Safe System Intersection Application for the Edmonton Capital Region– Pilot Project

Marcel J. Huculak, Volunteer Engineer, Capital Region Intersection Safety Partnership (CRISP)

Paper Prepared for presentation at the Road Safety Policy Development Session

Of the 2014 Conference of the

Transportation Association of Canada

Montreal, Quebec

Abstract

The Capital Region Intersection Safety Partnership (CRISP) conducted a pilot project on engineering applications of the Safe System approach. CRISP retained the Monash University Accident Research Centre (MUARC) in Melbourne, Australia to lead the project and apply the Safe System road safety philosophy to selected 'poorly performing' intersections in the City of Edmonton, Strathcona County and City of St. Albert (CRISP partner jurisdictions). The intent was to highlight differences between a traditional road-safety approach and a Safe System approach which might inform policy development.

Safe System is a road safety philosophy believing that an individual's safety is paramount to any other benefit which the transport network provides. Safe System does not tolerate serious injury and fatal collisions, regardless of the benefits that road users receive. This contrasts with current safety attitudes. For example in 2010 there were 2,227 fatalities and 11,226 serious injuries on Canadian roads that are accepted as a consequence of our transportation system.

Despite this philosophical disparity there is evidence that attitudes are changing. MUARC'S literature review found a growing world-wide willingness to consider intersection geometries that emphasise reduced speeds or improved impact angles. Roundabouts in particular are increasingly seen as a reasonable and safer alternative to traffic signals.

For this project MUARC applied their Kinetic Energy Management Model (KEMM) to sixteen problematic intersections in the Capital Region. KEMM is a conceptual model for evaluating the transfer of kinetic energy exchanged during a vehicular collision. Given vehicle impact speed and angle KEMM determines the amount of energy received by the human occupants and the likelihood that that energy will cause serious injury or death.

KEMM quantified the probability of a fatal or serious injury outcome for the existing geometries of the problematic intersections as well as several alternatives. KEMM also tested the sensitivity of impact speed. The results showed which intersection geometries performed better with respect to risk, and which intersection geometries or treatments can be Safe System compliant.

CRISP then sponsored a workshop for local transportation engineers to assess the feasibility of Safe System compliant treatments on the problematic intersections. There was strong interest in many of the treatments, including some innovative and previously untested treatments provided by the MUARC team. One surprising result from the workshop was the reluctance of local engineers to favour reduced speed limits or platform intersections, despite their relatively low implementation cost and strong safety benefits.

1.0 Introduction

The Capital Region Intersection Safety Partnership's (CRISP) mission is to enhance traffic safety in Alberta's Capital Region through sustained, collaborative and integrated evidence-based intersection safety initiatives. Consistent with its mission one of CRISP's goals is to standardize regional practises for intersection safety by 2016, which includes adopting a Safe System Approach.

In 2011 CRISP began a Safe System research project. CRISP retained the technical expertise of Monash University Accident Research Centre (MUARC) in Melbourne, Australia to lead the project. CRISP used a two phase approach to the project, and MUARC produced two corresponding reports:

> Phase I: "Intersection Study: An Application of Safe System Approach to Intersections in the Capital Region – Pilot Project. Phase I: Progress Report", Sujanie Peiris, David Logan, Nimmi Candappa, Bruce Corben, October 2012 (MUARC).
>
> Phase II: "An Application of the Safe System Approach to Intersections in the Capital Region – Pilot Project", Bruce Corben, Sujanie Peiris, Nimmi Candappa, David Logan, Casey Mackay, January 2014 (MUARC).

Both reports advanced CRISP's understanding of Safe System thinking.

This paper reports on key findings of this CRISP project. It includes a background to Safe System philosophy and a technical foundation, a Safe System literature review, as well as a Safe System Intersection Assessment tool for designers and planners. It also includes findings of a workshop for road design practitioners to assess the feasibility of designs aligned with Safe System principles for problematic intersections in the Alberta Capital Region.

2.0 Literature Review

MUARC conducted a targeted literature review of intersection designs that align with Safe System principles. The review was an update of an extensive literature review conducted by (Corben & Candappa, 2011), as part of *Victorian Intersection Project* jointly funded Transport Accident Commission (TAC) and VicRoads. The key findings of the literature review were as follows:

A. *There are many examples of Safe System integration in other countries:*

   Many European countries use credible speed limits. These are set on road design and function with appropriate enforcement. Road design is set to elicit more predictable behaviour by road users. In addition, roundabouts and turbo-roundabouts replace signalised intersections, reducing consequences of driver error.

   The United States promotes interchanges and intersections that eliminate at-grade left turn manoeuvres.

   In Australia, VicRoads is trialing some innovative intersection designs based on lower risk speeds and more favourable impact angles.

B. *There is a primary focus on speed:*

Speed plays a major role in determining the outcome of a collision in terms of serious injury or death.

The literature discusses treatments that reduce intersection approach speeds, such as gateway treatments, curves, road markings, and road narrowing. Even though these treatments are not at intersections the literature recognizes that they will reduce intersection speeds. Further, given their cost effectiveness these treatments should be viewed favourably.

C. *Specific designs aimed at reducing speeds are raised platforms, roundabouts, turbo roundabouts, and intersection safety cameras:*

Raised platforms are cost-effective. These treatments will reduce speed with the magnitude depending on the platform profile. Some disadvantages of platforms cited in the literature are environmental noise, increased pollution, and adverse impacts on emergency vehicles.

Roundabouts, including signalised roundabouts, are now widely accepted internationally. Many view roundabouts as having positive environmental impacts as well as ability to greatly reduce fatalities.

Turbo roundabouts are most popular in Europe. They provide channelization within the circulating roadway. Drivers therefore must know in advance which lane to enter the turbo roundabout in order to find the correct exit. The literature reports capacities equal to or higher than signals as well improved safety by up to 70%.

Intersection safety cameras enforce red light laws. They may be coupled with speed cameras. The literature shows these cameras reduce red light violations and consequently reduce the number of serious injuries at intersections.

D. *Technology based countermeasures for drivers are emerging:*

There are projects that use GPS data with radars, cameras and sensors to advise drivers (using in-vehicle technology) of other drivers who are violating traffic signals, of safe gaps to enter traffic streams, and of at-risk vulnerable road users. The literature recognizes that these technologies are in their infancy and that given the considerable investment in these technologies they are likely to penetrate into vehicle fleets in the near future.

Variable message signs can reduce speeds and inform drivers of hazards. The *Victorian Intersection Design* project is trialling a dynamic road sign to advise drivers of safe gaps to enter traffic streams.

An IT-based intervention is delaying the onset of green (or extending red) at a traffic signal when approaching vehicles enter the dilemma zone.

E. *Reconfiguring left turns is a common countermeasure:*

Several intersection types reconfigure left turns, including diverging diamond interchanges, jug-handle intersections, median U-turn, and the Paraflow intersection. There is limited safety discussion on these designs. While these designs reduce the number of conflict points they do not necessarily promote safer impact speeds or angles.

F. *Evidence suggests the Safe System approach results in large safety gains:*

Sweden, the Netherlands, and the United Kingdom reported 2.8, 3.9, and 3.1 deaths per 100,000 population respectively in 2010. In 2009 Canada reported 6.5. In 2002, prior to adopting a Safe System approach, Australia's road deaths per 100,000 population sat at 8.7. It decreased to 6.8 in 2010. While it is not possible to attribute Australia's decrease to the Safe System philosophy alone, the resulting shift in thinking and practice supports the decision to adopt the philosophy.

3.0 Gather Data – Select Intersections

Three municipal members of CRISP agreed to provide data for the project. They were the City of Edmonton (2011 population 812,201), Strathcona County (2011 population 92,490), and the City of St. Albert (2011 population 61,466).

The data were the most recent five years of collision, traffic volume, and control type. Each municipality conducted a statistical analysis then ranked the intersections from the most poorly performing to the best performing. A CRISP technical committee coordinated this work to attain reasonably consistent methodologies between the municipalities.

Generally each municipality based safety performance on the number of severe collisions. A severe collision is a motor vehicle collision resulting in a fatality or a major injury (requiring admittance to a hospital).

In some cases intersections were selected because of a relatively high severe collision rate (where rate is defined as number of crashes per entering vehicle). Edmonton also selected its 107 Avenue – 142 Street traffic circle in order to include a non-standard intersection type. This traffic circle has a high number of collisions but few severe collisions (the CRISP technical committee determined the intersection control as a traffic circle due to its relatively large inscribed diameter compared to a modern roundabout).

For St. Albert injury data did not distinguish between major and minor injuries. Therefore St. Albert used as a safety performance measure the number collisions including only collision types that tend to have more severe outcomes.

Using severity to rank intersection performance was a departure from typical procedures. The CRISP technical committee chose this different procedure to be consistent with Safe Systems philosophy. Normally, municipalities in the Alberta Capital Region use all collision types to rank safety performance.

Table 1 summarizes the most poorly-performing intersections for each municipality.

Table 1: Most poorly-performing intersections within each municipality.

City of Edmonton		
Site	**Control Type**	**Average Daily Traffic Volume**
107 Avenue NW & 142 Street NW	Traffic circle	
118 Avenue NW & 97 Street NW	Traffic signal	56,478
129 Avenue NW & 50 Street NW	Traffic signal	19,814

Site	Control Type	Average Daily Traffic Volume
Princess Elizabeth Avenue, 336 & 109 Street NW	Traffic signal	17,773
34 Avenue NW & 91 Street NW	Traffic signal	61,543
82 Avenue NW & 99 Street NW	Traffic signal	56,342
Strathcona County		
Baseline Road & Broadmoor Blvd	Traffic signal	51,218
Broadmoor Blvd & Lakeland Drive	Traffic signal	25,593
Wye Road & Clover Bar Road	Traffic signal	32,845
Wye Road & Ordze Road	Traffic signal	39,635
Wye Road & Sherwood Drive	Traffic signal	47,041
City of St. Albert		
St. Albert Trail @ Boudreau Rd / Giroux Rd	Traffic signal	59,790
St. Albert Trail @ Sturgeon Rd / St. Anne St	Traffic signal	66,717
Bellerose Dr @ Inglewood Dr	Traffic signal	24,453
St. Albert Tr @ Villeneuve Rd / Erin Ridge Rd	Traffic signal	35,905
Boudreau Rd @ Campbell Rd	Traffic signal	32,782

Table 2 summarises the better performing intersections for each municipality. For fair comparison purposes, these intersections have similar characteristics to those in Table 1 (multi-lane arterial roads with similar posted speed limits).

Table 2: Most well-performing intersections within each municipality.

City of Edmonton		
Site	**Control Type**	**Average daily Traffic volume**
111 Avenue NW & 156 Street NW	Traffic signal	54,308
34 Avenue NW & 99 Street NW	Traffic signal	54,227
42 Avenue NW & 106 Street NW	Traffic signal	17,633
Strathcona County		
Baseline Road & Sherwood Drive	Traffic signal	56,069
Sherwood Drive & Granada Blvd/Festival Way	Traffic signal	31,628
Wye Road & Brentwood Blvd	Traffic signal	40,160
City of St. Albert		
SAT @ St. Vital/Rivercrest Crescent	Traffic signal	52,086
Boudreau Road @ Erin Ridge Drive / Inglewood Drive	Traffic signal	24,892
Grange Drive @ Gervais Road	Traffic signal	23,031

4.0 Assess Relative Risk of Selected Intersections

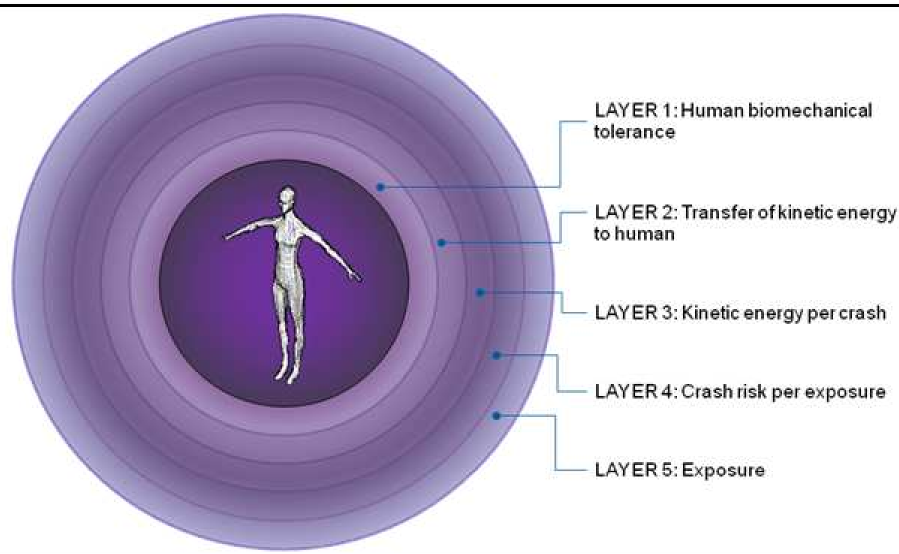
4.1 Background

One aspect of Safe System intersection design is to make choices that avoid collisions. However, if a collision occurs, a second Safe System aspect is fundamentally important. This second aspect is to ensure the collision is within the crashworthiness limits of vehicles and within the biomechanical tolerance limits of drivers, passengers, and vulnerable road users. Ensuring this aspect requires a means to assess collision severity.

MUARC employed its Kinetic Energy Management Model (KEMM) for this assessment. KEMM estimates the probability of a fatal or serious outcome for a collision, given speed and impact angle inputs. KEMM is a conceptual model that calculates the transfer of kinetic energy exchanged during a collision to human occupants. The model has five layers of protection to either prevent the collision or mitigate its effects.

Figure 1 shows KEMM graphically with the five layers of protection surrounding the vulnerable human at the centre.

Figure 1. The Five Layers of the Kinetic Energy Management Model



Details of each layer are as follows:

1) Layer 1, human biomechanical tolerance: minimising injury risk by understanding the tolerance of the human body to absorb energy. KEMM acknowledges that intrinsic human tolerance levels vary primarily with age, health status, gender and stature.
2) Layer 2, transfer of kinetic energy to human: managing the kinetic energy transfer to the human during a crash. The performance of the energy-absorbing characteristics and safety features in modern vehicles mainly determines this layer's effectiveness for a vehicle occupant.
3) Layer 3, kinetic energy per crash: at impact during a crash, the level of kinetic energy of the vehicle. Lower travel speeds offer the greatest potential for reducing levels of kinetic energy, while reducing mass also plays a role. Braking effectiveness, crash-avoidance systems, ABS-braking, brake-assist systems, and intelligent speed adaptation (ISA) are other relevant vehicle factors.

4) Layer 4, crash risk (probability) given exposure: This layer and Layer 5 target crash risk reduction. Measures influencing crash risk occurrence are important to the performance of Layer 4, such as ISA and crash-avoidance systems. Infrastructure changes can also reduce crash risk by improving visibility, reducing complexity, clarifying right of way, or reducing approach speeds.
5) Layer 5, exposure: This layer involves reducing crash risk through reduced exposure to conflicts. Alternative intersection designs and operations influence the performance of this layer. It also includes initiatives at system level such as reducing the number of intersections, or shifting modes from private motor vehicles to public transport. Using advanced traffic control and management systems or traveller information systems can also direct traffic along inherently safer routes.

In this study layers 4 and 5 are not addressed in detail. While crash risk must be minimised whenever possible, the primary goal herein is to design intersections so that any foreseeable crash occurs below the biomechanically tolerable levels of humans. That is, consider the inherent safety of an intersection in the event of a crash. The KEMM concept requires integration with the four major risk areas in the Safe System: the human, the vehicle, the road and roadside, and system operation (including speed).

4.2 Safe System Design Principles

The following are a set of design and operation principles developed within the context of the Safe System, Dutch Sustainable Safety and Swedish Vision Zero philosophies (Corben, van Nes, Candappa, Logan, & Archer, 2010):

1. **Fewer vehicles** – reducing the number of vehicles in use presents fewer collision opportunities;
2. **Fewer intersections** – reducing where possible the number of intersections within the road network concentrates more traffic movements at intersections with best-practice safety standards, thereby reducing high-risk conflict opportunities;
3. **Fewer conflict points per intersection** – simplifying intersections produces fewer conflict points and reduces the opportunities for crashes;
4. **Impact speeds and impact angles constrained to biomechanically tolerable levels** – in the event of a crash, designing to create speed and angle combinations that give low serious injury risk.

To elaborate further on the last design principle, analysing traffic collision kinematics shows:

- For 90° collisions impact speeds should not exceed 50 km/h for vehicle-to-vehicle collisions. (In this context impact speed and travel speed are assumed as the same. Braking is possible pre-crash, but past research (Chen, Cao, & Logan, 2011) shows that about 50% of impacts do not report braking prior to impact). For conflicts between vehicles and vulnerable road users (pedestrians, cyclists and motorcyclists), impact (and, therefore, travel) speeds should not exceed 30 km/h;
- For intersections with impact speeds between 50 km/h and 70 km/h, vehicle-to-vehicle conflicts must occur at less severe angles than 90° to ensure that the biomechanical tolerances of humans are not exceeded. Regardless of geometric layout to influence impact angles, travel speeds in areas where pedestrian and cycle traffic is allocated high priority should not exceed 30 km/h if pedestrian and cyclist risks of death are to remain below the nominated Safe System level of 10%.

- Where the above speed and angle combinations cannot be met, crash risk (probability and exposure, layers 4 and 5 of KEMM) must be reduced to a negligible level.

The three inner layers of the KEMM were modelled mathematically to provide a tool for objectively quantifying the safety of individual conflicts within an intersection. The model, known as KEMM-X, focusses primarily on better measuring the intrinsic safety of an intersection as a whole.

KEMM-X probabilities of fatality and of serious injury of 0.1 and 0.31 respectively represent a reference risk with the following conditions involving two typical light passenger vehicles:

- The vehicles have equal mass;
- The vehicles impact at 50 km/h;
- The vehicles have front seat occupants of average age and health;
- The vehicles impact at a 90^{o} angle.

Given that risk can never be zero, these probabilities represent the nominated values for Safe System compliance.

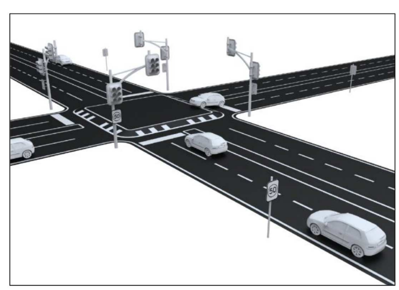
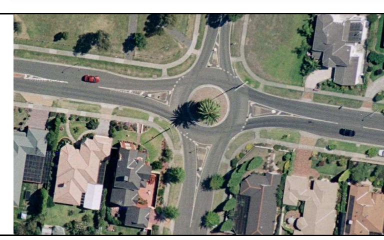
4.3 KEMM-X Application to Selected Intersections

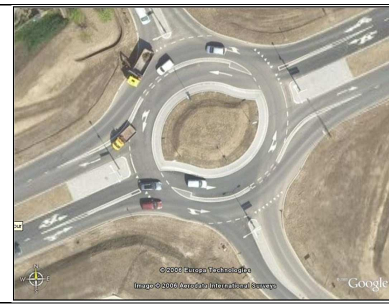
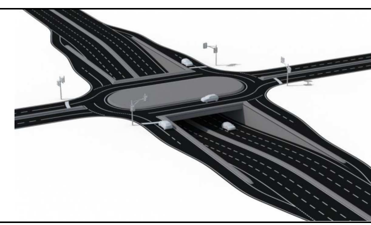
MUARC applied KEMM-X to the worst-performing intersections identified by the participating municipalities. In addition, MUARC applied KEMM-X to a number of other intersection types. The methodological details for the application are in the Phase I report to CRISP.

MUARC tested several intersection configurations. Descriptions of each follow and show pictorial examples where necessary:

Current – the current geometry and using the posted speed as guide for impact speed.

Current + Tolerance –In the Albert Capital Region the CRISP technical committee cited anecdotal evidence that travel speeds well above posted speeds are common. Thus MUARC tested the current geometry with an additional 15 km/h added to the input speed.

Platform an assumed platform intersection that would slow speeds of all vehicles entering the intersection to not more than 50 km/h for vehicle-to-vehicle collisions and not more than 30 km/h for vehicle-to-pedestrian or other vulnerable road user collisions (image developed by Liam Feguson and modified by Mike Mills, Faculty of Art and Design, Monash University, Sept. 2010)	
Roundabout an assumed modern roundabout intersection that would slow speeds and favourably change impact angles for all vehicles using the roundabout	

Turbo-Roundabout (design) an assumed turbo-roundabout intersection with an assumed 90^{o} collision angle due to the entry geometry **Turbo-Roundabout (likely)** an assumed turbo roundabout intersection with a flatter collision angle based on likely vehicle paths used by drivers	
Cut-through signalised intersection The cut-through intersection is an innovative design under consideration in Australia due to favourable safety and capacity characteristics. It is applicable to suburban and ex-urban situations. Controlled by near-side signals, through vehicles follow a circulating roadway while left turning vehicles follow a typical intersection path. Islands guide movements and are mountable.	
Squircle signalised intersection The squircle intersection is an innovative design under consideration in Australia due to favourable safety and capacity characteristics. It is an urban version of the cut-through intersection. Controlled by near-side signals, through vehicles follow a circulating roadway while left turning vehicles follow a typical intersection path. Islands guide movements and are mountable.	
Interchange an assumed grade separation with a form of roundabout control for movements no separated (image generated by Mike Mills, Faculty of Art and Design, Monash University, Sept. 2010)	

MUARC plotted test results for all selected intersections. This report uses three example intersections to illustrate the results (refer to the CRISP Phase I report for all results):

1. City of Edmonton's 107 Avenue – 142 Street – this was the only traffic circle tested in the study.
2. Strathcona County's Baseline Road – Broadmoor Boulevard – this is a good example of a suburban or ex-urban intersection with high volumes and higher posted speeds (70 km/h on the east/west Broadmoor Boulevard and 60 km/h on the north/south Broadmoor Boulevard)
3. St. Albert's Bellerose Drive and Inglewood Drive – a smaller intersection in a suburban setting with posted speeds of 50 km/h on both legs.

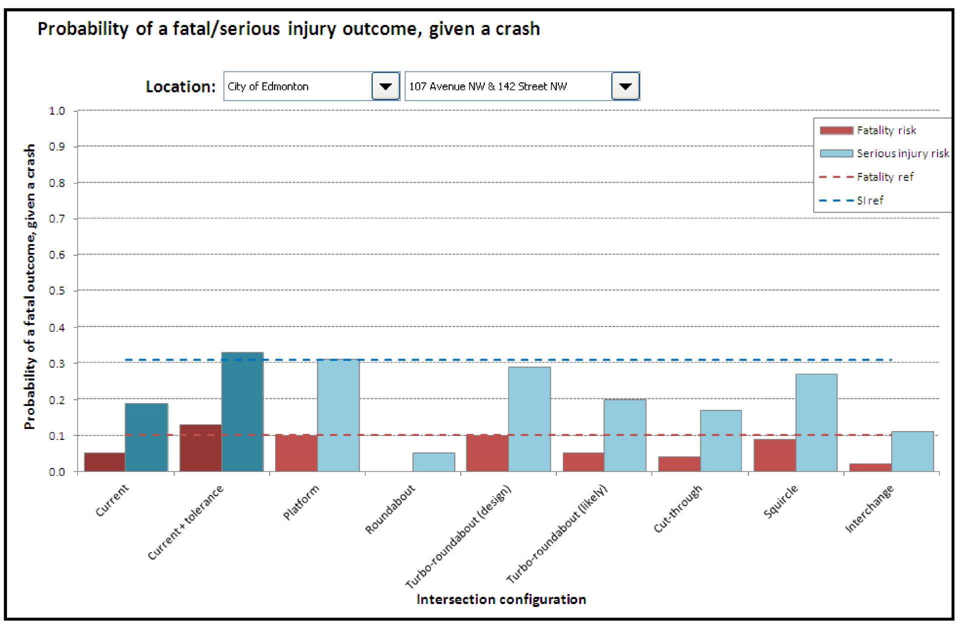
4.4 107 Avenue – 142 Street (Edmonton)

This traffic circle in Edmonton has an inscribed diameter of about 90m. The south leg has a posted speed of 50 km/h while the remaining three legs are at 60 km/h.

Figure 2. Air Photo of 107 Avenue – 142 Street

The following plot illustrates (Figure 3), given a crash, the probabilities of fatal and serious injury outcomes for the intersection types tested. It also shows the Safe System threshold criteria (dashed red line at 0.1 for fatal outcomes and dashed blue line at 0.31 for serious injury outcomes).

Figure 3. Probabilities of Fatal/Serious Injury Outcome, given a Crash at 107 Avenue – 142 Street



The current geometry meets the Safe System thresholds. The probability of fatality, given a collision, is about 5% while the probability of serious injury is just under 20%. This is due to the circle providing for lower entry speeds and more favourable crash angles. This result also aligns with the selected intersection collision severity data from Edmonton. The traffic circle had three serious injury collisions in five years; the next closest Edmonton intersection had at least nine serious injury collisions.

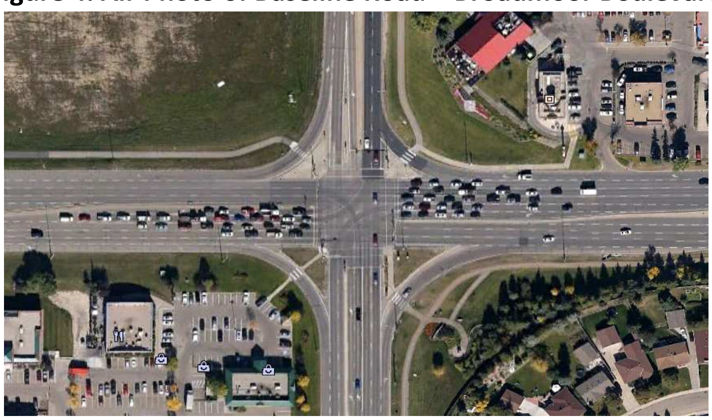
The current + tolerance scenario does not meet Safe System thresholds, although it is unlikely that vehicles are commonly travelling at 15 km/h above typical circulating speeds in the circle. All other intersection types meet Safe System thresholds at this location.

The platform, turbo-roundabout (design), and squircle do not perform as well as the circle. This is due to less favourable impact angles. The turbo roundabout (likely) and the cut-through perform similarly to the current circle. The interchange performs better and the roundabout performs best given its even tighter radius and still favourable impact angles.

4.5 Baseline Road – Broadmoor Boulevard (Strathcona County)

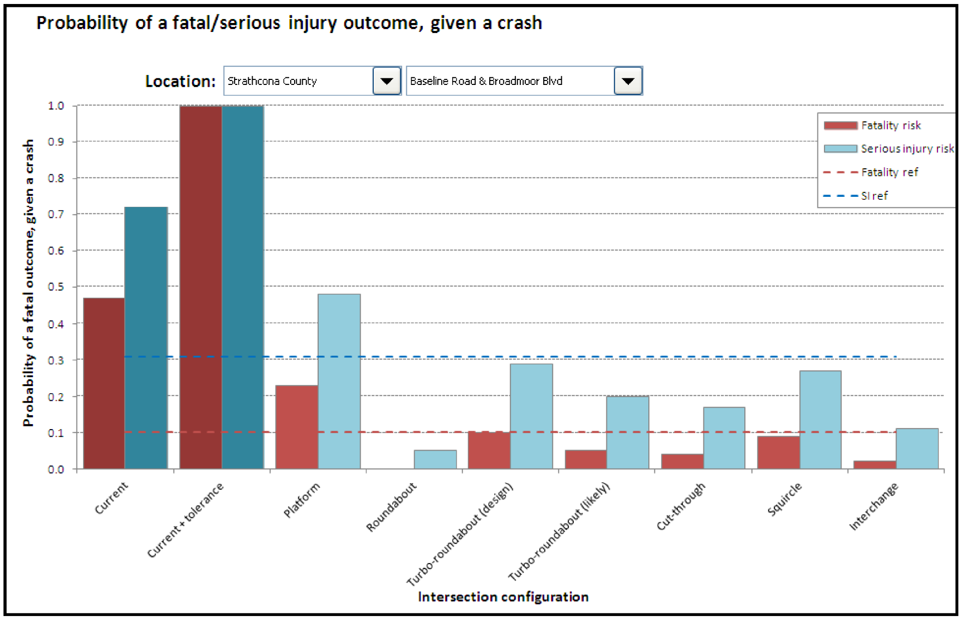
This is an intersection of two urban arterial roads in Strathcona County's urban service area known as Sherwood Park (2011 population of 64,733). The east/west Baseline Road is a six lane divided road posted at 70 km/h while Broadmoor Boulevard is four lanes posted at 60 km/h. The intersection control is a traffic signal with protected-only lead/lag left turn phases for the dual left turns on Baseline Road.

Figure 4. Air Photo of Baseline Road – Broadmoor Boulevard



The following plot illustrates, given a crash, the probabilities of fatal and serious injury outcomes for the intersection types tested.

Figure 5. Probabilities of Fatal/Serious Injury Outcome, given a Crash at Baseline Road – Broadmoor Boulevard



The current geometry does not meet Safe System thresholds. The probability of fatality, given a collision, is about 45% while the probability of serious injury is over 70%. This is due to the relative high speeds and the least favourable impact angle of 90°.

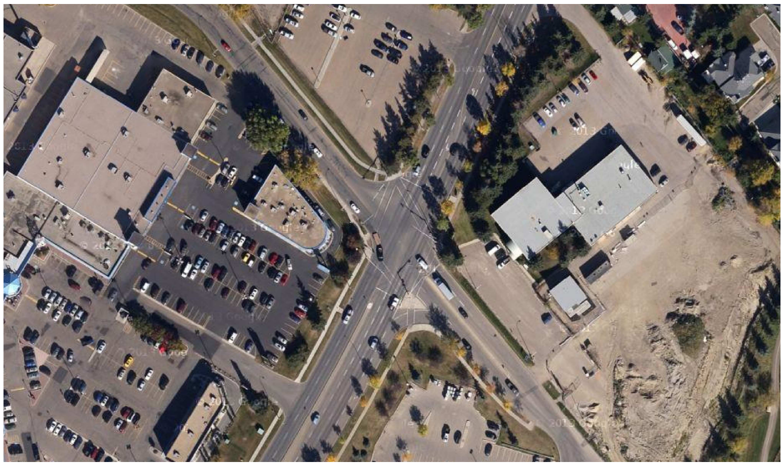
The current + tolerance scenario also does not meet Safe System thresholds. Rather alarmingly, it shows a 100% probability of a fatality given a crash. CRISP member enforcement agencies were concerned at how a relatively small tolerance can significantly change crash outcomes. As a result there is growing action toward tighter speed tolerances among CRISP members.

The high approach speeds also render the platform intersection as unable to meet the thresholds, although it is better than the current situation (note: the approach speeds were assumed high due to the high posted speed limits). All other intersection types perform similarly to the Edmonton intersection, because the assumptions used for model inputs did not change, given the lack of a design plan. This also speaks to the feasibility of some of these intersection types at this location.

4.6 Bellerose Drive and Inglewood Drive (St. Albert)

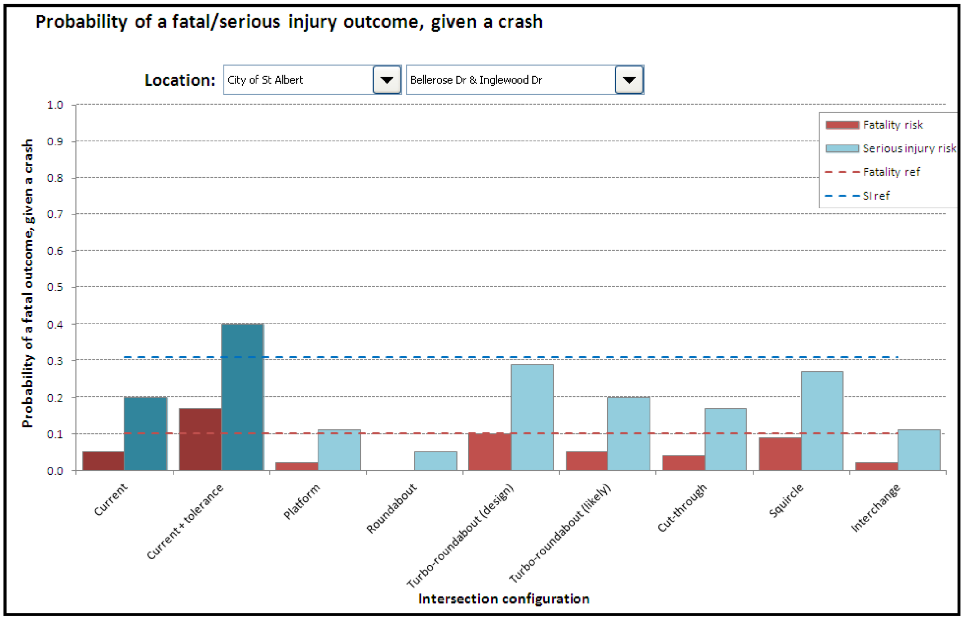
This is an intersection of a four lane arterial road (Bellrose Drive) with a two lane collector flared to four lanes at the intersection. Both roads are posted at 50 km/hr. The intersection is slightly skew.

Figure 6. Aerial Photo of Bellerose Drive – Inglewood Drive



The following plot illustrates, given a crash, the probabilities of fatal and serious injury outcomes for the intersection types tested.

Figure 7. Probabilities of Fatal/Serious Injury Outcome, Given a Crash at Bellerose Driver – Inglewood Drive



The current intersection meet Safe System thresholds. This is due to the lower posted speeds and the slight skew.

The current + tolerance scenario does not meet Safe System thresholds. Again this result demonstrated the importance of lower speed tolerances for enforcement agencies.

All other intersection configurations meet Safe System thresholds, although the turbo roundabout (design) and the squircle perform worse than the current intersection. The turbo roundabout (likely) and the cut-through give a similar performance to the current intersection. The platform, the interchange, and the roundabout improve performance compared to the current intersection, with the roundabout providing the best performance.

5.0 Workshop II – Assess Design Feasibility of Safe System Designs

MUARC and CRISP organised a workshop in Edmonton for local practitioners to assess the design feasibility of several intersection designs at some of the following selected intersections:

- Baseline Road & Broadmoor Boulevard, Strathcona County
- Wye Road & Sherwood Drive, Strathcona County
- 34 Avenue NW and 91 Street NW, Edmonton
- St Albert Trail and St Anne Street, St Albert
- St Albert Trail and Villeneuve Road, St Albert
- 107 Avenue and 142 Street, Edmonton

Workshop participants were asked the following questions about applying the intersection treatment at these intersections:

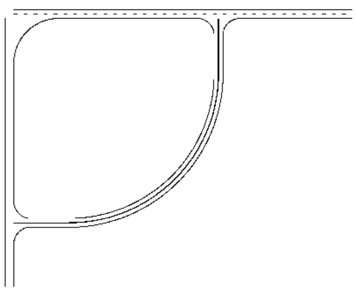
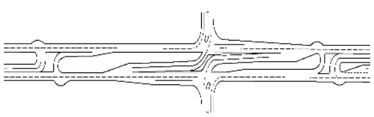
- What do you like about this configuration? What are its advantages/pros?
- What do you not like about this configuration? What are its disadvantages/cons?
- What changes or modifications would you make to this configuration? Describe any changes below, draw them on the plans provided or use the sticky notes to annotate the plans provided on the table

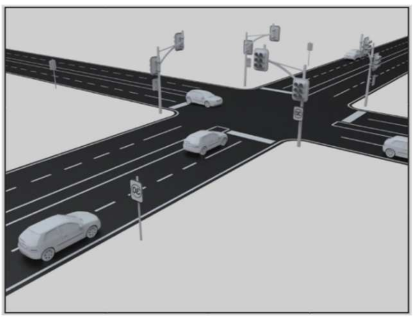
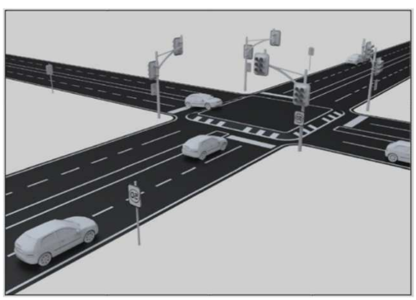
Concerns about intersection capacity/volume issues were the most common. Other concerns included 'driver confusion', requirements for longer signal cycles, or needs for rumble strips to help define driving paths. Participants also pointed to winter maintenance challenges in some designs. Generally participants thought the detailed design process could accommodate these concerns.

The single day workshop did not allow sufficient time for a thorough review of relevant background information nor a complete resolution of issues. Therefore the views captured at the workshop are more perception than hard, in-depth analysis. Table 3 summarises the participants' perceived advantages and disadvantages of each intersection design.

Table 3. Summary of Perceived Advantages and Disadvantages

Intersection Design	Perceived Advantages	Perceived Disadvantages
Squircle 	• Reduced collision speeds Favourable impact angles	• Capacity issues • Potential to cause driver confusion • Winter maintenance

Intersection Design	Perceived Advantages	Perceived Disadvantages
Cut-through 	• Less complicated than existing intersections • Reduce incidence of right angle and left turn across path collisions • Reduced number of conflict points • Reduced conflict speeds • Improved conflict angles	• Accommodating heavy vehicles • Signal timing issues
Quadrant Roadway 	• Reduced traffic volumes, improved capacity (subject to appropriate • signal timing) • Removal of problematic left-hand turns	• Land acquisition requirements • Rerouting of turning traffic along local streets • Some right-angle conflict points remain
Super Street 	• Reduced conflict points	• Higher speeds • Traffic flow ‘turbulence’
Turbo Roundabout 	• Improved conflict angles • Reduced speeds • Efficient use of land	• Capacity limitations • Winter maintenance • Accommodation for cyclists and pedestrians

Intersection Design	Perceived Advantages	Perceived Disadvantages
Roundabout 	• Elimination of right-angle impacts • Reduced conflict speeds • Improved conflict angles • Driver familiarity	• Capacity issues • Accommodation for heavy vehicles
Reduced Speed Limits and Raised Platforms  	• None noted	• Difficulty enforcing lower speed limits

Many of the participants' perceptions are within expectations. However, the MUARC team noted a concern with the perceptions regarding the Reduced Speed Limit and Raised Platform intersections. The local practitioners' perceptions of these treatments were negative. This was surprising to the MUARC team, because these two treatments directly address a key safety risk – speed, and they do so at a fraction of the cost of the other treatments.

Based on the feedback from workshop participants, Table 4 presents the preferred Safe System solutions. It is recognized that these preferences are based on a preliminary review of the intersections with little time to explore all technical issues to a normal standard of care. However these findings may serve to advance Safe System thinking.

Table 4. Safe System Solutions preferred by Workshop Participants

Jurisdiction	Selected Problematic Intersections	Preferred Solution Workshop Participants	Other Options
City of Edmonton	34 Avenue NW and 91 Street NW	Cut-through, with right-turn slip lanes	Diverging diamond interchange
	107 Avenue and 142 Street	Signalise current site	
Strathcona County	Baseline Road and Broadmoor Boulevard	Cut-through	Re-grading (stop-gap) Reduce approach speeds Limit allowed manoeuvres Grade separation ('fly over') Full interchange
	Wye Road and Sherwood Drive	Cut-through, with right-turn slip lanes	None
City of St. Albert	St Albert Trail and St Anne Street	Roundabout Turbo Roundabout	None
	St Albert Trail and Villeneuve Road	Roundabout	None

6.0 Road Safety Auditing and a Safe System Approach

6.1 Background – The Need for Road Safety Auditing

Road safety auditing began in the 1970s. At that time road safety practitioners recognised a more proactive approach to resolving black spots is to consider safety performance of the design at the planning and design stages.

If a road safety audit is not part of the design and planning process, the safety consequences are dire. Here is a typical sequence of events:

1. It typically takes three to five years of crash data to accumulate to confirm the safety problem.
2. Add another year to this process because the data collection lags behind by 3 to 12 months and it takes time to conduct a proper data analysis.
3. Then add one to two years to identify a solution, plan and design it, and secure funds to construct it.
4. Then finally add another year to construct the solution.

Thus a less safe intersection could operate for six to ten years, simply because a proper audit was not part of the original planning and design. During this time there could be many serious injury or fatal collisions.

6.2 A Safe System Approach

The following simple two-stage approach will meet Safe System intersection design aspirations:

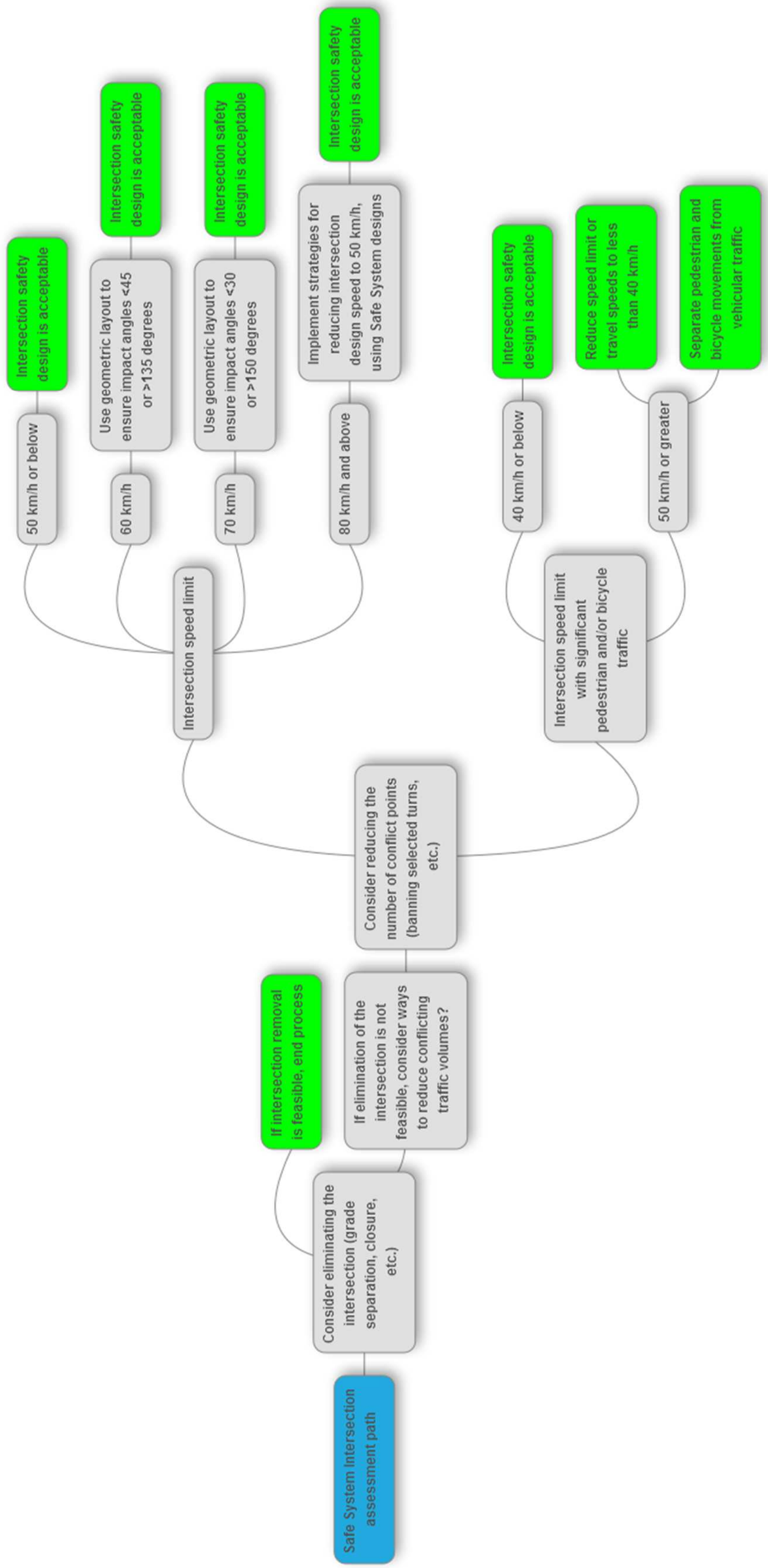
1. Reduce the risk of crashes as far as possible (ideally without limiting the potential to implement stage 2 design measures),
2. Any crashes that remain should be within the biomechanical limits of humans.

In many circumstances it is not possible to achieve the latter stage through engineering design and speed management. For example, for travel speeds above 70 km/h it is not possible to adjust the impact angle to achieve meet Safe System thresholds.

In such cases the only feasible option is reducing the risk of a crash occurring to negligible levels. The four principles for Safe System design identified in the MUARC Intersection Design Study (Corben, van Nes, Candappa, Logan, & Archer, 2010):

1. Fewer vehicles – reducing the number of vehicles in use presents fewer collision opportunities;
2. Fewer intersections – reducing where possible the number of intersections within the road network concentrates more traffic movements at intersections with best-practice safety standards, thereby reducing high-risk conflict opportunities;
3. Fewer conflict points per intersection – simplifying intersections produces fewer conflict points and reduces the opportunities for crashes;
4. Impact speeds and impact angles constrained to biomechanically tolerable levels – in the event of a crash, designing to create speed and angle combinations that give low serious injury risk.

The next page shows a graphical representation of this Safe System approach to intersection design. Read from left to right, the initial steps consider measures that reduce the risk as far as possible. As the steps move to the right, the focus shifts to creating more favourable impact speeds or impact angles.


Safe System Intersection assessment path
Consider eliminating the intersection (grade separation, closure, etc.)
If intersection removal is feasible, end process
If elimination of the intersection is not feasible, consider ways to reduce conflicting traffic volumes?
Consider reducing the number of conflict points (banning selected turns, etc.)
Intersection speed limit
50 km/h or below
Intersection safety design is acceptable
60 km/h
Use geometric layout to ensure impact angles <45 or >135 degrees
Intersection safety design is acceptable
70 km/h
Use geometric layout to ensure impact angles <30 or >150 degrees
Intersection safety design is acceptable
80 km/h and above
Implement strategies for reducing intersection design speed to 50 km/h, using Safe System designs
Intersection safety design is acceptable
Intersection speed limit with significant pedestrian and/or bicycle traffic
40 km/h or below
Intersection safety design is acceptable
50 km/h or greater
Reduce speed limit or travel speeds to less than 40 km/h
Separate pedestrian and bicycle movements from vehicular traffic

7.0 Conclusions and Recommendations

In 2011 CRISP retained the technical expertise of Monash University Accident Research Centre (MUARC) to lead a project regarding the Safe System approach to intersection safety. CRISP used a two phase approach to the project, and MUARC produced two corresponding reports. Both reports advanced CRISP's understanding of Safe System thinking.

This paper reported several key findings of this CRISP project, presented as the following conclusions:

C1. A literature review found the following key topics

a) There are many examples of Safe System integration in other countries.
b) There is a primary focus on speed.
c) Specific designs aimed at reducing speeds are raised platforms, roundabouts, turbo roundabouts, and intersection safety cameras.
d) Technology based countermeasures for drivers are emerging.
e) Reconfiguring left turns is a common countermeasure.
f) Evidence suggests the Safe System approach results in large safety gains.

C2. The Kinetic Energy Management Model (KEMM) provides a credible and objective method to assess intersection safety and to estimate safety performance against Safe System principles.

C3. In assessing three example intersections, a speed tolerance of 15 km/h dramatically increases the probabilities of fatal or serious injury outcomes should a crash occur.

C4. Edmonton's 107 Avenue – 142 Street intersection, controlled by a large inscribed diameter traffic circle, meets safe system thresholds if impact speeds are near the posted speeds. This is due to the reduced speeds and flatter crash impact angles.

C5. Strathcona County's Baseline Road – Broadmoor Boulevard intersection, controlled by a traffic signal, does not meet Safe System thresholds. This is due to the relatively high posted speed and 90 degree crash impact angle.

C6. St. Albert's Inglewood Drive – Bellerose Drive intersection, controlled by a traffic signal, meets Safe System thresholds. This is due to the relatively low posted speed (50 km/h in both directions) and a slightly skew crash impact angle.

C7. Several intersection types were assessed with the following general results:

a) A modern roundabout performs the best
b) An interchange also performed very well
c) Platform intersections can perform very well provided the design encourages speeds within Safe System thresholds
d) Turbo roundabouts, cut-through, and squircle intersections (the latter two being trialled) can all meet Safe System thresholds. Although the safety performance of this intersection is not as strong as those in the above three bullets, their capacity performance may be superior.

C8. CRISP sponsored a workshop for local practitioners to assess the design feasibility of Safe System intersections at selected intersections in the Alberta Capital Region. While many of the particpants' perceptions are within expectations the MUARC team noted a concern regarding the Reduced Speed Limit and Raised Platform intersections. The local practitioners' perceptions of these treatments were negative. This was surprising to the MUARC team, because these two treatments directly address a key safety risk – speed, and they do so at a fraction of the cost of the other treatments.

C9. Road Safety Audits are a proactive method to improve traffic safety performance. The audits avoid costly retro-fits as well as operating a less safe intersection for five to ten years.

C10. The Safe System Intersection Assessment Path, shown as the last diagram in this paper, is essentially a simple two-stage approach will meet Safe System intersection design aspirations:

a) Reduce the risk of crashes as far as possible
b) Any crashes that remain should be within the biomechanical limits of humans.

These conclusions lead to the following recommendations:

R1. Speed tolerances should be much less than 15 km/h.

R2. Road Safety Audits should be included as part the planning and design process for constructing transportation infrastructure.

R3. The Safe System Intersection Assessment Path should be adopted as part of the planning and design process for constructing transportation infrastructure.

References

Chen, H. Q., Cao, L., & Logan, D. (2011). An innovative method for categorising the contributing factors to intersection crashes using fault tree modelling. *International Journal of Crashworthiness*, 125-129.

Corben, B., & Candappa, N. (2011). *Intersection Study: Task 2 report. Targeted literature review.* Melbourne, Austtralia: Monash University Accident Research Centre.

Corben, B., van Nes, N., Candappa, N., Logan, D., & Archer, J. (2010). *Intersection Safety Study: Meeting Victoria's Intersection Challenge. Task 3: Development of the Kinetic Engergy Management Model and Safe Intersection Design Principles.* Melbourne: MUARC.