Cost-effective measures to improve crash and injury risk at rural intersections.

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Abstract

Crashes on rural roads are a major road safety problem, accounting for up to two-thirds of deaths and serious injuries worldwide. Rural intersections, in particular, are dangerous locations, accounting for over 30 percent of these rural crashes. Most collisions at intersections occur in high-speed settings, at intersections that are uncontrolled or controlled by stop or give-way signs, and often on low-volume, single-carriageway roads. This paper provides an overview of a systematic review of international literature, identifies 'best-practice' measures to reduce crash and injury risk at rural intersections and describes cutting-edge strategies and evaluation of infrastructure measures for managing safety at rural intersections. Cost-effective measures include: measures to reduce speed and speeding and the injury consequences, speed perception measures, roundabouts, traffic signals, grade-separation, channelisation, signing to clarify priority, removal of sight distance obstructions, provision of medians, skid-resistant pavements and limited access from side roads and driveways. The paper highlights the need to address key crash problems at rural intersections by developing and implementing a system-wide and comprehensive approach that fundamentally improves the operation and design of these locations.

Introduction

Rural road safety accounts for a considerable share of the total road safety problem in most western countries, with up to two-thirds of all road fatalities occurring on rural roads. Rural intersections in particular are problematic, being responsible for up to 30 percent of rural crashes which result in death and serious injury to vehicle occupants (Barker, Farmer & Taylor, 1999; Parliament of Victoria, 2002; Wilson & Dunn, 1994).

An extensive review of international literature on the key issues and current state of knowledge with regard to rural road safety and the impact of infrastructure on the frequency and severity of crashes was commissioned by the Swedish Road Administration (SRA). The review highlighted the key crash types on rural roads, identified cost-effective infrastructure safety measures, and made recommendations for a strategic plan to address the problems (see Oxley, Corben, Koppel, Fildes, Jacques, Symmons & Johnston, 2004). This paper presents a detailed review of the problems at rural intersections and makes recommendations for fundamental infrastructure improvements to the design and operation of rural intersections aimed to reduce crash and injury risk. An overview of other key crash problems in rural areas including single-vehicle run-off-road and head-on crashes, and identification of innovative infrastructure practice and philosophies to address these crash types is presented in a separate complementary paper (Oxley, Corben, Koppel & Johnston, 2005).

Contributing factors

Intersections are an important part of the roadway system and, by definition, are locations within the road network where the paths of vehicles cross. There are two types of intersections found on rural roads: at-grade intersections, generally found on all classes of rural roads other than freeways and motorways and include four-way cross roads, T-intersections, and private accesses; and, grade-separated intersections including overpasses and entrance and exit ramps, which are generally provided on highways, freeways and motorways with high design speeds and carrying high traffic volumes.

While the aims of intersection design are to improve traffic flow, reduce the number of points of conflict and reduce the likelihood of severe crashes, there are some geometric features that may increase crash and injury risk. The safety performance of an intersection is strongly influenced by decisions about spacing between intersections, type of control, hierarchy, size and geometry and the following geometric features have been shown to contribute to increased crash and injury risk at rural (and urban) intersections:

- Poor or inappropriate intersection control and signage,
- Poor or restricted sight distance,
- Poor or inappropriate delineation or alignment,
- Inadequate street lighting,
- Poor design of freeway interchange ramps, and
- Inappropriate design speed.

At-grade intersections

These are potentially the most hazardous parts of the road network because they present the driver with many potential points of conflict at high impact angles with other road users. Many of the most dangerous at-grade intersections are on low-volume, single-carriageway roads and roads approaching towns which are either uncontrolled or controlled by ‘stop’ or ‘give-way’ signs. Moreover, in rural settings, these types of intersections are even more dangerous because these conflicts often occur at high speeds. Given that vehicles are limited in their capacity to protect their occupants at speeds of 50 km/h or higher in these crash types, the result is often severe.

Collisions at at-grade intersections most commonly occur when a driver makes a poor gap selection or fails to give way. These crashes tend to occur when drivers fail to perceive the presence of an intersection, fail to select a safe gap in approaching traffic, or approach an intersection at a speed that will not allow them to avoid impacts with vehicles ahead, either slow-moving vehicles or stationary vehicles that are waiting to turn. Compounding problems here are high speed, high traffic volumes, high impact angles and restricted sight distances. Further, intersections controlled by ‘stop’ or ‘give-way’ signs invariably give priority to the major road. However, because of the relatively high speed of cross traffic, crashes caused by failure to stop or give way can be severe (Russell, Stokes & Rys, 1999).

While intersections controlled by traffic signals are usually, though not always, safer than those controlled by ‘stop’ or ‘give-way’ signs, there is also some suggestion that intersections that fail to provide fully-controlled turning phases, also pose difficulties for turning manoeuvres (Fildes, Oxley, Corben & Langford, 2004). Additionally, traffic signals operating in high-speed rural areas exhibit poorer safety records than in lower-speed environments.

Various other factors also contribute to poor rural intersection design. Reduced sight distance, for example, is an important feature. A sight distance problem occurs when the distance available to drivers to manoeuvre through the intersection (whether turning across traffic or crossing priority lanes) is less than the distance required to complete these manoeuvres and this is especially a problem on high-speed highways where lengthy sight distances are necessary (Bonneson, McCoy & Truby, 1993). Features such as provision of channelisation, delineation and alignment, can also affect crash risk, where poor design or maintenance of these features can create operational problems, particularly misperceptions by drivers of safe gaps and lane choice, and stability problems especially for large heavy vehicles.

An additional problem also lies in intersections between roads and rail lines in rural areas. The majority of rural highway-rail intersections (HRIs) are controlled passively, i.e., provision of warning signs placed on the road approaching a railroad. Here, the approaching driver is not alerted that a train is approaching and must search for the train themselves before deciding whether to proceed across the railway line. Active HRIs (provision of boom gates and flashing lights to alert drivers of an approaching train and block the road) are rarely provided at rural crossings and only when a large number of trains and road vehicles use the intersection daily. Passive HRIs are a significant safety issue, with in excess of 50 percent of any particular jurisdiction’s rural HRIs likely to be passive crossings (Russell, 2002; Wigglesworth, 2002).

Grade-separated intersections

Freeways are becoming more common within and between major cities and are often characterised by a higher safety level due, in part, to the provision of grade-separated intersections (i.e., interchanges). While it is argued that this provision, in conjunction with other factors such as control of access and the generally high standard of freeways, improves safety and operational performance on these roads, there is some concern that geometric features of entry and exit ramps can result in significant safety and operational problems (Harkey, Huang & Zegeer, 1996; Knoblauch, Nitzburg, Reinfurt, Council, Zegeer & Popkin, 1995; Malfetti & Winter, 1987).

Exit and entry areas of freeways are transitional areas that may require a substantial change in tracking. Merging manoeuvres should take place at the speed of the freeway traffic stream; therefore, entry acceleration ramps need to be long enough for drivers to accelerate to the speed of the freeway traffic. There is some evidence that crash rates are higher on shorter entry ramps than on longer ramps (Cirillo, 1970; Lundy, 1967; Reilly, Pfefer, Michaels, Polus & Schoen, 1989).

The design of exit ramps can also increase crash risk, particularly if signage is unclear or inappropriate, or road markings are inadequate (Taylor & McGee, 1973). In addition, the design of cross-road approaches to an exit ramp of a freeway can potentially lead to wrong-way movements, i.e., vehicles entering an exit ramp at the cross-road terminal. It seems that some ramp designs are more problematic and susceptible to wrong-way movements than others. Copelan (1989) argued that the 'full-diamond' interchange design can pose problems for drivers, because an off-ramp can be mistaken for a frontage road located parallel to the ramp. Parsonson and Marks (1979) also determined that 'partial-cloverleaf' ramps are susceptible to wrong-way movements because the entrance and exit ramps are in close proximity, while 'half-diamond' designs are susceptible because they are an incomplete interchange and drivers may make unintentional wrong-way entries.

Countermeasures and treatments at intersections

Given that vehicles have a limited potential to protect an occupant, and vehicle occupants are also limited in the mechanical forces that they can tolerate, improvements in intersection design should be seriously considered. Measures to address multi-vehicle crashes at intersections are outlined below and include: measures to reduce speed; grade-separated intersections; appropriate traffic control at at-grade intersections; adequate sight distance; delineation and alignment; warning signs; adequate lighting; and, active controls at rail crossings.

Treatments to reduce speed

Given that speed and speeding is a major contributor to trauma at rural intersections, measures to reduce speeds have great potential to minimise crash frequency and severity. There are a number of ways to manage speed on the approaches to intersections including reduction of speed limits, provision of traffic calming measures such as pavement narrowing, installation of refuge islands, and alteration of the road surface (particularly raising of the surface), provision of perceptual countermeasures, and provision of technologies to enhance speed limit compliance.

Provision of grade-separated intersections

Grade-separate intersections remove the major points of conflict and are generally provided on highways, freeways and motorways with high design speed and carrying high traffic volumes (Austroads, 1988; Hughes Amis & Walford, 1997). They are considered to greatly enhance safety, however, have lower BCRs due to their high capital cost, and are rarely considered for intersections on low-volume two-lane rural roads.

Improvements to geometric features of grade-separated intersections include: provision of longer entrance ramps (minimum lengths of between 240 and 280 m); provision of multiple advance warning signs before exit ramps; and, provision of traffic control devices (signs and pavement markings) to prohibit wrong-way movements on exit ramps from the minor intersecting road.

Provision of appropriate traffic control at at-grade intersections

The aims of traffic control at intersections are to provide safe and efficient operation, to clearly define the conflict area and which driver has priority, and provide advance warning of the intersection. There are different control types that may be suitable for one intersection but unsuitable for another. Moreover, there are decisions to be made as to which type of control is most cost-effective, particularly on low-volume rural roads. Traffic signals are less common in rural areas for a number of reasons; side-road traffic volumes may be too low to warrant their installation and the high travel speeds make safe stopping for red signals somewhat hazardous. Right-turning movements are known to constitute a relatively high crash and injury risk at traffic signals without fully controlled turn phases. This form of risk is even more acute on high-speed rural roads where it is critical that accurate judgements are made of the distance and speed to approaching traffic. Errors have the potential to result in severe outcomes. Thus, if traffic signals are to be used at rural intersections, full control of right-turning movements is highly desirable.

Roundabouts are becoming increasingly popular as safe traffic control devices. There are many reports of major benefits of roundabouts, contributing substantially to reductions in both crash and injury risk to vehicle occupants by fewer and simplified conflicts, reducing speed, and more favourable collision angles, leading to reduced crashes and costs. This applies to the main crash types occurring at rural intersections, namely, cross-traffic, turn-against, and, in some cases, rear-end crashes. Persaud, Retting, Gardner and Lord (2001) found significant reductions in crash severity at intersections in the USA that had been converted from other forms of traffic control (signals, 'stop' and 'give-way' signs) to roundabouts. Corben, Ambrose and Foong (1990) evaluated the effectiveness of the Victorian 'black-spot' treatment program in rural and metropolitan areas in 1979 and found that new roundabouts were the most impressive of the intersection treatments, showing casualty crash reductions of 81 percent. They estimated BCRs for all intersection treatments and found an overall BCR of 8.8 with a BCR of 19.1 for intersection treatments in rural areas. In the case of roundabouts constructed at 'black-spot' intersections (including non-metropolitan intersections), the estimated BCR was 7.5. No other treatment types, other than new traffic signals or remodelled traffic signals, were found to reduce crashes in a statistically reliable way. In their more recent evaluation of 'black-spot' treatments, Newstead and Corben (2001) also found that the most impressive of the intersection treatments, applicable to rural settings, was the construction of a new roundabout, where average reductions in casualty crash frequencies of 73 percent and in casualty crash cost of 87 percent were achieved. The estimated BCR for new roundabouts was 5.0.

Provision of adequate delineation and alignment

Channelisation and delineation of turning lanes, provision of medians and traffic islands, and provision of enhanced signing have been shown as effective measures to reduce crash and injury risk at at-grade intersections (Bonneson et al., 1993; Lydon, 1997). The provision of left or right-turning lanes or of acceleration/deceleration lanes can reduce rear-end crash and injury risk by avoiding the situations of slower or stationary vehicles in the path of faster vehicles approaching from behind. This problem is more pronounced in urban fringe areas (Tziotis, 1993). Associated benefits of channelisation and delineation include crash reductions between 30 and 60 percent and BCRs of 2.3 (Strate, 1980; McFarland, Griffin, Rollins, Stockton, Phillips & Dudek, 1979; Newstead & Corben, 2001; McKnight, McKnight & Tippetts, 1998). Improvements to channelisation and delineation include: the use of raised channelisation with raised reflective pavement markers for turning lanes; provision of features to prevent wrong lane-use when turning such as lane-use control signs, lane-use arrow markers, pavement markings and delineation of median noses; provision of painted edge-lines when unsealed shoulders are present; and provision of semi-mountable kerbs that are painted on the slope and at least a portion of the top surface.

The provision of wide medians as a form of intersection treatment can prevent drivers on the minor road crossing the divided road at high speed or mistaking the first carriageway as a two-way road and making a wrong way movement (Crowley & Seguin, 1986). Provision of wide medians with geometric features such as provision of 'divided highway crossing' sign to prevent wrong-way movements, adequate width to accommodate crossing manoeuvres of buses and trucks, and two-way, left-turn lanes (with estimated crash reductions of approximately 20 to 30%, particularly rear-end and sideswipe crashes) (Thakkar, 1984).

Provision of warning signs

These are provided to alert drivers of hazardous conditions that may not be apparent, such as the presence of intersections, particularly those with poor sight distance. These include flashing beacons, variable message signs and vehicle-activated signs. Provision of 'stop' or 'give-way' signals that are retro-reflective and conspicuous, holding lines and advance warning signs can also alert drivers of the presence of intersections on low-volume rural roads (Mace & Pollack, 1983). A combination of traffic signals and advance warning flashing beacons are thought to be an effective corrective measure at rural highway at-grade intersections and are regularly used in the USA, with reports that driver alertness or awareness to potential hazards were enhanced by flashers (Stackhouse & Cassidy, 1997).

Provision of adequate sight distance

Provision of adequate sight distance on approaches to and entering intersections, and when turning across oncoming traffic can reduce crash frequency and severity and studies have shown reductions of up to 67 percent in crashes where obstructions that inhibited sight distance were removed (Mitchell, 1972; both cited in Staplin et al., 1998; Strate, 1980). A minimum perception-reaction time value of around 5 s is recommended for rural intersections. Physical obstructions, severe grades and poor horizontal alignment contribute to inadequate sight distances that compromise driver safety, however, simply offsetting opposing turning lanes can ensure turning traffic will always have an unobstructed view of the entire intersection (Fildes et al., 2004; Staplin et al., 1998).

Provision of lighting at intersections

Adequate lighting at intersections is required to increase visibility of the roadway and its immediate environment at night, thereby enabling drivers to manoeuvre safely and efficiently through an intersection. In their examination of the effect of installation of street lights at rural intersections on crash risk, Preston and Schoenecker (1999) found a reduction in night-time crashes at intersections where lights were installed and noted that the benefits associated with the installation of street lighting at rural intersections outweighed the cost by a ratio of 15 to one.

Measures to improve safety at railroad intersections

Measures to improve safety at railroad intersections can be achieved by four major methods: i) requiring trains to slow or stop as they approach HRIs; ii) removal of the at-grade crossing; iii) modification of the crossing (e.g., conversion from passively controlled crossings to actively controlled crossings); and iv) convincing drivers to pay more attention and actively search for trains as they approach and set out to cross the rail line. Due to the prohibitive cost of upgrading passive rail-road intersections with active-warning devices, and the impracticalities associated with slowing trains as they approach HRIs, countermeasures should focus on improving the environment for drivers to make appropriate decisions. For example, improvements to sight lines by removing foliage, maintenance of the crossing so that drivers can devote a maximum amount of their attention to scanning for trains, and further encouraging drivers to slow down and search for trains, regardless of how infrequent trains are at the particular crossing (Wigglesworth, 2002).

Most promising countermeasures

In making recommendations for 'best-practice' infrastructure measures to effectively reduce crash and injury severity at rural intersections, various factors are considered including the influence of higher operating speeds, hazardous roadsides, poor road geometry compared to urban roads, multi-functionality and lower enforcement levels on country roads. It is important that, given the large dangers associated with rural intersections, simple infrastructure improvements to intersection design take place to create a safer travel environment whilst maintaining mobility.

For intersections in high-speed settings, most of the identified countermeasures are effective, to varying degrees, in reducing crash occurrence. However, few of these also substantially limit the risk of serious injury when crashes occur (e.g., traffic signals, channelisation, and lighting). What is required are measures that can reduce ***both*** crash frequency ***and*** the severity of injury. For example, for intersection crashes in high-speed rural settings, roundabouts have been shown to not only reduce crash frequency by some 70 to 90 percent, but they also reduce crash costs (reflecting injury severity) by around 90 percent. That is, roundabouts have been found to reduce, in a fundamental way, both crash risk and the risk of serious injury to the occupants of vehicles colliding at intersections.

Those initiatives that will have a fundamental change in intersection design and driver-road interface such as speed limit reductions, grade separation, and installation of new roundabouts are considered against initiatives that have an incremental change such as improved channelisation and delineation, improved sight distance, provision of warning signs and lighting.

In review of the current literature and practices of how to increase the safety at intersections on rural roads, the following important measures are recommended:

1. **Speed reduction** – speed has a fundamental relationship with both crash and injury risk. Substantial improvements are achievable for ***all*** crash types from minor reductions in travel speed and even smaller reductions in impact speed. For intersections, introduction of measures that reduce speed on approaches to intersections can greatly reduce the frequency and severity of crashes. At impact speeds often found in rural intersection crashes, modern-day vehicles, even those fitted with the best available safety features, offer very limited protection from serious injury to their occupants, particularly side-impact crashes at speeds of 50 km/h and higher. Infrastructure countermeasures that eliminate conflict or combine, in an optimal way, the management of speed and energy transfer at impact appear to offer the most promising options for enhancing rural intersection road safety.

2. **Grade-separated intersections** – have the potential to all but eliminate crash risk, but the high cost of grade-separation may make them less attractive than some other alternatives.

3. **Roundabouts** – can reduce crash risk at intersections by between 70 and 80 percent, crash costs by around 90 percent and have been found to result in BCRs of around 19 when constructed at rural intersections with a high crash record.

Conclusion

Collisions that occur at rural intersections, particularly those that are controlled by 'stop' or 'give-way' signs, and on high-speed, low-volume, single-carriageway roads, are a major source of death and disability with respect to the overall number of fatalities on roads and hence, fundamental improvements to rural intersection design and operation on rural roads are required.

By reviewing international literature, a set of 'best-practice' cost-effective measures was identified that have the potential to fundamentally reduce crash and injury risk at rural intersections. By considering roundabouts, grade-separated intersections and measures to actively reduce the speed at which drivers approach intersections such as speed limit reductions, perceptual countermeasures and other speed advisory warnings substantial gains in safety at rural intersections can be achieved.

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