ENGINEERING BASED MEASURES TO MANAGE SPEEDS ON RURAL ROADS

Blair Turner
Australian Road Research Board (ARRB)
Vermont South, Australia

ABSTRACT
Speed is a major contributor to crashes worldwide, including those on rural roads. The association of Australian and New Zealand road agencies (Austroads) has completed a program of research to provide guidance for managing speeds on these roads. The research focuses on road engineering based measures to address this problem. This paper provides a summary from this research, identifying speed-related treatments for higher risk locations. The research is based on an extensive review of literature, and trials of various treatments, particularly those used where speed reduction is likely to have greatest impact (e.g. curves, intersections and approaching small towns). Where available, information is provided on the expected speed and crash reduction from such treatments. Along with the general research findings, information is provided on an analysis to determine the effectiveness of vehicle activated signs; and the benefits of rural/urban gateway treatments.

1 INTRODUCTION
Worldwide, it is suggested that speed contributes to around one-third of all fatal crashes (OECD 2006). Previous research has demonstrated that speed is also a major contributor to crashes in rural areas in Australia and New Zealand. Armour and Cinquegrana (1990) reported that speed is the probable or possible cause of a quarter of rural serious crashes in Australia that involved single vehicles, while Haworth and Rechnitzer (1993) reported that around 20% of fatal crashes in rural areas involved excess speed. An analysis conducted as part of this study (reported in Austroads, in press; Turner, 2009) identified that around 30% of fatal crashes in Australasia were the result of speed (28% in Australia, and 31% in New Zealand). In addition, speed contributes to 20% of rural injuries in Australia, and 22% in New Zealand. The same research indicated that the number of crashes and fatalities due to speed remained relatively steady over the five-year period for which data was collected (2003 to 2007). Based on the data available, it was estimated that every year in Australia around 200 fatal crashes occurred on rural roads involving speed, while the figure for New Zealand is around 80 fatal crashes per year.

Guidance exists for addressing this issue on urban roads, but it appears there is less information available on measures to reduce speeds for rural areas. To address this issue, Austroads (the association of Australian and New Zealand road agencies) commissioned research to identify effective techniques to reduce speed and speed-related crashes in rural areas. The project aimed to identify and review established treatments, as well as innovative approaches to speed management. This objective was achieved through extensive review of previous research on this topic; consultation with experts in Australia and New Zealand (including workshops) as well as elsewhere in the world; crash investigation; and trials of
promising treatments. Early findings from this research were presented in Turner (2009), while this current paper provides an overview of the final project outcomes. Full details of this work, including a comprehensive list of references can be found in Austroads (in press).

The research was set within the Safe System framework, the guiding vision for road safety in Australia and New Zealand (Australian Transport Council 2011; Ministry of Transport 2010). The Safe System approach accepts that humans will make errors and take risks and, as such, crashes will continue to occur. In addition, humans are physically vulnerable, and are only able to withstand limited change in kinetic energy (e.g. during the rapid deceleration associated with a crash) before injury or death occurs. Therefore, infrastructure that takes account of these errors is required so that road users are able to avoid serious injury or death in the event of a crash. The Safe System aims to manage vehicles, road and roadside infrastructure, and speeds in order to minimise death and serious injury as a consequence of a road crash.

There is a strong relationship between the management of safe speeds and the provision of appropriate infrastructure when trying to achieve Safe System outcomes. In situations where adequate infrastructure exists (e.g. separation of road users and roadside protection), it is possible to have higher speeds. However, if we would like to achieve Safe System outcomes without the provision of such infrastructure, the other current alternative is to provide lower speed environments. Ultimately, speeds that match human tolerances are required. However, it is expected that it will take some time before such speed limits are widely used (or alternatively, adequate infrastructure is in place to facilitate higher speeds). Incremental improvements to safety can be made by reducing speeds by even small amounts (as demonstrated below).

2 THE LINK BETWEEN SPEED AND SAFETY OUTCOMES

The literature on this subject points to a very clear link between speed and crash outcomes. In an Australian study on rural speed, Kloeden et al. (2001) identified that the risk of involvement in a casualty crash more than doubles when travelling 10 km/h above the average speed of non-crash involved vehicles, and that it is nearly six times as great when travelling 20 km/h above that average speed.

Overseas, Elvik (2009) conducted an analysis of 115 separate speed studies across a number of countries. The study included 526 estimates of a change in the casualty rate in response to a change in speed. A meta-analysis was conducted on this combined data, and the results provide strong support for the ‘Power Model’. This shows that even small reductions in mean speed can result in substantial decreases in fatal and injury crashes. For example, a reduction in mean speed from 105 km/h to 100 km/h is expected to result in a 20% reduction in fatalities.

A direct causal link between speed and crash risk has also been firmly established. In a presentation to the Royal Statistical Society, Elvik (2004) concluded that there is a causal relationship between speed and road safety based on a number of arguments, including that:
There is a very strong statistical relationship between speed and road safety. It is difficult to think of any other risk factor that has a more powerful impact on accidents or injuries than speed.

The statistical relationship between speed and road safety is very consistent. When speed goes down, the number of accidents or injured road users also goes down in 95% of the cases. When speed goes up, the number of accidents or injured road users goes up in 71% of the cases.

The causal direction between speed and road safety is clear. Most of the evidence reviewed in this report comes from before-and-after studies, in which there can be no doubt about the fact that the cause comes before the effect in time. (p 3).

From research on the topic of speed, it is clear that excess speed is a substantial problem in rural areas (as it is in urban areas), and that for any given road, an increase in speed is likely to result in reductions in safety through a higher incidence of crashes and an increase in their severity outcome.

3 WHAT SOLUTIONS ARE AVAILABLE?
The main focus of this research was to identify the engineering-based treatments that might be used to manage speed on rural roads. Ideally, speeds would be reduced to levels that were within human tolerances in the event that a crash may occur. Some of the treatments identified were able to produce reductions of this scale (most notably the use of roundabouts at intersections), but many others produced only small reductions in speed. These treatments may not deliver Safe System speeds (i.e. situations where the speed would essentially eliminate the chance of a fatal or serious outcome in the event of a crash) but rather provide incremental safety improvements. These may also produce substantial safety benefits.

A compendium of good practice has been produced and provides information on each of these treatments (Austroads, in press). The effect of each of the key treatments has been identified where possible, including the likely speed and crash reductions. Treatments are provided for specific high risk locations on rural roads (curves, intersections, and the approach to towns) as well as for networks in general.

For completeness, non-engineering treatments for addressing speed were also discussed (including enforcement and penalties; education, training and publicity; and Intelligent Transport Systems) but did not form the main focus of the research.

A summary of treatments is provided in the tables below. Information is given on the treatment by road environment type (e.g. curve, intersection), the expected crash reduction (for casualty crashes), speed reduction (mean speed), and the extent of use in Australia and New Zealand.
A number of these treatments have been used extensively, and information regarding their implementation and effectiveness is well known. Others are emerging treatments or in trial stage. Some of these newer treatments have great potential to improve safety on rural roads.

A comprehensive list of references lies behind each of these values provided, but it is beyond the scope of this paper to provide each of these. For further information see Austroads (in press). It should be noted that the quality of literature upon which these findings are based is quite variable. In some cases the information relating to crash and speed reduction is quite robust, while in other cases there is more limited information. In many instances, further research is required to help firm up guidance on this issue.
4 TREATMENTS AT CURVES

<table>
<thead>
<tr>
<th>Treatment type</th>
<th>Brief description</th>
<th>Crash reduction</th>
<th>Speed reduction</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced warning signs</td>
<td>Used in advance of bends to raise attention level and slow down motorists.</td>
<td>25%</td>
<td>Unknown</td>
<td>Well established</td>
</tr>
<tr>
<td>Chevron alignment markers (CAMs)</td>
<td>Used to indicate presence and severity of curves.</td>
<td>30%</td>
<td>3.5 km/h</td>
<td>Well established</td>
</tr>
<tr>
<td>Speed advisory signs</td>
<td>Sometimes used to help indicate severity of a curve.</td>
<td>40%</td>
<td>Unknown</td>
<td>Well established</td>
</tr>
<tr>
<td>Other delineation devices</td>
<td>Includes guideposts, line marking, pavement markers, etc. to provide additional guidance for safe roadway negotiation.</td>
<td>5 – 20%</td>
<td>May increase</td>
<td>Well established</td>
</tr>
<tr>
<td>Vehicle activated signs</td>
<td>Once triggered by approaching speed exceeding threshold speed limit, sign displays the hazard.</td>
<td>35%</td>
<td>6 km/h</td>
<td>Emerging treatment</td>
</tr>
<tr>
<td>Transverse rumble strips</td>
<td>Audio-tactile treatments applied transversely or across the driving lane to warn of approaching curves.</td>
<td>Unknown</td>
<td>5 km/h</td>
<td>Shows promise</td>
</tr>
<tr>
<td>Perceptual countermeasures</td>
<td>Changing the motorists’ perception of the environment to improve safety, e.g. creating an illusion that a curve is tighter than it is in reality.</td>
<td>Unknown</td>
<td>10 km/h</td>
<td>Shows promise</td>
</tr>
<tr>
<td>Route-based curve treatments</td>
<td>Consistent application of curve treatment(s) along a route.</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Untested</td>
</tr>
<tr>
<td>Slow markings</td>
<td>Road markings in advance of a curve to indicate the need to slow down.</td>
<td>Unknown</td>
<td>5%</td>
<td>Untested</td>
</tr>
</tbody>
</table>

Of particular note for treatments at curves are the use of consistent route-based treatments at curves and vehicle activated signs (VAS). Information on the consistent application of treatments at curves appears to hold great potential for improving safety. UK (Helman et al. 2010), Danish (Herrstedt & Griebe 2001), and Portuguese (Cardoso 2005) research all point to the benefits of ‘banding’ curves according to risk, and applying appropriate curve treatments according to the risk. Consistent application of treatments at similar curves should lead to fewer surprises for motorists. It is encouraging to see that this emerging treatment is now being trialled in Australia, although the results from this work are still some time off.

This current research drew together the existing information on VAS from around Australia and New Zealand including published results from Burbridge et al. (2010) and Gardener & Kortegast (2010), as well as some unpublished material. A retrospective analysis was conducted on this data to estimate the effect of this treatment in different environments.
Given the limited budget available, and the retrospective nature of this evaluation, a control group was not used, limiting the validity of the findings. Therefore, the results should be treated with caution.

Casualty crash data was available from 16 sites (5 years of data before installation and between 1 to 5 years after installation). Speed data was available at only four sites, and this was provided in aggregated form thereby limiting the statistical power of the analysis. Indications were that VAS at curves can be effective at reducing mean speeds (up to a 6 km/h reduction in speeds at curves, with a mean reduction across all sites of 2.2 km/h) and 85th percentile speeds (up to a 8 km/h reduction in speeds, with a mean reduction across all sites of 5.2 km/h). There was also a trend towards a reduction in casualty crashes at these treated sites (37% reduction, with 1.49 casualty crashes per year per site before treatment, and 0.95 crashes per year after), although these results were not statistically significant. These results are reasonably consistent with previous research findings (e.g. Winnett and Wheeler, 2002, who found a 30% reduction in casualty crashes for VAS).

5 TREATMENTS AT INTERSECTIONS

<table>
<thead>
<tr>
<th>Treatment type</th>
<th>Brief description</th>
<th>Crash reduction</th>
<th>Speed reduction</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced warning signs</td>
<td>Used in advance of intersections to raise attention level and slow down motorists.</td>
<td>30%</td>
<td>Unknown</td>
<td>Well established</td>
</tr>
<tr>
<td>Roundabouts</td>
<td>Can reduce speeds and number of conflict points.</td>
<td>70%</td>
<td>4 km/h (30 m in advance)</td>
<td>Well established</td>
</tr>
<tr>
<td>Vehicle activated signs</td>
<td>Once triggered by approaching speed exceeding threshold speed limit, sign displays the hazard.</td>
<td>70%</td>
<td>5 km/h</td>
<td>Emerging treatment</td>
</tr>
<tr>
<td>Perceptual countermeasures</td>
<td>Changing the motorists’ perception of the environment to improve safety, e.g. ‘herringbone’ marking to make the lane appear narrower.</td>
<td>60%</td>
<td>8 km/h</td>
<td>Shows promise</td>
</tr>
<tr>
<td>Transverse rumble strips</td>
<td>Audio-tactile treatments applied transversely or across the driving lane to warn of approaching intersections.</td>
<td>20%</td>
<td>5 km/h</td>
<td>Shows promise</td>
</tr>
<tr>
<td>Speed limits</td>
<td>Reduced speed limits on approach and through intersections.</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Shows promise</td>
</tr>
<tr>
<td>Lane narrowing</td>
<td>Narrowed lanes through use of a wide median, or widened road shoulder.</td>
<td>30%</td>
<td>5 km/h</td>
<td>Shows promise</td>
</tr>
<tr>
<td>Variable speed limits (VSL)</td>
<td>Speed limits that activate when vehicles approach the intersection from a side road.</td>
<td>Unknown</td>
<td>17 km/h</td>
<td>Untested</td>
</tr>
</tbody>
</table>
At intersections, there are a number of established as well as emerging treatments. However, the only treatment that is likely to provide Safe System outcomes is the greater use of roundabouts. Well-designed rural roundabouts have the potential to reduce speeds to levels at which road users are likely to survive in situations where a crash does occur. Recent research, including the most recent evaluation of the Federal black spot program in Australia (BITRE 2012) identified that the use of roundabouts produced a 70% reduction in casualty crashes, and an 80% reduction in fatal crashes.

Other intersection treatments are likely to deliver substantial safety benefits. Of particular note was the use of VAS at intersections. The evaluation of VAS (discussed above) provided data on the effectiveness of VAS at intersections. Again, the sample sizes were small, and there was no control group, so results need to be treated with caution. Speed data was only available from six sites, with an average reduction in mean speed across these sites of 2 km/h (5 km/h for 85th percentile speeds). The reduction in casualty crashes was estimated to be 70% (falling from 1.74 crashes per year per site to 0.53). Crash data was only available from 10 intersection sites, and was not statistically significant. The reduction is greater than what might be expected from such a modest change in mean speed. This may be because such treatments have a greater benefit than just a reduction in speed, with motorist awareness also increased through the use of these signs.

Lowering of the mandatory speed limit on the approach to the intersection was identified as having the potential to provide reductions in speed, particularly when used in combination with other treatments (e.g. enhanced signing; see Austroads 2011). This treatment is being used increasingly in Australia, but further research is required to determine its effectiveness.

6 TREATMENTS ON APPROACH TO TOWNS/VILLAGES

<table>
<thead>
<tr>
<th>Treatment type</th>
<th>Brief description</th>
<th>Crash reduction</th>
<th>Speed reduction</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced warning signs</td>
<td>Signage warning of a lower speed environment ahead.</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Well established</td>
</tr>
<tr>
<td>Buffer zones</td>
<td>A short length of speed zone used to provide a stepped change between adjacent sections of road that have different speed limits.</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Well established</td>
</tr>
<tr>
<td>Rural thresholds /</td>
<td>Use of signs with other</td>
<td>35%</td>
<td>25 km/h</td>
<td>Well</td>
</tr>
</tbody>
</table>
The project produced useful information on the effect of rural threshold or gateway treatments when entering towns or villages. Crash data was obtained from 107 treated sites as part of the study. This data was collected retrospectively, and matched control sites (based on township size, road type and environment) were also selected. A simple before and after (with control) analysis was conducted on the data. A statistically significant casualty crash reduction of 26% was identified across all of the treated sites. Further analysis identified that gateways that provided a ‘pinch point’, or some form of road narrowing (including through painted hatching) were most effective (a statistically significant 35% reduction in casualty crashes, compared with no significant difference when just signs were used). Speed data was only available from four sites. An analysis of this data showed reductions in both mean and 85th percentile speeds of between 5 km/h to 20 km/h respectively. Consistent with the crash data above as well as previous research (e.g. Berger and Linauer 1998; Charlton and Baas 2006), there were indications that speed reductions were greater at locations with pinch points.

7 TREATMENTS ON ROUTES

<table>
<thead>
<tr>
<th>Treatment type</th>
<th>Brief description</th>
<th>Crash reduction</th>
<th>Speed reduction</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed limits</td>
<td>Setting an appropriate default rural speed limit.</td>
<td>Unknown</td>
<td>4 km/h</td>
<td>Emerging treatment</td>
</tr>
<tr>
<td>Road narrowing</td>
<td>Road narrowing to reduce speeds, using physical or perceptual measures, or a combination of both.</td>
<td>Unknown</td>
<td>5 km/h</td>
<td>Shows promise</td>
</tr>
<tr>
<td>Weather activated speed limit signs</td>
<td>Use of dynamic message signs to inform drivers of adverse weather conditions (e.g. fog, wind, snow) and static signs to inform of changes in speeds when these conditions are present.</td>
<td>Unknown</td>
<td>5 km/h</td>
<td>Shows promise</td>
</tr>
</tbody>
</table>

General reductions in speeds on routes appear to be harder to obtain. Changes to speed limits alone appeared to produce mixed results. Of greater benefit might be approaches that narrow the road using perceptual measures (e.g. wide centerlines and/or wide shoulders) as well as reducing the speed limit. If motorists were able to appreciate that such roads were of
lower standard (i.e. a lower point within the rural road hierarchy) then there may be greater
acceptance of the lower posted speed limit. Recent European trials point to potential benefits
from this approach (e.g. Jaarsma et al. 2011). Emerging evidence from Australia (e.g.
Whittaker 2012) also indicate the potential of combining these treatments.

8 SUMMARY
This project provides information to practitioners on effective measures (particularly
engineering-based measures) to reduce speeds on rural roads. There are some promising
emerging treatments that look to hold great potential in reducing speeds at key points on the
rural network. It is likely that combinations of treatments will in many cases be most
effective. Trials of such combinations are required before firmer recommendations can be
made. However, the information in this paper, as well as the project report (Austroads, in
press) could be used to guide this work.
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