal Railroad Administration, 2001*

4.3 Effect of upgrading from passive protection to flashing lights

An important part of the decision as to whether further research on train conspicuity is justified is the potential benefits likely to be realised in comparison to the benefits that might be realised from other approaches to improving safety at passive railway level crossings. The most obvious improvement is conversion of the crossing from passive to active, so it is important to understand the effect this change has on safety.

The literature review uncovered only one study which addressed this issue directly using a before and after study design.

As part of a wider study of railway level crossing protection, Schulte (1976) examined crashes at 245 crossings in California before and after the crossing protection was upgraded from crossbucks to flashing lights. He found that vehicle-train crashes decreased by 64 per cent after the installation of flashing lights, fatalities decreased by 83 per cent and injuries decreased by 84 per cent.

We can have confidence in these results, since studies which compare crash rates at passive crossings with crash rates at crossings with active protection give broadly similar results.

The FRA 'Railroad Safety Statistics' report is particularly useful in this regard, as it contains a table which compares different types of crossing protection per 100,000 average daily uses of the class of facility by road vehicles (equivalent to 36.5 million vehicles using the crossing per year). Table 6 has been extracted from that report.

TABLE 6:
Number of crashes and deaths and associated rates at railway level crossings with different types of protection in the USA, 2000

Crossing protection	*Crashes*	*Crashes per 100,000 ADT*	*Deaths*	*Deaths per 100,000 ADT*
Crossbucks	1,038	2.02	405	0.26
Stop Sign	315	4.53	103	0.57
Flashing lights	662	0.65	63	0.06
Gates	804	0.57	69	0.05

Source: *Extracted from Federal Railroad Administration, 2001*

The crash rate at flashing lights is 32 per cent of the rate at crossbucks, and 14 per cent of the rate at crossings controlled by Stop signs. The difference in the fatality rates is similar. Crash rates and fatality rates are higher at crossings with Stop signs than at those with crossbucks. To some extent this may be due to sight distance restrictions or other features which lead to higher crash rates, and to an unknown extent the result of changing to a Stop sign if a serious crash has occurred. Surprisingly, there is relatively little difference in the crash rate for flashing light and gates treatments.

4.4 The potential for improved conspicuity to reduce crashes at railway level crossings

In order to estimate how much increased conspicuity might reduce crashes at railway level crossings, it is necessary to consider how prevalent the different contributing factors are and to consider how effective increased conspicuity might be in each case.

Seven contributing factors related to the driver of the road vehicle have been identified:

- Not detecting the crossing
- Stalling
- Not detecting the train
- Being distracted
- Inaccurate expectancies
- Deliberate risk taking
- Misjudging train speed.

1. **Not detecting the crossing.** The first of these will not be considered further, as the earlier report on reducing collisions at passive crossings echoed the conclusions of the Monash Symposium that Australian practice at passive crossings leads the world. This is not to say that practice is so good that road users will never fail to detect a crossing, but rather a recognition that, for the time being at least, there is no additional sign or marking which is likely to make a substantial difference to detecting the presence of a crossing.
2. **Stalling.** The second issue, stalling, is sufficiently extensive to require recognition as a contributing factor. Cairney (1990) reported that 4 per cent of the vehicles hit at passively controlled crossings in New South Wales in the period were stalled on the crossing. Further support for stalling to be a problem of this approximate magnitude comes from analysis of the FRA Railroad Safety Statistics. Table 8-14 of that report classifies events as to whether the road vehicle was stalled, stopped, moving or trapped. On crossings controlled by crossbucks, 33 of 783 incidents were classified as 'stalled'; at crossings controlled by Stop signs, the number was 16 of 272. In total stalling contributed to 49 (or 2.5 per cent) of the 2,227 incidents included in that report. Thus relatively few incidents involved vehicles stalled on the crossing, and these incidents are not likely to be greatly affected by the conspicuity of the locomotive.
3. **Not detecting the train.** This factor is intimately bound up with the next two, distraction and expectancies, and it is difficult to draw clear distinctions between them. In many vehicle-to-vehicle collisions on the road network, 'looked but failed to see' is a classic description of the driver behaviour leading to a large number of crashes. The phenomenon is well established from early in-depth studies of road crashes (eg Sabey and Staughton 1975), and has been verified by detailed analysis of driver behaviour recorded in police investigations of crashes at the intersections of arterial and local roads in Melbourne (see Cairney and Catchpole 1996 for a summary). It is possible that some vehicle-train collisions may result from events of this type, in which the driver has no particular expectancy about the likelihood of a train being present at a crossing, but misses detecting it despite looking in the right direction. In view of the fact that most crashes at passive crossings involve people who are familiar with the crossings and have therefore established expectations regarding train frequency (e.g. Wigglesworth, 1979), this is likely to involve a small proportion of collisions only.

4. **Being distracted.** Drivers can only cope with a limited range of activities at any one time. Having to cope with aspects of the driving task which do not usually require attention may result in reduced attention to other aspects; safety-critical tasks may be among those which receive less attention. Wigglesworth (1978) drew attention to the importance of pavement surface as a distractor at railway level crossings, especially for motorcyclists for whom picking their way safely across an uneven crossing surface could be a very demanding task.

5. **Inaccurate expectancies.** Drivers develop strong expectancies regarding the performance of the road system and the way other drivers behave. Fuller (1991), amongst others, has described the process by which drivers come to develop what might loosely be called 'bad driving habits', eg by learning to travel at inappropriately high speeds through a process of receiving regular small rewards for exceeding the speed limit in the form of faster travel times or more satisfying driving, without encountering any adverse consequences.

   Wigglesworth (1978) described how a similar process may operate in building up expectations regarding the presence of trains at level crossings. Most crossing users live locally and use the crossing regularly. Many passive crossings carry little rail traffic, often of a seasonal nature. It is therefore possible for a drivers to be a regular user of a crossing, but rarely if ever to see a train using it, unless their habitual travel patterns coincide with train movements. In these circumstances, they develop a belief that trains are unlikely to be present, and cease to adopt suitable monitoring strategies or speeds, placing them at risk if they change their travel times to coincide with train movements, or if there are train movements outside the usual timetable.

   Active warning of the approach of a train is the most effective answer to these maladaptive expectancies. However, where this is not justified then providing a train with a powerful warning device is the next best thing. Writing more than 30 years ago, Aurelius and Korobow (1970) calculated that an audible warning capable of alerting the occupants of a road vehicle travelling at more than 105 km/h would have to be so loud that it would cause pain to train crews and local residents near the sound source (mounted on the locomotive). Wigglesworth (1976) also concluded that a train whistle loud enough to be an effective warning in an emergency situation would result in noise-induced hearing loss for train crews and trackside communities. Recent improvements in vehicle sound-proofing are likely to have further exacerbated the difficulty of audibly warning drivers of the approach of a train. The critical questions for the present paper are therefore whether more prominent *visual* signals are likely to lead to earlier detection by drivers who are not maintaining a high level of vigilance, and if so whether the likely outcomes justify the investment in research and development anticipated.

6. **Deliberate risk taking**. One final issue remains to be considered, and that is deliberate risk taking. Deliberate risk taking is more a feature of active crossings, particularly those with barriers which do not close off both sides of the carriageway. This is however not deemed to be a major problem at active crossings in Australia (Wigglesworth 2002), and there is no evidence to suggest that it applies at passive crossings in Australia.

   Risk-taking is not particularly relevant to the present discussion, since drivers have to be aware of the presence of a train and its speed before they can deliberately take risks. Improved train conspicuity might reduce unintentional risk taking if it enabled road users to make more accurate judgements of the speed or distance of the train; this possibility is discussed next.

7. **Misjudging train speed.** There is reason to believe that misjudging train speed may be a significant factor contributing to drivers of road vehicles making inappropriate decisions about the time available to cross in front of a train. One of the present authors had compelling subjective experience of this phenomenon in the course of supervising the Western Australian trial (Cairney et al. 2002). The experience of watching the train approach a crossing from the position at which a car would be stopped is that, long after the train is visible, it hardly seems to be moving. As the train comes close, it seems to pick up speed rapidly and seems to be travelling very fast through the crossing.

   Leibowitz (1985) comments on this issue, and attempts to explain it in terms of an established phenomenon that larger objects seem to be travelling at slower speeds, even for highly experienced observers, such as commercial pilots observing the movements of large and small aircraft. However, this does not seem to fit the phenomenon described in the preceding paragraph. This is more akin to the process described by Schiff (1965). A motorist waiting at the crossing has very little sense of the train moving through the environment. The dominant cue to the distance of the train is the visual angle of its image on the motorist's eye. The size of the image doubles every time distance is halved, so that to begin with, the train covers large distances with only small changes in the retinal image. The closer the train gets to the crossing, the larger the increases in image size become, but by the time the motorist gets a realistic idea of the train speed, the decision to proceed through the crossing may already have been made. A more extreme version of the problem may occur when the road vehicle and the train are approaching the crossing at right angles and at the same speed. There is no lateral motion of the image of the train in the motorist's field of view, and image size is again the dominant cue to distance. Missing from both these accounts is the concept of optic flow described by Gibson (1938) which has been very influential in clarifying understanding of relative motion. It seems likely that the relative contribution of these three potentially significant mechanisms can be disentangled by empirical investigation.

   Although there is some evidence to suggest that additional lighting can improve the accuracy of judgements of the time it will take a train to arrive, the improvements are small. Note that none of the theoretical propositions outlined in the preceding paragraph suggest that adding additional lighting would resolve this problem. Note, too, that when Carroll et al. (1995) tested the effect of different auxiliary lighting treatments on observers' ability to judge when a locomotive was a specified number of seconds from the crossing, they concluded that headlights plus auxiliary lights gave better results than headlights alone, and that crossing lights resulted in the most consistent improvements over the range of intervals provided. However, it should be said that there appears to be little difference among the treatments. Although Carroll et al. did not test strobe lights in combination with ditch lights, it seems unlikely this would substantially improve performance as there was little difference among the treatments. With the crossing lights, the maximum overestimation of the time it would take the locomotive to arrive was approximately 10 per cent, so that there is relatively little room to improve.

   In summary, there are good practical and theoretical reasons to believe that motorists have difficulty in judging train speeds at railway crossings. It is not possible to say how many collisions this difficulty contributes to.

The analysis above suggests that, in principle, increased conspicuity might be an effective way to reduce vehicle-train collisions. Consider the seven factors identified:

Not detecting the crossing in time is not considered to account for many crashes, as current standards for signing passive crossings in Australia are recognised as amongst the best in the world.

There are very few cases of stalled vehicles on the tracks, and deliberate risk taking is not possible unless the driver has already seen the train.

This leaves on the one hand, the related factors of not detecting the train, distraction and expectancies regarding the presence of a train, and on the other, misjudging the speed of the train. It is not known to what extent each of these factors contributes to collisions at railway level crossings. It seems inherently unlikely that adding more lights to the train would result in more accurate (or at least more cautious) perceptions of train speed. This leaves cases which involve not detecting the train, distraction and expectations that a train will not be present as events where adverse outcomes could be avoided by better train conspicuity. Unfortunately, without conducting further research on the events preceding level crossing crashes it is not possible to say what proportion of cases this involves, or by how much increased conspicuity (assuming effective increases in conspicuity were possible) is likely to reduce this.

5 LIGHTING STANDARDS

5.1 Draft Code of Practice

The Australian Rail Operations Unit, in consultation with the rail industry, is in the process of developing a draft Code of Practice for the Defined Interstate Rail Network to provide uniform guidance for the design and construction of rolling stock. The relevant volume of the Code includes provisions for lighting and reflectorised material on trains. The significant mandatory provisions of the draft relating to lighting and conspicuity are:

- Headlights with luminous intensity of 200,000 candelas should be fitted at each end of the locomotive.
- Colours and patterns applied to locomotives and rolling stock should be selected to enhance daytime visibility.
- Road visibility lights at each end of the locomotive, positioned low and set to face in towards the track centre line with an angle of 10–15 degrees between the beams. They may be incorporated into the low visibility/fog light equipment. The lights should not be less than 100 Watts each (NB in this draft standard, these are defined in terms of power requirements [Watts] rather than light output [candelas] as is the case for the headlights).

In the current draft of the Code of Practice, reflectors are optional, but where provided the reflective sheeting must be to Class 1A standard and there are mandatory provisions for minimum dimension, placement and colour. Note, however, that the draft Code of Practice is a voluntary code and subject to further change.

The Road Visibility Lights specified in the draft code of practice are not required to flash in a manner similar to the requirements of FRA Interim Rule #2 for Auxiliary External Lighting Systems. Carroll et al. (1995) found these to be the most effective of the auxiliary lighting systems tested, conferring an advantage of more than 10 per cent in terms of detection visibility over the other forms of auxiliary lighting tested. Note that the Draft Code of Practice does not prevent Road Visibility Lights being configured in this fashion.

5.2 Theoretical analysis of light array

Much of the work advocating auxiliary lighting for locomotives pre-dates ditch lights or crossing lights, and in fact identified crossing lights as more effective than strobe lights. Current best practice is for locomotives to be equipped with headlights and crossing lights. Since this standard treatment is so much brighter and casts light over a wider angle than a headlight alone, a much brighter additional light will be required to achieve an increase in conspicuity than was the case with the headlight alone.

It is essential that road users be aware of the presence of a train in ample time to stop when they are approaching a crossing. Stopping distances associated with different travel speeds are readily available, but the time taken to stop is not readily available. Following the rationale developed by Catchpole (2000), it is assumed that car drivers can brake with a deceleration rate of 5.6 m s–2, ie they can reduce speed by 20 km/h during every second of braking (longer braking times would be needed for many heavy vehicles). A road speed of 100 km/h would require a braking time of at least 5 seconds. When 2.5 seconds is added to take account of the reaction time of the driver, the total stopping time required is at least 7.5 seconds. It therefore seems reasonable to assume that, in order to detect and respond to the presence of a train, the car driver should have detected it at least 8 seconds before arriving at the track. For different train speeds, the minimum distance down the track that the train must be detected is shown in Table 7.

TABLE 7:
Minimum distance of train from crossing at which train must be seen

Train Speed (km/h)	*Minimum distance at which train must be seen (metres)*
60	134
80	178
100	222

The level of discomfort involved in very rapid braking may well influence a driver's decision as to whether to brake or take a chance on being able to continue safely through the crossing. It would therefore be desirable to enable the driver to detect the train at distances greater than those shown in Table 7 and hence allow the driver to bring the vehicle more gradually to a halt. However, this will often not be possible due to landforms and vegetation, so that longer-range conspicuity aids cannot be relied upon. The critical requirement for safe operation of passive crossings is that the train be reliably detectable at a distance of 222 metres under all natural lighting conditions. Current practice allows a more generous margin than this, with the whistle board located 400 metres in advance of crossings. On passing the whistle board, the driver sounds the locomotive's horn, at the same time switching on the crossing lights where these are available. Conventional practice therefore requires that steps be taken to warn drivers of road vehicles when the train is 400 metres from the crossing, and we may accept this as a desirable margin. At 60 km/h, this is approximately 24 seconds before the train reaches the crossing, and at 100 km/h, approximately 14 seconds.

It has long been established that conspicuity depends primarily on the contrast between an object and its background (see eg Cole and Jenkins 1980). At night, this contrast is readily achieved by providing the locomotive with lighting. Locomotive headlights are designed to give train crews an adequate view of the track ahead. Although they are powerful light sources, their light is cast in a narrow beam directed along the railway tracks, and they are not particularly effective in helping others see locomotives. Ditch lights or crossing lights on the other hand cast their light over a wide area at about the eye height of drivers of road vehicles and are effective conspicuity aids. By virtue of their alignment and alternating flashing mode of operation, crossing lights would appear to be particularly effective.

However, their impact is much less during daytime, especially in the bright daylight conditions typical of the Australian land mass over most of the year.

The question of adding more auxiliary lighting is more difficult. Under current standards, locomotives are already equipped with powerful light sources so that it will be difficult to improve conspicuity by adding additional light sources.

The placement of light sources on the locomotive used in the trials conducted by Cairney et al. (2002) are shown below. The headlight and crossing lights are typical of many locomotives in service, and the strobe unit was added for the purpose of the trials.

FIGURE 6:
Western Australian Government Railways locomotive equipped with the lighting equipment used by Cairney *et al*. 2002

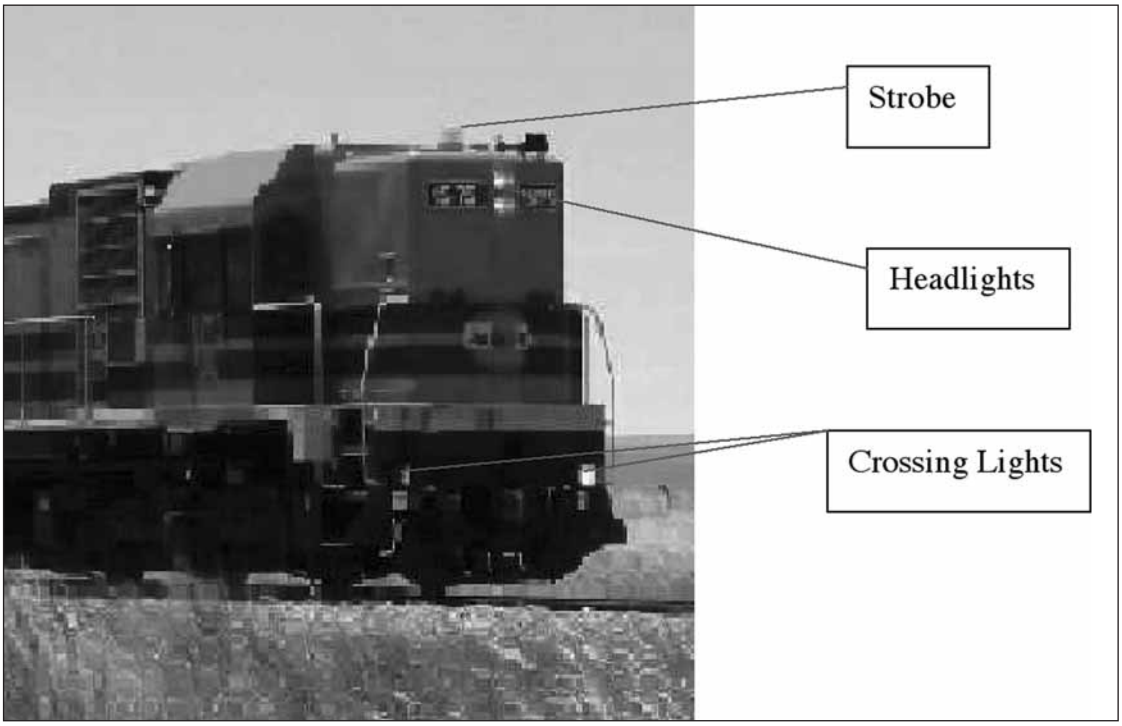
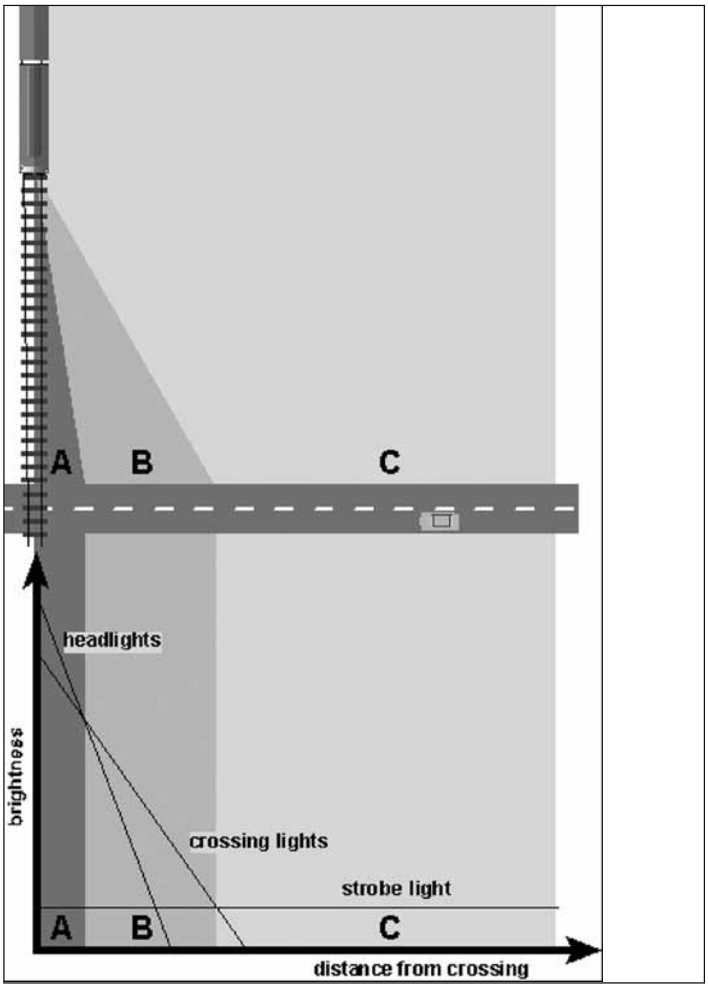


FIGURE 7:
Relationship between the brightness of different types of locomotive lighting and the distance of the observer (the driver of the road vehicle) from the crossing



The light output of the three light sources is shown in schematic form in Figure 7. The figure shows the variation in brightness of three locomotive-mounted light systems for drivers of vehicles at various distances from the crossing. In Zone A, close to the track, the locomotive headlights are directed close to the road vehicle and are seen as the brightest lights. Further from the track in Zone B, the headlights are not directed close to the road vehicle and the crossing lights are seen as brighter. Further still from the track in Zone C, neither the headlights nor the crossing lights are directed close to the road vehicle and the strobe is seen as brightest. In considering whether the addition of a strobe light would improve conspicuity, the questions of interest are:

- whether the transition from Zone B to Zone C is within the critical 222 metres identified in the discussion on stopping distances mentioned above;
- whether the strobe light (or any other additional light) is likely to be masked by the more powerful crossing lights; and
- whether the amount of light delivered by the strobe light is likely to provide a sufficient contrast with the background to provide a reliable additional signal which is likely to increase the conspicuity of the locomotive.

Modelling the photometric output of various combinations of devices should identify optimum treatments and give an indication of how successful the best of these is likely to be in improving conspicuity.

5.3 Empirical evidence of effectiveness of better auxiliary lighting

Enhanced locomotive conspicuity has been suggested in Australia both by individual researchers and by several Government Committees of Enquiry. In the former category, the first such proposal was made in Australia some 30 years ago (Cox, 1970). Since then, Ogden *et al*. (1971), Wigglesworth (1979, 1990) and Cairney (1991) have all advocated field trials to test the effectiveness of additional locomotive lighting to enhance conspicuity.

In the latter category, the two reports of the Expert Group on Road Safety (Meares, 1972, 1975) both suggested the fitting of flashing lights or rotating beacons, whilst the ARRB workshop on road safety at railway level crossings made the same recommendation (Macdonald, 1974).

Although there had been no Australian work on this topic, that proposal seemed well supported by American opinion. Thus, in one of the first, and still one of the best reviews, Schoppert and Hoy (1968) opined that ‘a rotating beam that shines more directly into the air might allow the motorist to detect the train before he could actually see it. A lighted panel, along the length of the locomotive, and other lighting arrangements, could also be tested’.

More importantly, there are at least six American studies that support this view. First was the authoritative work of Aurelius and Korobow (1971) whose field studies examined methods of making the train more visible to motorists. They recommended two high-output xenon strobe lamps, one on each side of the cab roof, whenever the train was moving, supplemented by lighted panels at night.

In the time available for the preparation of this report, it was not possible to examine the original copies of the next three field studies, and reliance is placed on the comprehensive review of ‘Driver behavior at rail-highway crossings’ (Lerner, Ratte and Walker 1989). Their review includes the study by Sanders, Aylworth and O’Benar (1974) who examined five different on-train alerting systems as well as the standard locomotive headlight, and concluded that the ‘most conspicuous was the pair of roof-mounted emergency vehicle xenon strobes’. In an additional comment on the same report, Carroll *et al*. (1995) make the important point that

‘In a study measuring the accuracy with which observers perceive time to train arrival based upon a locomotive’s alerting devices, Sanders *et al*. found differences in accuracy that varied by device.’

Lerner *et al*. also report on the work of Hopkins and Newfell (1975) who conducted a field study using two xenon strobes on locomotives and concluded that the strobes increased the conspicuity of the trains, especially at night and also on the field study by Devoe and Abernethy (1975) who reported that xenon strobe lights were both readily visible and ‘attention getting’ at distances up to one half-mile, noting that the “flashing strobes caused the environment around the train to pulsate with light, well before the strobes themselves were visible”.

In a different study, Lerner *et al*. cite the work of Hopkins (1980) who found that there were fewer accidents per locomotive mile when the accident rate for strobe-equipped locomotives was compared to that for unequipped locomotives although, as pointed out by the author, the sample size was too small to draw firm conclusions on a nationwide basis.

The most recent US field study was that of Carroll, Multer and Markos (1995) who found that ‘the use of selected alerting light systems, rather than use of the standard headlight alone, can improve locomotive conspicuity’.

Against that background, it is useful to review the recent report of the Western Australian field studies (Cairney, Cornwell and Mabbott, 2002). This study reviewed three lighting systems: (i) locomotive headlights alone; (ii) locomotive headlights and ditch lights; and (iii) locomotive headlights, ditch lights and a single roof-mounted strobe light. The report concluded that ‘Neither of the two auxiliary lighting treatments improved the conspicuity of the locomotive over that achieved by the standard headlights’.

These results can be explained in terms of the study design forced on the research team by the lighting equipment made available for testing, and by the opportunities for carrying out different comparisons in the limited time period available for carrying out field tests (one night and one morning). The crossing light tested was configured to start flashing when the locomotive whistle was sounded as the locomotive passed the whistle board approximately 400 metres from the crossing. By night, most observers had detected the train well before this point, generally on the basis of light reflections from the area surrounding the track. The strobe light had a similar onset to the crossing lights, and was always tested in conjunction with them. From the critical viewing positions, the crossing lights appeared to be much brighter than the strobe light, and in some cases masked it very effectively.

During daytime testing, none of the lights seemed to be particularly effective in the bright sunlit conditions on the day of the test.

In these circumstances, it is not surprising that neither of the auxiliary treatments were particularly helpful. The important point of the findings is that unlike previous studies, the strobe light was tested in conjunction with the crossing lights. While the earlier studies found strobe lights on their own to be an effective adjunct to the locomotive headlight, the Cairney *et al*. study indicated that that it was not effective when viewed in conjunction with headlights and crossing lights.

In terms of research methodology, Lerner *et al*. (1989) commented thus: ‘The on-train warning system that has received the most attention is the pair of roof-mounted xenon strobes which appear to be detectable from larger viewing angles and at greater distances than the standard headlight. *However, most evidence pertaining to strobe light effectiveness consists of subjective judgements of conspicuity, made by observers who were expecting to see a strobe-equipped train. It is unclear whether the roof-mounted strobe lights will facilitate detection of an approaching train* *under normal conditions, when drivers have not been informed about what feature to look for, and when they often do not expect to see a train*.' (emphasis added).

In the case of the hardware options available, the Western Australian study was directed to a locomotive fitted with a single strobe light, whereas the previous US reports have suggested at least two strobe lights.

In practice, the conspicuity of flashing lights may be deemed to be dependent on a number of factors, such as intensity, flash rate, flash duration, colour, number and location of warning lights (including on the train itself), sweep of beam, and so forth. There are other alternatives, such as the use of rotating beacons, fitting the locomotive with outlining amber lights (as on trucks in Australia) or illuminating the side of the locomotive. These are worthwhile topics for laboratory research as a prelude to definitive field studies.

In this context, it is relevant to point out that, since the number of locomotives is substantially less than the number of crossings, the use of train-mounted lights to increase conspicuity has clear cost advantages. On the other hand, increased locomotive conspicuity is of no advantage at those crossings where there are major sight restrictions imposed by topography and/or terrain, by such natural features as scrub or heavy forestation, and also by a variety of man-made structures.

TABLE 8.
Summary of studies on locomotive auxiliary lighting

Study	Base line lighting treatment	Additional treatment	Assessment method	Findings
Aurelius and Korobow (1971)	Assumed to be normal headlights	Roof-mounted xenon strobes, flashed alternately	Not known	Only strobe lights effective in attracting attention
Sanders et al. (1974)	Assumed to be normal headlights	Strobe light - 150 cycles/minute and 60 cycles/minute	Visibility. Observer estimation of arrival time	150 cycles/min more visible. 150 cycles/min had fewer underestimations of time to arrival (ie less likely to result in risky judgement).
Hopkins and Newfell (1975)	Assumed to be normal headlights	Variable intensity strobe lights	Subjective evaluation by observers and train crews	100-400 equivalent candelas adequate at night; 800-4000 equivalent candelas required during daytime.
Devoe and Abernethy (1975)	Assumed to be normal headlights	Xenon strobe lights	Subjective evaluations	Strobes were judged to be effective and attention getting. Two level system (day and night) recommended.
Hopkins (1980)	Assumed to be normal headlights	Strobe lights	Not known	Strobes appeared to be more effective at night than during day. Fewer crashes per locomotive/km, but sample is too small to permit wider inferences.
Carroll et al. (1995)	Standard headlight (2x350 watt sealed beam incandescent bulbs, horizontal and vertical width each 3.5 degrees)	Crossing Lights - (same as headlights, aimed horizontally parallel to the track, lateral aim not specified).	Distraction task Observers very close to track and only tested at one position.	All three auxiliary treatments tested in conjunction with headlight resulted in greater distance than headlight alone. Crossing light system was best.
		Ditch Lights - (same as headlights, aimed 15 degrees outward from track centre line.	Detection (peripheral vision).	Concerns about glare.
		Strobe Lights – (two xenon strobe units, 1000 effective candelas intensity, horizontal beam width 180 degrees).	Judge to arrive at crossing.	Time to arrival done equally well by day and night. Crossing light s resulted in most accurate judgements.
Cairney, Cornwell and Mabbott (2002).	Standard headlight	Crossing lights. Strobe light.	Distraction task; observers at varying distance from crossing. Detection. Judge Time to arrive at crossing.	Train detected at greater distances at night than during daytime under all lighting conditions. No evidence that auxiliary lighting improved detection distance or time to arrive at crossing.

6 POSSIBLE MEANS OF IMPROVING TRAIN CONSPICUITY

The critical aspects of road-vehicle–train collisions at passive level crossings which any improvements to conspicuity must address are:

- Daytime crashes are approximately 70 per cent of the problem, night-time crashes approximately 30 per cent.
- The road vehicle is struck by the train in 65 per cent of cases, and the road vehicle runs into the side of the train in approximately 35 per cent of cases. In fatal crashes, a higher percentage (approximately 80 per cent) involve the locomotive striking the road vehicle.

6.1 Possibilities for addressing daytime crashes

There would seem to be two possibilities for addressing the issue of daytime crashes through improved conspicuity.

First is the question of additional lighting. All the literature consulted so far reports that white strobe lights were used, which is unfortunate from the point of view of daytime conspicuity. Stephenson and Cairney (2001) asked observers to make comparative ratings of the effectiveness of a number of different colours of flashing beacons in a study to determine the most effective form of lighting for VicRoads' Incident Management Teams. Members of these teams were particularly concerned that the yellow lights with which they were equipped were now so widespread that they no longer conveyed any sense of emergency or authority. While white flashing beacons performed best at night, they were judged to be ineffective during daytime in comparison to coloured flashing beacons.

Adding a coloured filter over the strobe light would reduce light output, but it is anticipated that this would be more than compensated for by the addition of colour to the light source for daytime operation. However, existing signalling conventions in the railway environment severely restricts the available colours, red, yellow and green being reserved for critical applications in the signalling system. Two colours in common use remain. They are blue, used as part of the red-blue combination provided on emergency vehicles, and magenta. This colour is used in Victoria by enforcement officers, such as Wildlife and Fisheries Officers and Vehicle Inspectors. There may be other official or semi-official uses in other jurisdictions. Although it may be desirable to test the effects of coloured strobe lights on the daytime conspicuity of locomotives, it is questionable whether there are any suitable colours which have not been pre-empted for other uses.

The other possible way to improve daytime conspicuity for trains is to investigate the possible effects of colour schemes which contrast with the backgrounds against which the train is seen. Aurelius and Korobow (1971, summarised in Carroll *et al.* 1995) recognised that no single colour provides consistent contrast against all backgrounds, and made recommendations for contrasting colour schemes using wide bands of light and dark colours They suggest minimum dimensions of approximately 1 m vertically by 1.5 m horizontally to ensure visibility of a block of colour at a distance of 300 m. It seems unlikely that this recommendation can be substantially improved upon. However, some work would be required to identify colours which provide maximum contrast with the background against which trains are viewed. This may present some significant challenges as one train may operate in a variety of different environments, from arid range lands to grain fields at a different time of year to sclerophyll or rain forest.

Too much should not be expected from paint schemes, as the extent of the brightness contrast they can offer with the environment is limited and no data relating to train conspicuity appears to be available. Limited data from early studies of road vehicle crashes suggest that colour may be related to crash frequency. Viberg (1966 see ARRB, no date) demonstrated that bright coloured vehicles were under-represented in crashes and that dark coloured vehicles were over-represented. Cantilli (1969 see ARRB, no date) found that yellow vehicles had lower accident rates than black vehicles belonging to the same fleet. It should be recognised that the road operating environment is very different from railway level crossings.

6.2 Possibilities for addressing night-time crashes

Since headlights and crossing lights are such bright light sources, it seems unlikely that night-time conspicuity can be substantially improved by adding further lighting treatments. The challenge would seem to be in persuading all rail operators that their Visibility Lights should conform to the FRA standard for crossing lights rather than the minimum standard specified in the Code of Practice.

Adding a conspicuity aid to the sides of rolling stock may be a productive approach, since running into the side of trains accounts for 35 per cent of vehicle-train collisions. It was established in Section 4.1 that 70 per cent of crashes at passive crossing in Australia occur in daylight and 30 per cent at night. According to Glennon and Loumiet (1992 – see Section 4.2), 50 per cent of night-time crashes in the US are with the side of trains. Assuming that figure also applies in Australia, then approximately 15 per cent of crashes at passive crossings involve road vehicles running into the side of trains at night.

At time of writing, it was being debated whether the Code of Practice should leave reflective strips as an option or mandate them as a requirements. Where fitted, the class of reflective material and minimum dimensions are specified. Reflective strips have some limitations as a conspicuity aid. To be maximally effective, they require that the road vehicle's headlights shine onto the sheets at close to right angles, since the efficiency of retroreflective material in returning light to its source decreases with increasing entry angle. Consequently, they may be less effective when the crossing is not at right angles to the rail track. Their efficiency in reflecting light is also adversely affected if they are covered in dust or oil, or if the surface becomes abraded in service. Here again, the priority should probably be encouraging operators and regulators to adopt a known practice rather than further research at this time.

Many of the problems of reflective sheeting could be overcome and conspicuity greatly enhanced by replacing the reflective strips with active lighting. This may have reached a practical stage. A number of manufacturers currently offer intelligent illuminated pavement markers (or cat's eyes) for road applications. These units have solar powered batteries with light emitting diode (LED) displays, switching on when ambient light falls below a threshold level. If they prove to be sufficiently robust for the road environment, they may also be suitable for rail application, although there would remain several major challenges, such as ensuring they get sufficient sunlight to charge in a rail environment, a sufficiently high degree of reliability, and being affordable in terms of the benefits they are likely to deliver.

It is understood that railways have investigated internally illuminated options before, and that there are a number of problems associated with them. The need to check that all lights are working can be time consuming and disrupt schedules if replacements have to be found. There is a risk that illuminated treatments will create new exposure to liability, so that there would have to be substantial benefits before they would be worth proceeding with.

7 CONDUCT OF FUTURE RESEARCH

7.1 A research strategy to investigate train lighting

The case for further research has been developed in the preceding sections, and is summarised below. If it is decided that the scale of the problem and the potential benefits warrant further research, then it is recommended that the following procedure be followed in order to ensure an optimum answer and to contain the costs of the investigation.

Stage 1 - Photometric analysis and modelling

The principles of optics are well-established, as are human responses to light, both in terms of physiological processes and psychometrics (ie the perceived quality of stimuli in relation to their physical properties). It would therefore be relatively simple to model how effective a particular additional lighting treatment is likely to be under different arrangements of train lighting and under different ambient conditions. The major challenge for this approach is likely to be the effect of masking of auxiliary lighting by headlights and ditch lights.

Photometric modelling is a desk-top exercise which should yield a clear indication of whether a particular treatment is likely to increase the probability of the train being noticed under a range of ambient lighting conditions. As such, it ought to be a relatively low-cost exercise.

An indicative cost of $75,000 is suggested for this phase of the work, based on three months' senior professional time plus travel. It is anticipated that the three month's work would be made up of approximately two months' model development, plus two weeks' consultation and presentations, and two weeks refining the models and preparing a report. This stage of the research should not be rushed, and a year's elapsed time should be allowed to permit a wide range of options to be canvassed and a wide range of stakeholders consulted.

Stage 2 - Laboratory/static tests

Photometric analysis may have to be supplemented by laboratory measurements, or measurements of light output from devices on trains. Tests using human observers with stationary locomotives may also be necessary to resolve some of the unknowns in photometric modelling, such as the masking effect of headlights and crossing lights. Similar tests may also be desirable to give broad confirmation of the results of the photometric models. As this research will require only a stationary locomotive with participants viewing it from different angles, the cost will be fairly modest.

Stages 1 and 2 will provide a good indication of whether any proposed conspicuity-enhancing treatment would be likely to produce a worthwhile improvement in conspicuity. However, there is a major gap between demonstrating a theoretical improvement in conspicuity and demonstrating an increased probability that unalerted drivers will notice a train, and an even greater gap between demonstrating earlier detection and a reduction in collisions.

In the days before ditch lights or crossing lights became common treatments for locomotives, any type of conspicuity enhancement could plausibly be regarded as a worthwhile improvement. Since ditch or crossing lights have become accepted as part of normal practice, the probability of additional lighting, such as cab-mounted strobe lights, contributing any further conspicuity advantage is greatly diminished.

It is envisaged that this activity would run concurrently with Stage 1. An indicative cost is $15,000 for photometric testing. This would enable three separate measurement sessions by a team of three people, plus analysis and report preparation. It does not include the cost of modifying locomotives, or the provision of locomotives, rolling stock, rail personnel or rail facilities. If testing with human observers is required, then a further $5,000 should be budgeted for each session's testing required. This would cover the cost of ten observers and a team of four people for half a day, plus set-up, recruitment and data processing costs. A comprehensive program of human factors research could be expected to cost in the region of $30,000.

Stage 3 – Demonstrating a reduction in driver risk taking

Ultimately, if the effect of improved conspicuity on collisions is to be assessed, there is no alternative but to monitor crash statistics before and after the conspicuity enhancements are introduced. This is a relatively straightforward procedure that can be carried out at modest cost, provided an adequate system of recording crashes is in place which includes information on locomotives and rolling stock and their lighting and reflectorised equipment. The disadvantage is that it would take years – perhaps many years – to demonstrate an effect. The following example, although probably not viable as an actual experimental design, illustrates the difficulties of demonstrating statistically reliable results when small numbers of crashes are involved.

Consider a possible evaluation study based on a comparison of train-hit-car and car-hit-train events, assuming that we only address locomotive conspicuity to reduce train-hit-car events. For how many years would the study have to run to confidently establish whether mounting additional lights on locomotives leads to a reduction in train-hit-car crashes?

This question can be answered with the aid of the SPSS Sample Power software, provided that we know the number of passive crossing crashes per year; the number or proportion of these in which the train hits the car; the proportion of train-hit-car crashes that the treatment is expected to prevent; and the level of statistical significance required to accept a crash reduction as reliable. In Section 4.2, it was established that approximately 65 per cent of collisions involve trains hitting cars and 35 per cent cars hitting trains. Thus of approximately 40 collisions per year at passive crossings, around 26 involve trains hitting road vehicles. The significance level for such research is conventionally set at 5 per cent; that is, a crash reduction is regarded as 'significant' or 'reliable' if there is less than 5 per cent probability that such a reduction could have occurred as a result of random variations in crash frequency. This leaves just one outstanding requirement – an estimate of the proportion of train-hit-car crashes that the treatment is expected to prevent.

The likely effectiveness of additional lighting on locomotives was the topic of Section 4.4. The relevant issues were identified as not detecting the train, distraction and expectations that a train will not be present. It was concluded that "without conducting further research on the events preceding level crossing crashes it is not possible to say what proportion of cases this involves, or by how much increased conspicuity (assuming effective increases in conspicuity were possible) is likely to reduce this". In the absence of a firm estimate of the proportion of crashes likely to be prevented, it is necessary to consider the implications of both low and high levels of effectiveness. If additional lighting on locomotives were successful in preventing 10 per cent of train-hit-car crashes at passive crossings in the long term, the proposed study would require 9150 crashes – almost 230 years' data – to achieve a statistical power of 80 per cent, the conventional benchmark to be confident that 'real' effects will not be wrongly rejected. If, on the other hand, additional lighting on locomotives were successful in preventing 75 per cent of such crashes in the long term, the proposed study would be expected to yield a significant result based on as little as a single year of data – provided that the new treatment is fitted to every locomotive in Australia and that it does not also lead to a reduction in vehicle-hit-train crashes.

Another way to approach this issue would be to record the behaviour of drivers confronted with different conspicuity treatments on locomotives. The extent of their risk taking, deliberate or otherwise, can be gauged by the margin by which they avoid colliding with the train. This could be readily measured by having a video camera and recorder on the train, triggered when the whistle is sounded then running for a suitable interval (say 1 minute) which would enable events to be recorded from that point until the train had passed the crossing. Any vehicles crossing in front of the train would be recorded. Tapes would be accumulated, and the time interval between the vehicle clearing the crossing and the train arriving at the crossing retrieved by the research team in the laboratory. It is possible the study could be carried out at night as well as during the day. The purpose of the investigation would be to discover whether conspicuity treatments resulted in fewer 'near misses' than standard locomotive lighting or colour schemes. It would probably cost in the region of $10,000 to fit out and modify a locomotive for the purposes of such an investigation. Each tape would probably require one hour's analysis for every four hours of locomotive run time, although this would depend on the density of crossings on the railway lines over which the study was run and the number of road vehicles encountered. Thus a study covering 2000 hours of locomotive run time (1000 before and 1000 after) would require approximately twelve to fourteen weeks of data capture. A study of this size would cost in the region of $75,000. A pilot study to demonstrate the viability of the method is essential. Equipment and the pilot study would be estimated to cost $20,000. Thus the estimated total cost for Stage 3 is $105,000. The overall program of recommended research would cost up to $225,000.

7.2 Train conspicuity research in context

Train conspicuity is but one of the issues to be addressed in improving safety at passive crossings. Government agencies and other funding bodies should consider the potential costs and benefits of further research into train conspicuity in the light of these other issues.

At time of writing, a number of research providers have recently collaborated to produce a comprehensive program of research into improving safety at passive railway crossings which took into account the recommendations of the Monash Symposium and the views of rail operators and regulators. The program has been developed through the Rail Co-operative Research Centre at the University of Central Queensland, and has involved Monash University Accident Research Centre, ARRB Transport Research Ltd, and Queensland University of Technology. The program was presented to the Rail Safety Regulators for consideration at their 15 August 2002 meeting. The regulators took the proposal to the SCOT Rail Group Meeting on 16 August 2002 but no decision to support the program was made at that time.

The research tasks proposed in the program are:

- Increasing the Conspicuity of Locomotives and Rolling Stock
- Adequacy of Warning Signals for Road/Rail Drivers With Colour Vision Deficiency
- Ranking of the Safety of Passive Crossings
- The Effect of Road Surface on Approaches to Level Crossing on Drivers' Awareness of Trains
- Engineering Aspects of Safety at Level Crossings
- The Consequences of Increased Train Speed and the Leibowitz Illusion.

The present document essentially fulfils the first step in the first of these tasks, although with a narrower scope than envisaged in the proposed program, as it has not been possible to access original research reports or conduct photometric measurements and modelling in the manner envisaged in the proposal.

The important point is that this comprehensive program of work should not be lost sight of in any decisions relating to research on improved train conspicuity.

7.3 Information infrastructure for management of safety issues

A major frustration in conducting this review has been the incomplete data on railway level crossing crashes, and the incompatibility of recording systems between different jurisdictions. This contrasts unfavourably with the FRA Annual Report, 'Railroad Safety Statistics' (FRA 2001), referred to at several points throughout this report.

It would be a relatively simple matter for Australia to put together a similar report. Indeed, there are some aspects of the FRA report that could be improved upon, such as including prior events and subsequent events which affected either the occurrence or the outcome, more complete cross-tabulations, and indications if hazardous goods are involved in railway crossing incidents, whether carried by the train or the road vehicle.

Collection and regular analysis and publication of such data will enable better management of railway crossing safety, and greatly facilitate the underlying research. Although the resources required are not large, definite commitment and some investment is required if this issue is to progress.

It is suggested that the minimum requirements for a useful system are:

- A nationally agreed accident reporting system, used by all jurisdictions.
- Uniform forms or software for collecting information about collisions.
- A central data base, accessible by all stakeholders and independent researchers.
- The type of crossing control and other features related to risk management be part of the record.
- Conspicuity treatments operational on the locomotive at the time of the collision.
- A separate record for each vehicle occupant, linked to the accident.
- Usual details for driver, vehicle, environment, weather conditions.
- Regular (eg annual) compilation, interpretation and reporting of database contents.

8 PROSPECTS FOR PROGRESS

In Australia, the fatality rate at level crossings per 100,000 population is much lower than that in either the US or Finland. Crashes at passive crossings are also very low in absolute terms, accounting for an average of four deaths and six serious injuries per year. However, the high media profile generated by collisions between trains and road vehicles and the risk of events which will be costly in terms of road or rail user deaths and injuries, harm to the environment, or recovery and repair costs means they are events which cannot be ignored.

Treating trains rather than treating passive crossings is attractive because:

- It is a lower cost option, since there are about three times as many passive crossings as there are locomotives, and the cost of the devices is likely to be considerably less.
- It is unlikely that all passive crossings will be treated in the foreseeable future.
- It will take some time to install active treatments at all the sites where they are justified.

However, the effects on crash reduction are likely to be much smaller than the effect of providing active treatments.

The point also needs to be made that the Draft Code of Practice embodies high standards for locomotive lighting (ie headlight and visibility lights), so that achieving worthwhile improvements in conspicuity over and above this may not be possible.

The critical aspects of road-vehicle–train collisions at passive level crossings which any improvements to conspicuity must address are:

- Daytime crashes are approximately 70 per cent of the problem, night-time crashes approximately 30 per cent.
- The road vehicle is struck by the train in 65 per cent of cases, and the road vehicle runs into the side of the train in approximately 35 per cent of cases.

There appear to be major issues with how drivers of road vehicles perceive train speed at railway level crossings. It seems unlikely that improved train conspicuity will change speed perception to the extent that we could regard it as a significant safety improvement. On the other hand, the issues relating to the misperception of speed deserve further investigation.

So far as conspicuity goes, there would seem to be two issues worth investigating further:

- Strobe lighting. It is unfortunate that only white strobe lighting appears to have been trialed in the railway context so far, as other evidence shows that white flashing lights are relatively ineffective during daylight. The approach has been to increase the energy output of the strobe lights by approximately tenfold (equivalent to doubling their apparent brightness), whereas it may be more effective to add a coloured filter, despite the energy loss entailed. If this approach were to be followed, it would be essential to ensure that there is no potential confusion with existing road and rail signalling conventions.
- Locomotive colour. Aurelius and Korobow (1971) made recommendations for painting locomotives to maximise conspicuity. There may be scope for investigating the potential to significantly improve conspicuity by this means. The harsh, oily and grimy nature of the railway operating environment imposes some restrictions on how much could be achieved in this way.

If research were to proceed, then it is recommended that a three stage process be followed:

1. Photometric investigation of possible alternatives, along the lines outlined in Section 7.1. This would involve the application of physical laws to determine, for example, how bright a particular light would be at a given angle and viewing distance. It would also involve the application of well-established human factors data and principles to determine the extent to which the additional light is likely to be masked by other, stronger lights, and how effective it is likely to be in increasing conspicuity. This may include photometric testing of lights fitted to locomotives.
2. Laboratory testing of light outputs with human subjects to confirm photometric modelling and perhaps resolve issues that cannot be resolved by theoretical analysis. This may include viewing locomotives in rail yard situations.
3. Only once these alternatives have been fully explored and it can be demonstrated that there is a strong possibility that there are worthwhile gains in conspicuity to be had will it be worth considering proceeding to a field trial. This can best be accomplished by an investigation of the time margins adopted by drivers of road vehicles at railway level crossings using train-mounted video equipment.

As discussed in Section 7.1, the small number of crashes occurring at crossings means investigations in terms of crash reductions are unlikely to yield meaningful results unless the proportion of crashes prevented by the treatment is exceptionally high.

In the meantime, rail operators should be strongly encouraged to ensure that lighting systems on all locomotives comply with Code of Practice as soon as it is finalised, and that they configure visibility lights to conform to the FRA Interim Standard for Crossing Lights

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