Engineering based approaches to reducing rural speed

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Abstract

Speed has been identified as a major factor in the occurrence and severity of road crashes. While techniques to manage and moderate speeds in urban areas using different types of treatments have been developed and applied for many years, less has been done for roads in rural road environments. This paper presents initial results from Austroads funded research that seeks to identify and review different approaches to speed management on rural roads, with a particular focus on engineering based treatments. Some key results from an analysis of crash data and site investigations are presented to demonstrate the scale of the safety problem, and some of the factors involved in speed related crashes. The main focus of the paper is on engineering-based solutions. A comprehensive review of literature identified a number of established treatments that act to reduce speeds on rural roads. Where possible, the benefits of these treatments have been quantified. Also identified were a number of less well used as well as some innovative approaches to managing rural speed. The paper presents some of these results and outlines future plans for research on this topic.

Keywords

Speed; rural; road safety; treatments; crash reduction factors; literature review; data analysis; site inspections.

Introduction

Speed has been identified as a major factor in the occurrence and severity of road crashes [e.g. 1, 2, 3]. In the context of this paper speed relates to any road user who is travelling above the posted speed limit, or who is driving at a speed that is dangerous for the conditions (whether that be above or below the posted speed limit).

While the management and moderation of speeds in urban areas using different types of treatments have been developed and applied for many years, less has been done for high speed roads in rural areas to reduce speeds. The key objective of this Austroads funded research is to provide information on effective techniques to reduce speed and speed related crashes in rural areas. In order to achieve this objective, the project aims to identify existing treatments, and quantify the benefits of these. In addition there is also an objective to identify less well known or innovative approaches to speed management and to trial the most promising.

This paper presents the findings from the first year of a four year project on this topic, with the main focus being the identification of engineering based treatments that can be used to address rural speed related crashes. Although this review concentrates on engineering based approaches to reducing speed, it is recognised that non-engineering approaches also have a significant role to play in the reduction of speed on rural roads. The Austroads study is also examining the role of in-vehicle technology, enforcement, and training, publicity and education programs in improving safety. A coordinated response using all of these approaches is essential to maximise the safety benefits for rural roads.

The initial results of the work are being reported at an early stage to alert potential stakeholders to this project. Input to future stages of this work would be welcomed, particularly in regards to on-road trials of promising road safety treatments. In addition, any comments regarding treatments that are missing from this review would be welcomed.
The study is also set firmly within the context of the Safe System approach [4]. The approach accepts that humans will make errors while driving, and so 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. What is required is an infrastructure that takes account of these errors so that road users are able to avoid serious injury or death in the event of a crash. In addition, speeds need to be appropriate to the levels of risk present. Based on what is known about human biomechanical tolerances, the following speeds (Table 1) are likely to be survivable in a crash [5]:

Table 1: Biomechanical tolerances

<table>
<thead>
<tr>
<th>Crash type</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car/pedestrian</td>
<td>20-30 km/h</td>
</tr>
<tr>
<td>Car/motorcyclist</td>
<td>20-30 km/h</td>
</tr>
<tr>
<td>Car/tree or pole</td>
<td>30-40 km/h</td>
</tr>
<tr>
<td>Car/car (side impact)</td>
<td>50 km/h</td>
</tr>
<tr>
<td>Car/car (head-on)</td>
<td>70 km/h</td>
</tr>
</tbody>
</table>

Source: [5]

These figures are based on impact energy levels generally associated with survivable crashes in modern cars. Also the impact speed for car/car (head-on) crashes assumes vehicles of equal mass.

Although these are not expected to be immediately adopted as appropriate speed limits where these crash types might occur, they serve as medium to long term goals for situations where the infrastructure cannot be improved to eliminate these types of crashes (see [6] for a further discussion of this interaction between speed and infrastructure). A key emphasis is on reducing the severity of crashes, as in many cases the elimination of crashes may be unachievable.

The purpose of this paper is to present a brief overview of the research conducted to date, but more importantly to alert safety professionals to the engineering based countermeasures that have been identified. Some of the initial results from an analysis of speed-related crashes in Australia and New Zealand are presented, as are an overview of findings from site inspections of speed related crash sites.

Methods

The results presented in this paper are based on:
- an analysis of crash data from Australia and New Zealand on rural speed crashes
- an investigation of sites where speed was known to have been a contributory factor
- the findings from a literature review.

To identify the key factors associated with speed related crashes in rural Australia and New Zealand, an analysis of road authority crash data was undertaken. Data for speed related crashes in rural locations in New Zealand and some Australian jurisdictions was disaggregated by variables reflecting:
- temporal characteristics (e.g. time of day)
- site characteristics (e.g. speed limit)
- crash characteristics (e.g. DCA category)
- environmental conditions (e.g. light conditions)
- road user characteristics (e.g. controller age and vehicle type).

Casualty crash data for New South Wales, Queensland, Western Australia, South Australia, Tasmania, Northern Territory and New Zealand was used in the analysis. No Victorian or ACT data was analysed, as the VicRoads and ACT crash databases do not include causation factor information (including speed). This data was compared to data for crashes in the same environments that did not involve speed. Only descriptive statistical analysis was performed.

There are issues of reliability when using contributory factors in crash analysis. The information regarding causality is typically subjective, and may be influenced by a number of factors. For example,
there may be a tendency to suggest speed was a factor in situations where specific road conditions are present, or with specific types of drivers. All results therefore need to be treated with some caution.

The second task involved a series of investigations undertaken at a number of sites in New South Wales (NSW), Queensland (QLD) and Western Australia (WA). The purpose of this task was to help identify factors that may have contributed or could potentially contribute to the occurrence of speed related crashes in rural areas. A total of 49 sites were investigated.

Eligible sites chosen for further investigation were selected through GIS analysis. Road sections were divided up into 200 m midblock sections. Casualty crashes where speed was thought to be a contributing factor (recorded through police reports) were then grouped to individual locations.

The locations were then sorted in descending order with the top approximately 30 sites (based on casualty crash numbers) for each state being selected as being eligible for further site investigations. A selection of these sites was then investigated. A team of engineers (typically involving either two or three members) assessed road engineering features at sites using safety checklists based loosely on road safety audit procedures. Factors that were thought to contribute to crash occurrence were recorded at each of the sites inspected, and

It is not suggested that the sites selected are the 'worst' crash sites where speed was identified as a contributory factor. It is also recognised that it is likely that many crashes where speed is a factor are not recorded as such. However, it is expected that the sites will constitute a sample of locations where speed is identified as a key contributory factor in the occurrence of crashes.

A search of the published literature on the topic of speed produced around 9000 reports and articles. To review all of these was beyond the scope of this study. Instead, a selective review was conducted that aimed to identify key reference documents relating to speed management for rural roads. Major topics for review included speed management within the Safe System context; how drivers select their speed (with particular reference to factors relating to the road environment); and the treatment of speed through road engineering related treatments. This paper concentrates on the last of these issues.

Results

The data analysis identified that speed (either travelling above the speed limit, or too fast for the prevailing conditions below the speed limit) is a significant contributor to deaths and injuries in both Australia and New Zealand. Around 28% of all fatal crashes in Australia, and 31% in New Zealand are recorded as being attributed to speed. In addition, it is estimated that speed contributes to 20% of rural injuries in Australia, and 22% in New Zealand. It is likely that these figures are an under-estimate of the true extent of speeding [7, 8].

Crashes that were identified as having speed as a contributing factor were compared with crashes where speed was not identified as being a factor. The analysis identified some key findings, including that a higher proportion of speed crashes occur:

- at night or in the early morning
- on curved roads
- midblock (as opposed to intersections)
- on hilly roads
- on wet roads.

A higher proportion of speed related crashes involve:

- not wearing a seatbelt
- alcohol or drugs
- motorists aged 17 – 24 years
- motorcycles.

Site investigations of locations where speed was known to have been a contributory factor in crashes identified a number of other issues that might contribute to the occurrence of speed related crashes, including poor delineation (e.g. signing, guideposts, and raised reflective pavement markers); the
presence of roadside hazards (e.g. trees and poles); lack of adequate road shoulders; loose material on the road; and poor sight distance. A number of these issues could be rectified through improved maintenance, while others will require more substantial infrastructure investment.

The full results from this research will be released in time, but the main focus of this paper is on the results of the literature review relating to road engineering treatments to address driver speed. The review identified three road environments where reductions in speed are likely to have a significant safety benefit. These were at:

- rural curves
- rural intersections
- transitions from high speed to low speed environments (e.g. entering a rural town).

Information was also obtained on methods to reduce speeds on routes or across the whole rural road network. A summary of these results, including the estimated crash and speed reduction is provided in Table 2.

**Rural bends**

The following treatments were identified for potential use at rural bends:

- advance warning signs
- chevron alignment markers
- speed advisory signs
- route based curve treatments
- other delineation devices (e.g. line markings, guideposts etc.)
- vehicle activated signs
- transverse rumble strips
- perceptual countermeasures.

Of the existing treatments, advance warning signs, chevron alignment markers and speed advisory signs seem to have a demonstrated benefit in reducing speeds at curves and improving safety. However, it was apparent that these are often installed in an ad hoc manner, often in response to high crash locations. A consistent approach is recommended, whereby whole routes (or better still, whole networks) are assessed to determine the severity of curves, and a consistent signing regime used based on this severity. The approach documented by Cardoso [9] and Herrstedt & Greibe [10] are both to be recommended.

Other delineation devices (line markings, guideposts etc.) do not necessarily have an impact on driver speed at curves (there is limited evidence to show that speeds may actually increase if used in isolation, e.g. [11]). However, they do have other safety benefits, potentially resulting in a net safety benefit.

Several new treatments were identified from the review, the most promising of which appears to be vehicle activated signs. These signs are usually activated for a short time (around 4 seconds) when an approaching vehicle exceeds a threshold speed limit (normally set at the 50th percentile speed as measured prior to the introduction of the signs). Once triggered, the sign displays the hazard, and may include a message to slow down. A further explanation of these signs can be found in Winnett and Wheeler [12].

Audio-tactile treatments (transverse rumble strips) have been applied transversely, or across the driving lane, to warn motorists of approaching curves with the intention of increasing awareness and slowing drivers. Although transverse rumble strips have been used in a number of locations there is little objective information available on their effectiveness in terms of speed or crash reduction at curves. McGee and Hanscom [13] reported that there is no conclusive evidence of roadway rumble strip effectiveness in reducing crashes at curves, but that they do tend to reduce speed, in most cases, but not to a practical level. The UK Department for Transport [14] described a trial of a variant of rumble strips called
‘rumblewaves’. These are a quieter alternative to conventional rumble strips, creating noise and vibration within the vehicle driving on it, but not significantly increasing noise levels for those outside the vehicles. Rumblewaves have been tested on the approach to rural bends, but were found to have minimal impact on speed reduction (less than 1 km/h at the trial location).

Perceptual countermeasures are intended to improve safety through a change in the motorists’ perception of the environment. As a speed countermeasure they can help give the impression that motorists are travelling faster than they actually are. Recent work in Australia has evaluated the effectiveness of perceptual countermeasures, including measures at curves. A study by Macaulay et al. [15] found that the use of enhanced edge post spacing, with ascending post heights for curves (to give the impression of a more severe curve) produced mixed results.

**Rural intersections**

Key engineering treatments were identified as being potentially useful for slowing vehicles on the approach to rural intersections. These included:

- advance warning signs
- vehicle activated signs
- roundabouts
- platforms
- perceptual countermeasures
- transverse rumble strips
- speed limits and variable speed limits.

Advance warning signs are used extensively to inform motorists of an intersection ahead. There appears to be a significant benefit from use of these signs, although it is unclear whether this benefit is mostly for those approaching from the side road, or for those on the through road (although it is likely to be for the former).

Well designed roundabouts (particularly those that slow vehicles on the approach to the intersection) have been found to have considerable benefit for high speed roads in reducing high severity outcomes. In Australia, reductions in casualties of between 60 and 70% have been identified [16, 17].

Newer treatments that show some promise include raised platforms (used in some European rural roads, although the benefit is still unknown), perceptual countermeasures (which have produced limited benefits during trials to date in Australia, but have been shown to be effective in the UK) and transverse rumble strips.

Speed limits have been used at a number of rural intersections in Australia in order to reduce speeds, but the effect of this approach has not been evaluated. In Europe, variable speed limits have been trialled, and appear to have meet with some success [18].

**Transitions from high speed to low speed environments**

A number of techniques were assessed at locations where there is a transition from high speed roads to low speed environments (e.g. on the entry to a rural town). Treatments included:

- advance warning
- buffer zones
- count-down signs
- transverse rumble strips
• pavement numerals/speed limit markings
• rural thresholds/gateway treatments.

When used in isolation, these treatments appear to have limited benefits in reducing speeds and improving safety. However, when used in combination, treatments can have significant effects. Rural thresholds, which often use a combination of signs and road markings appear to produce reductions in speed of up to 15 km/h at the transition point [19]. These are used widely in New Zealand and the UK, but have had limited use in Australia. However, research highlights the need to sustain speed reductions by implementing further measures within a town or village [20].

Rural routes and networks
Fewer options were identified that can be used to slow speeds on a rural route or network-wide basis. The treatments identified included the following:
• speed limits
• road narrowing.

A detailed discussion on an appropriate rural default speed limit was outside the scope of this initial study. However, there are various studies that examine the topic of an appropriate rural speed limit [21, 22, 5]. To summarise this work, it appears that rural limits in Australia and New Zealand are generally higher than the safest countries in the world. It is very likely that there would be large safety benefits from a reduction in the default rural speed limit, particularly for undivided roads.

Speed limits less than the default rural limit (i.e. for specific sections of road, rather than for the rural network as a whole) have traditionally been applied when there is an increase in roadside development and activity (e.g. a small township). More recently, lower speed limits have been applied in locations where there is no, or very little roadside development, but rather due to other types of risk (for instance, adverse horizontal alignment). Evaluations are currently being conducted on the effect of this approach (including an extensive trial in New Zealand), but to date there is very little objective information available.

Road narrowing has been used extensively in urban areas, but less so in rural areas. Measures used to narrow roads may be physical (for example, installation of kerb build-outs or roadside islands), perceptual (often through the use of painted markings) or a combination of both. Perceptual measures have the advantage that they typically do not introduce a roadside hazard, whereas physical measures can.

Road narrowing has been used for rural roads in a number of countries. Perhaps most widely reported is the new ‘2 – 1’ (two minus one) system used in some European countries. This system involves the removal of the road centreline, and installation of a broken edgeline. The road is effectively narrowed to one lane in total (e.g. [23]). To date there has been little in the way of evaluation of this approach.

Table 2 provides a summary of the results obtained to date through the review of literature. Information on crash reduction as well as reduction in speed is provided where this is available. A subjective measure of confidence in the results is also provided. This is based on issues such as the robustness of the methodology used in research, the number of studies on this issue, consistency of results, and country where the research was conducted.
Table 2: Summary of engineering treatments investigated

<table>
<thead>
<tr>
<th>Treatment type</th>
<th>Crash reduction</th>
<th>Mean speed reduction</th>
<th>85% speed reduction</th>
<th>Confidence in results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rural bends</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advance warning signs</td>
<td>30%</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Medium</td>
</tr>
<tr>
<td>Chevron alignment markers</td>
<td>30%</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Medium</td>
</tr>
<tr>
<td>Speed advisory signs</td>
<td>13 – 60%</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Medium</td>
</tr>
<tr>
<td>Vehicle activated signs</td>
<td>30 – 35%</td>
<td>3 – 11 km/h</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td>Other delineation devices</td>
<td>Various</td>
<td>May increase</td>
<td>May increase</td>
<td>Low</td>
</tr>
<tr>
<td>Transverse rumble strips</td>
<td>Unknown</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Low</td>
</tr>
<tr>
<td>Perceptual countermeasures</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td>Route based curve treatments</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Rural intersections</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advance warning signs</td>
<td>30%</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Medium</td>
</tr>
<tr>
<td>Vehicle activated signs</td>
<td>30 – 35%</td>
<td>3 – 11 km/h</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td>Roundabouts</td>
<td>50 – 70%</td>
<td>Unknown</td>
<td>Unknown</td>
<td>High</td>
</tr>
<tr>
<td>Platforms</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td>Perceptual countermeasures</td>
<td>15 – 60%</td>
<td>2 – 9 km/h</td>
<td>9 – 11 km/h</td>
<td>Low</td>
</tr>
<tr>
<td>Transverse rumble strips</td>
<td>Unknown</td>
<td>4 – 12 km/h</td>
<td>Unknown</td>
<td>Medium</td>
</tr>
<tr>
<td>Speed limits</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td>Variable speed limits</td>
<td>Unknown</td>
<td>17 km/h</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Transition zones</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advance warning</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Low</td>
</tr>
<tr>
<td>Buffer zones</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Low</td>
</tr>
<tr>
<td>Count-down signs</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Low</td>
</tr>
<tr>
<td>Transverse rumble strips</td>
<td>Minimal</td>
<td>2 – 3 km/h</td>
<td>2 – 4 km/h</td>
<td>Low</td>
</tr>
<tr>
<td>Pavement numerals / speed limit</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Low</td>
</tr>
<tr>
<td>markings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural thresholds / Gateway treatments</td>
<td>15 – 27%</td>
<td>2 – 15 km/h</td>
<td>Unknown</td>
<td>Medium</td>
</tr>
<tr>
<td>Vehicle activated devices</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Networks and routes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed limits</td>
<td>Various</td>
<td>Various</td>
<td>Various</td>
<td>Medium</td>
</tr>
<tr>
<td>Variable speed limits</td>
<td>10%</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Low</td>
</tr>
<tr>
<td>Road narrowing</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Low</td>
</tr>
</tbody>
</table>

Discussion

Road users travelling above the speed limit, or too fast for the prevailing conditions are a significant safety problem on rural roads. From a review of Australian and New Zealand data, it appears that speed contributes to almost a third of fatal crashes on rural roads, and one in five casualty crashes. These figures are likely to underestimate the true extent of speed as a causal factor in rural crashes.
A number of engineering based treatments have been identified that may assist in reducing speed and casualties at key locations on the rural road network, or across the network as a whole. Reasonable evidence exists on the effectiveness for some of these treatments, while for others there is little objective data (mostly because they are relatively new and untried, and require some assessment to determine effectiveness).

The next stage of this project involves workshops in each Australian state, and in New Zealand to determine gaps in knowledge (e.g. treatments that have been overlooked to date in this review); to determine which treatments are thought likely to deliver good safety benefits; and to plan future trials of these treatments. In addition, data will be collected on a number of treatments already used in Australia and New Zealand to help improve knowledge about the effectiveness of these treatments.

The ultimate aim of this project is to issue advice on effective treatments that can be used by practitioners to reduce operating speeds and therefore improve safety on the rural road network.

References