INNOVATIVE INTERSECTION DESIGNS BETTER ALIGNING WITH SAFE SYSTEM

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ABSTRACT
In response to continuing serious injury trauma at intersections, an in-depth investigation was completed of crashes at intersections in Victoria, Australia. Adopting a “green-fields” approach, a primary goal of the investigation was to determine the fundamental design principles required to create intersection designs that are better aligned with the Safe System philosophy. A key principle identified was the need to limit side impact crash speeds to under 50 km/h, recognising that the biomechanical tolerance of the human body exceeds its threshold when exposed to speeds greater than this. Minimising angles and conflict points were also identified as important principles. The investigation generated a number of existing and new designs that incorporate these principles. This paper presents some of these designs along with a general discussion on implementation possibilities of the designs.

1 INTRODUCTION
A road intersection is the crossing or merging of two or more roads. By its very nature, intersections are the points of highest conflict within the road network. Crashes at intersections result in injuries of high severity, and are a significant crash problem both in Australia and internationally. Nearly 1500 casualty crashes occurred at intersections in Australia. Around 800 fatalities and 8,000 serious injuries occurred at intersections annually in Canada between 2002 and 2004[1] while around a third of all crashes in China occurred at intersections [2], similar to proportions in Australia.

Intersection design is an important factor affecting not only safety but also the capacity, general efficiency and operating costs of the traffic network. It is often suggested that the main goal of intersection design is to facilitate the safe and efficient movement of vehicles and road-users through the intersection. However, current approaches to intersection design and operation in highly motorised countries are commonly driven primarily by capacity and performance considerations and safety is often given a lower priority. Findings from a detailed literature review completed as part of the investigation suggested much literature exists in improving existing intersection designs through the use of traditional methods and vehicle technology [3-5]. However, little research appears to challenge fundamental aspects of existing designs, and critically question the ability of these designs to provide safe travel through the intersection [6].
This study used as its foundation the principles of physics to identify the main factors that need to be addressed in an attempt to minimise the risk of serious injury in the event of a collision. At most intersection controls, when two vehicles are travelling from adjacent directions on collision path, there is potential for the two vehicles to collide at 90 degrees, the most severe of impact angles. Depending on the travel speeds of the vehicles, this can generate kinetic energy levels in an impact far greater than the biomechanical tolerance of a human body, [7] and forces beyond what a typical vehicle structure can be expected to resist. That is, at intersection controls such as traffic signals, and Stop and Give Way sign regulated intersections, it is possible, given driver error or driver non compliance to regulations, for a high injury severity crash to occur. Other intersection controls such as roundabouts appear to limit the potential for serious injury collisions given the induced speed reductions and lowered impact angles.

This study evaluated the relative features of the respective intersection controls to identify the key principles necessary for generating fundamental safety improvements at intersections. Adopting a ‘green fields’ approach, the study was framed around the question, ‘what would intersections look like if they were designed so that road users are unlikely to be killed or seriously injured travelling through it?”. The paper presents a number of new and existing intersection designs and measures generated through international study tours, or through innovative thinking. Two of the designs are currently being evaluated in driver simulation trials and depending on the results may be included in on-road trials in Victoria in the coming year.

1.1 Safe System
Based on the Swedish Vision Zero [7] and the Dutch Sustainable Safety road safety strategies [8], Safe System is founded on a strong ethical platform which states that safety of the roaduser needs to be given highest priority, over and above traffic capacity and traffic movement considerations. Safe System philosophy encourages the creation of a road system that minimises the likelihood of sustaining serious or fatal injury given a collision. The Safe System is underpinned by several key principles. The first of these is recognition of the limits of human performance, specifically in terms of biomechanical tolerances as well as the propensity for humans to perform imperfectly within the created road system. Further, the Safe System is based on a shared responsibility between users, and designers and operators to assure low-risk outcomes. This entails road users complying with key road rules, including the observance of speed limits, restraint use, driving unimpaired by alcohol or other drugs, and travelling in vehicles with good safety features. Given satisfactory levels of compliance, the system designers are responsible for ensuring that no foreseeable crash results in death or serious injury, by providing a forgiving road design. The adoption of the Safe System road safety philosophy represents a profound shift in thinking and insight in the Australian society’s efforts to curb road trauma.
1.2 Safe System at Intersections
At intersections, drivers of vehicles of different mass, size, shape and engine power, or even manual power interact and negotiate the intersection to proceed through it in a safe and timely manner. When on occasion this negotiation leads to a collision, environmental factors, road maintenance factors, driver behaviour and skill, vehicle structure and technology can all play a role in ultimately affecting the outcome of this collision. Overarching all these factors however, speed is acknowledged as the primary factor in defining the potential for a crash and the eventual outcome [9-11]. Naturally, the greater the impact speed, the greater likelihood of vehicle intrusion, and ultimately the greater likelihood of severe occupant injury.

There is general acceptance that 90 degree collisions involving impact speeds greater than 50 km/h encroach this threshold [7, 11]. To provide a forgiving road system then, the ideal intersection design would need to be designed to prevent collisions occurring beyond this speed threshold.

**Key Safety Principle:** Based on this research, it was identified that a key principle in creating designs that embody the Safe System ideals would be *restraining impact (travel) speed to less than 50 km/h.*

**Supporting Principles:** this key principle is supported by *avoiding impact angles of 90 degrees through modified intersection geometry.* Right-angled crashes are potentially the most severe crash angle as the full force of the impact is directed laterally in to the side of the vehicle, with a high likelihood of vehicle intrusion. More acute crash angles result in only the lateral component of the force being directed in to the vehicle producing less severe crash dynamics. Figure 1 demonstrates the influence of reducing angle of impact on the kinetic energy (and hence, force) transferrable to the vehicle. It also demonstrates the reduction in impact angle required, for a given travel speed, to limit the kinetic energy of a crash to below identified threshold. To support further the key safety principle, where feasible, *seek to minimise conflict points at the intersection* through reduction in permissible movements and design features.
It can be argued that the risk of severe injury is reduced firstly by preventing the collision altogether. Collisions can be avoided by minimising exposure to the factors contributing to collision risk, namely, by limiting driver exposure to intersections; and minimising driver exposure to other vehicles at the intersection. Therefore, other design principles for Safe System intersection design include minimising intersections within a given route, and minimising vehicle volumes through the intersection. Discussion of these principles is beyond the scope of this paper.

2 DESIGNS

The following designs attempt to incorporate the first principle for Safe System intersection designs. These were either created as part of the study or identified through literature and overseas study tours as designs worthy of trial in Victoria. Within this stage of the study, only vehicle to vehicle collisions, and specifically passenger vehicle collisions, were considered. Subsequent stages of the study are likely to consider the specific needs of other road users, especially pedestrians and cyclists.

2.1 Cut-Through

In essence, the roundabout comprises many of the principles identified above. A well designed roundabout induces lower travel speed as the driver proceeds through the intersection. Ninety
degree collisions are minimised through the creation of acute angle movements through the intersection. The central island dramatically reduces the number of conflict points at the intersection, from the typical 32 conflict points at a cross intersection to 8. In this way, the roundabout represents an intersection design aligned with Safe System. However, roundabouts are not often utilised at major road intersections in Victoria due to traffic capacity, and traffic movement considerations.

The following design presents a means of incorporating the safety benefits of roundabouts at signalised intersections, thereby retaining the advantages of both means of intersection control. The design comprises central islands introduced within a signalised intersection (Figure 2). Named the “Cut-Through”, the design permits drivers of turning right to “cut through” the central island, while through vehicles travel through the intersection via deflected travel paths. The island minimises the angle of collision through this deflection. Drivers are slowed down on approach to the intersection by the need to negotiate the central island. Where right turns at the intersection are fully controlled by a red turning arrow, the cut through option ensures the right turning vehicles from either direction do not ‘interlock’ with each other. Optional additions to the design include raised lane separators on approach to the intersection, and straightening of the approaches as with the Turbo Roundabout (described in the following section). The Cut-Through will not be signed as a roundabout, it is intended to operate as a signalised intersection, with in-built favourable angles.

This design is considered to have a high alignment with the Safe System. The speed reduction is effected by the design and does not rely on driver compliance to speed limits. Additionally, the reduced angles and the central islands create a driving environment that minimises the potential for high severity crashes. Conflict points are also reduced. The potential safety benefits of the design include the reduced speed, angle and conflict points as well as it being a design that can be accommodated at an intersection where capacity and traffic movement are an issue.

This design is envisaged to be suitable for the larger arterial roads with existing traffic signals, where the risks of high side impact crashes are still high. As part of the study, this design is being evaluated using MUARC’s driver simulator to assess driver understanding of the design and the expected driver behaviour. The simulation will investigate the success of retaining signal pedestal location in their current location to permit minimum modification to the site, reducing costs, as well as minimising roadside objects. Some challenges to its implementation include ensuring the design produces the intended reductions in speed and impact angle while not creating manoeuvrability concerns, particularly for heavy vehicles; installation costs; and presenting clear delineation for the driver so the design is not used as a roundabout.
2.2 Squircle

The “Squircle”, (Figure 3) named for its squared-off islands, is a variation of the Cut-Through, and can be used within more constrained intersection geometries. The Squircle is intended to operate in similar fashion to the Cut-Through, installed within a signalised intersection. It has similar benefits to the Cut-Through, including the reduced speed, angle and conflict points but has the added advantage of being able to be accommodated within restricted intersection geometries.

This design is considered to have a high alignment with Safe System as the speed reduction is effected by the design and does not rely on driver compliance to speed limits. Additionally, the reduced angles, conflict points and the central islands create a driving environment that minimises the potential for high severity crashes.

This design can be considered at intersections where there is a need to manipulate traffic movement through the intersection and where there are restricted intersection geometries. This design is more suited to local or collector roads, while the Cut-Through is more suited to the roads of larger width and greater traffic volumes. As part of the study, this design is being evaluated using MUARC’s driver simulator to assess driver understanding of the design and the expected driver behaviour. The simulation will investigate the success of retaining signal pedestal location in their current location to permit minimum modification to the site, reducing costs, as well as minimising roadside objects. Some challenges of implementation include...
ensuring the design produces the intended reductions in speed and angle while not creating manoeuverability concerns; installation costs; and presenting clear delineation for the driver.

Further investigation can be undertaken to consider the feasibility of including similar islands on two-lane two way unsignalised intersections, to minimise the angle and lower approach speeds at these unsignalised intersections.

2.3 Turbo Roundabout
Multi-lane roundabouts do not exhibit all the safety benefits of single-lane roundabouts and may not always align with Safe System goals. The additional lanes within these roundabouts allow vehicles to cut across the lanes and crashes of higher severity can result. Turbo roundabouts address this deficiency by introducing raised lane separators between the lanes to restrict movement across the lanes within the roundabout. Originating in The Netherlands, the Turbo roundabout design involves spiral vehicle paths through the intersection, raised lane separators, and perpendicular, rather than sweeping, approaches to the roundabout (Figure 4). On approach to the roundabout, directional delineation and signage is used to assist drivers select the required lane for their intended destination.

This design is considered to have a high alignment with Safe System as the speed reduction is effected by the design and does not rely on driver compliance to speed limits. The lane separators physically reduce potential for drivers cutting across the lanes and creating the
potential for greater impact angles. Through these measures, speeds within a multi-lane roundabout are once again minimised, favourable angles are enforced, and the likelihood of severe crash outcomes are minimised. That is, the potential advantage of the Turbo roundabout is that it recreates the safety benefits of a single roundabout within a multi-lane roundabout. Additionally, an evaluation of the effects of the design on capacity suggests an increased capacity of between 25-35% for a two-lane Turbo when compared to a traditional two-lane roundabout [12].

This design can be considered particularly at two-lane roundabouts to improve safety levels at the existing roundabout. The design is appropriate and has been used overseas on larger arterial roads and highways. As part of the study, an on-road trial is planned in Melbourne to assess driver behaviour as well as any impact on traffic. Some challenges to implementing this design could be mitigating the initial driver unfamiliarity with the design, and ensuring adequate and appropriate signage is provided for easy negotiation through the intersection.

2.4 Elevated Stoplines
Elevated Stoplines are mild elevations just beyond the stopline that induce speed reduction of vehicles through the intersection. Used in The Netherlands (Figure 5), various speed profiles have been used to suit the requirements of the specific road type and can be designed to limit

![Image](attachment:image.png)
travel speeds to 50 km/h through the intersection. Figure 5 presents a similar version of this applied on a local road in Melbourne, including pedestrian facilities.

This design is considered to have a medium to high alignment with Safe System. Firstly, the key principle, that of speed reduction to tolerable levels, is achieved in the design. In particular, this speed reduction is effected by the design itself, and does not rely on driver compliance to speed limits. That is, the raised humps are likely to produce a speed reduction and it is less likely for drivers to inadvertently or deliberately travel through the intersection at higher speeds. Therefore even if there was to be a side impact collision, the collision would be occurring at much lower speeds and vehicle intrusion is likely to be minimal, meeting the Safe System objective of low injury risk. Secondly, the measure can also provide additional safety benefits for pedestrians at the intersection, further enhancing its safety benefits. The design does not reduce the number of conflict points at the intersection, nor does it reduce impact angle but these are not considered a significant concern given the speed reduction.

This design can be considered at most signalised intersections, the profile of the raised hump dependent on the existing posted speed limit and the desired speed reduction. The measure can be considered for use on roads with a propensity for red light running. Implementation challenges include public acceptance and the provision of sufficient warning to the driver. An on-road trial is planned for Victoria.

![Image of elevated stoplines](image_url)

**Figure 5: Elevated Stoplines as seen in the Netherlands; Safe System alignment estimation**

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<th>SS</th>
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2.5 Raised Intersections

Similar to Elevated Stoplines, raised intersections create an obstacle on approach to the intersection to induce speed reduction. Different to the Elevated stoplines where only the section of road immediately after the stopline is raised, this design relies on the entire intersection being raised in order to reduce the speeds through the intersection (Figure 7). Raised intersections are used commonly in many European countries and less frequently in Australia.

A potential benefit of this measure is that it addresses the need to minimise the speed of potential impact by physically slowing vehicles on approach to intersection. Raised intersections can highlight the intersection clearly, induce speed reductions on approach to the intersection, and can create a traffic calming effect.

As with the Elevated Stoplines, this design is considered to have a medium to high alignment with Safe System. Again, the key principle, that of speed reduction to tolerable levels, is achieved in the design. Specifically, this speed reduction is effected by the design itself, and does not rely on driver compliance to speed limits. That is, it is less likely for drivers to inadvertently or deliberately travel through the intersection at higher speeds. Therefore even if there was to be a side impact collision, the collision would be occurring at much lower speeds and vehicle intrusion is likely to be minimal, meeting the Safe System objective of low injury risk. The measure can also provide additional safety benefits for pedestrians at the intersection, if the raised section includes the pedestrian crosswalks. The design does not reduce the number of conflict points at the intersection, however, nor does it reduce impact angle; these are not considered a significant a concern given the speed reduction.

The design is suitable for undivided roads with low volumes and a low emphasis on traffic movement. This measure is not considered suitable for roads with trams, as in Melbourne, Australia. It is recommended that the intersection be raised to include the pedestrian crossings as
well, to provide the benefits of the reduced speed for the pedestrians crossing. Challenges can include the expense of raising the whole intersection, potential noise impacts, and public acceptance of the measure. As part of the study, an on-road trial is likely to be completed in Melbourne in 2013/2014.

2.6 Default Intersection Speed Limits

The above measures are intended to reduce speed reductions at intersections to below 50 km/h. A more direct and simpler means of doing this is through the introduction of default intersection speed limits, or “green light speeds”. In Victoria, Australia, various speed limits are introduced within the road system to address areas of particular concern, including school speed limits, shopping strip speed limits, local road speed limits [13]. The introduction of such speed limits recognises that there is increased pedestrian activity and a heightened risk of pedestrian collision at schools, in the vicinity of shops and on local roads. Or, stated another way, the reduced speed limits indicate a heightened risk of injury collision. Similarly, intersections are regarded as the point of highest conflict within the road system. Through the introduction of default speed limits
at intersection, the heightened risk at intersections can be recognised and mitigated, economically and simply.

This design is considered to have a medium alignment with Safe System. This measure relies on the compliance of the driver to produce its safety benefits, leaving open potential for drivers to inadvertently or deliberately travel through the intersection at much higher speeds. Nonetheless, the creation of a low speed environment is an integral component to Safe System intersection design. Given non-adherence to posted speed limits can be as low as 10% in some areas of Australia [11], this measure can address a large percentage of potential crashes at a fraction of the cost of some of the infrastructural measures.

A default intersection speed limit can be considered to lower risk of collision and injury. If implemented, it is recommended that all signalised intersections be subject to the default speed limit rather than on a selective basis, for consistency. The point after which the speed limits apply would be ideally where the vehicle can be brought to a complete stop prior to entering the intersection. This would be typically, around 40 m for 60 km/h and around 63 m for 80 km/h speed limits [14]. However, for consistency, a distance 50 m prior to the stopline is considered a suitable location at which to introduce the default intersection speed limits. Linemarking may be the clearest means of demarcating the speed limits. A horizontal line can indicate the boundaries of the intersection (Figure 8), and create the need for the driver to drive across the line further highlighting entry in to a “high risk” zone. To reinforce this speed limit, posted speed limit signs can be introduced within the intersection “zone”, and a media campaign could be utilised to promote the “green light speed”, underpinned by an extensive speed enforcement program. The potential benefit of this measure is the creation of more Safe System compatible speeds without the high infrastructure costs. Challenges would be to gain community support and ensure a clear introduction of the measure to minimise driver confusion, as well as compliance to speed limits.
3 CONCLUSIONS

While many past studies investigate means of improving existing intersection designs, few studies appear to challenge the capability of these designs to eventually eliminate serious injury at intersections. Traffic volumes, travel speeds, vehicle models, vehicle sizes have greatly modified over the years of motorisation. It appears somewhat remiss of us then to expect the original intersection designs to continue to adequately facilitate safe progression through intersections, particularly with crash statistics highlighting a significant on-going safety problem associated with many current intersection designs [15].

Ample research supports the key role speed plays in creating a safe road network. Similarly, it is well recognised that humans will continue to make errors while using the road network and cannot be expected to use the designed system perfectly, each time. In order to answer the research question posed, ‘what would intersections look like if they were designed so that road users are unlikely to be killed or seriously injured travelling through it?”’, Safe System compatible intersection designs would need to take account of both these components. This study identified key principles necessary to meet the Safe System goal of no death or injury, and presented designs that embody these principles. These designs presented here are only a few of many sane and wild, practical and not-so-practical, design options that emerged from much creative doodling and brainstorming. Among the less conservative design ideas, the creative use of linemarking or laser lighting can present an economical means of defining deflected travel
paths through the intersection without the use of infrastructural measures. Alternatively, increasingly advanced technology presents the option of introducing automated crash friendly barriers and bollards linked to traffic signals which could create the necessary physical deterrents to red light running. These designs are presented here partly as a means of opening discussion and generating further exploration and brainstorming of intersection designs that are likely to minimise the risk of serious injury at intersections. There is no doubt there will be many creative means of incorporating these principles into designs. In general though, it is believed the designs would need to contain some form of vertical or horizontal deflection to necessitate the driver to reduce speed on approach, aligning with the principle of 50 km/h intersection travel speeds. Means of reducing conflict points would also need to be considered. Designs that separate through vehicles from turning vehicles can reduce conflict points, capitalising on the fact that the majority of vehicles at an intersection are passing through the intersection rather than turning at the intersection. Irrespective of the final means of combining these various design facets, the main focus must remain on the safe movement of vehicles across conflicting paths with minimum risk of injury or death to the roaduser.

REFERENCES


