Making Roundabouts a Safe System Solution for Motorcyclists

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Abstract

Motorcyclists are very vulnerable road users. In Victoria, riders account for 15% of deaths and serious injuries. Over 30% of motorcycle crashes occur at intersections (VicRoads Road Crash Information System (RCIS)).

Roundabouts are considered a ‘Safe System solution’ for intersections because they constrain speeds and impact angles to within biomechanically tolerable levels. VicRoads Safer Roads Infrastructure Program Guidelines (2012) estimate that a roundabout will reduce overall casualty crashes by 85%.

Although roundabouts are a positive road safety treatment for motorcyclists they do not show as dramatic a reduction in road trauma as they do for cars. Scully et al. (2006) and Schoon and van Minnen (1993) estimate that roundabouts only reduce causality crashes for motorcyclists by between 36% and 77%. Between 2008 and 2012, there were 159 motorcyclists killed and seriously injured at roundabouts in Victoria. This represents 25% of all serious and fatal crashes at roundabouts (RCIS).

This paper reviews roundabout design, maintenance and operation that may influence motorcycle safety. This includes turbo-roundabouts. It also reports the results of an in-depth engineering investigation of some roundabouts in Victoria where motorcycle crashes have occurred.

Factors identified and discussed include; geometric design, sight distance, lighting, pavement markings, signing, landscaping, street furniture, speed limits and surface issues. This paper begins the work requested in the 2013 Austroads report *Improving the Performance of Safe System Infrastructure* wherein it states:
“Despite the positive [road safety] results, the two-wheeler risks at roundabouts need to be further reduced in order to reach the Safe System objectives.”

BACKGROUND

In the last 40 years, significant improvements in road safety have been achieved for passenger vehicle occupants across most of the developed world. In Australia, there were 3694 road users killed in the year 1975. In 2005, there were 1636 fatalities on Australian roads and that figure has continued to drop to 1193 in the year 2013. The rate of fatalities per registered vehicle has also declined consistently over that period. The 2005 fatality rate per 10,000 registered vehicles has declined by 73% since 1975 and by 49% since 1990. Similar trends are evident in rates per population and per kilometres travelled. These improvements have been attributed to increased compliance with seatbelt wearing laws, improved enforcement and management of high risk behaviours such as speeding and drink driving, regulating admittance to the road system, major improvements in vehicle crash protection systems and crashworthiness and road infrastructure upgrades and blackspot remediation.

Road trauma levels for motorcyclists have also improved. The exposure data available for motorcyclists is more variable, but the rate of motorcycle fatalities per kilometre travelled has reduced by approximately 36% since 2000. Motorcyclists, and other vulnerable road users, have benefited from reductions in vehicle speeds across the network, reduced drink driving/riding, and new research indicates that motorcyclists have benefited equivalently to passenger vehicle occupants from blackspot improvement programs. However, the absolute number of motorcycle fatalities has hardly dropped since 1990 and their risk relative to enclosed passenger vehicles continues to increase. Based on Australian Bureau of Statistics survey of motor vehicle use and police reported road crashes across Australia, the risk of motorcyclists being involved in a fatal motorcycle crash is currently 31 times higher than for enclosed vehicle passengers per kilometre travelled. Figure 1 shows the relative increase in the rate of fatalities per kilometre travelled of motorcyclists versus passenger vehicle occupants in Australia.

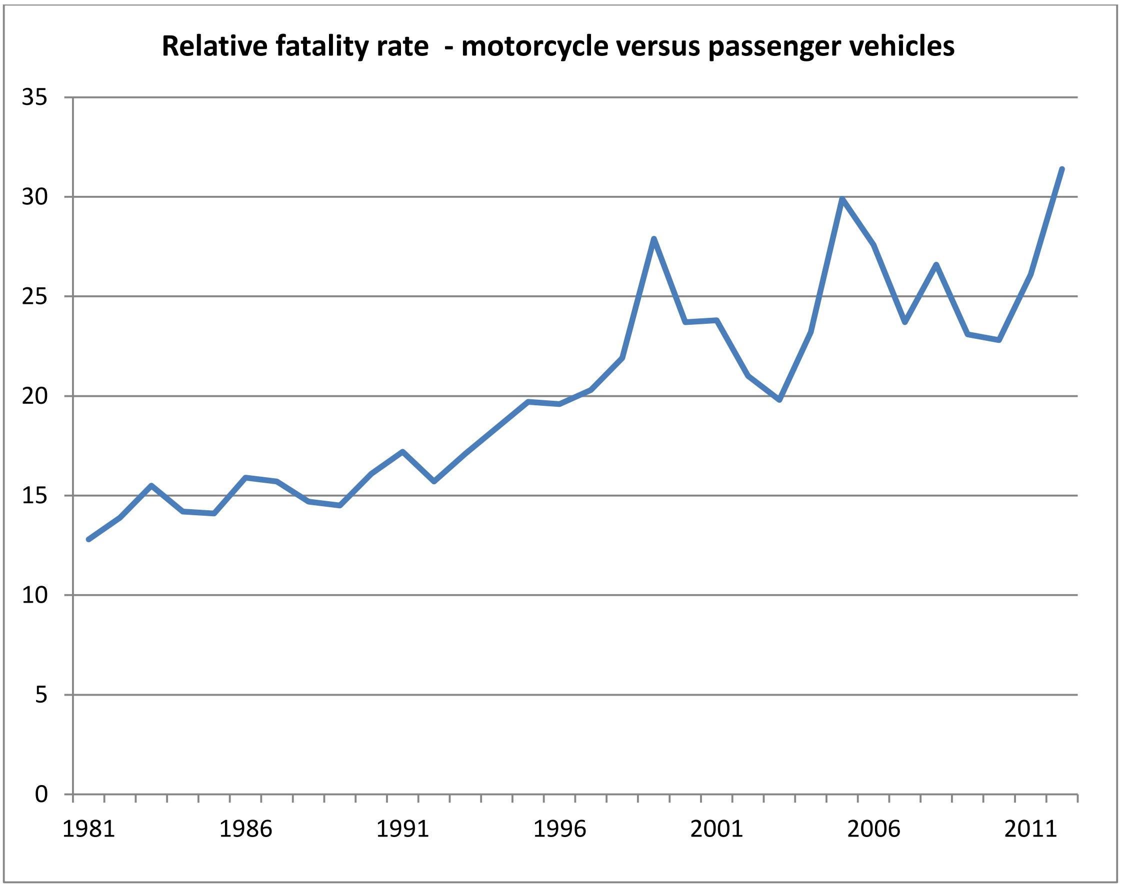

Figure 1. The rate of motorcyclist fatalities per kilometre travelled relative to passenger vehicle occupants in Australia 1981 -2012

Based on the relative risk shown in Figure 1, if all the motorcycle travel for the last 25 years had been undertaken in cars over 5000 lives could have been saved.

The high rate of motorcycle trauma principally relates to the inherent instability of the motorcycle and the occupant being essentially unprotected except for a helmet and non-compulsory motorcycle protective gear. While the importance of specially designed protective gear, especially a helmet, must be recognised (Haworth et al, 1997), the capacity of this gear to protect a rider from impact injury at speeds above 30km/h is very limited. This places a rider at the same level of vulnerability as a cyclist or pedestrian. However, motorcycles are promoted strongly as freedom machines with exhilarating performance capabilities. When used as a performance machine, there is basically no road system that can be feasibly designed or managed to limit collision forces to within human biomechanical tolerances. Thus, fitting motorcycling into current 'Safe System' approaches to road transport management is undoubtedly a huge challenge.

The levels of motorcycle ownership and usage patterns have changed dramatically over recent decades influenced by changes in demographics, development and financial climates. Key influences in motorcycle usage in developed nations include the so called "Baby Boomers" seeking freedom and excitement after their children have left home, as well as traffic congestion and fuel prices influencing commuters and inner urban residents to seek convenient personal and economical mobility. The uptrend in motorcycle usage for both utility and recreational purposes shows little sign of abating, but is yet to be assigned any major status in safety or transport planning since its sharp growth has advanced only from a low base. However, vulnerable road users, and motorcyclists in particular, are likely to represent relatively larger proportions of road trauma in the future. Safety professionals will need to find ways of incorporating motorcycling within Safe System planning or jurisdictions will be unable to meet road safety targets.

This paper explores the Safe System implications of roundabouts in relation to motorcycles.

SAFE SYSTEM APPROACH

The concept of a safe transport system is one in which the user of the system can expect to travel within the regulations of the system and not be exposed to life threatening injury or death. Safe System design incorporates mechanisms to reduce human error, but the guiding principle is to design out violence from the system. To achieve this, kinetic energy during collisions must be absorbed or directed away from system users so that they do not experience forces beyond human biomechanical tolerance when control errors occur. This is not just a design philosophy but a moral imperative to not accept death or disabling injuries as an inevitable consequence of road transport mobility.

Road transport system design needs to account for all factors that control kinetic energy. Kinetic energy can be described by the following equation:

$$E = \frac{1}{2} mv^2$$

Where E is kinetic energy, m is mass and v is velocity.

Kinetic energy can be reduced by decreasing the mass of vehicles, minimising mass incompatibility (e.g., large vehicles crashing into small ones), lowering velocity or redirecting the energy away from the human body. The key system elements that can manage kinetic energy are vehicle travel speeds or impact speeds, vehicle design and development of safe road infrastructure as shown in the following diagram. The diagram also acknowledges the importance of road user behaviour both in setting the parameters of design, but also in minimising the need to manage energy. These elements include providing education and information to support road users, providing regulated admittance to the system, having alert and compliant road users and supporting legislation and enforcement of road rules as well as continuing to develop knowledge bases to understand crashes and risk.

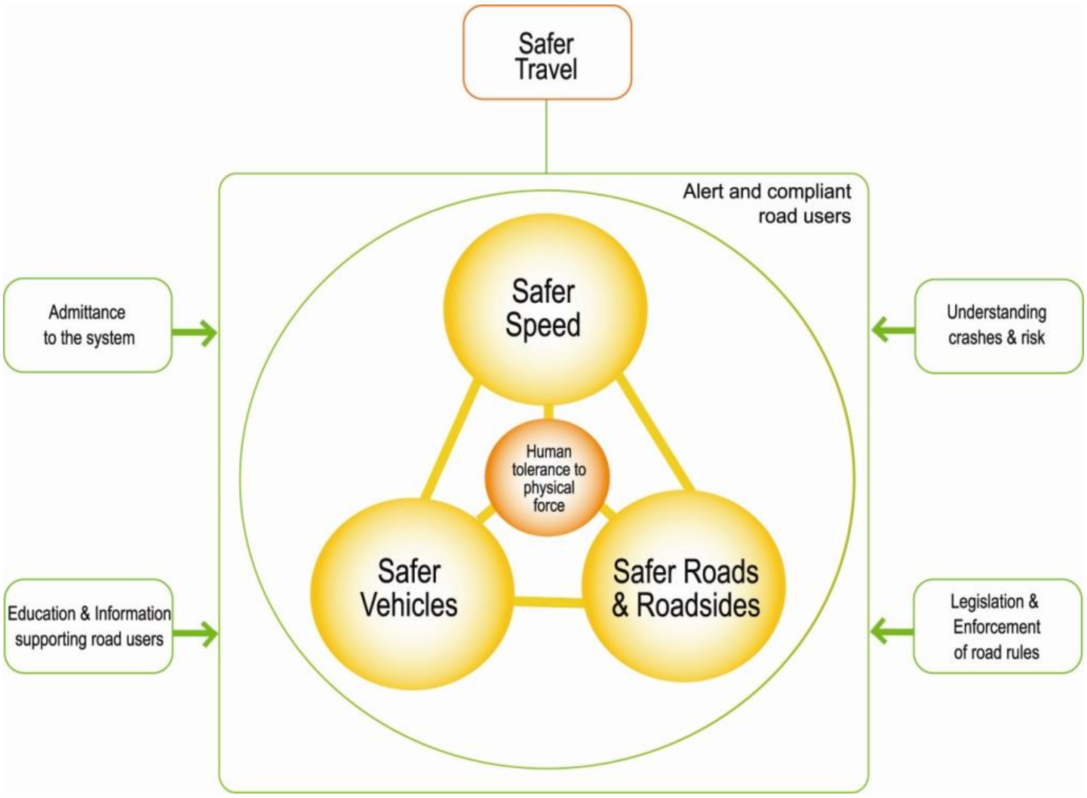

Figure 2. Diagram of the Safe System approach adopted in Victoria, Australia.

Riders of motorcycles are physically interacting with the system, but conceptually are riding outside the principles of a Safe System. This results from an inherent safety incompatibility of the vehicle, road user and environment at typical (and legal) motorcycle travel speeds. However, this incompatibility is seriously compounded by the lack of system planning and design for motorcyclists.

If the transport system was fundamentally redesigned and reconstructed from its foundations using Safe System principles, motorcycling would not be permissible in the system or would be limited to areas of separated traffic space with strict speed limits. However, it is not acceptable to disregard motorcyclists because they are incompatible with contemporary thinking. The Safe System is being adapted progressively and incrementally to a transport system that already exists, and exists with legitimate integrated road users such as motorcyclists. As such, the Safe System thinking has to evolve to adequately accommodate all users into its design. This is a required focus of future Safe System specifications.

Thus this paper seeks to examine methods by which both speed reduction and traffic segregation can be implemented at roundabouts.

ROUNDABOUTS

Jurewitz et al. (2013) examined roundabouts as one of five possible infrastructure solutions. They found that roundabouts are very effective in reducing severe injury crashes (37–40%) and, in particular, fatal crashes (60–100%). This level of stepwise road safety improvement demonstrates good progress towards the Safe System objectives. As shown in Table 1, reproduced from Scully et al. (2006), roundabouts are twice as safe as traffic signals for motor vehicles, but almost the reverse is true for motorcycles. There were 159 motorcyclists killed and seriously injured at roundabouts in Victoria between 2008 and 2012. This represents 25% of all serious and fatal crashes at roundabouts (VicRoads Road Crash Information System).

Table 1: Estimated percentage casualty motorcycle crash reductions attributable to Intersection treatments for the Victorian $240M blackspot program compared with casualty crash reductions involving all types of vehicles

Intersection Treatment Type	Motorcycle Crashes		All Types of Crashes	
	Est. % Casualty Crash Reduction (95% CL)	Statistical Significance Probability	Est. % Casualty Crash Reduction (95% CL)	Statistical Significance Probability
2.1: Roundabout	36.8 (-25.9, 68.2)	0.192	74.0 (67.5, 79.1)	<0.0001
2.2: Signal Treatment	52.4 (29.0, 68.1)	0.0003	35.0 (28.7, 40.8)	<0.0001
2.3: Improved Definition	56.0 (-29.9, 85.1)	0.1372	36.1 (19.0, 49.6)	0.0002
2.4: Enhanced Signage	-27.3 (-435.9, 69.8)	0.742	33.2 (-2.4, 56.5)	0.0641
2.5: Change Geometry	***	***	64.6 (30.5, 82.0)	0.0026
2.6: Add Lane	***	***	48.0 (35.9, 57.7)	<0.0001
2.7: Speed Reduction	6.6 (-170.8, 67.8)	0.900	-15.8 (-57.0, 14.6)	0.3439
2.8: Other Treatments	-31.9 (-206.6, 43.2)	0.519	38.3 (19.3, 52.8)	0.0004

The study of the Victorian crash data revealed that the following crash types were more common at roundabouts:

- adjacent direction (especially cyclists and then motorcyclists)
- off-path on straight (especially motorcyclists)
- same direction for cyclists.

The investigations showed that roundabouts have a strong potential for achieving the Safe System objectives. The focus of further investigation should be on preventing severe injury arising from these three crash types. A particular focus should be directed to two-wheeler road users, especially when travelling on 50 to 60 km/h roads. Solutions benefitting these two road user groups are likely to benefit drivers of four-wheel vehicles as well. In particular

Further investigation of potential improvements towards the Safe System objectives should also cover:

- speed management on approaches to urban roundabouts, especially in 50 and 60 km/h speed limits
- effect of light and lighting – visibility of vulnerable road users (particularly two-wheelers)

- greater separation and/or new design solutions for safe inclusion of cyclists on local road roundabouts
- design features which may reduce crash severity for two-wheelers (e.g. roadside and centre island objects, surfaces)
- better understanding of roundabout approach skid resistance at higher speeds, including for motorcyclists.

Despite the positive results, the two-wheeler risks at roundabouts need to be further reduced in order to reach the Safe System objectives.

The first edition of the US Department of Transportation information guide on roundabouts (Robinson et al., 2000) notes that the number of personal injury entry-circulating crashes (including fatalities) per year per roundabout approach (A) can be expressed as:

$A = F \exp (0.2 P)$

Where F is a factor that depends on the roundabout design criteria and the number of vehicles, and P is the percentage of motorcycles using the roundabout (as a percentage). The key point to note is that the crashes increase exponentially as motorcycle use increases.

ROUNDABOUT DESIGN

The Austroads Guide to Road Design that deals with roundabouts is Part 4B (Austroads, 2009). It has a separate chapter that deals with pedestrians and cyclists, but there is no specific information on design in relation to motorcycles, with the assumption in the document that the term motor vehicles covers both motor cars and motor cycles. The guide does, however, note that “provision of lighting in accordance with AS/NZS 1158 becomes even more important (especially to motorcyclists) if profiled encroachment areas are incorporated into the design.”

Roundabouts are a safer option for car drivers in most circumstances because they reduce speed and offset the angles of potential collision. However, they do rely on constant give way behaviour rather than providing clear right of way which is a larger risk factor for motorcyclists. Nevertheless, given the right design antecedents, motorcycles could still benefit from the safety advantages of roundabouts. The key is designers having a full appreciation of Safe System design for all road users.

As noted above, lighting is one of the design features that can be adjusted to make roundabouts safer for motorcyclists. From our literature review, consultation with riders, detailed crash and design characteristics analysis of 5 roundabouts in Victoria, we believe the influencing factors are geometric design, sight distance, lighting, pavement markings, signing, landscaping, street furniture, speed limits and surface issues. Thus, items that improve motorcyclist safety at roundabouts include:

- Run-off or run-through areas clear of unforgiving roadside furniture.
- Mountable curbing so as to prevent a sudden jolt when a motorcycle strikes the curb.
- Adequate skid resistant surfaces.
- Flexible signage and road furniture that will bend upon impact rather than injure a motorcyclist that strikes it.
- Suitable camber and crossfall.

- Turbo-roundabouts.

We consider the last three items in more detail.

Signage

Between September 2006 and April 2009, nine barrier protection trial sites trial sites were established and a number of “motorcycle-friendly” infrastructure improvements at Victorian roundabouts were also trialled. The purpose of these trials was to test the performance of five motorcycle friendly signage and barrier protection products (Stack Cushion, Rubrail & Polybuffer barrier protection, and SupaFlex signs & PolySafe posts) with regard to durability, installation, maintenance, and safety.

Since the installation of flexible signage with frangible posts and barrier protection, there has been one casualty motorcycle crash, which occurred at the South Gippsland Hwy/Westernport Rd intersection. The crash report does not indicate whether the rider struck the signage or the guardrail with barrier protection.

Crossfall

There are a variety of possible methods for the vertical design of a circulatory roadway within a multilane roundabout. However, two primary methods are typically used (Rodegerdts et al., 2010): outward sloping and crowned circulatory roadways:

Outward sloping. This is the most common type of vertical design for roundabouts in the United States. The circulatory roadway is graded independently of the rest of each approach, with the circulatory roadway outward draining with a grade of 1.5 to 3%. This is most practical in relatively flat terrain, as hilly terrain may require warping of the profile and possibly an alternative vertical design.

Crowned circulatory roadway. The circulatory roadway is crowned with approximately two-thirds of the width sloping toward the central island and one-third sloping outward. This may alternatively be reversed so that half of the circulatory roadway slopes toward the central island. The maximum recommended cross slope is 2%. Asphalt paving surfaces are recommended under this type of application to produce a smoothed crown shape. This method is primarily intended for consideration at multilane roundabouts. Other vertical design options include:

• Existing grade lines (non-planar). It is often desirable to use the existing ground elevation, to the extent possible, to reduce overall changes in vertical profile. At the intersection of two major roadways, this may result in two crown lines crossing one another, with the circulating roadway warping between the crown lines to provide the drainage. This is no different from a major signalized crossroad. However, it can affect driver comfort and lane discipline through the roundabout.

• Tilted plane. This method allows the existing road grade line to be maintained. An example is where two roadways currently cross with 2% grade on Road A and 3% grade on Road B. The roundabout should be designed as a plane surface sitting on those two grade lines. The uphill sides of the circulating roadway would have inward slopes of +2% and +3% respectively, with the downhill sections having (negative) crossfalls of −2 and −3%. The section with the steepest crossfall could be modified slightly so that no slope exceeded −2.5%.

- Folded plane. The folded plane is a similar concept to the tilted plane, where one direction follows the ruling grade and the crown line of one of the roads. The plane of the circulating roadway is folded about the grade line of the road. The ruling grade line can be flat through to about 10%. In a flat area, the two folded planes would typically have a grade differential of 4 to 5%.

In Victoria the usual practice is for the crossfall to be outward sloping. In Queensland and the ACT roundabouts have inward sloping crossfall, which may, in analogy with a velodrome, be expected to improve motorcycle traction and thus motorcycle safety.

Figure 3 – Turbo-roundabout north of Rotterdam in the Netherlands

Turbo-roundabouts

A turbo-roundabout, illustrated in Figure 3, is a particular type of roundabout where all lanes are bounded by traffic signs and by non-mountable curbs installed at entering and circulating lanes. Turbo-roundabouts also have a very particular shape to accomplish the splitting of traffic streams and to prevent cars weaving through. These aspects make turbo-roundabouts more appropriate than roundabouts when a higher level of safety has to be guaranteed, particularly in presence of relevant pedestrian and two-wheels traffic volumes. Only in some traffic conditions, turbo-roundabouts can offer higher capacities than conventional double-lanes roundabouts, so if more capacity must be guaranteed a bypass lane can be added to the turbo-roundabout's layout. Corrierea & Guerrieri (2012) present a closed-form model for the estimation of capacity, delays and level of service of turbo-roundabouts equipped with right-turn bypass lanes, considering the effect of geometric slip lane schemes, control type, vehicular and pedestrian flow. Silvaa et al. (2014) note that though researchers agree as to the safety benefits of turbo-roundabouts, improvement in terms of capacity is still open to discussion. They show that only in very specific and rare cases of traffic demand, can a turbo-roundabout be expected to provide more capacity than a double- lane conventional roundabout of similar size.

However, even though researchers agree on the safety benefits of turbo-roundabouts for motorcyclists, the motor cycle community does not agree[1]. The UK Motorcycle Action Group says it has halted plans for kerbs between lanes on UK roundabouts, which posed a threat to motorcycle safety. MAG policy advisor Dr Leon Mannings is quoted as having said: "We instantly saw that such a scheme would create new hazards for riders that could cause serious or fatal injuries. Far from reducing risks, it would massively increase them - and probably for cyclists too. Raised kerbs between lanes on bends are a dangerous obstacle for all two wheelers."

DISCUSSION AND CONCLUSIONS

Although roundabouts are a positive road safety treatment for motorcyclists they do not show as dramatic a reduction in road trauma as they do for cars.

This paper reviewed roundabout design, maintenance and operation that may influence motorcycle safety. Three items require particular attention in the future:

- Flexible signage and road furniture that will bend upon impact rather than injure a motorcyclist that strikes it.
- Suitable camber and crossfall.
- Turbo-roundabouts.

Our review indicates that there is insufficient information on the effects of roundabout crossfall on motor cycle safety whereas in the case of turbo-roundabouts there is a risk communication issue wherein the technical information claims improved motorcycle safety at turbo-roundabouts whereas the motorcycle community sees the kerbs between lanes on a turbo-roundabout as leading to decreased motorcycle safety. This dichotomy of views needs more detailed examination.

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