Road Safety Engineering Risk Assessment – Recent and Future Research

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Abstract

The Australian Road Research Board (ARRB) has been conducting an extensive range of research aimed at identifying and measuring the level of risk associated with different road stereotypes, and at the reduction in this risk resulting from changes in road design standards and from remedial treatments. This Austroads funded research is designed to aid policy makers and practitioners in assessing risk and prioritising treatment on their roads so as to achieve optimal crash risk reduction for the available budget.

Research topics include the development of crash rates databases, investigation of risk reduction for safety treatments in different environments, the implications of varying design standards, information on local road safety schemes, use of crash cost as an indication of severity, an in-depth investigation of rural head-on, intersection and run-off-road crashes, the safety implications of road deterioration, an investigation of crash risk migration, and the effect of using multiple countermeasures.

This paper provides examples of the results from some of this research.

Introduction

The management of the road network to provide safe road transport is a key performance indicator for road authorities, and fundamental to providing the community with a 'safe road system', a key objective of the Australian National Road Safety Strategy. To assist authorities manage road based crash risk, ARRB Research is undertaking a major Austroads' funded research program to assess risk involving road, traffic and roadside infrastructure. The results will provide road authorities with more effective tools to reduce road crashes and injuries. The initial research program was aimed at developing a basis for prioritising the treatment of deficiencies identified by road safety audits. ARRB used the results of this research to develop the Road Safety Risk Manager (RSRM), a CD-based 'expert system' to assist in the prioritisation of road safety treatments. Ongoing research is aimed at better defining the relationship between road elements and crash risk.

This paper reports on results from the most recent two years of research, and highlights forthcoming research. Results are provided on the following areas of research:

- development of crash rate databases
- investigation of risk reduction for safety treatments in different environments
- the implications of varying design standards
- information on local road safety schemes
- use of crash costs as an indication of severity
- an in-depth investigation of rural head-on, intersection and run-off-road crashes
- the safety implications of road asset deterioration
- an investigation of crash risk migration
- the effect of using multiple countermeasures at a site.

Research Results

Crash rate databases

The key objective for this task was to collect data from each of the Australasian jurisdictions in order to build crash rate databases, primarily to determine the different levels of risk associated with various road types. Crash rates are more useful than crash numbers because they take into account exposure (traffic volumes). This allows the calculation of overall risk for different road types, and can be used for comparisons (e.g. for divided versus undivided roads, sealed versus unsealed roads, undivided major urban versus undivided major rural, roundabouts versus traffic signals, or T intersections versus X intersections etc.). Specific road sections or intersections can be compared with this average to determine the high risk locations.

Crash, traffic and road inventory data was requested from each jurisdiction, and where available was combined using geographic information systems (GIS). A lack of spatial coding was identified through this research, as well as a lack of detailed information on traffic volumes. Despite these limitations, crash rates have been identified for the state road network in New South Wales (although this is limited to rural mid-block locations), Queensland, South Australia, Victoria and Western Australia. Data was not collected from New Zealand as comprehensive data on crash rates already exists. Crash rates have also been generated for a case study local government area.

The crash rates generated include information on mid-block and intersection crash rates. The data is provided as an estimate of crash rates for different road environments, including single or divided carriageway, urban and rural roads, number of approaches at intersections and type of traffic control. The information provides a 'snapshot' of crash rates at the current time, but has been designed to allow an update as new information becomes available.

An example of the results for mid-block crash rates (CR) in Victoria is presented in Table 1

Table 1: Victoria - mid-blocks

	100 million VKT 5 Yrs	Fatal crashes	Fatal CR	Injury crashes	Injury CR	All crashes	Total CR
Carriageway							
Single	1046.59	820	0.78	27480	26.26	28300	27.04
Divided	874.28	322	0.37	14444	16.52	14766	16.89
Environment							
Urban	913.34	376	0.41	23651	25.90	24027	26.31
Outer-urban	348.05	231	0.66	7626	21.91	7857	22.57
Rural	659.49	535	0.81	10647	16.14	11182	16.96

Future work will involve further analysis of the database with the opportunity to conduct more thorough analysis on different road environments, and also to conduct some fundamental research. Topics may include the identification of differential crash rates by land use type and estimating the effect on risk of unequal flows on approaches to intersections.

Investigation of risk reduction for various safety treatments in different environments

Based on extensive reviews of literature, estimated crash reductions have been developed for 36 road safety treatment types. Table 2 provides a list of the treatment types addressed

Local and international research has been assessed, and adapted for use in the Australasian context. Where possible, the expected reduction in different road environments has been determined. As an example, Table 3 presents the results for the installation of splitter and median islands at intersections.

A rating scale indicating the methodological robustness of research has been developed, and was a useful tool in assessing the quality of research, and in determining how much weighting to apply to each study that contributed to the final reduction figure (to date this has only been used to qualitatively weight results, but it may be possible to use this scale to apply a numerical weighting).

The rating scale is shown in Table 4

Table 2: Treatment types for which crash reduction estimates were derived

Accesses	Intersection - signal visibility
Clear zone - batter rounding	Line marking - profile edge line
Clear zone - general	Median crossovers
Clear zone - length hazard	Midblock turning provision
Clear zone - point hazard	Off road delineation - guide posts
Delineation - RRPMs	Overtaking
Intersection - advanced warning	Pavement markings - centreline
Intersection - control beacons	Pavement markings - edgeline
Intersection - intersection road types	Pavement markings - speed limits
Intersection - left turn lane	Pavement markings - words and symbols
Intersection - linked signals	Pedestrian/cyclist
Intersection - red light camera	Sight distance
Intersection - right turn phase	Signs - advisory
Intersection - right turn lane	Signs - regulatory
Intersection - right turn lane (extend length)	Street lighting
Intersection - splitter and median islands	Speed (change in limit and change in mean speed)
Intersection - roundabout (single versus multiple lane)	Traffic calming
Intersection - signal timing	Work zones

Table 3: Estimated crash reduction from installation of splitter and median islands

Issue	Environment type	% reduction
Channelisation at intersections – plitter and median islands	Splitter island – all environments	40%
	Splitter island – rural	35%
	Splitter island – urban	40%
	Splitter island – T intersection	45%
	Splitter island – X intersection	40%
	Median island – mountable	15%
	Median island – non-mountable	25%

Due to a lack of robust research evidence, for the majority of treatment types only a medium level of confidence has been applied. Despite this, these estimates are based on the best available information, and should be considered by practitioners when estimating crash reductions for these treatment types.

Areas for further research were identified based on gaps in knowledge. In order to address these gaps, data will need to be collected or trials undertaken.

Based on the poor methodology identified in much of the research, some form of guidance or training in evaluation is required to assist practitioners and those evaluating research. The framework for assessing methodological robustness (see Table 4) may be used to help advise research funders on the confidence they should place in proposed research. With a better understanding of this issue, it is likely that better quality research will be produced.

Through reviews of the relevant literature and an analysis based on data collected from site visits, this part of the project has led to the development of models that may be used by practitioners to determine the appropriate balance between road design standards, road safety benefits and costs. Issues of importance included horizontal and vertical alignment, sight distance, cross section (including pavement width and shoulder type) and roadside elements (e.g. clear zones). As an example, figures for relative risk relating to horizontal alignment have been calculated for use in Australian and New Zealand conditions. These are provided in Table 5. This table indicates that the level of risk at a horizontal curve of 200 m radius is estimated to be 3.9 times that of a curve of 1400 m radius.

However, a lack of reliable information on a number of issues was highlighted and it is recommended that further research be conducted into the relationship between crash risk and the standards adopted for geometric design elements. Key issues where robust information is lacking include the safety of curves with a radius below 500 m, the most effective combinations of shoulder width, lane width and shoulder type, and crash risk and horizontal alignment for typical situations in urban and outer urban areas. It is recommended that the large amount of data collected on geometric alignment and cross section be analysed in association with crash data to develop information on these and other key issues.

Table 4: Study rating system

Study type	Descriptive statistics only	Simple statistical analysis	Complex statistical analysis
Simple study – no controls, no traffic volume	1	1	(not likely)
Study without control group but traffic volume	2	2	(not likely)
Study using comparison group/all crashes etc. to control for general crash trends	3	4	5
Study controlling for general crash trends and the regression-to-the-mean effect, generally using controls based on similar sites	3	4	5
Study using matched comparison group, based on crash rates controlling for general trends and regression-to-the-mean	3	4	5

Implications of varying design standards

The purpose of this research was to identify road design elements that affect road safety, and examine the extent to which the variation of standards applied to each element of design (e.g. design speed, sight distance, cross section) affects the safety performance of roads in different environments (e.g. urban and rural).

Table 5: Relative risk factors for horizontal curvature

Radius (m)	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
Relative risk	6.0	3.9	3.0	2.7	1.9	1.6	1.4	1.3	1.3	1.2	1.2	1.1	1.0	1.0

Information on local road safety schemes

Based on concerns that treatments implemented on state road networks may differ in type and effectiveness to those used on local road systems, this part of the project sought to provide better knowledge of the success, or otherwise, of treatments used on local roads. This study compared the types of treatments used on local roads with those used on state road networks. Attempts were also made to identify the effectiveness of treatments in these different environments, although this was only possible through an analysis of the predicted benefit of schemes and not actual outcomes. There are weaknesses in using the predicted benefit, as this may differ greatly from actual scheme benefits. Differences in treatments used were identified and are shown in Figure 1.

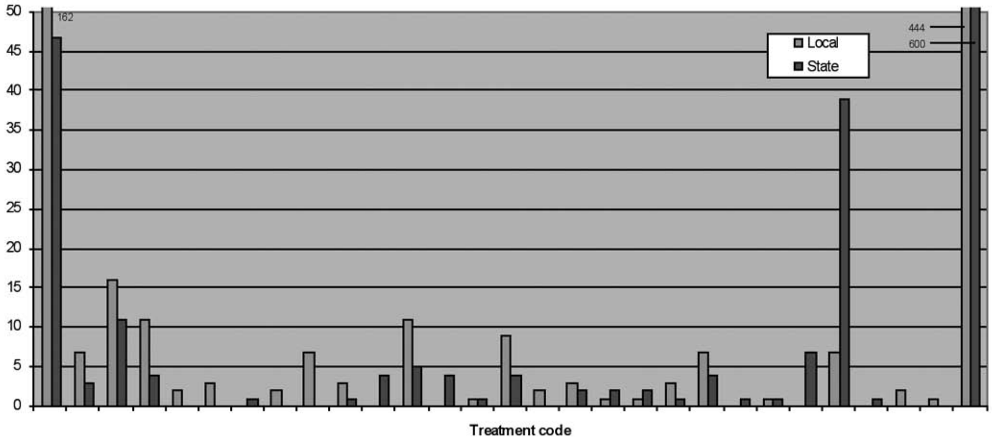

Figure 1: Number of blackspot sites treated, by treatment type

This figure provides information on Australian schemes as approved by the Federal blackspot program between 1996/97 and 1999/2000, 51% (745 projects) of which were on state roads and 49% (706) on local roads. Of interest were the higher proportion of roundabouts installed on local roads, the higher proportion of signals projects on local roads, and the higher proportion of shoulder sealing projects on state road networks. Results from New Zealand's crash monitoring system showed a similar trend.

For the Australian sites, the predicted benefit-cost ratio (BCR) from the blackspot submission was available for analysis, and was used as a proxy for the effectiveness of a treatment type. Across all of the Australian data, the average BCR for all local road treatments was 10.7 and the average for state roads was 8.7. Some marked differences were found in the expected BCR between local and state road treatments. For example, the predicted effectiveness of remodelling of signals and provision of a pedestrian refuge is around double on local roads compared with state roads. The predicted effectiveness of traffic islands and reduced radius on a left-turn slip lane is around double on state roads compared with local roads.

It was concluded that there are differences in the types of treatments used on local roads compared with those used on the state road network. Information on the expected safety benefits indicated that there were also differences for many treatments. It is recommended that where possible, future evaluations of blackspot effectiveness include analysis by state and local road to provide further guidance on this topic.

Use of crash cost as an indication of severity

This part of the research aimed to improve the relevance, accuracy and potential use of crash costs as computed for road user movement crash types. These costs are important in their own right, and as proxy measures of average crash severity. A revised method for estimating these crash costs was developed, and preliminary estimates for 30 June 2005 developed for seven Australian jurisdictions covering twenty crash group categories. Equivalent estimates for New Zealand were not developed, as detailed crash costs already exist. Detail in estimates included cross tabulation by area of operation and speed limit, the latter level having not previously been available in Australian estimates. A measure of reconciliation between road user movement crash costs and severity of outcome crash costs was also achieved.

In-depth investigation of rural head-on, intersection and run-off-road crashes

This part of the research explored the incidence and causes of rural head-on, rural intersection, and rural run-off-road crashes, and identified possible countermeasures to combat these crash types. A literature review on causes and possible countermeasures for each of these crash types was conducted. This review also assessed the level of crash reduction that could be expected from each of these measures. Crash causes for head-on and intersection crashes were also assessed based on an extensive analysis of crash data from each Australasian jurisdiction. Site visits were undertaken at locations throughout Australasia where a high incidence of these two crash types were identified, with similar work planned for run-off-road crashes in the coming year.

The review of the literature revealed that these three crash types were the leading cause of crashes in rural areas. The causes of run-off-road crashes included road alignment, surface condition, shoulder conditions and various behavioural issues, including driver fatigue, inattention and excess speed. Those for head-on crashes were similar (run-off-road crashes sometimes lead to head-on crashes due to over correction), with the addition of overtaking as an issue. Rural intersection crashes were often due to a lack of adequate site distance, excess speed and intersection complexity.

Treatments were similar for rural head-on and run-off-road crashes, and included measures to improve delineation (e.g. warning signs and chevrons), shoulder treatments (including profile edgelines for run-off-road crashes), barriers (including wire-rope barriers), surface treatments, and improved curve geometry / realignment. Head-on crashes were also addressed with the addition of overtaking lanes and improved lane separation.

Treatments for rural intersection crashes included the installation of rural roundabouts, surface treatments, improved sight distance (e.g. removing obstructions), reduced speeds, advanced warning and street lighting. The expected crash reduction from each of these measures was identified where possible.

Safety implications of road asset deterioration

The objective of this project was to provide guidance to road safety managers about the risk associated with sub-standard assets and the risk-reduction benefits associated with their restoration. This will enable safety investments involving the restoration of asset condition to be considered on the same basis as other safety investments such as the provision of new facilities or the remodelling of existing facilities. The following issues were included in the assessment, and where possible, models developed for each:

- skid resistance
- macrotexture
- roughness
- rutting
- drainage
- edge wear
- edge drop
- unsealed shoulder condition
- line marking
- guide posts
- retro-reflective pavement markers
- signs
- roadside vegetation.

Information has been provided on the point at which the asset becomes unsafe. As an example, in the case of edge drop (the drop from the top of the paved surface to the underlying gravel surface), the point at which safety is adversely affected is an elevation change of 75 mm. In addition, information is provided as to the expected increase in crashes at this point (1.5% in the case of edge drop).

Investigation of crash risk migration

This research sought to develop an understanding of the potential for Crash Risk Migration (CRM) to occur with a range of road safety improvement treatments. CRM is defined in this context as a change occurring in a particular part of the network (that may be made in order to improve safety or traffic flow) that may also influence other parts of the network. CRM is examined because its effects have been claimed to have the potential to impact significantly on the evaluation of the success of safety programs, treatments and countermeasures. However, the potential mechanisms of CRM are not well understood. The focus of this study was on situations where CRM may occur as a result of traffic redistribution. Some studies appear to show that CRM may occur due to traffic redistribution.

Although not an exhaustive list, the following treatments were identified as having the potential to cause CRM:

- turn controls or bans
- major changes to a route such as parking changes
- bridge closure
- localised speed limit changes
- intersection changes e.g. signalisation, turn phase timing change, turning lanes
- traffic calming
- lane additions
- addition of overtaking lanes
- pedestrian treatments at intersections and at mid-block locations
- railway crossing control
- mid block turning provision.

Effect of using multiple countermeasures

An extensive amount of research has been conducted on the effectiveness of various treatments in terms of crash reduction. In most cases this research attempts to quantify the effectiveness of single treatments so that advice can be provided to practitioners on which single treatment might be most effective to address crash risk. However, it is often the case that more than one treatment is used at the same location. For example, where there is a problem at a rural bend with vehicles leaving the road, attempts may be made to improve delineation through the use of signs and line markings, and improvements may also be made to the skid resistance of the road surface. When multiple treatments are used, it is difficult to determine the cumulative effect that these treatments have, as the reductions from each measure are not likely to be additive. The purpose of this review was to determine what information is available to assist practitioners in determining the effect of using multiple countermeasures.

Based on an analysis of New Zealand data it was found that multiple treatments were used at around 80% of crash locations. A review of the literature revealed several commonly used equations that attempt to account for the diminishing benefit from using multiple treatments. The most common was of the following form:

$$CRFt = CRF1+(1-CRF1)CRF2+(1-CRF1)(1-CRF2)CRF3+ \ldots$$

where: CRFt = total crash reduction

CRFx = individual crash reductions.

As an example, if three treatments are being considered in one location, with respective reductions of 40%, 25% and 20%, the results would be as follows:

$$CRFt = 0.4 + (1\text{-}0.4) \times 0.25 + (1\text{-}0.4) \times (1\text{-}0.25) \times 0.2$$

$$= 0.4 + 0.6 \times 0.25 + 0.6 \times 0.75 \times 0.2$$

$$= 0.4 + 0.15 + 0.09$$

= 0.64, or a 64% reduction in crashes.

A 64% reduction in crashes is obviously less than the 85% reduction that would be calculated if each reduction was added together.

However, of the equations identified in the literature, none appear to have been validated. An attempt at validation was made based on New Zealand crash monitoring data. An analysis was undertaken on the crash reduction effectiveness of several single treatments, and this information was compared with the effect when using these same treatments in combination.

The results showed that existing equations over-estimate the combined benefits of treatments. Based on the results of this analysis, it is recommended that crash reduction estimates derived using these equations be multiplied by 0.66 to provide a more accurate estimate of actual reduction (in the example above, instead of a 64% reduction, a 42% reduction should be used). It was also recommended that attempts be made to prioritise the combinations of treatments that are most commonly used, and then a program of research undertaken to identify crash reductions from these combinations.

Future Research

There are two more years of Austroads funded research on this topic, and a number of research projects are planned. Research in 2006/07 includes further updating of information on the expected crash reduction from various treatments based on published literature. In addition, based on gaps in knowledge identified in the earlier research (i.e. where there is inadequate published literature), a number of high priority issues will be assessed through an analysis of monitoring data and/or field trials.

The research will also examine the issue of treatment life. In determining the benefits of a safety scheme, treatment life has a large influence (potentially larger than the expected crash reduction), although little robust information exists on this issue. It is planned to provide advice to jurisdictions so that more accurate treatment life figures can be used.

A study will be conducted on crashes on unsealed roads, including a review of literature, and an analysis of crash data including the calculation of crash rates for these types of roads.

A further area of work will involve a review of the automatic collection of road and roadside data of relevance to road safety risk (e.g. horizontal and vertical alignment, road surface condition, and clear zone width). An assessment will be made as to what road features can currently be automatically collected through vehicle mounted sensors, and an evaluation made of priority issues for which it is not currently possible to collect such data. If possible, new data collection techniques will be developed. This project has the potential to increase the accuracy, but decrease the resource demands for safety related data collection. DISSEMINATION OF RESULTS

Project reports are currently being produced providing fuller details on the results of this work. These should be available from early next year from the Austroads website (www.austroads.com.au). ARRB is also producing a series of project newsletters titled the Road safety risk reporter. A number of these have been produced, with more in progress. Links will be provided from this newsletter to full reports where appropriate. Copies of newsletters can be found on the ARRB website at www.arrb.com.au, or by emailing riskreporter@arrb.com.au.

The results of the research program will also be used to update the Road Safety Risk Manager (RSRM) and NetRisk software. The RSRM expert system was launched in 2002 to provide authorities with a tool to manage, prioritise and track the status of road safety treatments on their networks (1). NetRisk is a new tool to identify high risk locations on a road network based on road features (2). The models incorporated in the software continue to be updated as part of the research program and this objective forms an important component of the ongoing research.

Summary

ARRB is involved in an ongoing series of Austroads funded research projects on road safety engineering risk assessment. Results from this research will be disseminated through reports, as well as a newsletter, the Road safety risk reporter. The results will also be made available to practitioners through the Road Safety Risk Manager and NetRisk software.

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Testing the Pedestrian Safety of Bull Bars: Methods and Results

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Abstract

Thirteen bull bars and five models of vehicle were tested to measure their performance in pedestrian impact tests. Three types of test were selected for the assessment: two tests using an impactor representing the upper leg of an adult pedestrian and a test with an impactor representing the head of a child. The headform impact and one of the upper legform impacts were with the top rail of the bull bar and the second upper legform impact was with the bumper section of the bull bar. Equivalent locations on the vehicles to which the bull bars attach were also tested. The tests were conducted at 30 km/h. The tests showed that the steel bull bars tested presented the highest risk of injury of any configuration tested. Aluminium/alloy bull bars also performed worse than the vehicles tested, but to a lesser extent than the steel bull bars. Overall, the polymer bull bars tested performed best and slightly better than the front of the vehicles tested.

Introduction

Four-wheel-drive (4WD) vehicles are used by many motorists who do most of their driving in urban environments. Much has been spoken and written on the safety implications of these vehicles and the bull bars that are fitted to them. While bull bars are sometimes mounted on 'recreational' 4WDs, they may also be installed on work vehicles, conventional passenger cars and derivatives and heavy vehicles.

The extent to which bull bars are involved in pedestrian collisions and injury is not clear from readily available data. In 1996, the Federal Office of Road Safety estimated that bull bars were certainly involved in 12% of fatal pedestrian collisions but may be involved in as many as 20% (1), although it is not clear how the latter estimate was arrived at, nor whether these figures represent an increased risk of death due to the presence of the

bull bar. More recently Attewell and Glase (2) used Australian crash data to try to estimate the effect of bull bars on fatality statistics. They could not draw firm conclusions due to the incompleteness on the bull bar status of vehicles in their fatality database. Furthermore, there were (and are) few data on bull bar fitment rates, so it was difficult to estimate risks associated with bull bar fitment. Attewell and Glase note that data on bull bar fitment rates would facilitate the estimation of relative risks of injury and death associated with bull bars.

Previous physical tests of the type to be reported in this paper have shown that bull bars can increase the severity of impacts with pedestrians but that not all bull bars are equally dangerous (3, 4). Attewell and Glase (2) conclude that, on balance and given the results of such impact tests, bull bars are likely to increase the risk of injury to pedestrians.

For many vehicle owners who drive their vehicles in mainly urban environments, bull bars rarely perform their ostensible purpose – protecting the vehicle in the event of an animal