RURAL ROUNDABOUTS AND THEIR APPLICATION IN NEW ZEALAND

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ABSTRACT

This paper presents research on the design and operational guidelines required for the safe application of rural roundabouts, documents current national and international practices, and defines a set of criteria and recommendations suitable for New Zealand.

1.0 Introduction

In New Zealand, roundabouts have traditionally been used for urban intersection control, but they have recently been used in fringe areas between rural and urban environments. In the search for a cost-effective and safe form of control of rural intersections, the concept of a "rural roundabout" has been suggested.

The number and density of vehicle conflict points that exist at an intersection directly influences the frequency of crashes. The potential for severe conflicts at roundabouts (i.e. right-angle conflict points) is virtually eliminated through the use of a roundabout. The potential for minor conflicts is halved in the case of a four-arm roundabout, but remains constant for a three-arm roundabout. The density of the conflict points is also decreased.

Although the potential for serious injury crashes is decreased, the actual number of crashes may increase due to the roundabouts' operating characteristics. Roundabouts can be associated with an increase in minor injury and non-injury crashes (i.e. nose-to-tail crashes on the approach, and low angle merging and diverging crashes). The potential for a crash to occur at a roundabout is the probability of an exposure resulting in a crash (the risk, say), multiplied by the exposure (a function of the traffic volume). The low absolute speeds associated with well-designed roundabouts allow drivers increased time to react to a potential crash (i.e. a reduced risk), as well as reducing differential speeds and injury severity. The Transfund NZ Project Evaluation Manual allows only a 40-60% crash reduction when estimating the crash cost savings for replacing priority control with a roundabout.

The level of demand that rural roundabouts may impose on drivers needs to be considered during the feasibility and design processes. A rural driving environment can generally be expected to induce a lower level of alertness, by placing a lower demand on the driver than does an urban environment. The presence of a roundabout in a rural environment may require supplementary measures on the approach, to warn drivers so they can negotiate it safely.

Specific guidelines need to be established for safe and effective implementation of roundabouts in a rural environment. Several factors need to be considered, both in terms of the geometric design and possible effects on the users, with special consideration given to reducing the speed differentials between conflicting traffic streams.

This paper presents research investigating the design and operational guidelines required for the safe application of roundabouts in rural environments, documents and compares current practices (both national and international), and defines a set of criteria and recommendations suitable for New Zealand based on current "best practice".

2.0 Design Speed

Controlling vehicle speeds through the roundabout, to ensure they are about 50 km/h, is a critical geometric design objective that must be met to ensure the safe operation of the roundabout. In rural environments the 85^{th} percentile speeds are commonly about 111 km/h (LTSA, 2000), so a speed reduction of over 50 km/h may be required at a rural roundabout. A well-designed roundabout will also minimise the relative speeds between vehicles, while accommodating the largest and least manoeuvrable legal vehicle (rural roundabouts may have a much greater proportion of large trucks than their urban counterparts).

The operational speed of a roundabout is determined by the geometry of the roundabout, in particular the radius of the fastest and flattest path that a straight-through vehicle may take. The smallest radius along the fastest path usually occurs on the circulatory roadway as the vehicle curves around the central island. The entry path radius should not be significantly larger than the circulatory radius, to limit the speed reduction required to safely negotiate the latter curve. Adequate deflection is critical to safe operation of a roundabout, various studies indicating crash frequency and severity increase as the deflection reduces (Austroads, 1993).

Increasing vehicle path curvature decreases the difference in speeds of entering and circulating vehicles, but also increases the difference in side friction between adjacent circulating traffic streams in multilane roundabouts. A study in Queensland (QDMR, 2000) showed that greater side friction between adjacent traffic streams results in more vehicles cutting across lanes and a higher potential for sideswipe crashes. To minimise the potential of crashes at a roundabout an 'optimal' design speed is required.

The speed (v) of a vehicle on a circular path is related to the path radius (R) as follows:

$$(e + f) = \frac{v^2}{gR} \tag{2.1}$$

where e is the superelevation, f is the coefficient of sideways friction, and g is the acceleration due to gravity. The value for the design side friction coefficient varies with vehicle speed, and Austroads (1999) suggests for rural road design that the maximum design value be 0.35 at 50 km/h, decreasing to 0.11 at 120 km/h. Different design guides indicate different adjustments for speed, but both the US Department of Transportation (2000) and Austroads (1993) roundabout design guides recommend a value of 0.2 at 50 km/h. The difference in the Austroads side friction coefficient values for general rural road design and for roundabout design is interesting, and apparently stems from vehicle occupants accepting different rates of radial acceleration on a roundabout than they would accept on a normal road alignment.

The conventional wisdom is that to achieve circulating speeds about 50 km/h the appropriate radius would need to be about 100m. International experience indicates that the use of radii of about 100m results in high circulating speeds (i.e. distinctly greater than 50 km/h). While equation 2.1 might be fine for designing large radii curves, alternative methods need to be used in the case of roundabouts. Indeed, the speed-radius relationship (equation 2.1) indicates that v=50 km/h when R=100 m, f=0.2 and e=0. The value of superelevation will depend upon the path; for an elevated central island, there is a negative e-value for R_2 and R_4 and a positive e-value for R_5 (see Figure 2.1). The design guidelines differ in whether they allow for superelevation and the design side friction coefficient; ignoring superelevation and using a design side friction less than the available friction can lead to excessive path radii and hence excessive operating speeds.

The path radius varies as a roundabout is traversed, and safe operation of a roundabout requires minimal variation in the design speeds for consecutive geometric elements (Figure 2.1 shows the five critical path radii that must be checked for each approach). Safe operation also requires minimal variation in the speeds of conflicting traffic streams; as well as reducing crash rates and severity, it increases entry capacity by reducing the critical gap required.

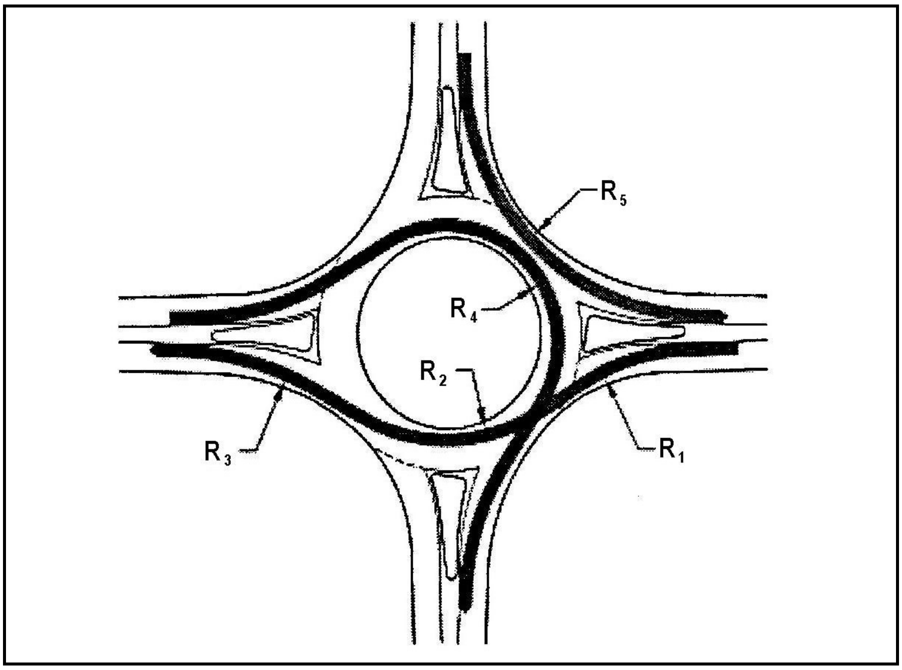

Figure 2.1: Travel path radii (USDoT, 2000).

In Figure 2.1, R_1 (the entry path radius) is the minimum radius on the fastest straight-through path prior to the "Give Way" line. R_2 (the circulating path radius) is the minimum radius on the fastest straight-through path around the central island. R_3 (the exit path radius) is the minimum radius on the fastest straight-through path into the exit. R_4 (the right-turn path radius) is the minimum radius on the path of the conflicting right-turn movement. R_5 (the left-turn path radius) is the minimum radius on the fastest path of a left-turning vehicle.

On the fastest straight-through path, it is desirable for R_1 to be smaller than R_2, which in turn should be smaller than R_3 (to avoid the need for drivers to slow down within the roundabout in order to safely negotiate it), but the design speed difference for each successive radius should be preferably less than 10 km/hr (USDoT, 2000). This ensures that speeds will be reduced to their lowest level at the roundabout entry and will thereby reduce the likelihood of loss-of-control crashes. It also helps to reduce the speed differential between entering and circulating traffic.

3.0 Sight Distance

Rural areas are typically high-speed environments, and it is imperative for safe roundabout operation that the appropriate sight distance criteria are met. However, providing more than the required minimum sight distance can be hazardous. Greater sight distances can result in higher speeds that will be detrimental to the safety performance of the intersection. It is also important that the sight distances provided must be consistent for all approaches to the roundabout. If one approach leg has better sight distance than the others it allows vehicles on that leg to approach the roundabout at much faster speeds than vehicles on the other entries.

Vehicles on the approach arms with restricted sight distances may have insufficient time to react to the arrival of fast moving vehicles and crashes may result. The design guides use different terminology when explaining sight distance requirements and there is variation in the calculation methods, but each addressed the following three sight distance criteria.

The first is the provision of approach sight distance (ASD) so drivers can see roundabouts and stop before reaching them if necessary. Adequate approach sight distance should be provided to the "Give Way" lines and, as an absolute minimum, to the nose of the splitter island. The required minimum approach sight distances from the Austroads guide, which both the Queensland, and Maryland guides are based on, are given by the equation:

$$\mathrm{ASD} = \mathrm{R_T V} + \frac{\mathrm{V}^2}{2\mathrm{d}} \tag{3.1}$$

where R_T is the perception-reaction time, V is the initial speed, and d is the deceleration rate.

Values of R_T and d must be assumed in order to compute the values of ASD appropriate to a specified initial speed. The driver perception-reaction time depends on the nature and strength of stimulus and the psychological state of the driver. As a rural roundabout is likely to be an isolated alignment feature, a value of 2.5 seconds is the minimum that should be used for the perception-reaction time. The equation implies no deceleration during the perception-reaction time, followed by constant deceleration until the vehicle is stopped.

The American guide (USDoT, 2000) uses equation 3.1 but assumes a constant vehicle deceleration of 3.4 m/s^2 for all initial speeds. This assumption is questionable, as deceleration can vary with both the initial velocity and road surface characteristics. The British guide (TD 9/93, 1993) gives a range for the minimum stopping distance measured to the "Give Way" line. The range is given as 165 – 225m (at 100 km/h approach speed) and 225 – 300m (at 120km/h approach speed) with the first distance being the "one step below desirable minimum" and the second value being the "desirable minimum".

The second criterion (Austroads, 1993) is provision of entering sight distance (ESD), so drivers can enter roundabouts without impeding the circulating traffic. A stationary driver at the "Give Way" line should have a clear line of sight to approaching traffic entering the roundabout from an approach immediately to the right, for at least a distance representing the travel time equal to the critical acceptance gap. The speed of the approaching traffic should be taken as the 85th percentile speed, which on a rural roundabout with appropriate approach geometry should be not much more than 50 km/h. The ESD can be calculated as follows:

$$\mathrm{ESD} = \mathrm{R_T V} + \frac{\mathrm{V}^2}{2\mathrm{a}} \tag{3.2}$$

where R_T is the perception-reaction time, V is the final speed (the speed of circulating vehicles, if they are not to be impeded), and a is the acceleration rate for an entering vehicle.

ESD should be checked with respect to vehicles in the circulating roadway having entered from other approaches. The speed of these vehicles should be based on the 85th percentile speed of the circulating carriageway. For rural roundabouts this speed should be not much more than 50 km/h. The corresponding sight distance (e.g. across the central island) should be based on a critical gap of four to five seconds (Austroads, 1993), representing a distance of up to 100 metres at 20 m/s or 72 km/h, allowing the vehicle on the approach arm sufficient time to enter the circulating carriageway safely.

The third criterion is that drivers approaching the roundabout should be able to see other vehicles entering ahead of, or to the right of them, well before the former reach the 'Give Way" line, through the provision of a clear sight triangle. The outside edge of the sight triangle represents the critical amount of sight distance required for safe operation of the roundabout, and should define the legal boundary of the road reserve. This will enable the driver of a vehicle on an approach arm to observe a car on the conflicting arm (or circulating carriageway) moving into a collision situation, and to decelerate to a stop before reaching the collision point. This distance (the safe intersection sight distance, SISD) comprises the distance travelled in 3 seconds (the observation time) at the 85th percentile operating speed for the approaching vehicles, plus an alerted stopping distance. It can be estimated as follows:

$$\mathrm{SISD} = T_O V + R_T V + \frac{V^2}{2d} \tag{3.3}$$

where T_O is the observation time (3 s), R_T is the perception-reaction time, V is the initial speed of approaching vehicles, and d is the deceleration rate of approaching vehicles.

The American recommendations (USDoT, 2000) have been based on the British guideline (TD 16/93, 1993), recommending that the approach leg of the sight triangle should be limited to 15m. This limitation restricting the sight distance is intended to require vehicles to slow down on the approaches prior to entry to the roundabout, to allow them to focus on any pedestrian/cycle crossing prior to entry. The provision of excessive visibility at entry (or intervisibility between adjacent entries) can result in higher than desired approach and entry speeds for the provided geometry. Sight distance restrictions should be considered and may involve the selective use of landscaping.

The American guide calculates the length (b) of the conflicting sight triangle for vehicles entering the roundabout facing conflicting traffic on the circulating carriageway as follows:

$$b = (V_{Major})(t_c) \tag{3.4}$$

where V_{Major} is the design speed of the conflicting movements and t_C is the critical gap (6.5 s typically) for entering the major (or priority) flow. The two conflicting traffic streams (i.e. the entering stream and the circulating stream) should be checked at each entry. The critical gap of 6.5 seconds used with equation 3.4 is based on American research, and is relatively large. Research in Australia (Troutbeck, 1993) supports the American research, with the minimum critical gap required for a car to enter in front of another car being 5.37 seconds or 6.6 seconds when entering in front of a truck.

A good correlation between the Austroads and American methods exists at the lower approach speeds but as the approach speeds increase, a marked difference in the results is evident. The American method has much lower sight distance requirements but these could be directly attributed to the sight distances being restricted to 15m from the 'Give Way" line for the vehicle on the approach leg.

4.0 Roundabout Layout

For a driver to maintain a well controlled transition through a rural roundabout the geometry needs to produce a safe and controlled reduction in the drivers' speeds on the approach, limit speeds through the roundabout and allow a safe transition back to normal speeds after exiting. If the central island diameter is too large, circulating speeds may increase as vehicles progress through the roundabout. In terms of the design guidelines the central island diameter is based on limitations imposed on the inscribed circle diameter, which includes both the central island diameter and the circulating carriageway width.

The Queensland and American guidelines have a very similar method for determining the required circulatory carriageway width based on the design vehicle (a 20m B-train in New Zealand). To establish the circulating carriageway width of single lane roundabouts, an offset of 0.6m from each edge of the design vehicle path to the lane edge/kerb should be provided. The circulating carriageway width of dual lane roundabouts would normally need to cater for the movement of the largest anticipated vehicle alongside a passenger car. A distance of 1.2m on the outside edge of the two vehicle paths, and a distance of 0.6m from the edge of the two vehicle paths to the lane edge or kerb, should be provided. The required carriageway width for dual circulating lanes is nominally 3.2m greater than for single lane roundabouts. The value of 3.2m allows for a 2m wide passenger car with an additional 0.6m clearance on either side.

The inscribed circle diameter is obtained from the combination of carriageway width and central island diameter. The American guide (USDoT, 2000) recommends that for a single lane and double lane rural roundabout, the maximum inscribed circle diameter should be limited to 40m and 60m respectively. This is based on the requirement of limiting circulating speeds within the roundabout. The Queensland guide (QDMR, 2000) recommends that for a rural speed environment, the minimum central island diameter for single and double lane roundabouts should be 25m and 40m respectively. With the design vehicle (a 20m B-train), the required circulating carriageway widths are approximately 8.5m (single lane) and 10m (double lane), and these equate to recommendations for an inscribed circle diameter of 42m for a single lane roundabout and 60m for a double lane roundabout. There is an almost perfect agreement between the two guides with respect to this aspect of roundabout design.

In general the use of smaller inscribed circle diameters will result in better motorist safety as lower speeds are maintained. In a high-speed rural environment, the design of the approach and circulating geometry to obtain a maximum acceptable circulating speed of 50 km/h is more critical than in low-speed environments. The use of larger inscribed circle diameters allows for the provision of better geometry, leading to a decrease in vehicle approach speeds. However, very large diameters should be avoided, as they will result in high circulating speeds and crashes of greater severity.

The high-speed environment requires a large speed decrease before the entry curve. To avoid an excessive decrease in speed at the entry curve, a series of reverse curves can be used leading up to the entry curve. This limits the maximum demand placed on drivers and forces them to decrease speed in a more controlled (i.e. gradual) and safe manner. The Queensland guideline (QDMR, 2000) for reverse curves, on which the American guide (USDoT, 2000) is based, recommends the use of reverse curves when the speed environment is in excess of 80 km/h (i.e. virtually all rural situations). To avoid 'driver surprise' it is recommended that the speed decrease between successive horizontal geometric elements be limited to a maximum of 20 km/h. This is greater than the desirable and absolute maximum thresholds of 10 km/h and 15 km/h recommended in the rural roads design guide (Austroads, 1999).

It was found in a Queensland study (QDMR, 1998) that shifting the approach roadway laterally by 7m usually enables adequate curvature to be obtained while keeping the curve lengths to a reasonable minimum. Consideration also needs to be given to the effect that the reverse curves will have on crashes. It may be found that whilst the new roundabout may have very few crashes, crashes may migrate and may occur on the reverse curves prior to the roundabout, where there would otherwise have been none. Due to the risk of inducing accidents prior to the roundabout it may be preferable to stay with a straight approach, and control entry speeds via other measures (such as improved signage and pavement markings).

Entry curves have the function of encouraging drivers to slow down before entry onto the circulating carriageway of the roundabout. The French and American guidelines favour the centred or radial entry in preference to the staggered entry that is favoured by the Australian and British guidelines. The centred or radial alignment creates consistency between the entry and exit speeds, and helps to maintain a low speed differential between the entering and circulating vehicles. The staggered entry geometry enforces much lower entry speeds, as deflection is increased markedly, but much higher exit speeds are allowed as a result.

Rural roundabouts can be designed so that the departure speeds are higher than the entry speeds. Departure curvature should be made as easy as possible for drivers to negotiate, allowing acceleration out of the roundabout, but it is undesirable to allow too much acceleration if there is a pedestrian/cycle crossing point located on the departure. Therefore, the departure radius should not be substantially larger than the circulating radius. The Queensland guide (QDMR, 2000) recommends that a straight path tangential to the circulating radius is preferable for departing vehicles, in contrast to a curved entry path.

The consensus view in all of the guidelines is that for roundabouts in high-speed areas the splitter islands should extend at least 60m back from the "Give Way" line. This emphasises to drivers that they are approaching a roundabout and must slow down. Ideally the splitter islands and their associated painted markings would extend back a distance to where drivers would be expected to undertake comfortable deceleration up to the "Give Way" line.

5.0 Other Design Issues

Whilst roundabouts have an excellent safety record for most vehicle types through the effect that they have on crash reduction, this is not the case for cyclists. A recent publication by Transfund (Traffic Design Group, 2000) showed cyclists were involved in 15% of crashes at urban roundabouts in New Zealand (a higher proportion than for any other form of urban intersection control). This is consistent with experience overseas, and assuming that rural roundabouts would yield similar results (although the number of cyclists is likely be less in rural situations), particular emphasis needs to be placed on the provision of adequate cyclist facilities at the design stage.

A designer has two general options. They can treat the cyclists as vehicles and accommodate them with the other traffic using the roundabout; this requires cyclists to act in a defensive manner and does not give them a false sense of security (there is 'zero' security). Alternatively they can separate cyclists from the other traffic via the provision of separate facilities bypassing the roundabout (this is typical European practice). It is recommended (QDMR, 2000) that special provisions for cyclists are desirable when the cumulative approach traffic volume exceeds 10,000 vehicles per day, or the roundabout is multi-lane, or the vehicle speeds through the roundabout exceed 50 km/h.

The British guide (TD 16/93, 1993) requires the provision of appropriate levels of skidding resistance, to facilitate the large decrease in speed that is required to achieve the roundabout safe operating speed of 50 km/h. Skid resistance requirements tend to be site specific and depend largely on the weather conditions that would be expected.

Provision of road lighting at rural roundabouts would be regarded as a mandatory safety requirement (see clause 8.6 of AS/NZS 1158). Roundabouts are an obstruction in the roadway and drivers need to see them well in advance so as to avoid a collision with them. It is also essential that the approaching drivers not be misled by the lighting configuration.

The use of yellow transverse pavement markings (Denton, 1971) as a speed reduction method is intended to influence the driver to slow down after a period of sustained speed, during which they become ‘speed-adapted’. Speed-adaptation is the phenomenon experienced by drivers who, after leaving a high speed road on which they have become used to sustained speeds of up to 110 km/h, find driving at moderate speeds (around 50 km/h) exceedingly slow (Helliar-Symons, 1981). The pavement markings, if placed with exponentially decreasing spacing as the hazard is approach, impart the sensation of speeding-up to drivers travelling at a constant speed. Drivers thus tend to decrease speed, to have constant time intervals between passing over the markings.

Helliar-Symons conducted a large-scale evaluation of such markings at the approaches to 47 large roundabouts. He concluded that the markings produced a 57% reduction in speed related crashes and a 52% reduction in all crashes (whether or not speed related) involving a vehicle crossing the markings. Other findings were:

- they appeared to maintain their effectiveness for at least four years;
- they were highly cost beneficial;
- they appeared to be most effective in reducing fatal and serious injury crashes whilst still reducing slight injury crashes;
- they were more effective in daylight than during darkness;
- they appeared to be more effective when the road surface was wet rather than when it was dry.

Some concern has been expressed that a learning effect may result in drivers ignoring such markings if they are repeatedly encountered in the course of their journey. To maximise their effectiveness, their use should be restricted to sites that fit certain pre-set criteria with regards to the required reduction in approach speeds for safe negotiation of the roundabout.

The use of yellow transverse pavement markings in NZ may be problematic due to the special significance of yellow pavement markings. It may be that white markings would perform equally well. Care would need to be taken that the markings on the road surface did not have a detrimental effect on the friction properties and skid resistance. It must be noted the provision of good approach geometry to the roundabout should in itself safely reduce vehicle approach speeds. Speed reduction measures such as pavement markings should only be installed as a secondary measure where appropriate geometry cannot be achieved.

Transverse rumble strips (creating at least a 4 dB increase in noise) have also been used on the approaches to hazards, providing both vibratory and audible warning to the driver of the upcoming hazard. Results from a British study (Watts, 1978) on the effectiveness of rumble areas showed that small but statistically significant reductions in speed occurred. As with the yellow bar markings there are concerns that a learning effect may result in drivers ignoring the rumble devices if they are encountered frequently over the course of a journey, so their use needs to be restricted and based on set criteria. The speed control qualities of rumble devices over a long period of time are not entirely proven.

Invercargill City Council has used rumble strips as a speed reduction measure in rural locations at the approaches to intersections where excessive speed is the dominant crash factor present. Before and after studies of the mean vehicle speeds at the trial site indicated a statistically significant reduction in the mean vehicle speeds post installation of the rumble strips. As a result of the trial it has been recommended that rumble strips be implemented at various other 'black spot" localities within Invercargill.

The provision of appropriate signs and markings in a conspicuous and consistent manner is critical for the safe operation of roundabouts located in a rural environment. Drivers need to be provided with adequate advance warning of the intersection, instilling caution, and allowing speeds to be adjusted accordingly. New Zealand law deems an intersection to operate as a roundabout only with the provision of a PW-8 (Rotary Junction Ahead) sign, requiring approaching traffic to give way to all circulating traffic. In effect there is a series of tee-junctions, with the circulating carriageway being the straight through road having priority. Current legislation also requires the use of a 'Give Way" sign on each approach. Ideally these two signs could be incorporated into a single sign (following New South Wales (Australia) and UK practice) to produce a regulatory roundabout sign as shown in Figure 5.1. The roundabout sign means 'Slow Down", prepare to 'Give Way" and if necessary stop to avoid a collision. Implementation of such a sign would require a change to the traffic regulations.

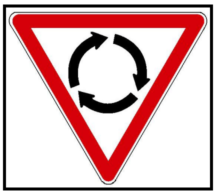

Figure 5.1: NSW and UK roundabout regulatory sign.

Current practice has been to install large destination signs on the high speed approaches to a rural roundabout, and such signs are crucial in giving drivers sufficient advance warning of the upcoming roundabout and giving clear directional instructions. These signs should be coupled with good directional signage located at the roundabout, and may incorporate messages (e.g. 'Christchurch traffic use left lane") where lane positioning is crucial. It is recommended that temporary advance warning signs stating 'New Roundabout Ahead" be displayed for a reasonable time to allow motorists to adjust to new intersection layouts.

Many different forms and variations of circulating lane markings for roundabouts exist internationally, and have been used with varying degrees of success. The MOTSAM guide gives three different marking that can be used to delineate the circulating lanes of a multi-lane roundabout in NZ. However, there is divided opinion on whether lane lines should be used, and if used what is the most appropriate form of lane marking.

Raised reflective pavement markers (RRPM's) and reflective chevron sight boards are useful for enhancing the delineation of the roundabout. Red RRPM's are recommended for delineating the approach and entry curves into the roundabout. Further applications of RRPM's are to delineate the approach centreline and the circulating carriageway lanes. They could also be utilised in a manner similar to transverse pavement markings on the approaches to the roundabout, as a means of slowing traffic. Chevron sight boards should be provided for each approach lane, located directly in front of the lane on the central island. The use of a series of single chevrons (on the splitter island) may be justified on the entry curves.

6.0 New Zealand Experience

We now describe four rural roundabouts and their performance, and then compare their performance with the guidelines in the Transfund Project Evaluation Manual.

6.1 Pound Rd / Buchanans Rd Intersection (Christchurch)

Construction of the roundabout (single circulating lane, 20m central island diameter) at the junction of Pound and Buchanans Roads (replacing an X-intersection) occurred in mid-1997. The sum of the inflows was approximately 6,000 vehicles per day at the time of construction.

In the 4 years following construction, the severity of injury crashes was reduced substantially, with a 100% reduction in injury crashes, and only three non-injury crashes were reported. The calculated crash cost saving from installing the roundabout is approximately $236,000 p.a.

6.1 Wairakei Rd / Russley Rd Intersection (Christchurch)

Construction of the roundabout (dual circulating lane, 30m central island diameter) at the junction of Wairakei and Russley Roads (replacing a priority X-intersection), occurred in mid-1998. The sum of the inflows was approximately 18,000 vehicles per day at the time.

The severity of the injury crashes was reduced substantially, with only one minor injury crash and one non-injury crash reported in the 3 years following construction. There was a 97% reduction in injury crashes and a 70% reduction in the number of non-injury crashes. The calculated crash cost saving is approximately $555,000 p.a.

6.2 Harewood Rd /Johns Rd / Russley Rd Intersection (Christchurch)

Construction of the roundabout (dual circulating lane, 30m central island diameter) at the junction of Harewood, Johns and Russley Roads (replacing a priority X-intersection), took place in late-1996. The sum of the inflows was approximately 18,000 vehicles per day.

The severity of the injury crashes was reduced substantially, with only three minor injury crashes and nine non-injury crashes reported in the 4.5 years following the construction of the roundabout. There was an 86% reduction in injury crashes and the calculated crash cost saving from installing the roundabout is approximately $627,000 p.a.

6.3 Ngongotaha Rd / State Highway 5 Intersection (Rotorua)

Construction of the roundabout (single circulating lane, 25m central island diameter) at the junction of SH5/Ngongotaha Road (replacing a T-intersection) took place early in 1993. The sum of the inflows was approximately 16,000 vehicles per day at the time of construction. This roundabout also incorporated a low angle entry and departure (continuous) slip lane for traffic travelling from Rotorua to Hamilton on State Highway 5.

There was a 96% reduction in injury crashes and a 66% reduction in the number of non-injury crashes, and the calculated crash cost saving is approximately $1,200,000 p.a.

6.4 Comparison with PEM Guidelines

It is likely that crash cost savings rather than capacity will determine the feasibility (benefit-cost ratio) of using rural roundabouts. Oppenhuis and Parish (2000) state that "much reliance is placed on the guidance contained within the Transfund NZ Project Evaluation Manual (PEM), which covers both the crash-by-crash and crash rate methods for estimating accident reductions. For the experienced analysts this is normally relatively straight forward, but for those less experienced the process has often proven difficult. The result is that a large number of projects are either over estimated or under estimated in respect of predicted crash savings".

Typical accident reductions for rural areas are given in the Project Evaluation Manual. Table A6.5(b) allows a 30 – 50% decrease in night time crashes contributed to by poor lighting if road lighting is installed or improved to meet NZS 1158: 1997, and a 40 – 60% reduction in crossing (type J) and right turn (type L) crashes when changing from priority control to a roundabout.

For this study, crash data for the period 1980 to May 2000 were obtained for each intersection from the LTSA, and crashes were categorised as fatal, serious injury, minor injury and non-injury. The crash costs savings were estimated using the crash costs in Table A6.9 of the PEM. The results indicate strongly that the rural roundabouts have been very cost-effective, with crash savings ranging from $236,000 to $1,200,000 p.a. The actual injury crashes reductions are 86-100% (much larger than the 40-60% suggested in the PEM).

7.0 Conclusions

The following recommendations are based on international best practice and are believed to be the fundamental requirements for the safe use of rural roundabouts in New Zealand.

- Design operating circulating speed of 50 km/h.
- Ensure speed consistency between conflicting traffic streams.
- Satisfy all three sight distance criteria, but ensure intervisibility sight distances are not so large that drivers are encouraged to approach the roundabout much faster than the geometry of the roundabout will allow them to proceed safely.
- Ensure circulating carriageway width sufficient for the design vehicle.
- Inscribed circle diameter should be approximately 35 – 40m for single-lane roundabouts and approximately 60m for dual-lane roundabouts.
- Splitter islands should be at least 60m in length (i.e. equivalent to a comfortable deceleration distance on the approach to the roundabout).
- Ensure lighting of the roundabout meets AS/NZS 1158:1997 standard.
- Signs and markings should comply with MOTSAM (should review the use of PW-8 sign and consider implementing new roundabout sign as per Figure 5.1).
- Speed reduction measures should be applied where necessary.
- Drivers should be educated as to the presence and use of rural roundabouts.

The four NZ rural roundabouts have performed very well. Their designs are consistent with international 'best practice' and there have been large reductions in the frequency and severity of crashes, resulting in substantially greater crash cost savings than indicated in the Transfund NZ Project Evaluation Manual. It is concluded that rural roundabouts can be implemented safely in New Zealand, provided they are designed in accordance with international 'best practice'. It would help if we had a NZ design guide based on international 'best practice'.

This research has focused upon the safety aspects of rural roundabouts. They do have other effects, including imposing extra delay upon users of the main road while reducing delay for minor road users. The balancing of accident cost savings against travel cost increases is a very contentious matter, but it should be borne in mind that main road users can benefit from the use of well-designed roundabouts, through the reduced probability of being involved in a high severity crash with vehicles emerging from (or turning into) minor roads.

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