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A driving simulator evaluation of potential speed reductions using two innovative designs for signalised urban intersections

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ABSTRACT

Intersections are typically associated with a higher level of crash risk than other types of facilities on the road network. Standard cross-road intersections are particularly hazardous because by their very design, drivers may travel through at speeds that are incompatible with human biomechanical tolerance should a crash occur. Further, drivers are exposed to dangerous conflict angles, which are likely to result in serious injury. This paper examines the effectiveness of two new intersection designs aimed at restricting potentially dangerous conflict angles while reducing driver speeds through the intersection. These designs, named the "Cut-Through" and the "Squircle", incorporate key features of both signalised intersections and roundabouts. The intersections are controlled by signals similar to a signalised roundabout. Instead of a standard central island, right turning traffic (equivalent to left turns in jurisdictions that drive on the right) cut through the central island, thereby avoiding traffic interlocks and delays that can occur with the traditional signalised roundabout. Across two driving simulator studies, vehicle speed data were collected on approach to and through each of the proposed intersection designs. Performance was benchmarked against equivalent standard signalised cross-road intersections and standard non-signalised roundabouts. Notably, drivers reduced their speeds by approximately 30–40% when negotiating both the Cut-Through and the Squircle compared to the standard signalised intersections. The safety potentials of the two new intersection designs are discussed within the guidelines of the Safe Systems principles.

1. Introduction

Intersections are a necessary yet dangerous part of the road network. In the USA, approximately 40% of recorded motor vehicle collisions occur at intersections (Choi, 2010). In Australia, drivers are three to four times more likely to be involved in a crash at or near a major intersection compared to a mid-block stretch of road (Jurewicz and Turner, 2010). Recent statistics show that across the four Australian states with the highest annual road tolls, intersection crashes comprise one-fifth to one-third of annual fatalities. Specifically, fatal crashes at intersections accounted for 19% of the 2012 road toll in New South Wales (Centre for Road Safety, 2013); 20% of the 2011 road toll in Queensland (Transportation and Main Roads, 2012); 30% of the 2013 road toll in Victoria (Transport Accident Commission, 2015) and 35% of the 2012 road toll in Western Australia (Bramwell et al., 2014).

A large number of both fatal and serious injury crashes occur at signalised four-way intersections in urban areas (Choi, 2010; Hoareau et al., 2011; Jurewicz and Bennett, 2008; Transportation and Main Roads, 2012). A higher level of traffic volume may, in part, explain the frequency of crashes at these types of locations. However, crash severity can be attributed to the standard crossroad design (Hoareau et al., 2011), which affords many more conflict points compared to other designs. For example, a standard single-lane four-way intersection consists of four times the number of conflict points compared to roundabouts (32 vs. 8; Gross et al., 2013). The risk comes not only from more potential points of conflict but also the collision angles and resulting injuries. For example, analysis of crashes at signalised intersections in Victoria, Australia, revealed the most common serious injury crashes were

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those with 90° impacts. These included right-turn across traffic incidents (equivalent to left-turn in right-side drive countries) and collisions with orthogonal traffic (Hoareau et al., 2011). Such collisions pose the greatest risk for serious injury when impact occurs at high speeds, due to the potential for vehicle intrusion (Tingvall and Haworth, 1999).

A problem with many intersection designs is that they allow drivers to pass through at the posted speed limit, which can be a speed conducive to severe injury in common impact scenarios (Corben, 2005; Tingvall and Haworth, 1999). The number of serious injuries at traffic intersections can be decreased by reducing impact speeds. For example, Tingvall and Haworth (1999) suggest that travel speeds should be limited to: 30 km/h in areas where vehicles can directly conflict with pedestrians; 50 km/h when side impacts between vehicles are possible, as is the case with most four-way standard signalised intersections; and 70 km/h if only frontal collisions are possible. In Australia, current signalised intersection designs that permit local and arterial roads to cross are typically in posted speed zones of 50–80 km/h or more, considerably higher than the recommendations by Tingvall and Haworth. The faster travel speeds allowed at these intersections are likely to lead to severe injury should an impact occur at a dangerous angle afforded by the intersection design (Corben et al., 2004).

One way of improving intersection safety is to embed intersection design within the Safe Systems approach. The Safe systems approach was developed as part of Australia's move toward Vision Zero, the pledge that no road user should be killed or seriously injured on Australian roads (Tingvall and Haworth, 1999). To achieve this, dramatic shifts in infrastructure design and acceptable speed allowances need to be made and this can be done across four pillars of Safe System design: Safe roads and roadsides, Safe vehicles, Safe road use, and Safe speeds (Corben et al., 2010a). Safe Systems approaches to design consider the road network as a sum of its individual parts and therefore failures in one part of the system must be considered within the entire network (see Underwood and Waterson, 2013). Underlying design principles should therefore put the safety of the road user above other considerations in the network and design the road network in a manner that restricts speed and limits or anticipates driver error, such that fatal and serious injury crashes are minimised (Australian Transport Council, 2011). In particular, a Safe System intersection design would accommodate for any failures of the driver to obey the traffic signal, restrict travel speed to more tolerable levels of speed and contain fewer and less dangerous potential conflict points (Australian Transport Council, 2011; Candappa et al., 2015; Corben et al., 2010b).

Candappa et al. (2015) evaluated several current and proposed intersection designs in terms of their compliance with Safe System principles. These fundamental principles define thresholds for vehicle speed and impact angles to maintain biomechanical tolerance for road users should a collision occur. Candappa et al. suggested that the standard signalised intersection design has low compatibility with Safe Systems principles due to the high speeds through the intersection and the 90° conflict angles. In contrast, roundabout intersections are highly compatible with Safe System principles because their design enforces slower travel speeds and creates more favourable conflict angles. However, while roundabouts provide clear safety benefits, it is more difficult to control and manipulate traffic flow at roundabouts compared to signalised intersections, resulting in delays and potential interlocks of some movements (i.e., Bared and Edara, 2005). Roundabouts can also be costly to implement, as current design standards require large areas of roadway and surrounding land for design implementation.

Given that standard signalised intersections have poor safety performance, that there are concerns about traffic flow at roundabouts, and it is not always feasible to convert intersections to roundabouts (either with or without signals), there is a clear need for innovative intersection designs to address current, unacceptable levels of road trauma. One particularly promising avenue is new designs that combine elements of both signalised intersections and roundabouts. These permit more affordable safety upgrades to existing signalised intersections without encroaching on surrounding land or compromising direct control of traffic flow (Candappa et al., 2015). With these design principles in mind, Corben et al. (2010a) proposed two new intersection designs, referred to as the *Cut-Through* and the *Squircle* intersections. In Candappa et al.'s (2015) subsequent evaluation, both the Cut-Through and Squircle were found to be strongly Safe System-compliant.

The Cut-Through (see Fig. 1) is an alternative designed for connecting two arterial roads with speed limits of 70 or 80 km/h. The Cut-Through is a signalised intersection incorporating geometric elements of a roundabout design to enforce slower travel speeds for through-traffic that traverse lanes outside the centre circle. In contrast to the standard signalised intersection, where drivers would usually enter at speeds approximating the speed limit, the Cut-Through is likely to induce slower speeds, more similar to those on traditional non-signalised roundabouts, on approach to, and through, the intersection. Another advantage of the Cut-Through over the traditional signalised intersection design is the improvement in potential impact angle. Vehicles proceeding through the intersection are far less likely to collide with vehicles from an adjacent direction at 90° due to the geometric layout of the central island. Moreover, drivers intending to turn right use lanes that cut through the central island and are also afforded protection from 90° impact angles for right turn crashes. This cut through aspect further alleviates interlock potential in the diamond right turning phase, which can occur when traditional roundabouts are signalised and include one or more fully controlled phases.

The Squircle (see Fig. 2) is a proposed alternative to standard signalised intersections in posted speed zones of 50–60 km/h. The Squircle design facilitates the same flow of traffic as the Cut-Through. It is controlled by traffic signals and drivers turning right use lanes which cut through the centre of the Squircle island. However, in contrast to the Cut-Through, the traffic islands in the Squircle intersection form a small 'squared' island, not a traditional circle. Through-traffic traverse around the edges of the island, which enforce slower travel speeds due to their geometric properties. The benefit of the Squircle is that it can be adapted to the smaller intersections found on undivided arterial roads and does not require encroachment onto the surrounding infrastructure, as does a larger roundabout. This can be particularly useful in locations where there is limited space to widen the intersection.

The Cut-Through and Squircle designs were developed by road safety experts as part of a larger study on Safe System intersection design for roads in Victoria, Australia (Corben et al., 2010a). In this study, which adopted a "green fields" approach, intersection designs were driven by the fundamental aim of developing infrastructure where "road users were unlikely to be killed or seriously injured when travelling through it" (Candappa et al., 2013). While the Cut-Through and Squircle designs are better aligned with Safe System principles, compared to standard signalised intersections (Candappa et al., 2015), the effectiveness of each in terms of speed reduction needs to be examined. Speed reduction is a key component of the Safe-systems approach. Therefore, two driving simulator-based studies were conducted to evaluate whether the Cut-Through (Study I) and the Squircle (Study II) were effective in reducing vehicle speed. In both instances it was expected that vehicle speeds, on approach to and through these intersections, would be significantly slower when compared to the standard signalised intersection and therefore better aligned with Safe System principles.