



An Application of Safe System Approach to Intersections in the Capital Region

Progress Report

FINAL

PHASE 1

By

Sujanie Peiris
David Logan
Nimmi Candappa
Bruce Corben

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Author(s):

Peiris, S.
Logan, D. B.
Candappa, N.
Corben, B.

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Abstract:

This progress report is intended to summarise the outcomes of Phase One (Tasks 1 to 5) of the CRISP Intersection Project being undertaken by MUARC. Therefore, summaries of the statistical analysis that was undertaken to determine five poorly- and three well-performing intersections from each jurisdiction, a listing of the intersections finally chosen for this investigation, a summary of the workshop that was conducted and the main findings of the updated literature review will be provided. As part of Task 5, KEMM-X ratings which determine the probability of a fatality or serious injury occurring at any of the identified intersections (by taking into account impact angle and signed speed limits) will be presented.

This work highlights the extent of the intersection trauma problem in the City of Edmonton, Strathcona County and City of St. Albert. The problematic sites have been studied and throughout the tasks, factors which contribute to the observed number of injurious collisions, noted. Task 5 of this work demonstrates that the currently posted speed limits and those which are currently tolerated are beyond those which can be considered Safe System compliant. Therefore, it is suggested that greater attention be given to making intersections within the jurisdictions more forgiving of human error and hence, more in line with the Safe System philosophy.

Key Words:

Disclaimer

Intersection safety, innovation, infrastructural design, intersection geometry, driver behaviour, Safe System	This report is disseminated in the interest of information exchange. The views expressed here are those of the authors, and not necessarily those of Monash University
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Monash University Accident Research Centre,
Building 70, Clayton Campus, Victoria, 3800, Australia.
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363
www.monash.edu.au/muarc

Preface

Project Manager / Team Leader:

- Dr. Bruce Corben

Research Team:

- Sujanie Peiris
- Effie Hoareau
- Nimmi Candappa
- David Logan

Contributorship Statement

David Logan and Sujanie Peiris calculated the KEMM-X fatality and serious injury ratings for the identified Edmonton intersections and Safe System compliant intersection designs. Nimmi Candappa provided valuable advice regarding various aspects of the report and feedback following the visit to Edmonton.

Sujanie Peiris wrote the report.

Dr Bruce Corben provided guidance and input throughout.

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Ethics Statement

Ethics approval was not required for this project.

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1.0 SUMMARY OF TASK 1 & TASK 2

1.1 Aims

- *Each jurisdiction within CRISP to analyse collision statistics at local intersections over the most recently available five-year period to gain a clear understanding of intersection-specific safety issues within the three municipalities.*
- *MUARC in consultation with CRISP, to identify and select five intersections exhibiting poor safety performance and three well-performing intersections from each jurisdiction. These intersections will be the subject of more detailed assessment with respect to the development of 'Safe System designs' in later stages.*

1.2 Methodology

Each jurisdiction was able to provide MUARC with the most recent five-years of collision, traffic volume and control type data for the main intersections within the jurisdictions. Using these data, each municipality conducted a statistical analysis and ranked the intersections from the most poorly-performing to the best-performing sites. MUARC provided direction and advice regarding which variables to use in order to identify the five most poorly-performing and three most well-performing intersections. It was suggested that given Safe System thinking, fatality and serious injury causing collisions (instead of minor injury and property damage causing collisions), be used to identify these sites and those with comparable traffic volumes be chosen. This task enabled the Cities of Edmonton and St. Albert and Strathcona County, and MUARC, to understand any limitations in the data which existed, take account of these limitations and gain an understanding of the extent of the intersection trauma problem within the three jurisdictions.

The data which the City of St. Albert provided did not distinguish between *major* and *minor* injuries. Instead, the data identified collisions which were simply 'injury-related' or involved a fatality. Given this, St. Albert collision data were sorted based on collision types that are more likely to have a severe outcome. These collisions, according to St. Albert's classification of data, were identified as 'Left Turn Across Path, Failed to Observe Traffic Signal, Stop Sign Violation, Failed to Yield ROW (No Control), Yield Sign Violation, Failed to Yield to Pedestrian, Pedestrian Error / Violation, Failed to Yield to Cyclist'. Given that 'Left Turn Across Path' was one of the most problematic and frequently occurring collision types, intersections with the largest number of injury-related collisions resulting from this collision type were identified and ranked by MUARC to identify the sites which were performing most poorly (Table 1). Using this information, as well as statistical analyses coupled with expert judgement and familiarity with the sites, each jurisdiction confirmed their five most poorly-performing and three well-performing intersections.

1.3 Results

Poorly-performing intersections were ranked (Table 1) based on the number of major injuries and fatalities (for Strathcona County and City of Edmonton) or the number of injury-causing collisions resulting from the 'Left Turn Across Path' collision type (City of St. Albert).

Table 1: The ten most poorly-performing intersections within each jurisdiction.

	City of St Albert	City of Edmonton	Strathcona County
1	St. Albert Tr @ Boudreau Rd & Giroux Rd	118 Av NW & 97 St NW	Baseline Rd & Clover Bar Rd
2	St. Albert Tr @ Hebert & Gervais	34 Av NW & 91 St NW	Wye Rd & Sherwood Dr
3	St. Albert Tr @ Bellerose Dr & McKenney Ave	Princess Elizabeth Av, 336 & 109 St NW	Baseline Rd & 17 St
4	St. Albert Tr @ Sturgeon Rd & St. Anne St	129 Av NW & 50 St NW	Baseline Rd & Broadview Dr
5	Bellerose Dr @ Inglewood Dr	82 Av NW & 99 St NW	Broadmoor Blvd & Lakeland Dr
6	Boudreau Rd @ Bellerose Dr	111 Av NW & 109 St NW	Broadmoor Blvd & Strathcona Dr
7	St. Albert Tr @ Lennox Dr & Inglewood Dr	137 Av NW & 93 St NW	Wye Rd & Ash St
8	St. Albert Tr @ Gate Ave	127 Av NW & 97 St NW	Baseline Rd & Broadmoor Blvd
9	St. Albert Tr @ Villeneuve Rd & Erin Ridge Rd	104 Av NW & 109 St NW	Sherwood Dr & Fir St
10	Boudreau Rd @ Sir Winston Churchill Ave	137 Av NW & 50 St NW	Wye Rd & Clover Bar Rd

For each municipality, the five most poorly-performing intersections and three well-performing intersections were chosen, drawing upon the local knowledge within the three municipalities (Table 2 and Table 3, respectively).

Table 2: Five most poorly-performing intersections within each jurisdiction.

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
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: Three most well-performing intersections within each jurisdiction.

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

1.4 Conclusion

There was good agreement between the intersections selected by the CRISP municipalities for further study and the intersections which MUARC found in its statistical analysis to warrant investigation. The selection of specific intersections to be used for the remainder of the study concluded Task 1 and Task 2.

2.0 SUMMARY OF TASK 3

2.1 Aims

- *MUARC to conduct a targeted literature review of improved, Safe System compliant intersection designs.*

2.2 Methodology

Various databases were searched for recent publications related to intersection design and Safe System compliance of road architecture which would directly affect an individual's ability to navigate through an intersection. These databases, amongst many, included Engineering Information (EI) Compendex, Engineering Village and the Transportation Research Information Services (TRIS) Database. Publications were also sourced from scientific journals and reports published by reputable traffic-safety related organisations world-wide. All publications cited in the final report were referenced accordingly, enabling original source information to be reviewed if necessary.

The targeted literature review was an update of the extensive literature review of innovative infrastructural measures that improve intersection safety, conducted by Candappa and Corben (2011), as part of the Transport Accident Commission (TAC)- and VicRoads-funded, *Victorian Intersection Project*. This latter study reviewed literature published until 2008. Given that this document is to stand as a supplement to the aforementioned literature review, it focussed largely on scientific studies published post-2008.

2.3 Results

Intersection collisions claim hundreds of thousands of lives every year, worldwide. In Australia, of the road collisions which kill approximately 1,500 Australians and hospitalise another 30,000 annually, 32% are attributed to impacts that occur at intersections (Australian Transport Council, 2010). In the US, intersection collisions claimed over 7,700 lives in 2008 alone (Golembiewski and Chandler, 2011). In Canada, the most recent statistics suggest that an average of 809 people die in intersection-related collisions annually (Transport Canada 2008). Worldwide, intersection collisions are estimated to have caused 1.2 million deaths and 50 million injuries in the past decade (Harding 2006).

The Safe System approach is a road-safety philosophy that is based on a fundamental belief that an individual's safety and well-being are paramount, above and beyond any other benefit which the transport network can provide. Further, it brings to attention that humans will always make mistakes when using the road-transport system and, given the limited biomechanical tolerance of humans, roads should be designed to be forgiving of human error. In principle, the Safe System concept attempts to eliminate transport-related death and serious injury. While there are four cornerstones to this concept, these being *Safe Road Use*, *Safe Roads and Roadsides*, *Safe Speeds* and *Safe Vehicles*, this review focused on the two which most closely influence intersection safety – Safe Roads and Roadsides, and Safe Speeds, while taking into consideration Safe Vehicles and Safe Road Use. Scientific publications related to innovative intersection designs, particularly with regard to these cornerstones, and published post-2008 have been reviewed.

Many European countries are successfully integrating Safe System principles into their roads and infrastructure. Credible speed limits, for example, are proposed to be set based on the specifics of road design and function, and are appropriately enforced to ensure high compliance with speed limits (Aarts et al., 2010). Roads are being designed so that they elicit more predictable behaviour by road users. Roundabouts and turbo roundabouts are replacing signalised intersections, thereby reducing the consequences of human error when road users do make mistakes. In the US,

promotion of interchanges and intersections which eliminate left-turn-across traffic manoeuvres is evident. Intersection research in Australia and Canada is more in line with that of the European nations, with a large focus on best-practice infrastructure and Safe System compliance. In Victoria, the Transport Accident Commission (TAC)-funded *Intersection Design Project*, being managed by VicRoads, is in a phase of trialling a number of innovative intersection designs. These designs, in line with Safe System principles, are heavily based on achieving low-risk speeds through intersections and creating more favourable impact angles in the event of collisions. Such changes in design and operation are likely to bring about large and lasting safety gains for the road-transport system.

Speed plays a fundamentally important role in intersection collisions. While turn-across traffic, cross-traffic and rear-end impacts occur frequently at both urban and rural intersections, the speeds at which these impacts occur determine the survivability of the vehicle occupants. Choosing a safe driving speed is a difficult concept and being able to accurately judge another driver's approach speed is equally, if not more challenging. The inability of a driver to choose a safe gap in traffic, often contributes to the more severe collisions observed at intersections. Therefore, treatments which influence driver speed have been reviewed. That is, treatments which effectively reduce approach speeds at intersections, including gateway treatments (such as visual cues), curves and road markings, and road narrowing are discussed. While these are not intersection-specific treatments, it is recognised that reducing route speeds often influence intersection speeds (McLean et al. 2010). Concepts such as Self-explaining Roads (which originated in the Netherlands) and Essential Recognisability Characteristics which are practised throughout Europe have been shown to effectively reduce route speeds by up to 15 km/h on local roads (Schermers et al. 2010). Treatments which prompt such effects should be viewed favourably given their cost-effectiveness.

More specific infrastructural measures which are aimed at reducing intersection speeds include raised platforms, roundabouts (including with signals) and turbo roundabouts. While raised platforms within intersections or at the approach to intersections are cost-effective and have proven safety benefits given their ability to reduce speeds (the exact magnitude of speeds reduced being highly dependent on site conditions and the profile used), they are also associated with environmental noise, increased pollution and adverse effects on emergency vehicle response times (Ahn and Rakh 2009; McLean et al. 2010; Wewalwala and Sonnadara 2011). Roundabouts, conversely, are now being widely implemented internationally due to their positive environmental impact as well as ability to reduce fatalities greatly. Turbo roundabouts, although still most popular in Europe, are able to deliver high capacity traffic performance, equal to and sometimes greater than signalised intersections, and are up to 70% safer than priority controlled signals. Speed enforcement has also been shown to be an effective means of reducing intersection speeds. Red light cameras, coupled with and without speed cameras, have reduced the number of individuals who run red lights and, consequently, have also reduced the number of serious injury collisions at intersections (Budd et al. 2011; Hu et al. 2011).

In addition to speed reduction countermeasures, several technology-based projects which attempt to minimise the incidence and severity of intersection collisions are also being conducted world-wide. Projects, such as the development of prototypes for the Cooperative Intersection Collision Avoidance System (CICAS), Cooperative Intersection Safety System (CISS) and Dedicated Direct Short Range Communication (DSRC) systems, use GPS data with radars, cameras and sensors to warn drivers (using in-vehicle technology), of other drivers who are violating traffic signals, safe gaps to cross traffic and of at-risk, vulnerable road users. While these technologies are in their trial phases, with only a limited number of vehicles fitted with these technologies and/or in confined, suitably equipped spaces, monetary investments into these projects are considerable, and are likely to accelerate the penetration of these technologies into the vehicle fleets in the near future.

Variable message signs, on the other hand, are currently being utilised worldwide in order to successfully reduce travel speeds, intersection approach speeds and inform drivers of hazards

(McLean et al. 2010; Ray et al. 2008; Tay and Barros 2008). The *Victorian Intersection Design* project is currently in the process of trialling a dynamic road sign that will advise drivers of safe gaps to cross/enter unsignalised intersections.

Archer and Young (2009) proposed using an IT-based intervention to delay the onset of the green signal and extend the all-red safety time of signals based on vehicles entering the dilemma zone. This technology, if successful, would prevent vehicles from red-light running and, consequently, reduce the number of collisions associated with this violation.

Several infrastructural changes to intersections have also been reviewed, with particular emphasis given to intersections which eliminate the left hand turn (for traffic driving on the right hand side of the road). The effectiveness of the diverging diamond interchange, jug-handle intersection and median u-turn, as well as the Paraflow intersections and the reduced-conflict intersection have been discussed in terms of the most recent publications. While these discussions are limited, given that the intersection designs don't necessarily promote safer impact speeds or angles when collisions do occur, the designs do reduce the number of conflict points. Consequently, there is likely to be an improvement on current designs for signalised intersections.

To date, large safety gains have been attributed to the adoption of Safe System approaches (Johansson 2009). In 2010, Sweden, the Netherlands and the United Kingdom reported 2.8, 3.9 and 3.1 road deaths per 100,000 population, respectively. In Australia, this figure was 6.8 (Australian Transport Council)¹, compared to 8.7 in 2002 prior to the adoption of Safe System (Australian Transport Safety Bureau. 2004). This compares to 6.5 deaths per 100,000 population in Canada, 2009 (2010 motor vehicle fatality figures were not available)². While it is not possible to conclude that the adoption of the Safe System philosophy has, on its own, brought about this improvement, the shift in thinking and practice which has taken place in Australia over the past decade tends to support the decision to adopt the approach.

The concept of Safe System shapes as a successful one with the potential to bring about large safety gains. Efforts to improve intersection designs and more precisely manage travel speeds are likely to continue to culminate in a safer and more forgiving road-transport system. The findings show that the rate of discovery of new and innovative intersection designs is tapering, as the majority of designs and layouts are variations to those which currently exist, making IT-based solutions a more attractive option for new opportunities in the future. However, careful consideration should be given to the role that technology can play in helping to lessen both the incidence and the severity of intersection trauma. Future solutions which are based on the guiding principles of the Safe System and on principles founded in basic physics, rather than relying on incremental change that may not prove to be permanent, should be favoured.

2.4 Conclusion

A review of recent literature suggested that infrastructural interventions such as roundabouts, turbo roundabouts and grade-separated interchanges are being more readily considered world-wide as alternative designs to signalised intersections. Most 'new' designs that are published in the literature are often variations of these basic designs, with a particular emphasis on either reducing impact speeds or the number of points of conflict, or alternatively, improving impact angles. Literature presents multiple intersection layouts which eliminate left turns at intersections (in

¹ Australian Transport Council. 2010. National Road Safety Strategy 2011-2020: draft for consultation. http://www.infrastructure.gov.au/roads/safety/national_road_safety_strategy/index.aspx. Canberra, ACT: Australian Transport Council.

² Statistics Canada, 2009, <http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/demo02a-eng.htm> and Transport Canada, <http://www.tc.gc.ca/eng/roadsafety/tp-tp3322-2009-1173.htm>, accessed 12 June 2012.

countries where traffic drives on the right hand side of the road). There is also a significant emphasis placed on the importance of reduced and enforced lower speeds at junctions, in recognition that speed is fundamental in determining the amount of kinetic energy exchanged during a collision between vehicles and with other road user types.

Where road authorities and organisations cannot justify monetary investments on infrastructure that improves intersection safety, investments are being made to use technology to reduce collision likelihood. Using GPS data, various sensors and radars, algorithms are being developed so that vehicles are able to communicate with each other, as well as with other vehicles and vulnerable road users at intersections to reduce collision likelihood. While most of the technologies discussed are still in their trial phases, and unlikely to be fully implemented in the near future, gap assist technologies and dynamic/variable signs are showing more promise in terms of their ability to reduce intersection speeds and hence bring about enhanced intersection safety. Findings show that while the rate of discovery of new and innovative intersection designs is tapering, largely being variations to those which currently exist, IT-based solutions are likely to attract more attention in the future. However, careful consideration should be given to the role that technology can play in helping to lessen the incidence and severity of intersection trauma on today's societies. Technologies which manage and/or moderate vehicle speeds at intersections, during periods of elevated collision risk, should be given priority.

3.0 SUMMARY OF TASK 4

3.1 Aims

- *MUARC to conduct a workshop in Edmonton to generate new intersection designs and review all intersection designs under consideration.*

3.2 Methodology

A workshop, coinciding with *Edmonton's International Conference on Urban Traffic Safety* was used as a means of gathering together delegates to discuss existing and identify new, innovative Safe System compliant intersection designs and apply these (conceptually) to the problematic intersections identified in Task 2.

As an introduction to the workshop, representatives of the Capital Region municipalities presented three typical problematic sites (i.e. one from each jurisdiction), explaining the site, describing control operations (e.g., permissive protected vs. protected-only), any existing enforcement measures, traffic volumes, vehicle type composition, approach speeds and any known speed issues, geometric features and possible problems with signage and sight distances. MUARC then provided an overview on recent findings from literature and a presentation of Safe System compliant innovative intersection designs generated during the Victorian Intersection Design Project. This was followed by breakout sessions where delegates were formed into three groups, and each group was asked to consider one of the presented problematic sites. During this session, MUARC provided a copy of all available intersection designs considered applicable to Safe System aspirations, including ITS-based solutions, and encouraged local practitioners and road safety experts in Edmonton, to provide constructive, practical feedback on these designs and their applicability to the Edmonton setting. Participants were given the opportunity to propose any new design ideas which met the Safe System aspiration and to address any specific priorities of the Capital region.

3.3 Results

The following intersections were presented as being typically representative of the intersection-trauma problem within the three jurisdictions.

- 34th Avenue NW, 91 Street NW (City of Edmonton)
- St. Albert Trail @ Boudreau Rd and Giroux Rd. (City of St Albert)
- Wye Road and Sherwood Drive (Strathcona County)

Following this, a presentation was made by MUARC of all new and innovative intersection designs that were generated as a result of the Victorian Intersection Design project. Participants were provided copies of these designs, and split into three large groups, where each group was asked to tackle one problematic intersection that was presented by the CRISP representatives. This generated much-wanted discussion and ideas about how the newer designs could be implemented. While there was a natural tendency by the groups to start with conventional countermeasures, very good progress was made on considering the conditions under which new design ideas might apply.

3.4 Conclusion

Intersection problems being faced in Edmonton, and more widely in Canada, are similar to those challenging Victorian road authorities and their counterparts in other states of Australia. The main driver faults highlighted in the crash data provided by the Cities of Edmonton and St. Albert were

the Left-Turn-Across Path, Follow Too Closely (resulting in rear end collisions) and Failure to Observe Signal, the latter commonly producing high severity side impact collisions. These collision types, respectively, are described as Left-Turn-Across Path, Rear End and Right Angle in the data provided by Strathcona County. That is, the two municipalities use different terminology when coding the collisions. While the Cities of Edmonton and St. Albert use driver actions from a common collision report, to describe certain collision types as driver faults, such as, Follow too Closely (to describe rear end collisions) and Failure to Observe Signal (to describe right-angled impacts), Strathcona County use the terms, 'Rear End' and 'Right Angle' to describe the collisions. Due to the inconsistency in collision coding, care has been taken when comparing collision types between municipalities to ensure that only the same crash types are compared, notwithstanding the different names given to each crash type.

Discussion at the conference and subsequent workshop reinforced the need to access solutions that produce significant safety impacts rather than incremental improvements. Designs based on the Safe System principles provide opportunity for such improvements. Further discussion on these designs, as well as the creation of new designs, and active exploration of design application opportunities, are encouraged.

4.0 SUMMARY OF TASK 5

4.1 Aims

- *Assess the relative risks of a selected number of intersection designs in terms of their likelihood of preventing death or severe injury in the event of a collision.*

4.2 Background

While one aspect of selecting safe intersection designs is to consider collision avoidance, it is fundamental to the Safe System philosophy to ensure that any collisions that do occur, take place within the crashworthiness limits of vehicles and within the biomechanical tolerance limits of drivers, passengers and vulnerable road users. Ensuring that kinetic energies generated in a collision are tolerable by both vehicles and humans substantially reduces the chances of serious injury and death. However, given that human biomechanical tolerances and vehicle crashworthiness often cannot be accurately quantified in real-world situations, a model has been developed to estimate the safety level of an intersection by using other factors that contribute to impact energy, such as the speed and angle of impact. The Kinetic Energy Management Model for Intersections (KEMM-X) estimates relative risk of a fatal or serious injury outcome, given a collision, for a conflict between two vehicles within an intersection and will be used to estimate the safety benefits of the worst-case conflict type for each intersection design under consideration.

4.2.1 Kinetic Energy Management Model

The Kinetic Energy Management Model (KEMM) is a conceptual model for limiting the transfer of kinetic (motion) energy exchanged during a collision to the human to levels below those which can cause serious injury or death. According to the model, (Figure 1) five layers of protection are used to either prevent the collision (by deflecting energy) or mitigate its effects (by absorbing energy).

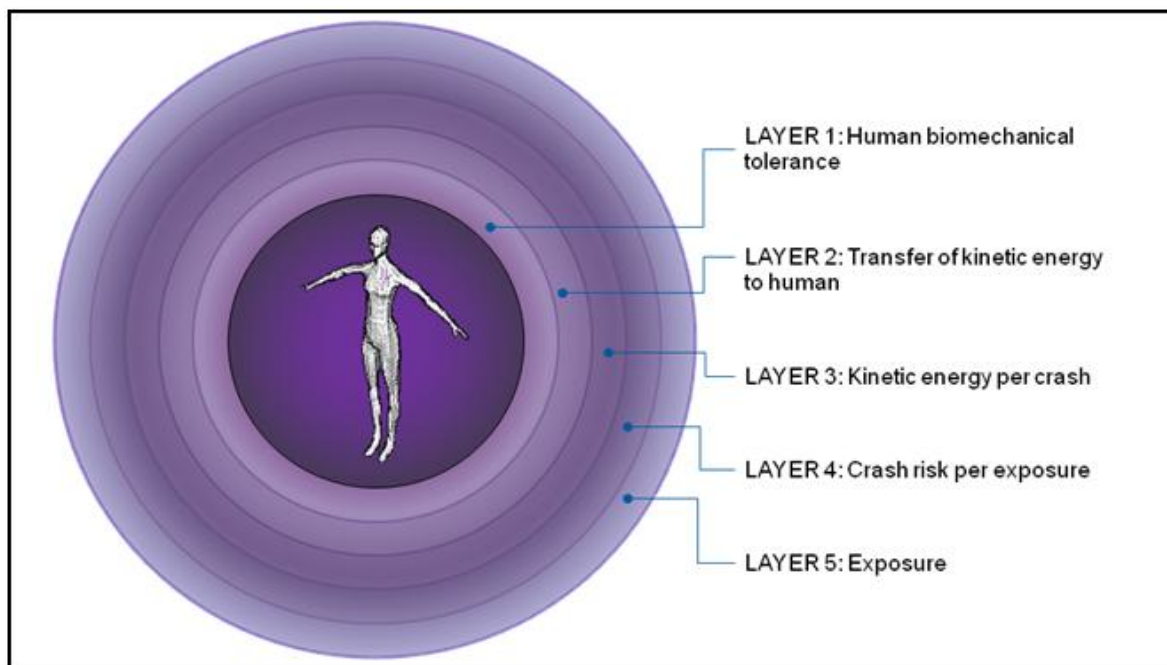


Figure 1: A graphical representation of the Kinetic Energy Management Model (KEMM), showing the vulnerable human at the centre and the five layers of protection.

- Layer 1, human biomechanical tolerance: minimisation of injury risk by understanding the tolerance of the human body to absorb energy. Intrinsic human tolerance levels vary primarily with age, health status, gender and stature.
- Layer 2, transfer of kinetic energy to human: management of the transfer of kinetic energy to the human during a collision. The effectiveness of this layer for a vehicle occupant is related predominantly to the performance of the energy-absorbing characteristics and safety features in modern vehicles.
- Layer 3, kinetic energy per collision: level of kinetic energy of the vehicle at impact during a collision. Lower travel speeds offer the greatest potential for minimising levels of kinetic energy, with the reduction of mass also playing a role. Other relevant vehicle factors include braking effectiveness, and collision-avoidance systems, ABS-braking, brake-assist systems, and intelligent speed adaptation (ISA).
- Layer 4, collision risk given exposure: This layer and Layer 5 are targeted at collision risk reduction. Measures that influence the risk of a collision occurring are important to the performance of Layer 4, such as ISA and collision-avoidance systems. Changes to infrastructure can reduce collision risk by improving visibility, reducing complexity or reducing approach speeds.
- Layer 5, exposure: reduction in collision risk through reduced exposure to conflicts. Alternative intersection designs influence the performance of this layer, as well as initiatives at system level such as reductions in the number of intersections, or mode shifts from private motor vehicles to public transport. The use of advanced traffic control and management systems or traveller information systems can also be used to direct traffic along safer routes.

Layers 4 and 5 are not addressed in detail in this outline, as the view has been taken that while crash risk must be minimised whenever possible, the primary goal is to design intersections so that any foreseeable collision occurs below the biomechanically tolerable levels of humans. That is, the model considers the inherent safety of an intersection in the event of a collision. The KEMM concept is then integrated with the four major risk areas in the Safe System: the human, the vehicle, the road and roadside, and system operation (including speed).

4.22 Design Principles

A set of design principles was developed within the context of the Safe System, Dutch Sustainable Safety and Swedish Vision Zero philosophies. Taking into account the requirements of each of these, the following four intersection design and operation principles were formulated:

1. **Fewer vehicles** – by reducing the number of vehicles in use, fewer opportunities for collisions will arise;
2. **Fewer intersections** – by minimising the number of intersections within the road network, and concentrating more traffic movements at intersections with best-practice safety standards, fewer opportunities for high-risk conflict should arise;
3. **Fewer conflict points per intersection** – by simplifying intersections to produce fewer conflict points, the opportunities for collisions at a given intersection should fall. The resultant reduction in complexity should also have a positive effect on safety;
4. **Impact speeds and impact angles constrained to biomechanically tolerable levels** – by designing to create speed and angle combinations that result in a low

risk of serious injury in the event of a collision. Analysis of the kinematics of traffic collisions shows that:

- For 90° collisions, impact (and, therefore, travel³) speeds should not exceed 50 km/h for vehicle-to-vehicle collisions. For conflicts between vehicles and unprotected road users (i.e. pedestrians, cyclists and motorcyclists), impact (and, therefore, travel) speeds should not exceed 30 km/h;
- For intersections located in speed limits greater than 50 km/h and not greater than 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, collision risk must be reduced to a negligible level.

The inner three layers of the KEMM, relating to the risk of serious injury or death given a collision, have been modelled mathematically to provide a tool for objectively quantifying the safety of individual conflicts within an intersection. The model, known as KEMM-X, has a primary focus on better measuring the intrinsic safety of the intersection as a whole. The development of the mathematical model has not been presented in this report, but a detailed explanation of the conceptual form of the model can be found in Corben et al., (2004). Using the model, the probability of a fatal and serious injury outcome for the conflict judged most severe for each existing intersection as well as the innovative designs (Appendix 2) has been calculated and presented.

In summary, a KEMM-X probability of a fatality value of 0.1 and probability of a serious injury of 0.31, represents the reference risks of a fatality and serious injury occurring when two typical light passenger vehicles of equal mass travelling at 50 km/h containing front-seat occupants of average age and health impact each other at a 90° angle (with no braking applied). Since no level of risk can ever guarantee that a fatality or serious injury outcome will not eventuate from a collision, the above level of risk has been nominated as the threshold below which an impact may be considered to be Safe System compliant. The Excel tables (attached) show the probability of a fatality and serious injury occurring for the worst-case conflict type at each intersection and compares this with the reference, Safe System impact (i.e. two vehicles travelling at 50 km/h impacting at 90°). A KEMM-X fatality rating of 0.04, for example, indicates that the risk of a fatality is 0.4 times that of the reference collision, namely 50/50/90. This also represents a 60% lower chance (i.e. $((0.1 - 0.04)/0.1) * 100$) of a fatality occurring.

It is noteworthy that if the probability of a fatality is 0.0 at any given intersection/innovative design, then the risk compared to the reference 50/50/90, is also zero. Note also that the maximum relative risk of a fatality and serious injury is 10 and 3.2 times greater (respectively) than the reference intersection conflict configuration, since probability values cannot exceed 1.

³ It is clear that, in some instances, braking may be possible prior to a crash and therefore the impact speed might be lower than the travel speed. However, past research using an in-depth crash database (Chen et al., 2011) has shown that in around 50% of impacts, no braking was reported prior to the crash and a worst case scenario should assume this.

4.3 Methodology

Each of the intersections identified by CRISP as either well-performing or poorly-performing was evaluated with the KEMM-X model. That is, a probability of a fatality value, $Pr(F)$, and a probability of a serious injury value, $Pr(SI)$, were calculated for the conflict situation judged to be the most severe for each of the intersections at the speeds at which they are currently intended to operate at (i.e. at the posted speed limits). The calculations were then performed for each site at speeds when an enforcement tolerance value is applied (e.g., 15 km/h greater than the posted speed limits). While it is acknowledged that the specific tolerances may vary between jurisdictions and levels of enforcement (depending on the jurisdiction) may act as deterrents to drivers, the + 15 km/h calculations were used to demonstrate the increased risks of death/serious injury which are present at higher speeds. The calculations were performed assuming that collisions occurred at the worst potential impact angle at each site. Typically, this was 90° for a cross intersection. In the instances where the intersection accommodated two travel speeds, e.g., 50 km/h on one street and 60 km/h on the intersecting street, then it was always assumed that the impacting vehicle (V2) was travelling faster than the vehicle being impacted (V1). This situation is likely to cause a more severe outcome for vehicle occupants of the struck vehicle, and, therefore, represents a ‘worst-case’, but nevertheless realistic, scenario.

Following this, the KEMM-X $Pr(F)$ and $Pr(SI)$ values were calculated for each of the innovative intersection designs presented during Task 4 (refer to Appendix 2 for images of the specific designs). It was assumed that each of these designs would be applied to the problematic intersections conceptually. However, without knowing the exact configurations and dimensions of the intersections, some assumptions were made with regard to speeds and impact angles. These assumptions are as follows:

4.4 Assumptions

Roundabouts

While the exact entry and traversing angle depends on several factors (including the inscribed circle diameter, maximum entry/exit width, entry angle, entry radius, maximum entry path deflection and curvature and maximum circulatory width), it was assumed that a roundabout introduced at any given problematic site would be of reasonable curvature to create a significant amount of horizontal deflection for traversing traffic. An impact angle of 150° (i.e. 30° between impacting vehicles) was assumed.

It was also assumed that the roundabouts would be designed for an entry speed of 30 or 40 km/h, but assuming ‘worst-case’ scenario, calculations were performed using an impact speed of 50 km/h.

Platforms

The exact reduction in speed that can be achieved by the platforms is dependent on the speed profile. Given that the chosen profile for each intersection is yet to be determined, it was assumed that the platforms would achieve a speed reduction of 10 km/h. That is, when performing the calculations, the currently posted speed limits were reduced by 10 km/h. This is likely to be a conservative estimate.

It is noteworthy that if implementing or trialling platforms for use at the poorly performing intersections, there are a number of potential implementation scenarios that should be considered. A platform with a 60 km/h speed profile and accompanying advisory signs, for example, is one means of achieving reduced intersection speeds. Alternatively, introducing platforms with 50 km/h speed profiles, accompanied by an enforced 50 km/h speed limit is likely to achieve greater reductions in speed and hence bring about larger safety gains.

Turbo Roundabouts

Turbo roundabouts are designed in such a way that the lanes which feed into the roundabout come in at right angles to the circular island. This forces new traffic entering the roundabout to stop and give way to already circulating vehicles, and when ready, enter at a 90° angle (Fortuijn 2009). Therefore, this was the impacting angle used in KEMM-X. It was also assumed that turbo roundabouts have a relatively low design entry speed (of approximately 30 km/h) and traversing speed of 50 km/h, and so these were assumed to be the impacting speeds. Despite the design entry angle for this design being 90°, it was observed that typical real-world angles can be more favourable than this. As a result, an angle of 120° was also trialled in KEMM-X.

Cut-through Signalised Intersection.

Given the innovative nature of the cut-through design and the fact that they have not yet been implemented in the real-world, it was a challenge to estimate typical impact angles and speeds. Using the graphical images of a conceptual design it was assumed that 90° impacts may, in theory, still be possible. However, due to the raised islands and forced deflections, it was assumed that high impacting speeds would not. This was confirmed by VicRoads traffic engineers (since this intersection is in the design process for trialling in Victoria). Therefore, it was assumed that the worst possible impact that could occur at a cut-through layout would be a right-angled collision at 40 km/h.

The specific dimensions of the cut-through design (as with the other innovative intersection designs, including the Squirrel), is likely to determine the entry speeds, circulating speeds and impact angles. These dimensions will be highly dependent on the existing geometry of the intersections and the design speeds and design angles. While the worst likely scenario has been assumed for the purposes of calculations, actual designs may achieve more favourable impact angles and speeds than estimated in this report.

Squirrel

As with the above, it was difficult to predict real-world impact angles and speeds for a Squirrel, given that these are not yet implemented. It was assumed that speed reductions would be more difficult to achieve using a Squirrel, given the islands created to cause deflection are smaller and less rounded than a typical roundabout. To be reasonably conservative, an impact speed of 50 km/h and impact angle of 15° from a side impact (105°) were used.

Grade-Separated Interchanges

Introducing grade separated interchanges at the problematic sites is likely to eliminate cross-traffic collisions, since bi-directional traffic would be physically separated. In this case, the worst impacts would occur during merging, when vehicles entering the main traffic stream collide with those on the main stream.

Assuming grade separation, reasonable travel speeds could be encouraged due to the low risk of impacts between opposing directions of traffic. If merging traffic was then encouraged to build up its speed to match free flowing traffic, then a worst-case impact speed matching that of free-flowing traffic could be expected. For the purpose of this study, a free-flowing speed and hence impacting speed of 70 km/h for both vehicles was assumed, and a worst-potential impact angle of 150° was assumed (i.e. an impact during merging, Figure 2).

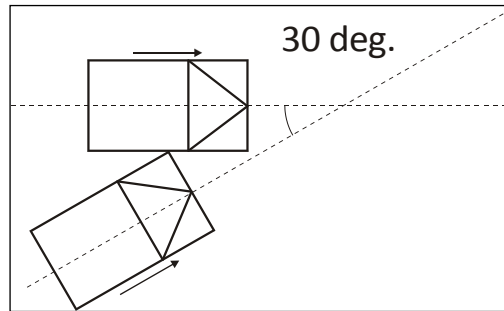


Figure 2: A graphic of what is described as a 150° impact between two vehicles.

Default reduced speed, 50 km/h

It was assumed that speed limits would be reduced at the problematic sites and these lower limits would be adequately enforced, and adhered to by the driving population. For this calculation, it was assumed that speeds would be 50 km/h at the intersection, with no change in impact angle to the current situation.

4.5 Results and Discussion

A results table showing the probability of a fatality and serious injury for the worst conflicts occurring at each of the identified problematic sites is provided. The probabilities are given assuming that the vehicles impact each other at the currently posted speeds and, as a second scenario, assuming that the impacts occur at travel speeds which are understood to be reasonably commonplace within the CRISP municipalities (i.e. at 15 km/h above the posted speed limits). The probability of a fatality and serious injury occurring at each intersection is also calculated assuming that each of the sites is replaced by an innovative intersection design. For each calculation, it was assumed that two vehicles collide at an impact angle that represents the highest risk to severe injury.

Results show that of the poorly performing intersections, the safest intersection is 107 Avenue NW and 142 Street NW, Edmonton. This is not surprising given the intersection is a traffic circle, which promotes both lower entry speeds and safer impact angles. Collision statistics show that there have been only three major injuries at the site (2006-2010), compared to at least nine major injuries at each of the other sites identified as problematic within Edmonton. The most dangerous intersection in Edmonton, according to the KEMM-X assessment, appears to be 34 Avenue NW and 91 Street NW (Edmonton) where the probability of a fatality and serious injury occurring in the event of an impact could be as high as 0.47 and 0.72, respectively, significantly greater than the reference threshold. This is supported by the collision data which show there have been 88 injuries at the site, with nine of these being major injuries. The collision statistics also indicate that 129 Avenue NW and 50 Street NW is one of the most poorly-performing sites given there has been 23 injuries in total, of which nine were serious and one was a fatality. This site had a probability of fatality of 0.23 and probability of serious injury of 0.48. Surprisingly, this site also experiences lower volumes during the day (19,814 average daily traffic) compared to the other sites within Edmonton.

Due to the similarity in posted speeds on roads which comprise the identified Strathcona intersections, and all being typical cross-intersections, probabilities of a fatality and serious injury, given a collision, are similar across the sites (0.5 and 0.7 respectively). That is, should a collision occur at any one of the identified intersections within Strathcona County, there is a 50% probability of a fatality and a 70% probability of a serious injury occurring. According to the Safe System philosophy, the Pr(F) and Pf(SI) at the sites, compared to the reference impact of 50/50/90, is almost 5.0 and 2.3 times greater, respectively, than should be tolerated.

Despite all intersections within Strathcona County having a similar Pr(F) and Pr(SI) ratings, the collision statistics, indicate that the incidence of collisions amongst the five intersections within the county vary greatly. While Baseline Road & Broadmoor Blvd had the largest number of injuries (113 in total), only one serious injury was noted at the site. Conversely, six major injuries (and 80 minor injuries) were noted at Wye Road & Sherwood Drive. The other identified intersections, despite having similar probabilities of serious injuries and fatalities, had two major injuries at most (per site). Again, it is likely that factors, such as traffic volume, signal phasing and sight distances contribute towards the incidence of collisions. A more detailed study would be needed to gain a better understanding of the explanatory factors, especially traffic volume.

The identified intersections in St. Albert (excluding Belrose Drive and Inglewood Drive) show a 23% likelihood of a fatality and a 49% likelihood of serious injury for the worst conflict due to the high speeds and 90° impact angles that characterise these sites. The total number of collisions vary from four to thirteen over the period analysed. While the number of serious injury causing collisions cannot be identified (due to limitations in the data), it can be assumed that collisions which occur at these sites have high injury risk due to the prevalence of high speeds.

The fatality and serious injury risks are further increased at the common travel speeds. Probabilities of death and serious injury at the tolerated speeds can be double what they are at the posted speed limits. The probability of a fatality and serious injury occurring at the intersections within Strathcona County at the commonly observed speeds, for example, is 100%. That is, should two cars, both exceeding the posted speed limit by 15 km/h collide at a 90° angle, the estimated probability of death to an average vehicle occupant is almost 1.0. The toleration of the commonly observed speeds should be given serious consideration, given the increased likelihood of a fatality should an impact at these speeds occur.

All intersections were also hypothetically replaced by innovative intersection designs. Conclusions on the most appropriate innovative intersection and safest for each site, however, cannot be drawn from this work so far, as there are a number of variables that need to be considered when modifying an existing intersection. At this stage, several assumptions have been made to perform the risk calculations. The exact dimensions of a roundabout, for example, or the speed profile of platforms, will influence the injury risks of collisions greatly, depending on the impact angles and speeds experienced. Similarly, while the cut-through signal design can potentially be designed to achieve a highly favourable impact angle and speed reductions, this was not assumed to be the case. Instead, working in general with a 'worst-case' scenario, probabilities of fatalities and serious injuries are provided. The results presented in this report should be reviewed and potentially revised, once the designs are finalised. Charts demonstrating the probability of a fatality or serious injury occurring at the intersection identified as 'poorly performing' (within the three jurisdictions), in their current operating conditions, and when hypothetically replaced by the innovative intersection designs, are presented in Appendix 3.

Interestingly, of the identified 'better-performing' intersections, only two sites (42 Avenue NW and 106 Street NW, Edmonton, and Grange Dr and Gervais Rd, St. Albert) fall within the Safe System definition of a safe intersection ($\text{Pr(F)} \leq 0.1$, $\text{Pr(SI)} \leq 0.31$). Other intersections, despite having a low number of recorded injurious collisions at the sites, accommodate potentially dangerous impacts. Baseline Road and Sherwood Drive, and, Wye Road and Brentwood Blvd in Strathcona County in particular appear high risk, since calculations using KEMM-X show that a collision at the sites would present a probability of fatality and probability of serious injury that is 4.7 and 2.3 times greater than the reference threshold. While low traffic volumes as well as some compatible speeds between traffic from intersecting roads, could be partially responsible for the reduced incidence of collisions observed at these sites, more effort into enforcing lower speeds will substantially reduce the risks of death and serious injury.

4.6 Conclusion

In summary, this work shows that the currently observed speeds within the three jurisdictions will lead to intersection conflicts with significantly higher risks of death and serious injury for vehicle occupants than those that occur at the posted speed limit. Consideration should be given to reducing potential impact speeds by lowering the posted speed limits and/or achieving much better levels of compliance with speed limits. Further, in line with Safe System philosophies, the intersections could be made more forgiving of human error by accommodating more favourable impact angles, potentially through the introduction of innovative intersection designs.

Roundabouts are a well-established form of intersection control, capable of handling efficiently a wide range of traffic volumes and flow distributions. Priority should be given to this form of control, including the possible use of full or part-time traffic signals, in all or selected approaches, if needed to overcome operational challenges. Other designs which moderate travel speeds, preferably to 50 km/h or below, eliminate turn-across traffic collisions, and/or create less threatening angles at impact are also to be favoured.

5.0 References

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Appendix 1

Introduction

This section highlights the current safety problems with intersections within the Cities of Edmonton and St. Albert, and the County of Strathcona. It discusses the role of exposure (traffic volume) and a selection of design and operational factors that are believed to contribute to the incidence, severity or both, of a number of the highest priority collision types found across the three jurisdictions. It is concluded that while some of these factors can be addressed to reduce the levels of death and severe injury at intersections across the CRISP municipalities, there will remain a substantial problem involving high injury risk collisions, such as the right-angle/side-impact collision and the collisions involving left-turners across the path of approaching vehicles, especially at intersections controlled by traffic signals. To adequately address this residual risk of death and severe injury, new designs and new ways of operating the traffic system will be needed to achieve Safe System outcomes.

Casualty Collisions and Collision Rates

In order to attempt to explain the differences in casualty collision numbers observed at the intersections identified as performing well or poorly, collision numbers and collision rates for the identified intersections were plotted on one graph, using the data provided by CRISP (Figure 1). The collision rates show the number of casualty collisions per 100,000 vehicles entering each intersection (using traffic volume data 2006-2010). Collision numbers and collision rates were only calculated for the identified sites within the City of Edmonton and Strathcona County, given that casualty collision data were readily available only for the intersections within these jurisdictions (that is, these figures were not plotted for the City of St. Albert due to limitations in the data available).

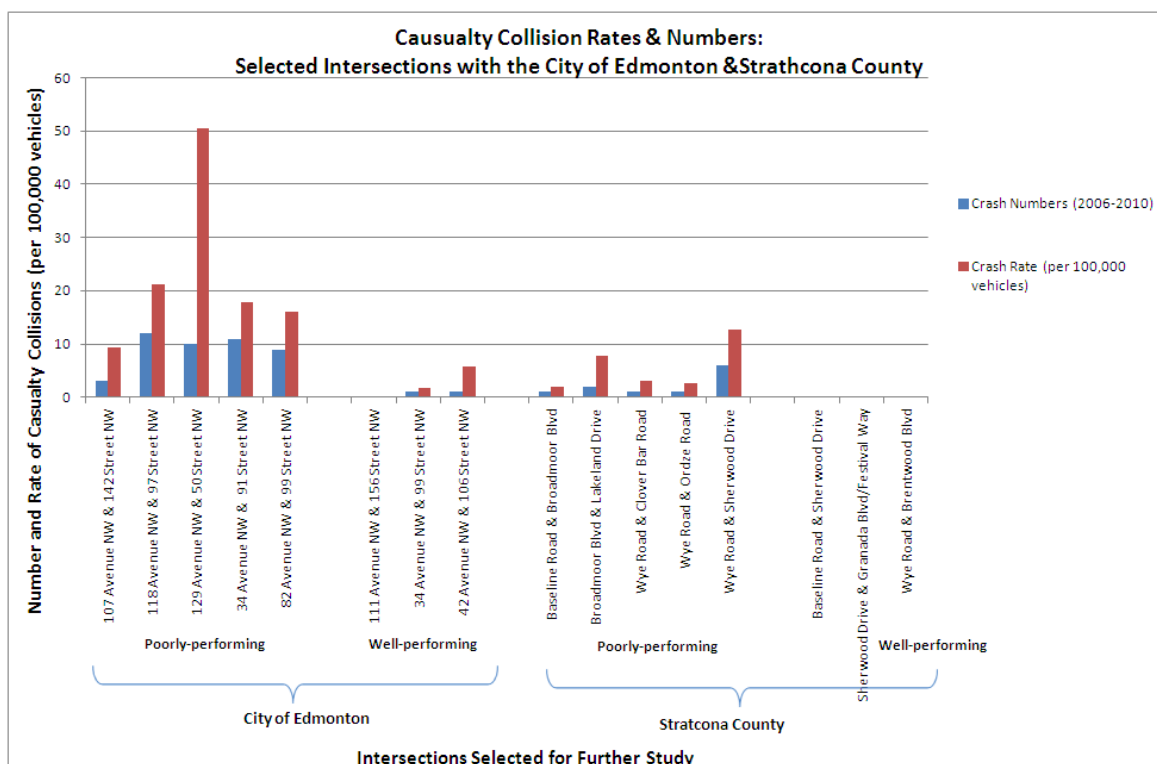


Figure 1: Casualty collisions within the City of Edmonton and Strathcona County (2006-2010)

The plot (Figure 1) shows that, for intersections that have performed poorly within both jurisdictions, the collision numbers are typically representative of traffic volumes. Therefore, excluding 129 Avenue NW and 50 Street NW in the City of Edmonton, collision rates at the poorly performing intersections within the City of Edmonton and Strathcona County are fairly comparable and indicative of the daily volume of vehicles entering the sites.

The collision rate calculated for 129 Avenue NW and 50 Street NW, however, is relatively high given it shows a collision rate greater than 50 injurious collisions per 100,000 vehicles entering. There were no serious or fatal injuries at the intersections classified as performing well within Strathcona County, and for this reason, no bars are showing in the chart where Strathcona County's 'well-performing' intersections are presented.

While there is a general upward trend in the relationship between traffic volume and the number of casualty crashes, there is evidence to suggest that even at high volumes, some intersections experience low crash numbers. Figure 2 shows crash frequency plotted against average daily traffic volume at the selected intersections within the City of Edmonton and Strathcona County respectively. Systematic investigation of these differences, beyond the effects of random variation, would be required to understand better, the possible influence of design and operational decisions on safety performance of specific intersections. While it is noted that the City of Edmonton and Strathcona County code crash types differently, the aggregation of data (in Figure 2) is unaffected by this, since data is based only on severity level (i.e. casualty crashes) and is independent of crash type.

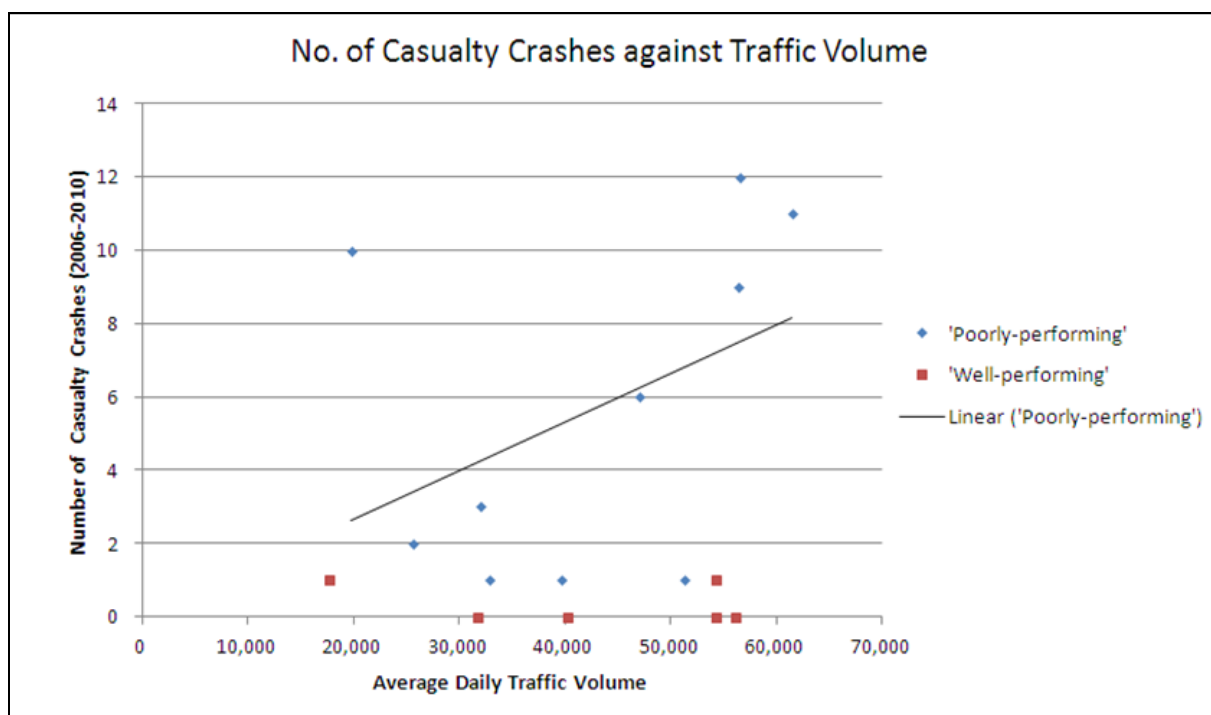


Figure 2: A plot of casualty crash frequency against average daily traffic volume at the selected intersections (City of Edmonton and Strathcona County).

Contributing Factors and Traditional Solutions

There are a number of factors which may explain the large differences in collision rate (Table 1).

Table 1: Factors which may contribute towards an increased collision frequency and severity

Issue	Opportunities to Address
<i>Speed limits</i> <ul style="list-style-type: none"> Commonly exceed Safe System speeds by 10-20 km/h and are rarely posted at 50 km/h or less 85th percentile speeds typically 15+ km/h above posted speed limit 	<ul style="list-style-type: none"> Install speed cameras Reduce speed limits Reduce enforcement tolerances
<i>LTA Conflicts</i> <ul style="list-style-type: none"> Failure to select safe gaps (a human trait) Protected-permissive largely ineffective as a countermeasure Protected-prohibited highly effective as a countermeasure but rarely used due to perceived detrimental impacts on operation Wide carriage ways and opposing left-turners make gap choice more difficult 	<ul style="list-style-type: none"> Use protected-prohibited turn phases or use alternative intersection designs which eliminate the need for the LTA manoeuvre
<i>Intersection geometry and delineation</i> <ul style="list-style-type: none"> Generally intersections are designed at 90° and the conflict area is expansive Delineation is of limited effect due to climate/snow clearing. Positioning of signal hardware could be improved / signals may be poorly visible in certain weather conditions Line markings may be misleading at certain sites Possible lane alignment issues, sight distance issues and worn surfaces 	<ul style="list-style-type: none"> Little scope to address without reducing capacity Improved delineation offers only minor safety gains Improved visibility of signals using LED displays but offers only minor safety gains Practical problems with maintaining line markings to a high standard Could be addressed with some realignment and resurfacing, but with only minor safety gains expected
<i>Traffic flow</i> Rising demand for additional road space to meet the on-going growth in traffic	<ul style="list-style-type: none"> Little scope to address without fundamental changes to the transport system.

Overall, the intersections that are performing well also have low collision rates, while the intersections that are performing poorly have higher collision rates; this suggests that the differences in safety outcomes are not adequately explained by traffic volumes alone.

The number of conflict points, travel speeds, impact angles and traffic volumes are similar across all intersections (except for the traffic circle in Edmonton). While factors such as those presented in Table 1 may be responsible for some of the differences observed in collision numbers at the different sites, a more detailed and analytical traffic-engineering analysis of the intersections may be required, in order to provide greater insight as to why certain intersections perform better than others, when variables such as speed, impact angle and volume are held constant. It is also

important to recognise that the differences in safety performance of the intersections analysed here may well be due, in some significant part, to the random variation that occurs in collision occurrence across traffic systems. When collision data are analysed in this way to identify poorly-performing locations, some locations will appear bad at a particular time, and others will be judged as good. With the passage of time, a comparable analysis may result in contradictory conclusions, simply due to the randomness that characterises collision occurrence, both in time and space. Pursuing this issue in greater depth is beyond the current project scope.

Towards Safe System Design and Operation

Ultimately, while addressing the factors listed in Table 1 may influence collision numbers and severities, any safety gains are likely to be modest (yet worthwhile) and may not prove to be lasting improvements in safety. It is the view of the authors that large and lasting road safety benefits will be achieved only by viewing traffic safety according to the principles of the Safe System (or indeed, the Swedish Vision Zero or the Dutch Sustainable Safety philosophies, upon which the Safe System is based). For this reason, this study has focused heavily on reviewing the road trauma problem within the three jurisdictions by applying the philosophy and principles that underpin the Safe System; in the case of intersection safety, this entails the reduction in the number of conflict points and the reduction in travel speeds within intersections, as well as designing for less severe impact angles for the most threatening collision configurations. Application of Safe System thinking encourages more ambitious changes either through the implementation of innovative intersection designs, or modification to existing sites. For further gains to be made on a large scale in the future, new approaches are needed to create a traffic environment that is forgiving of the types of common human errors characterising today's road-transport system.

Appendix 2

Images of intersection designs for which the probability of a fatality and serious injury have been calculated have been included below. For the calculations, the worst potential impact angle and speeds which the designs could accommodate were used, with all estimates being conservative.

Raised Platforms at Intersections

Raised platforms and accompanying speed reduction signs are countermeasures which encourage drivers to adhere to Safe System compliant intersection speeds.

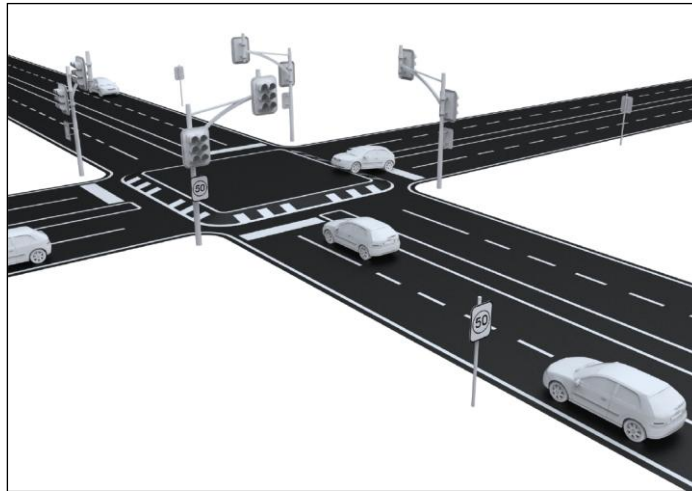


Figure 1. An image showing raised platforms at an intersection.
Image developed by Liam Ferguson and modified by Mike Mills, Faculty of Art and Design, Monash University, Sept. 2010.

Roundabout

A standard roundabout at the intersection of two roads prompts reductions in speeds and improves conflict angles due to the geometry which promotes horizontal deflection.

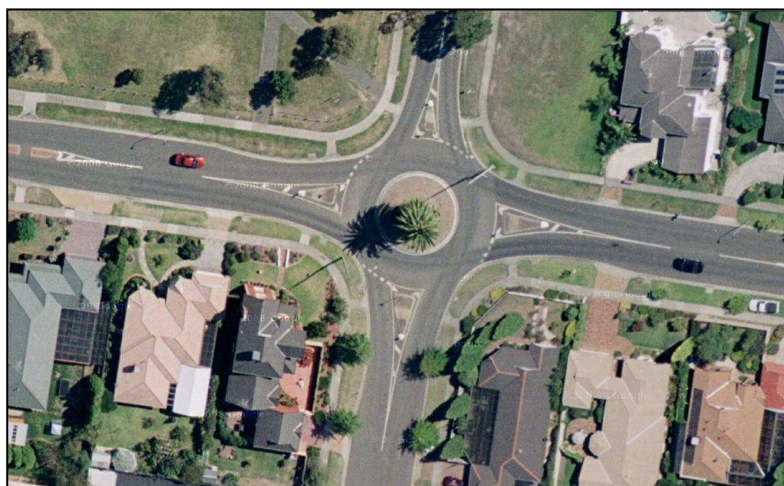


Figure 2. An aerial view of a typical roundabout at the intersection of two local side roads in suburban Melbourne
(Image obtained from Google Maps, 12th October, 2010)

Turbo Roundabouts

A turbo roundabout is characterised by having two lanes of traffic per direction, often separated by raised platforms to physically prevent traffic from changing lanes while traversing the roundabout. The design entry speeds are typically lower at a turbo roundabout compared to a traditional circular roundabout.



Figure 3. Image of a turbo roundabout in use in Europe

Cut-through Signalised Intersection

It is expected that the cut-through signalised intersection could be used as a treatment at arterial-arterial cross-roads. The cut-through lanes allow right turning traffic to proceed through the roundabout while through-traffic proceed with some deflection and at reduced speeds. It's anticipated that traffic signals would be used to control traffic through the intersection.



Figure 4. An image of a cut-through signalised intersection graphically inserted at a typical arterial-arterial intersection in Melbourne.

Image created by Mike Mills from Art and Design, Monash University. Sept 2010.

The Squirrel

At a Squirrel, the cut-through lanes will allow right turning traffic to proceed through the Squirrel while through-traffic can proceed with some deflection created by the presence of islands. The Squirrel is likely to be complimented by traffic signals to assist traffic flow.



Figure 5. An image of a Squirrel which has been graphically inserted at a typical arterial – arterial intersection in Melbourne.

Image generated by Mike Mills from Art and Design, Monash University, Sept 2010.

Grade-Separated Interchange

Grade-separated interchanges separate the two directions of traffic so that the possibility of head-on collisions is eliminated. Further, if designed appropriately, such as combined with a roundabout, grade-separated intersections can promote safer entry speeds and more favourable impact angles.

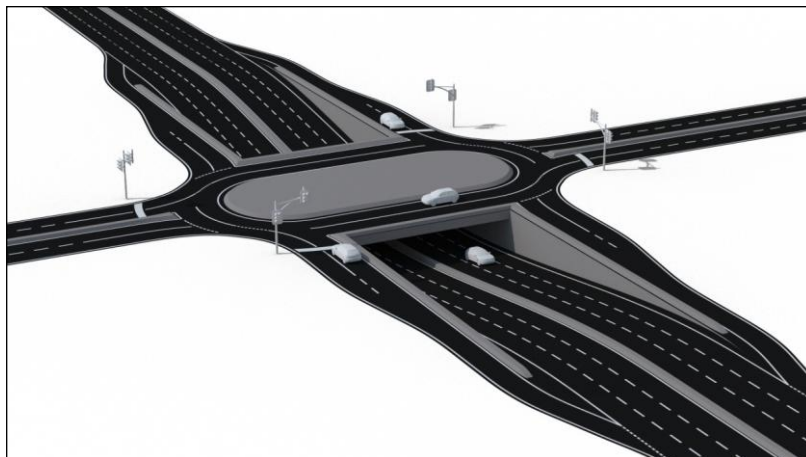


Figure 6. A schematic of a grade-separated roundabout.

Image generated by Mike Mills, Faculty of Art and Design, Monash University, Sept. 2010.

Reduced Default Speed Limit

An intersection with reduced default speed limits should be enforced using red-light speed cameras and prominent signs to inform drivers of the change in speed when traversing the intersection. For the purposes of study, a reduced default speed limit of 50 km/h was assumed.

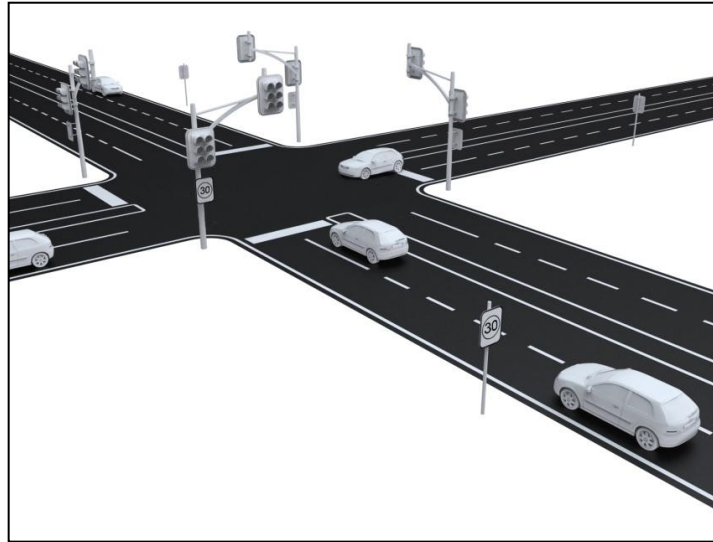


Figure 7. A schematic showing an intersection with approach speeds of 30km/h. Image developed by Liam Ferguson and modified by Mike Mills, Faculty of Art and Design, Monash University, Sept. 2010.

Appendix 3

Below, are a number of charts which demonstrate the probability of a fatal outcome at the intersections identified as ‘poorly performing’ within the three jurisdictions discussed. These are the probabilities of a fatal/serious injury outcome occurring, given a crash occurs, assuming that the intersections operate at the currently posted speeds (‘Current’), the tolerated speeds (typically 15 km/h above the posted, ‘Current + tolerance’) and assuming that the intersections are replaced by a number of hypothetical intersection configurations.

City of Edmonton

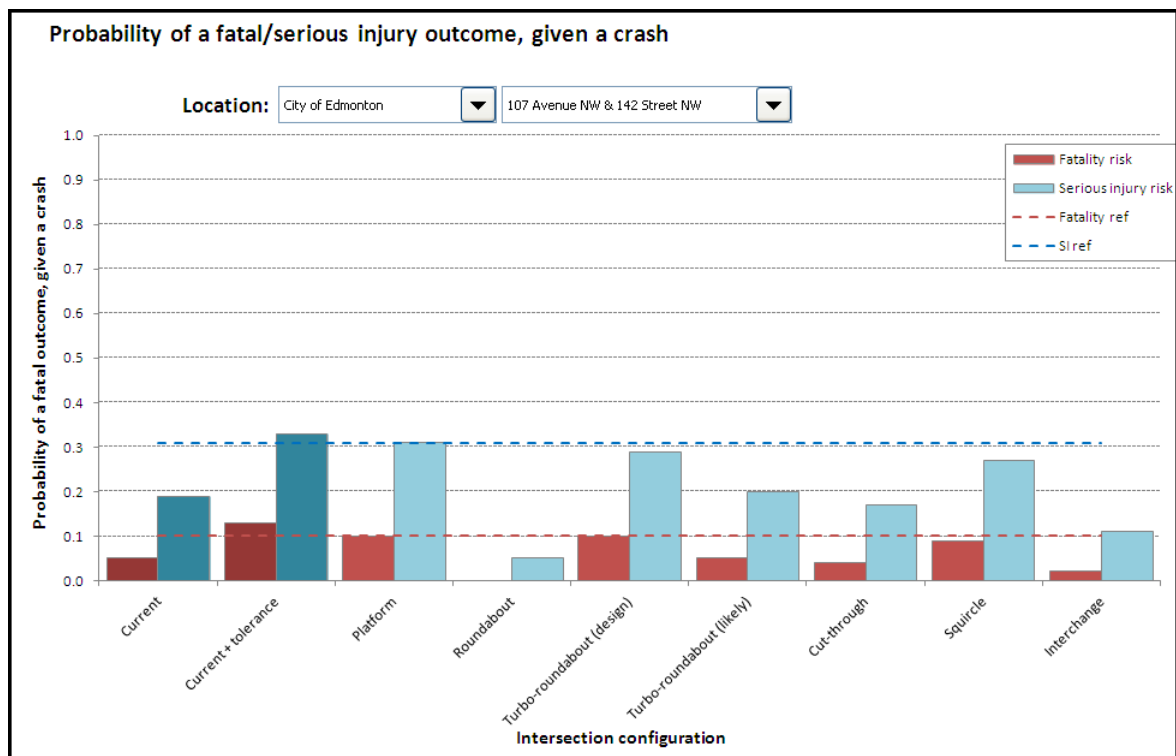


Chart 1: Intersection of 107 Avenue NW (60 km/h) and 142 Street NW (60 km/h)

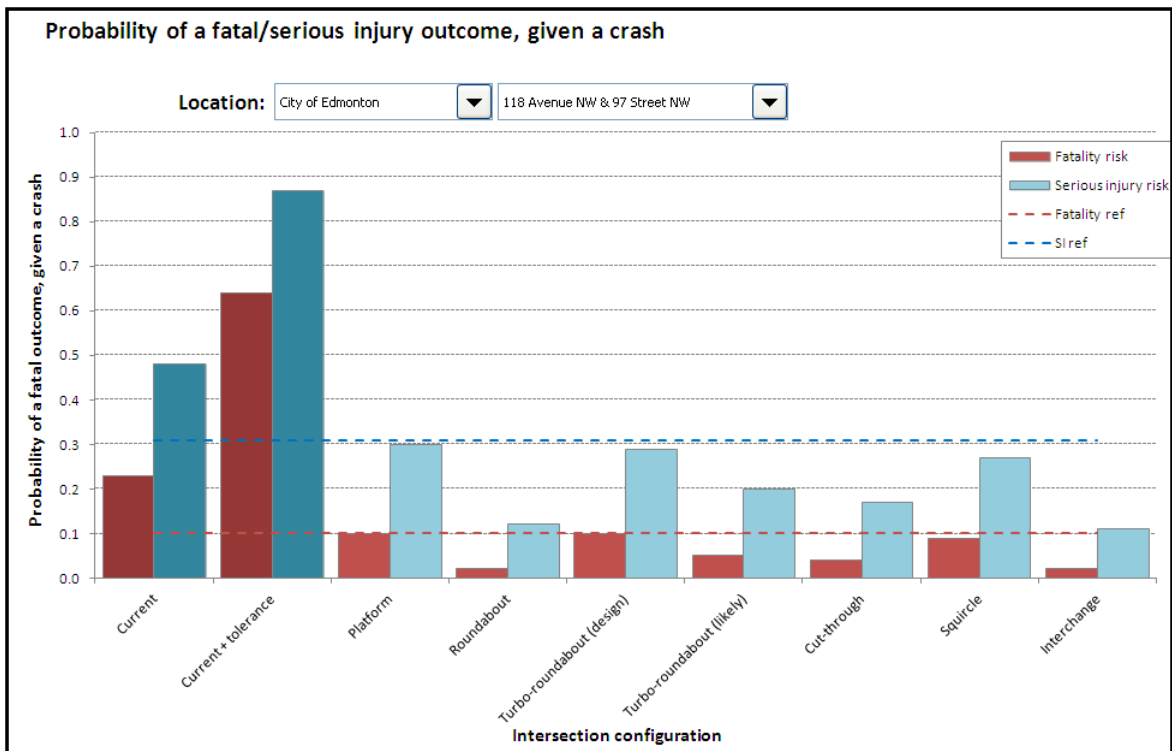


Chart 2: Intersection of 118 Avenue NW (50 km/h) and 97 Street NW (60 km/h)

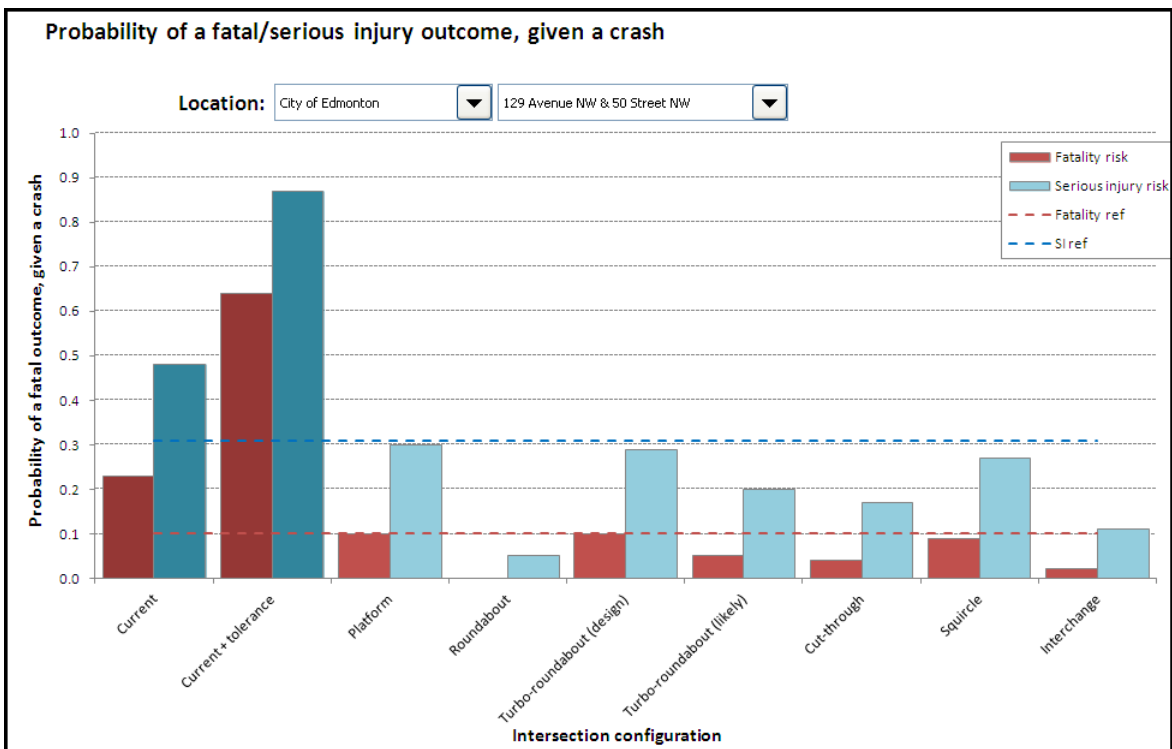


Chart 3: Intersection of 129 Avenue NW (50 km/h) and 50 Street NW (60 km/h)

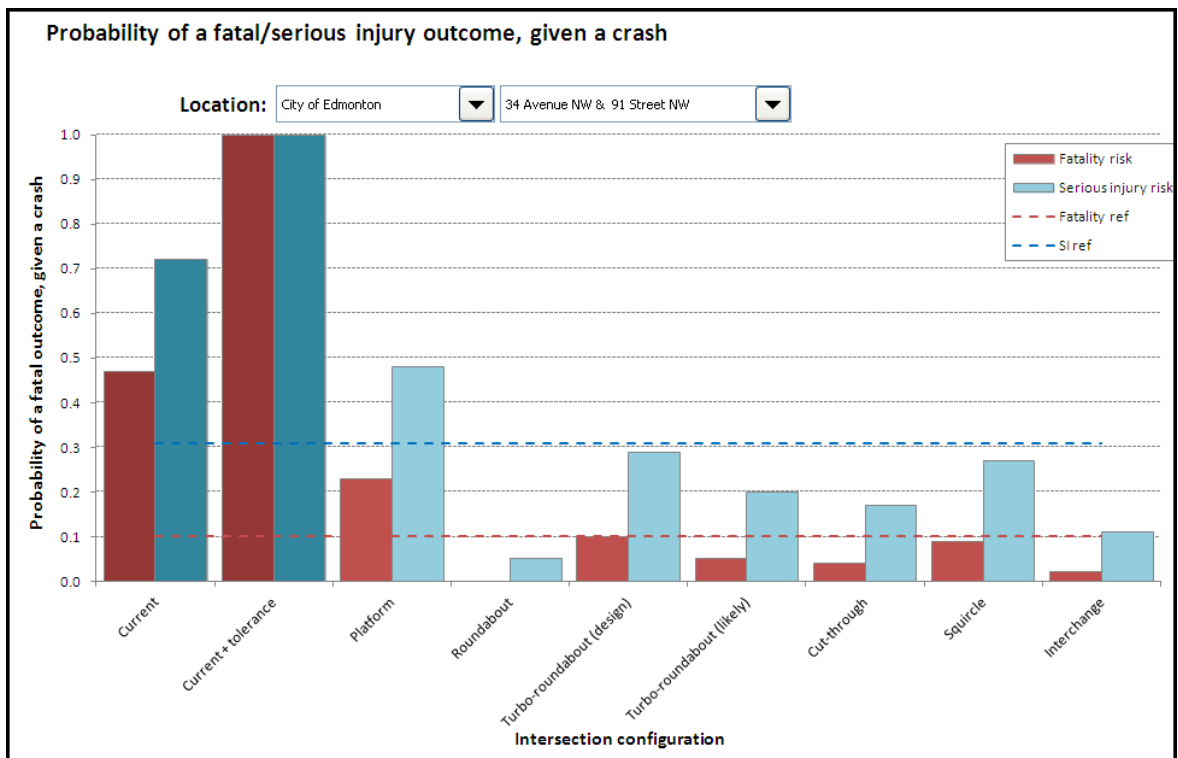


Chart 4: Intersection of 34 Avenue NW (60 km/h) and 91 Street NW (70 km/h)

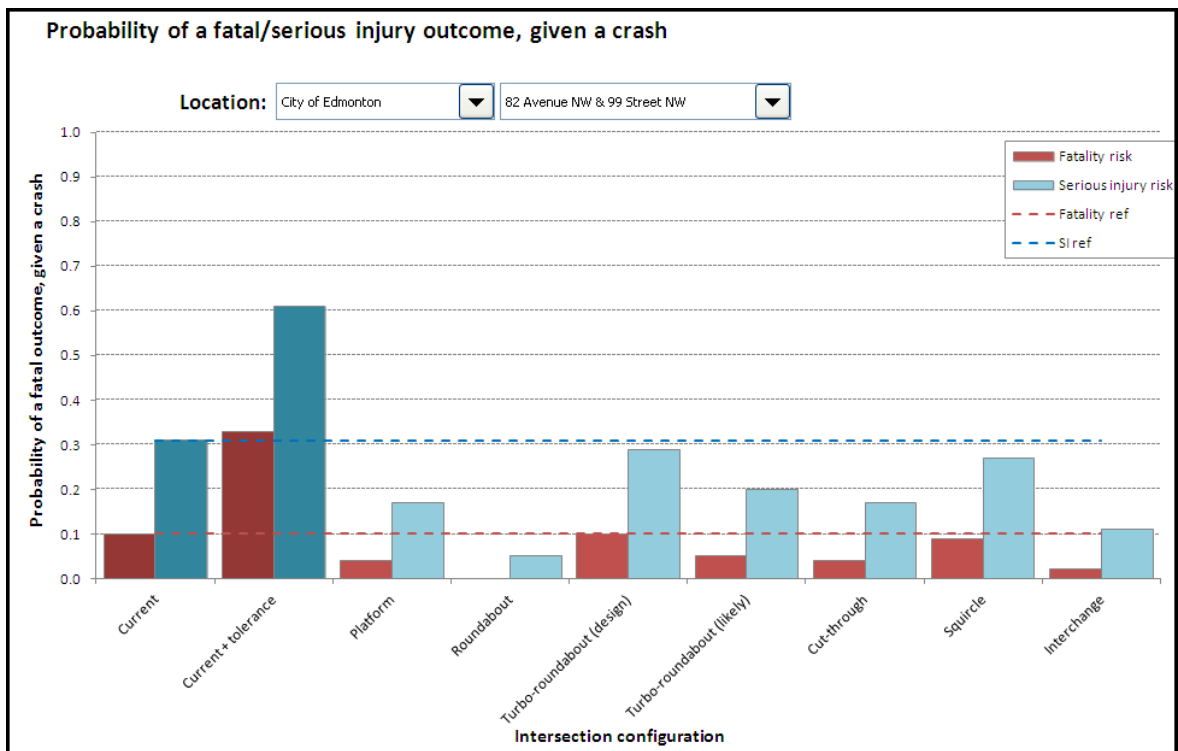


Chart 5: Intersection of 82 Avenue NW (50 km/h) and 99 Street NW (50 km/h)

Strathcona County

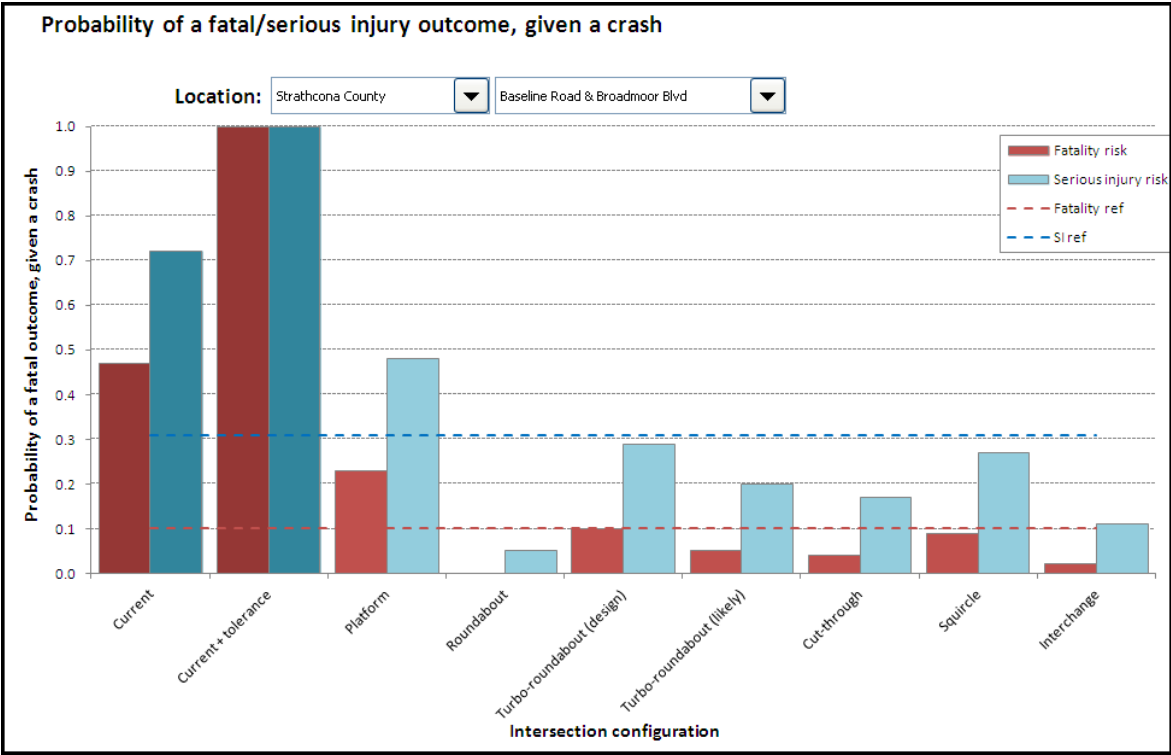


Chart 6: Intersection of Baseline Road (70 km/h) and Broadmoor Blvd (60 km/h)

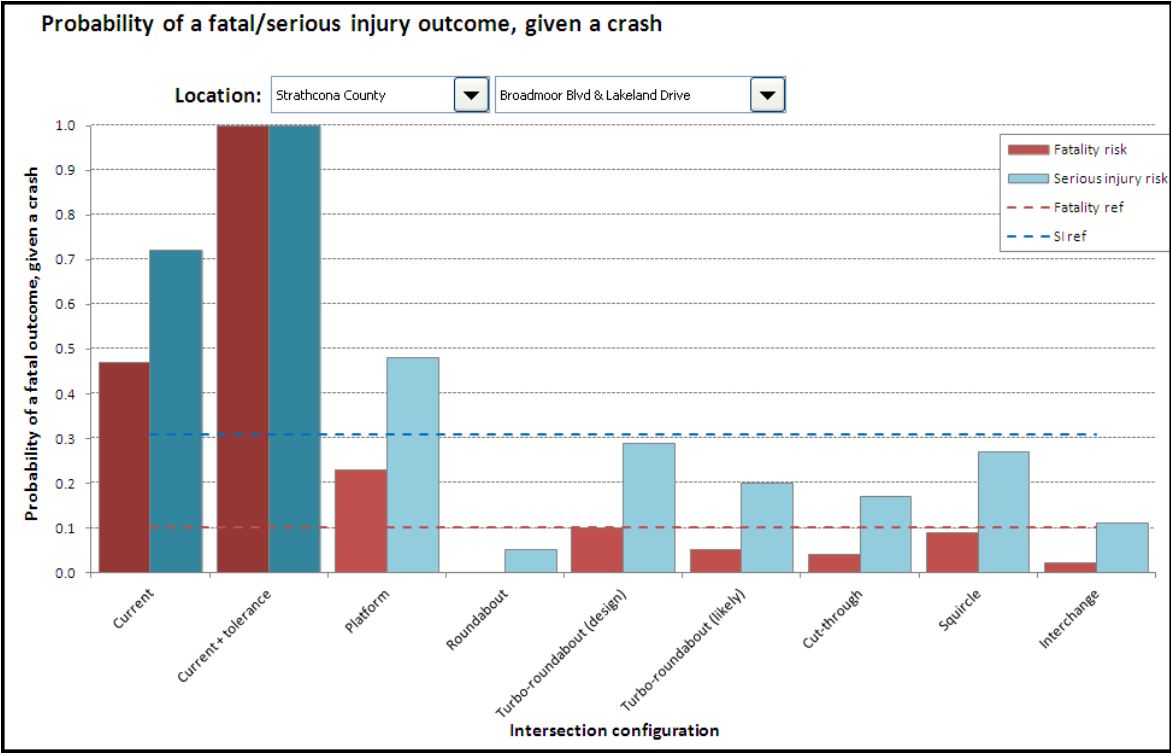


Chart 7: Intersection of Broadmoor Blvd (70 km/h) and Lakeland Drive (60 km/h)

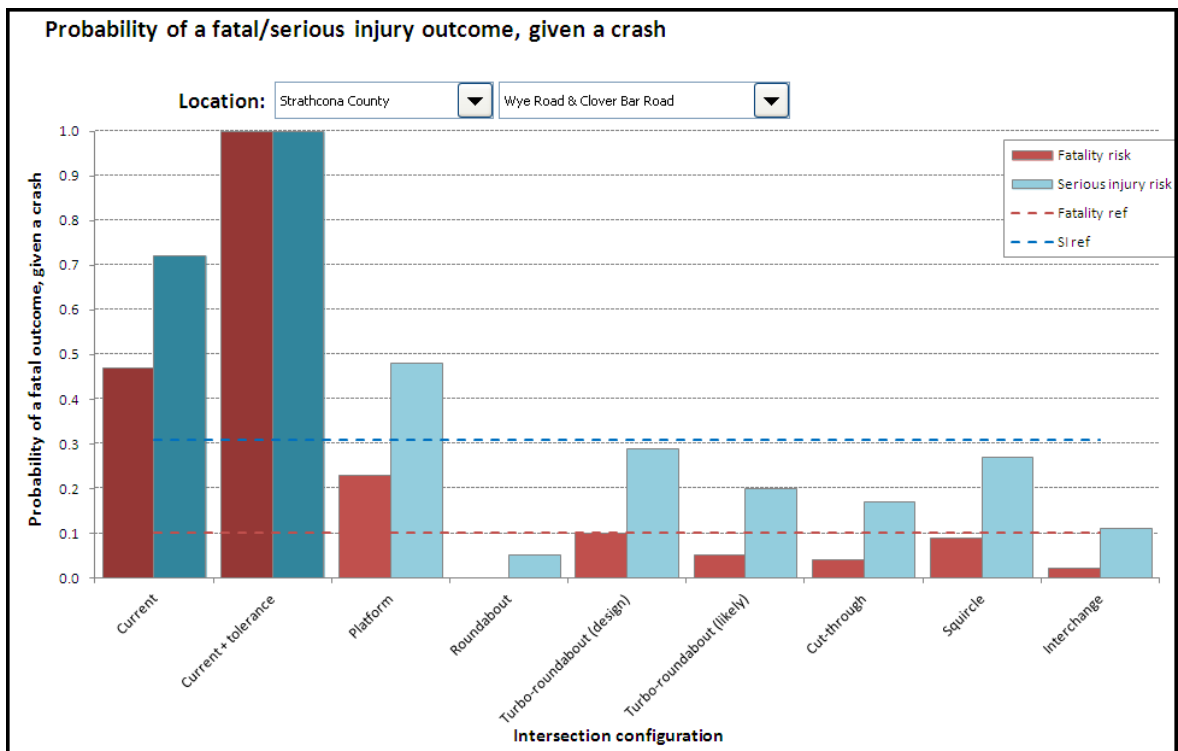


Chart 8: Intersection of Wye Road (70 km/h) and Clover Bar Road (60 km/h)

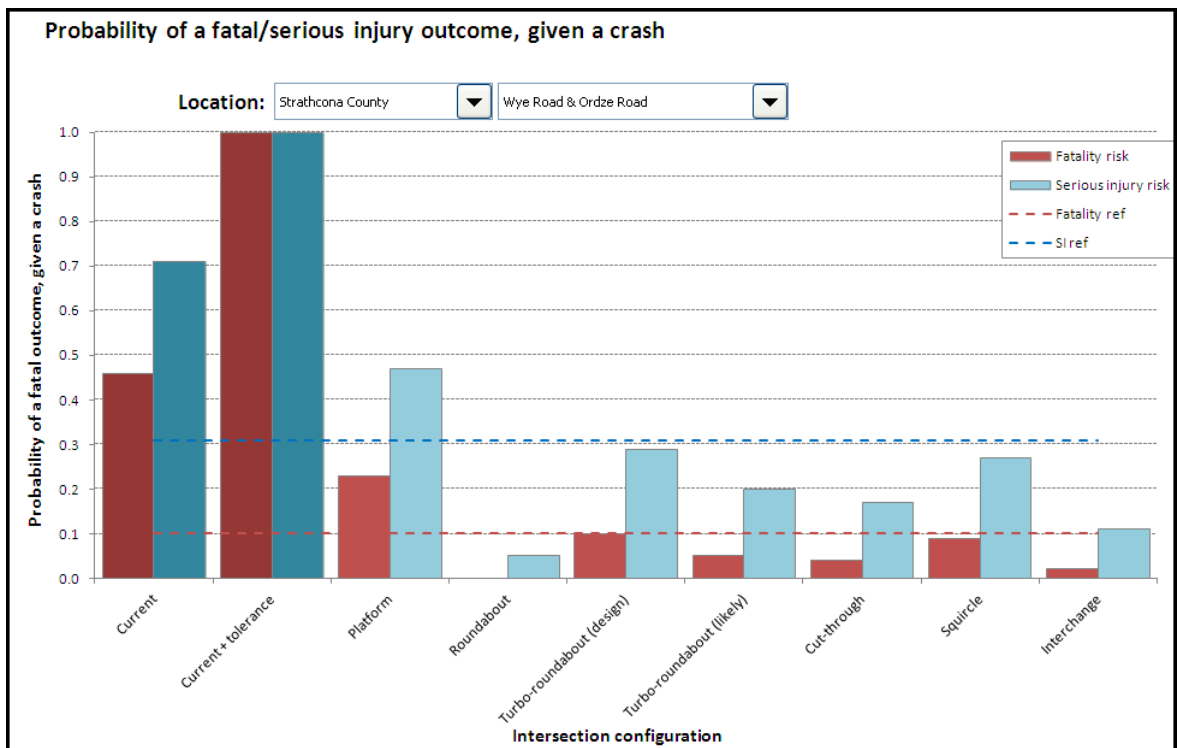


Chart 9: Intersection of Wye Road (70 km/h) and Ordze Road (50 km/h)

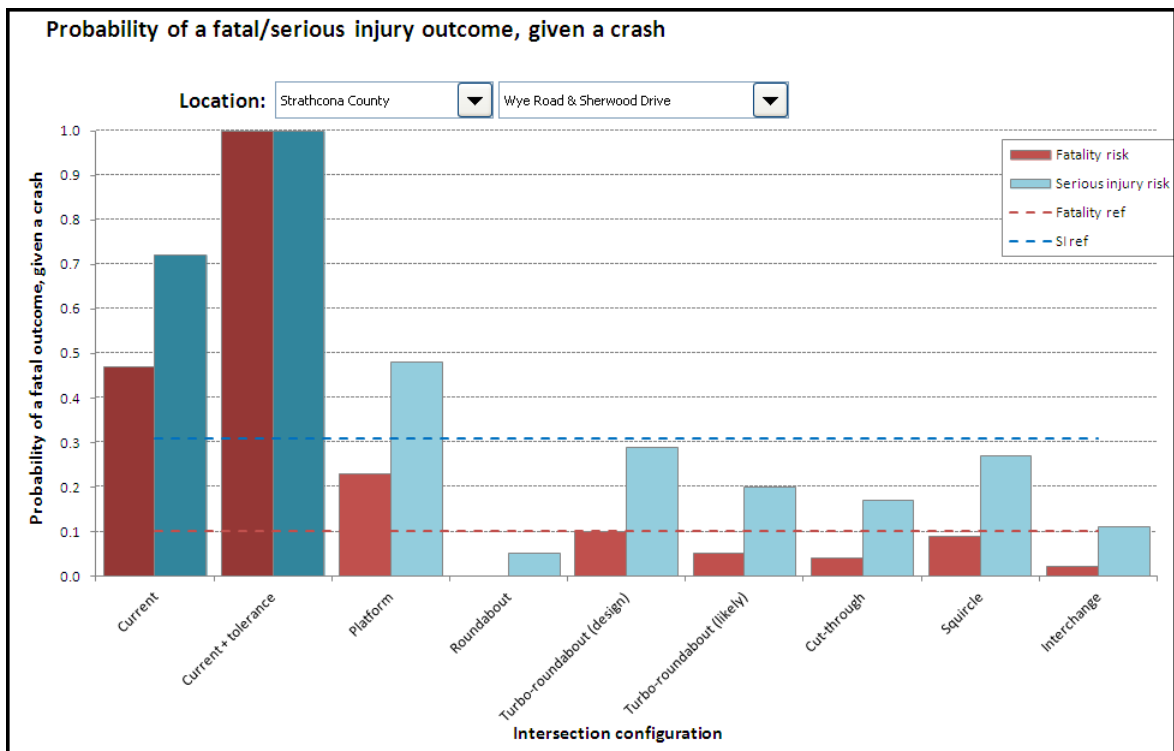


Chart 10: Intersection of Wye Road (70 km/h) Sherwood Drive (60 km/h)

City of St. Albert

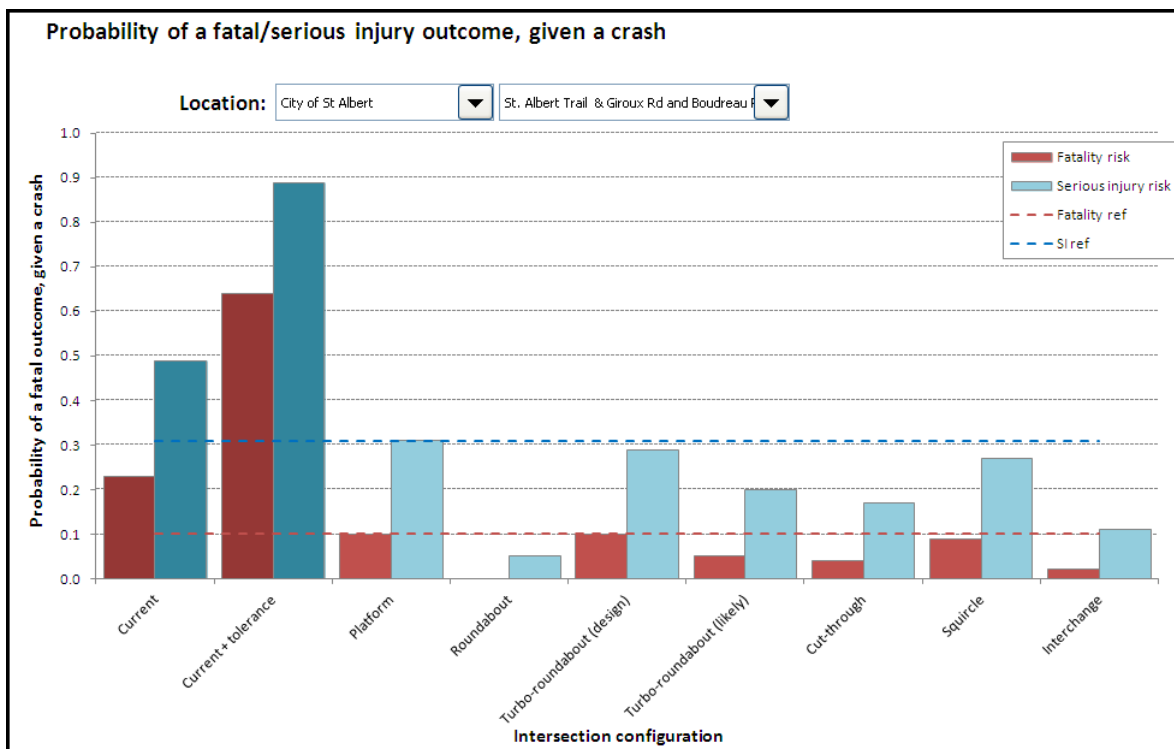


Chart 11: Intersection of St. Albert Trail (60 km/h) and Giroux Rd and Boudreau Rd (60 km/h)

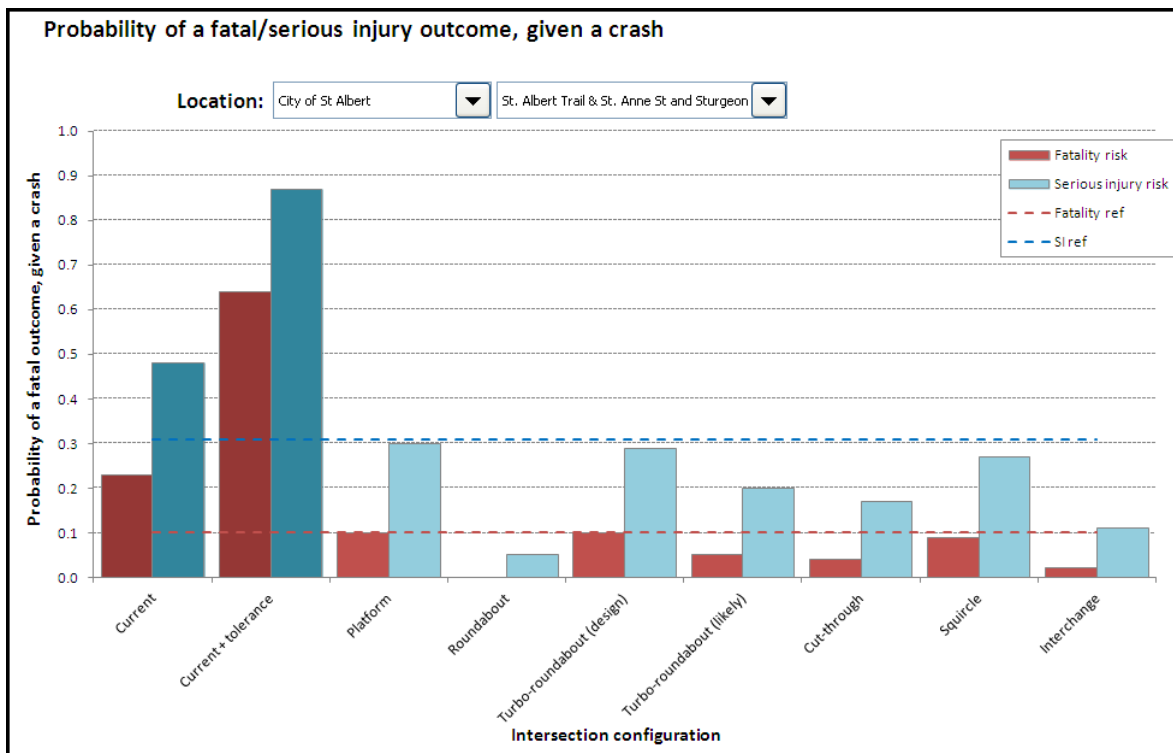


Chart 12: Intersection of St. Albert Trail (60 km/h) and St. Anne St and Sturgeon Rd (50 km/h)

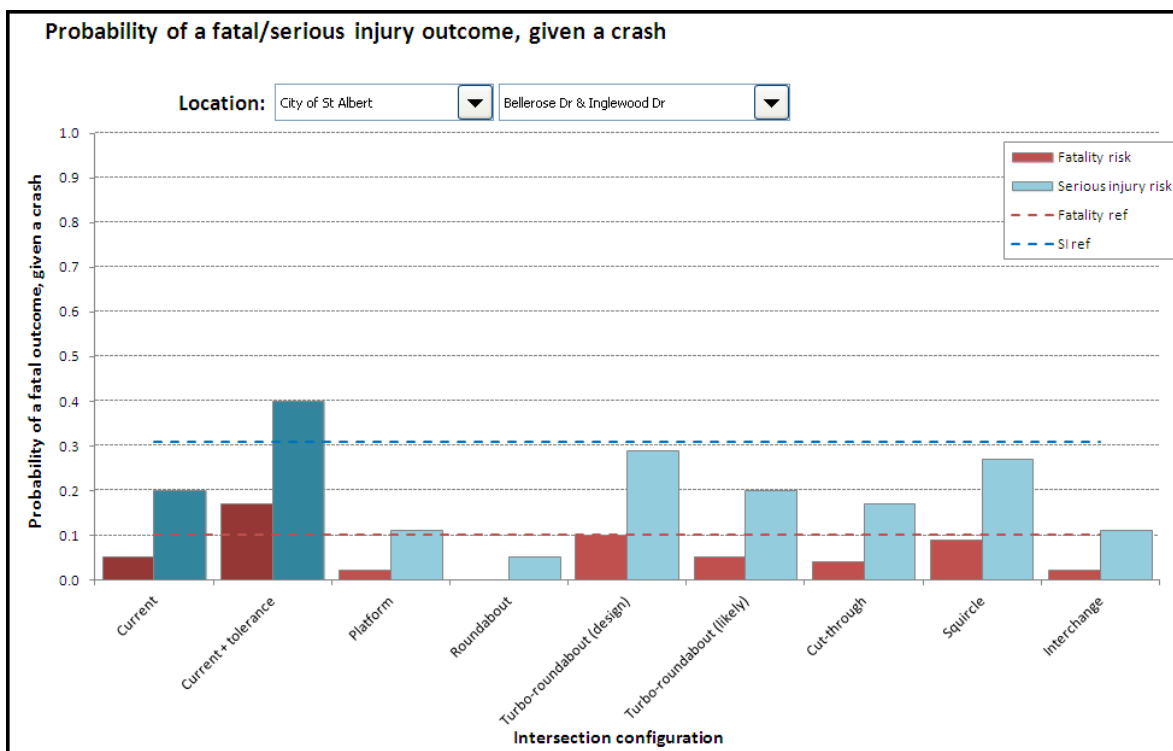


Chart 13: Intersection of Bellerose Dr (50 km/h) and Inglewood Dr (50 km/h)

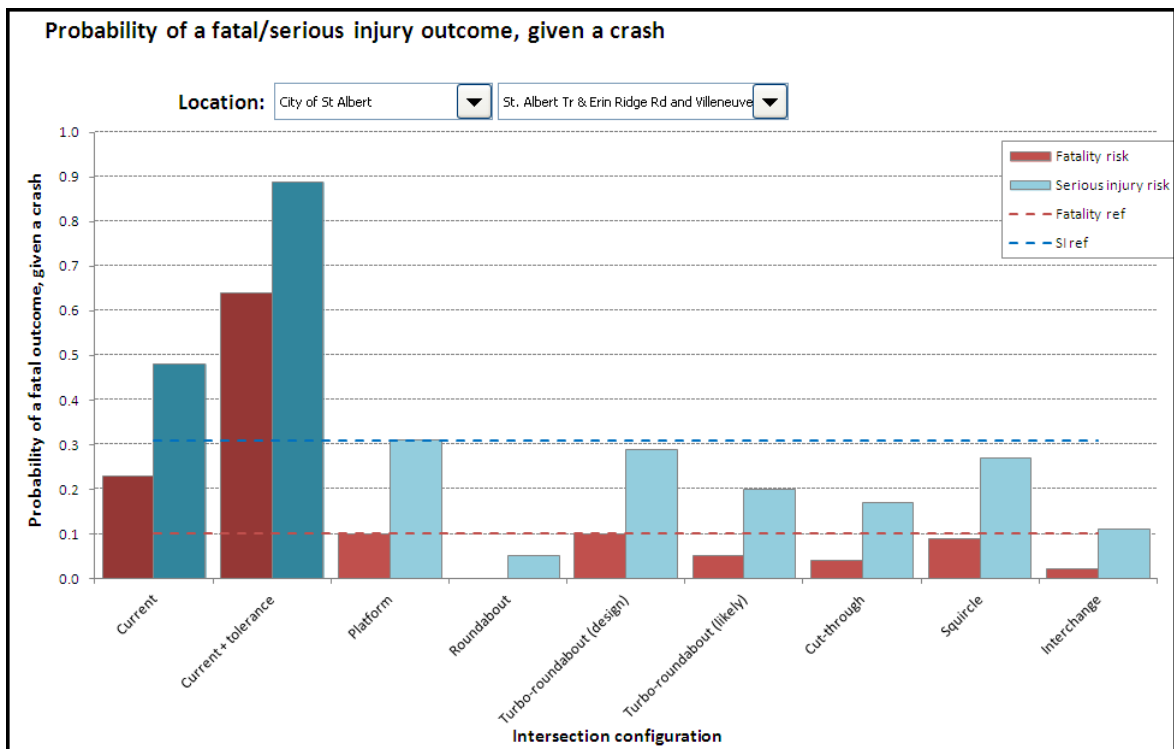


Chart 14: Intersection of St. Albert Tr (60 km/h) and Erin Ridge Rd (50 km/h) and Villeneuve Rd (60 km/h)

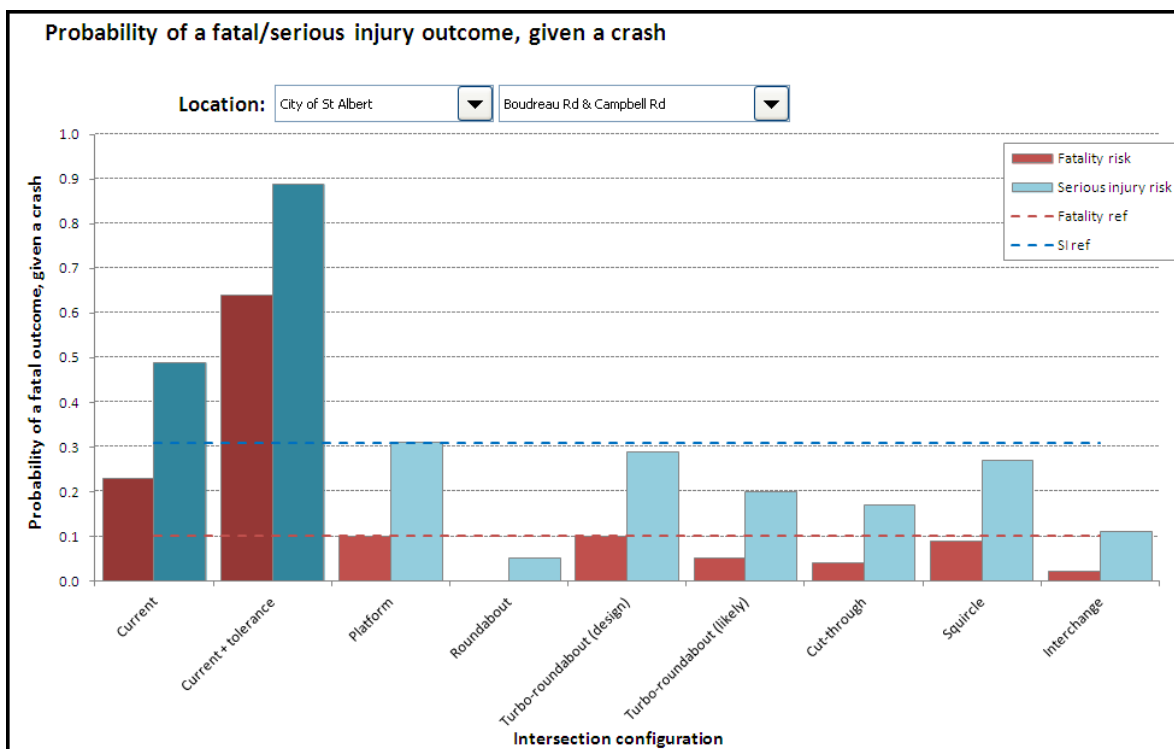


Chart 15: Intersection of Boudreau Rd (60 km/h) and Campbell Rd (60 km/h)