Putting the Connectivity in C-ITS – Investigating pathways to accelerate the uptake of road safety and efficiency technologies

Victoria Road Safety Data Analysis

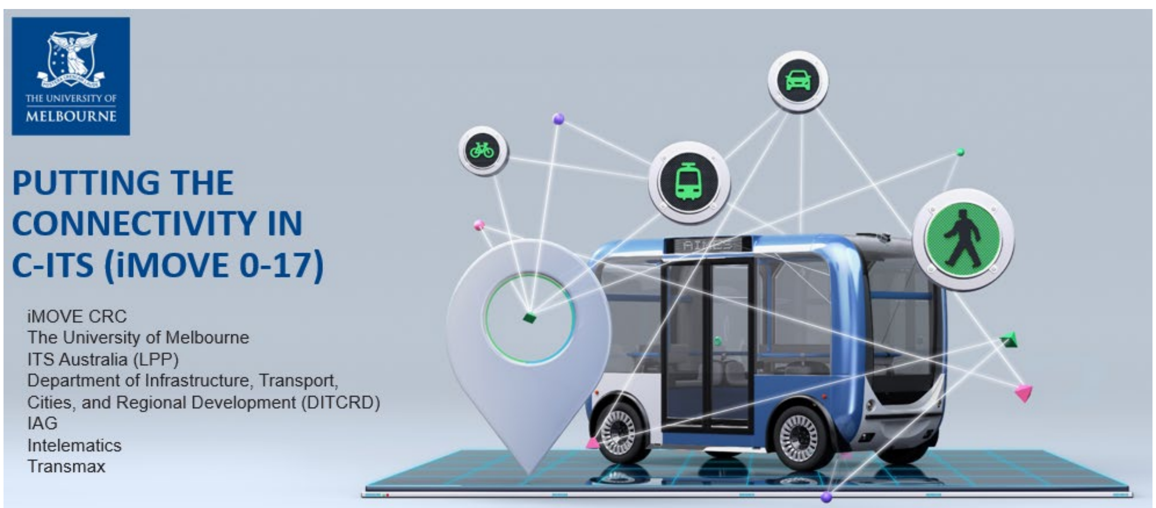
University of Melbourne

Neema Nassir, Jessica Tong, Patricia Lavieri

Majid Sarvi, Peter Sweatman

ITS Australia

Stacey Ryan, Susan Harris



October 2020

The University of Melbourne

Acknowledgements

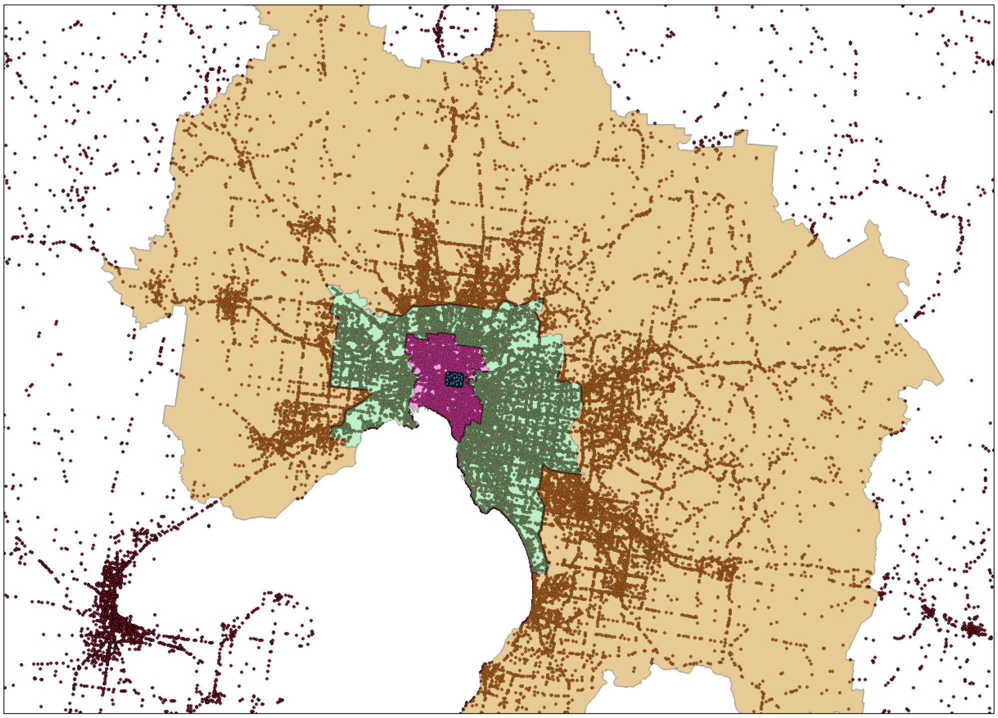
ITS Australia led this project with research partner The University of Melbourne through iMOVE to better understand how connectivity and intelligent transport systems can improve safety and productivity outcomes for our communities and networks. We would like to thank our project partners and participants:

- The Department of Infrastructure, Transport, Regional Development and Communications
- IAG
- Intelematics
- Transmax

This research is funded by iMOVE CRC and supported by the Cooperative Research Centres program, an Australian Commonwealth Government initiative.

Victorian Road Safety Data Analysis

In order to gain a quantitative understanding of the potential safety benefits of the C-ITS communication technologies in the Australian context, we conducted a comprehensive data analysis with the crash record open database from the Victorian Department of Transport. The crash dataset used in this analysis includes information from all crashes in the state of Victoria, from January 2006 to August 2019, where at least one person was injured. This dataset includes detailed information for every crash event, including crash type and location, crash severity, roadway geometry and type, traffic control devices, lighting and atmospheric conditions, etc., as well as basic information about vehicles and road users involved in the crash event.



Locations of Road Crashes in Victoria

In Section 1 of this report, we present an overview of basic statistics of crash occurrence in the state of Victoria, including statistics on crash severity by different crash types, modes and regions. In Section 2, we summarise a set of dominant C-ITS communication technologies that are widely trialled for crash reduction objectives, both nationally and internationally. We also identify the addressable market for each use case to understand the scale of potential impacts associated with each use case of the technology. In Section 3 we provide insights that are derived from the addressable market and provide a summary of the expected benefits which the use cases considered have in relation to geographics, vehicles involved, and the C-ITS deployment timeline.

Contents

1 Overview of Crashes in Victoria 4
1.1 Crash Type Categories 4
1.2 Geographic Region, Speed Zone, and Lighting Conditions 5
1.3 Vehicle Types 7
2 C-ITS Applications 8
2.1 European Roadmap to Deployment 8
2.2 Use Cases and Implementation Scenarios 9
2.3 Road Crashes Addressed by Use Cases 11
3 Conclusions and Recommendations 14
Appendix A: VicRoads Crash Classifications 17
Appendix B: Victorian Road Safety Data Summary 19

1 Overview of Crashes in Victoria

This section presents overall summary statistics associated with dominant crash types in Victoria and essential information related to crash severity, environment, and vehicular modes involved.

1.1 Crash Type Categories

VicRoads has identified 10 crash type categories that represent the majority of fatal and serious injury crashes. These categories represent a high-level classification but also include detailed level sub-categories based on the standard DCA coding (definition for classifying accident) presented in Appendix A: VicRoads Crash Classifications.

- Pedestrian (DCA 100-109)
- Cross traffic (DCA 110)
- Right turn near (DCA 113)
- Head on - not overtaking (DCA 120)
- Right turn against (121)
- Rear end (DCA 130-132)
- Head on - overtaking (DCA 150-159)
- Off path on straight (DCA 170-179)
- Off path on curve (DCA 180-184)
- Other

Table 1.1 shows the number of fatal crashes (where at least one person died), serious injury crashes (where at least one person sent to hospital, possibly admitted) and other injury crashes, associated with each crash type category. Out of the total 186,546 crashes, 3,528 were fatal, 64,904 lead to serious injuries and another 118,114 crashes lead to other injuries.

Table 1.1 Crash Types by classification and severity of injury (Victoria, 2006-2019)

Crash Type	Fatal	Serious Injury	Other Injury	Total
Cross traffic	161	4,042	8,631	*12,834*
Head on - not overtaking	518	2,980	2,583	*6,081*
Head on - overtaking	101	820	1,115	*2,036*
Off path on curve	532	5,930	6,961	*13,423*
Off path on straight	927	15,357	18,660	*34,944*
Pedestrian	554	7,454	9,821	*17,829*
Rear end	151	7,615	27,107	*34,873*
Right turn against	128	5,609	10,487	*16,224*
Right turn near	105	3,020	5,648	*8,773*
Other	351	12,077	27,101	*39,529*
Total	**3,528**	**64,904**	**118,114**	**186,546**

The crash type "Off path on straight" which is associated with 10 crash definitions (DCA 170-179) is the most numerous fatal crash type in Victoria, followed by crashes with "Pedestrian (DCA 100-109)", "Off path on curve (DCA 180-184)" and "Head on - not overtaking (DCA 120)".

1.2 Geographic Region, Speed Zone, and Lighting Conditions

Figure 1.1 depicts major fatal crash types and their geographical distribution in the state. "Pedestrian" fatal crashes occur most dominantly in the Melbourne metropolitan area, while the other three most common fatal crash types ("Off path on straight", "Off path on curve" and "Head on - not overtaking") are more numerous in rural and remote regions.

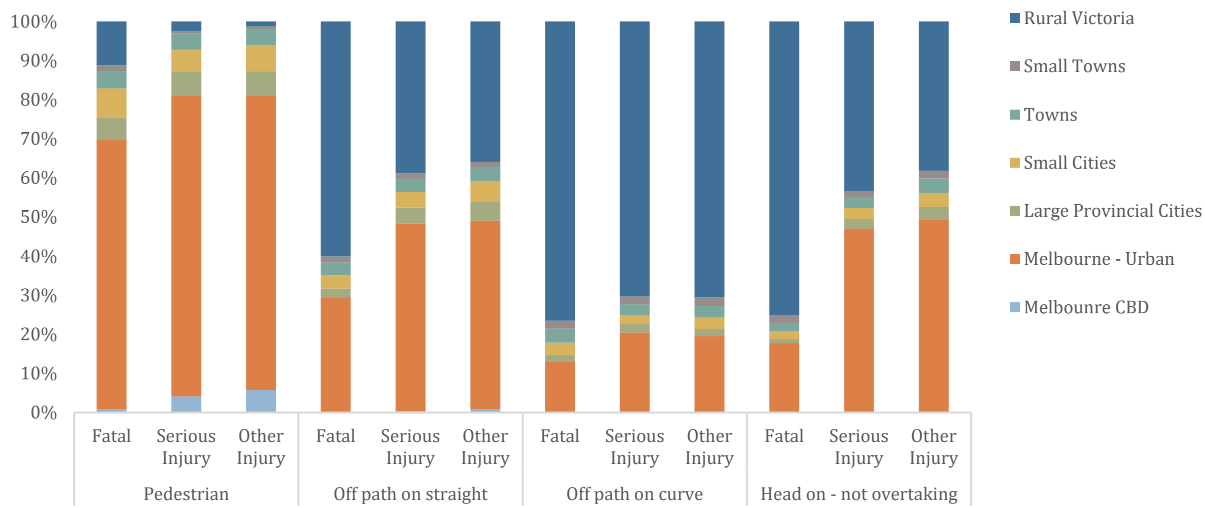


Figure 1.1 Proportion of crashes by severity, geographic region, and classification

"Head on - overtaking (DCA 150-159)" is not as frequent as the other categories, however, these crashes have a higher fatality rate than average (5% vs 2%). These crashes are also more common in rural and remote regions (Figure 1.2) and more frequent in higher speed zones (Figure 1.3).

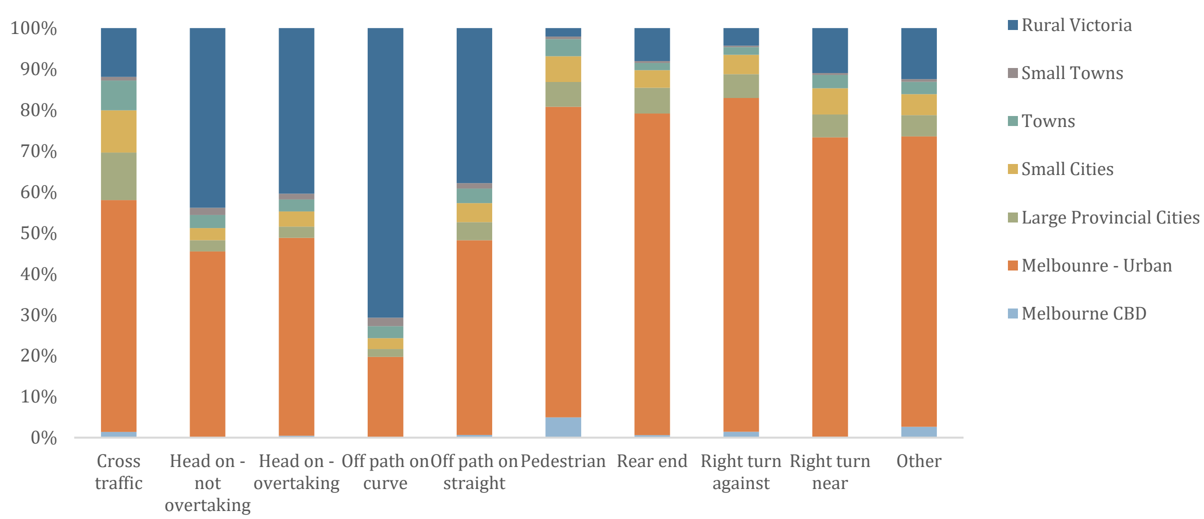


Figure 1.2 Crashes by geographic region and classification

"Rear end (DCA 130-132)", "Cross traffic (DCA 110)", "Right turn near (DCA 113)", "Right turn against (121)" are less severe on average, but very frequent especially in the Melbourne metropolitan area (Figure 1.2). More information regarding crash types, severity, vehicles involved, geographic region and roadway geometry is presented in Appendix B: Victorian Road Safety Data Summary.

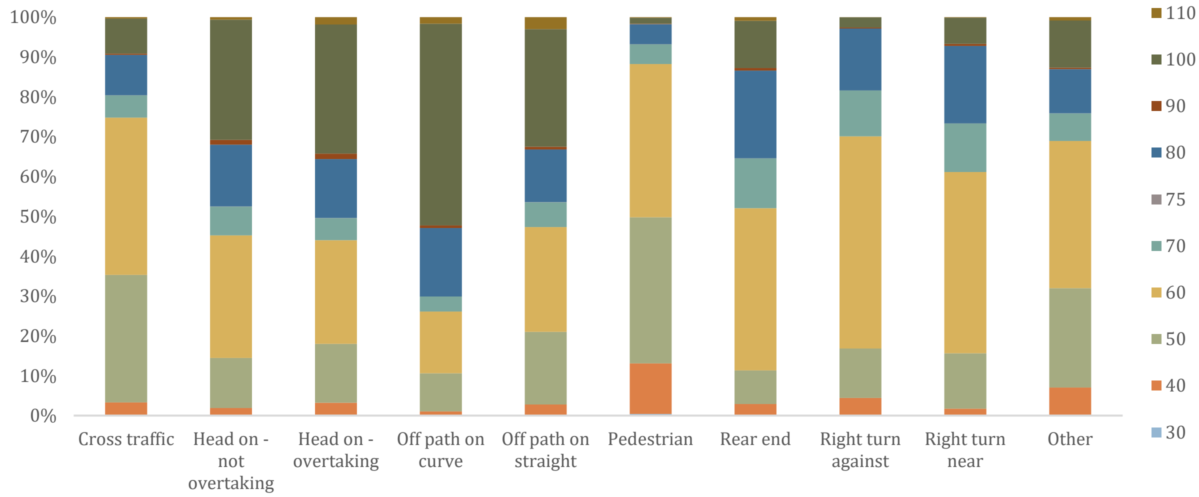


Figure 1.3 Crashes by classification and speed zone

From the perspective of roadway lighting conditions, the majority of Victorian crashes happen during daylight hours (Figure 1.4); however, the three regional fatal crash categories ("Off path on straight", "Off path on curve" and "Head on - not overtaking") occur more than others during hours of darkness and on road segments without proper lighting condition.

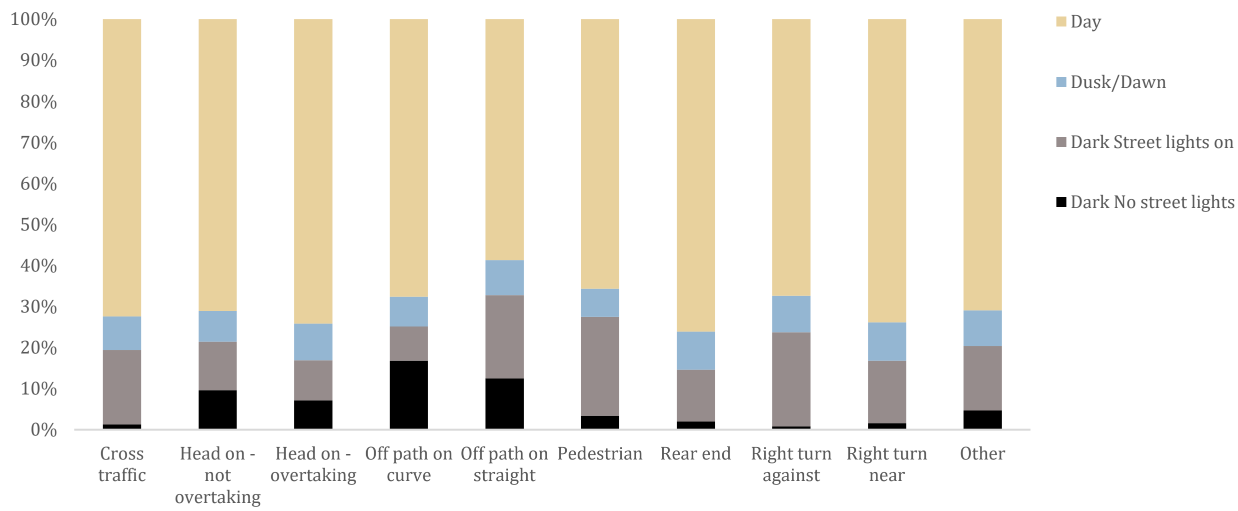


Figure 1.4 Crash type by street lighting condition

1.3 Vehicle Types

On average, 1.8 vehicles are involved per crash in Victoria. This includes vehicles from all possible modes of transport. Table 1.2 summarises all modes into five major vehicle types: car, truck, motorcycle, bike and other. Cars are the most dominant type of vehicles involved in crashes; however, trucks and motorcycles are over-represented in fatal crashes.

Table 1.2 No. of vehicles involved by type and severity of injury

Vehicles Types	Fatal	Serious Injury	Other Injury	Total
Car	3,987	84,696	175,147	*263,830*
Truck	710	5,451	9,319	*15,480*
Motorcycle	626	11,734	13,891	*26,251*
Bike	145	5,643	13,865	*19,653*
Other	84	2,235	5,270	*7,589*
Total	**5,552**	**109,759**	**217,492**	**332,803**

About half of fatal car crashes are associated with two dominant crash types of "Off path on straight" and "Head on - not overtaking" (Figure 1.5). The dominant fatal crash types for trucks accidents are "Head on - not overtaking" and "Pedestrians" crashes. For motorcycles, "Off path on straight", "Off path on curve" and "Head on - not overtaking" are the dominant fatal crash types. For pedal cycles, the leading fatal crash type is "Rear end". More information regarding crash types, severity, and vehicles involved is presented in Appendix B: Victorian Road Safety Data Summary.

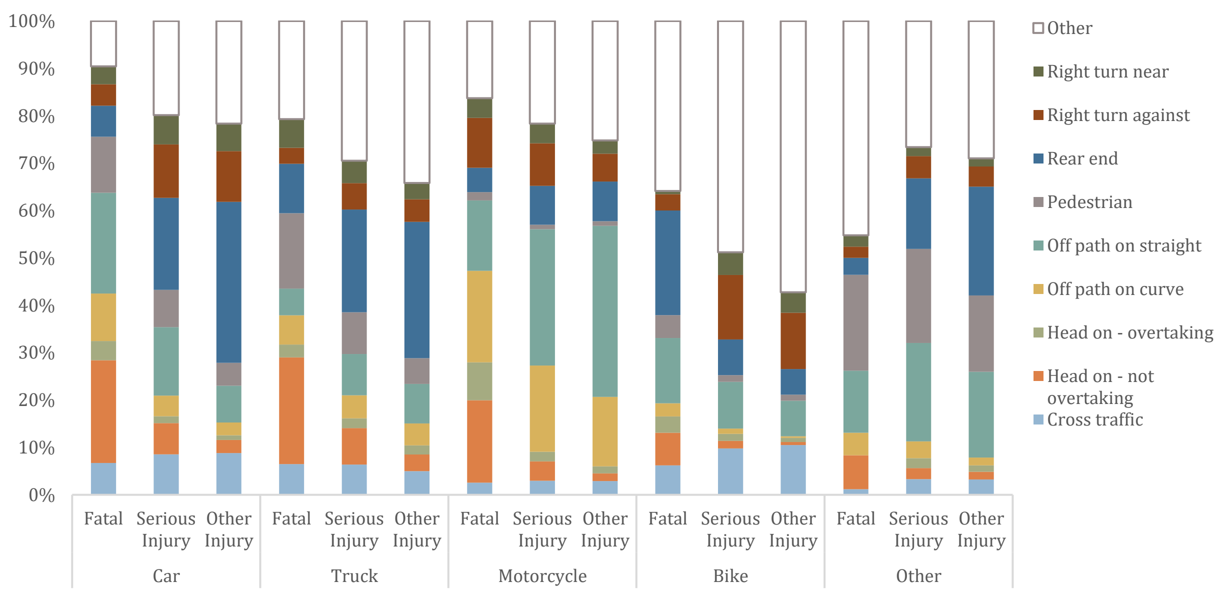


Figure 1.5 Proportion of vehicles involved by type, severity, and classification

The main takeaway here is that each type of road user is prone to a certain set of crash types and this mix varies across modes and different urban environments. As a result, a diverse set of C-ITS communication use cases can potentially lead to the most extensive crash reductions with distributed benefits over all transport modes and both in Melbourne Metropolitan area and rural/remote regions. Section 2 presents a summary list of communication technology use cases that can address a wide range of crash types that are dominant in Victoria.

2 C-ITS Applications

Co-operative intelligent transport systems refer to levels of cooperation between vehicles and their environment; this includes vehicles equipped with Advanced Driver Assistance Systems (ADAS), information exchange with infrastructure, and vehicle-to-other entity communication. C-ITS emerging technologies provide vehicle connectivity and communications with other vehicles (V2V), infrastructure (V2I), and other entities such as motorcycles, pedal cycles, and pedestrians (V2X). These communications will enable connected and automated vehicles (CAVs) to potentially deliver a range of benefits, particularly in road safety and traffic network performance.

There are numerous use cases for connected vehicles which have been trialled and simulated by government endorsed agencies, industry, and in academia. These trials aim to test and demonstrate the safety, environmental, and mobility benefits which connected vehicles (CVs) can provide; road safety applications are the focus of these trials and use cases. We investigate use cases that are expected to provide road safety benefits and identify the proportion of potential crashes that these use cases can address. While the analysis is based on Victorian crashes, the conclusions drawn are relevant to Australia in general.

2.1 European Roadmap to Deployment

Given that Australia is expected to follow the European standards for C-ITS deployment, the European Roadmap to Deployment assists in considering the many stages of deployment despite the differing policy environments. The deployment model is shown in Table 2.1 along with potential safety use cases that are applicable given the level of service and connectivity available. These safety use cases note the difference between awareness and warning messages; specifically, awareness messages are not time-critical and act to provide infrastructure- and location-related safety awareness, while warning messages are time-critical due to the presence of an imminent threat. “Day 1” use cases are expected to be for awareness purposes, while the use cases in “Day 2 and 3+” provide more time-critical and safety-specific warnings.

The model also assumes that the level of automation increases with time. That is, Day 1 C-ITS applications are provided for low levels of automation (and potentially low penetration), but are still effective for increasing awareness of risks and for the dissemination of information to drivers, while, Day 3+ activities assume that there are mid to high levels of technology penetration, as well as high, if not fully automated vehicles available for cooperative use cases. This roadmap is intended to demonstrate a potential model for achieving cooperative automated driving with the objective of crash free road transport and optimal traffic flow.

Table 2.1 European Roadmap to Deployment: Expected Services and Use Cases

Timeframe	Expected Services	Message Types	Potential Use Cases
Day 1 Awareness driving via status data	Cooperative awareness and decentralised notification; and Basic infrastructure support	Cooperative Awareness Message (CAM); Decentralised Environmental Notification (DENM); Basic Safety Message (BSM); Signal Phase and Time (SPaT); Road/lane topology and traffic manoeuvre (MAPEM); In-vehicle-Information Message (IVI); VRU Awareness Message (VAM)	• In-vehicle signage • Hazard Awareness • Intersection Awareness • Curve Speed Warning

Timeframe	Expected Services	Message Types	Potential Use Cases
Day 2 Sensing driving via sensor data	Improved cooperative awareness and decentralised notification; Collective Perception; and Improved Infrastructure Support	Collective Perception Message (CPM)	• Intersection Movement Assist • Red Light Violator Warning • Right Turn Assist
			• Cooperative Forward Collision Warning • Cooperative Blind Spot Warning/Lane Change Warning • Do Not Pass Warning
Day 3+ Cooperative driving via intention and coordination data	Trajectory/manoeuvre sharing; and Coordination/negotiation; and VRU active advertisement	Manoeuvre Coordination Message (MCM); and Platooning Control Message (PCM)	• Vulnerable Road User protection/ Pedestrian Safety Messages

2.2 Use Cases and Implementation Scenarios

A description for each of the use cases investigated in this analysis is presented in Table 2.2 along with any estimated benefits from previous trials and research papers including Austroads' *Safety Benefits of Cooperative ITS and Automated Driving in Australia and New Zealand 2017*, the Safety Pilot Model Deployment, the National Highway Traffic Safety Administration, and Australian-based trials including CAVI, CITI, and AIMES.

We investigate eight use cases, the first being Lane Keep Assist, an advanced driver assistance system (ADAS). This an ADAS-only application – all following use cases are an improvement on ADAS functionalities and are assumed to require communication technologies. That is, use cases such as forward collision warning and intersection movement assist amongst others require some level of ADAS or similar sensing hardware to function effectively.

Table 2.2 C-ITS Road Safety Use Cases

Use Case and Description	Deployment Timeframe
Lane Keep Assist (LKA)	***ADAS-only***
LKA is an advanced driver assistance system (ADAS) which does not require communication between the vehicle and its surrounding environment and instead relies on sensing hardware such as cameras. LKA acts as an automated corrective system which responds to cases of drifting manoeuvres and immediately recorrects a vehicles course to be within lane markings.	
Curve Speed Warning (CSW)	***Day 1***
CSW aims to address *single vehicle crashes* associated with excessive speed in the negotiation of roadway curves. The application compares the car's speed with a safe speed for the curve in question and warns the driver to slow down. Austroads provided an estimated 19-29% effectiveness range for the use of CSW with human intervention which is projected to prevent 75-115 fatal and serious injury (FSI) crashes in Australia.	

Use Case and Description	Deployment Timeframe
Cooperative Forward Collision Warning (CFCW)	***Day 2***
CFCW, also known as stopped or slow vehicle warning, acts to warn drivers of a threat ahead (e.g. stopped, or slowed vehicle), based on information provided by neighbouring vehicles and operates without the need for the ranging sensors used in traditional FCW Advanced Driver Assistance Systems. The lead vehicle is able to convey a message to following vehicles (V2V communication), mitigating or reducing the outcome of rear-end collisions for vehicles travelling in the same lane. Austroads' research report estimated a 20-32% crash avoidance effectiveness when the warning was acted upon by a human driver, and a 44-69% effectiveness when intervention following the warning was automated.	
Right Turn Assist (RTA)	***Day 2***
RTA is another intersection-specific collision avoidance warning which alerts the driver of potential collision with an oncoming vehicle from opposing direction while making a turn at both signalised and unsignalised intersections using V2V communication. This case is discussed specifically due to the safety benefits which are expected, and significant amount of testing and simulation which has been completed. This use case is expected to provide the highest benefit in situations where the driver's line of sight is obscured by other vehicles, road curvature, or road infrastructure. Austroads estimated RTA had an effectiveness range between 27-42% for human intervention cases, increasing to 54-85% when assuming automation was present.	
Do Not Pass Warning (DNPW)	***Day 2***
An Overtake or Do Not Pass Warning (DNPW) operates with V2V communication and alerts the driver that it is unsafe to perform an overtaking manoeuvre as there is an oncoming vehicle. This feature is expected only to operate when the driver has activated their turn signal and therefore does not have the ability to address situations when the driver unintentionally drifts into the oncoming lane. Research funded by the Texas Department of Transportation simulated and trialled DSRC-based V2V warnings for overtaking manoeuvres on two-lane rural highways. This research found that an overtaking warning was successfully sent and received in 77-96% of trials depending on the specific configurations. This use case was also successfully trialled in the SPMD.	
Intersection Movement Assist (IMA)	***Day 2***
IMA is an application designed to address common crash types at intersections. IMA acts to warn the driver that entering an intersection is unsafe due to another vehicle approaching from a lateral direction. This V2V communication exchanges basic safety messages (BSMs) that contain information that can be translated into the distance between two vehicles and the time to collision.	
Cooperative Blind Spot Warning/Lane Change Warning (CBSW/LCW)	***Day 2/3***
Blind Spot Warning (BSW) and Lane Change Warning (LCW) are ADAS functions which warn the driver when a potentially dangerous lane change manoeuvre is detected. With the use of connected vehicle technology, these functions can be enhanced to allow lane change warnings to operate at greater ranges, eliminating a key drawback of lane change warning and allowing for the development of similar applications like Overtake Assistance. Cooperative BSW/LCW can potentially remove the need for sensors within the vehicle to detect the lane change movement, instead, the vehicles performing these manoeuvres may be able to broadcast their movements to surrounding vehicles (V2V communication).	
Pedestrian Safety Messages (PSM)	***Day 3+***
Connectivity has also opened gateways to novel vulnerable road user (VRU) safety applications. VRUs are often considered as non-motorised road users, including pedestrians and pedal cyclists, and may also include motorcyclists and various electrified machines for micromobility. Vehicle to pedestrian collisions usually lead to severe injury or fatality on the pedestrian's part, accentuating the need to protect non-motorised vulnerable road users as a priority. There is a lack of worldwide trials targeting warnings of conflict between a vehicle and vulnerable road users. However, Australian trials including AIMES, CAVI, and the Towards Zero CAV, are investigating these use cases; currently, only qualitative results for expected benefits of connectivity for VRUs have been reported.	

2.3 Road Crashes Addressed by Use Cases

Using the DCA codes provided by VicRoads to understand the factors involved in a recorded road crashes, we estimate the percentage of crashes (based on 2006 to 2019 data) which can be addressed by the use cases presented in Table 2.2 above. The full definition for each DCA code is presented in Appendix A: VicRoads Crash Classifications.

Table 2.3 details the specific crash classifications that can be addressed with each use case considered. Both Pedestrian Safety Messages, and Intersection Movement Assist are expected to address the highest number of crash classifications, although this does not necessarily correlate to a higher proportion of crashes addressed overall.

Table 2.3 Types of crashes (DCA codes) that can be addressed by road safety use cases

Deployment and Use Case		**Crashes addressed (DCA codes)**
ADAS	Lane Keep Assist (LKA)	133, 160, 170, 171, 172, 173
Day 1	Curve Speed Warning (CSW)	180, 181, 182, 183, 184, 189
2	Cooperative Forward Collision Warning (CFCW)	130, 131, 132
2	Do Not Pass Warning (DNPW)	150, 151, 152, 153, 159
2	Intersection Movement Assist (IMA)	110, 111, 112, 113, 114, 115, 116, 117, 118, 119
2	Right Turn Assist (RTA)	121, 123, 124
2/3	Cooperative Blind Spot Warning (CBSW/LCW)	134, 135, 136, 137, 142, 147, 154
3+	Pedestrian Safety Messages (PSM)	100, 101, 102, 103, 104, 105, 106, 107, 108, 109

Assuming the crashes classified above are addressed by the use cases presented, we examine the expected proportion of crashes that could be reduced based on several factors including the severity of injury, geographic region, and type of vehicle involved.

Figure 2.1 shows approximately 80% of all crashes, for all levels of severity can be addressed in aggregate by the eight use cases presented. The deployment of vehicles equipped with ADAS functions along with the connectivity required for Day 1 applications accounts for a little over 40% of all fatal injury crashes. Interestingly, lane keep assist functions have the potential to prevent the highest proportion of fatal crashes.

When C-ITS deployment reaches Day 2, more than 60% of all crashes have the potential to be avoided. The ability for vehicles to provide intersection movement assist and cooperative forward collision warning will help in preventing a significant portion of the serious and other injury crashes on Victorian roads. Meanwhile, the Day 1 use case, curve speed warning, is expected to prevent approximately 10% of fatal crashes.

We note that these percentages are only a proportion of crashes that could potentially be addressed, and the measures provided are only indicative of the scale to which C-ITS applications can improve safety across the network. With this in mind, understanding the potential of Day 3+ applications is of particular interest given the ability for pedestrian safety messages to address crashes involving the most vulnerable road users. Pedestrian safety messages have the potential to address approximately 20% of fatal injuries; this use case has been underexplored in global trials, although some Australian trials have investigated such messages. As previously observed in Section 1.2, fatal pedestrian injuries are most prevalent in higher density metropolitan areas, thus, use cases addressing crashes involving pedestrians are an important avenue of investigation.

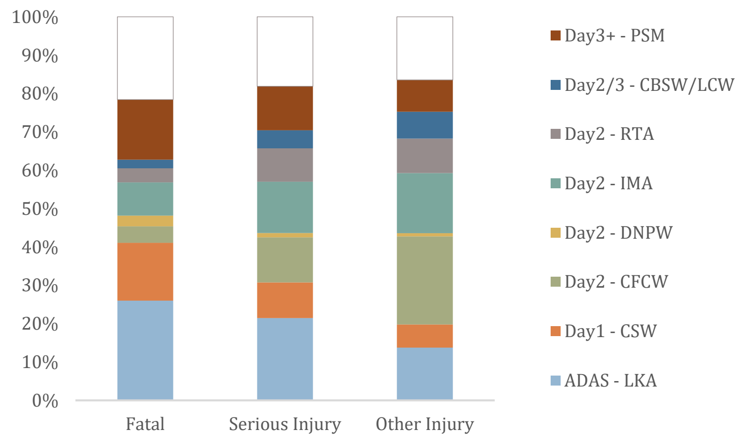


Figure 2.1 Proportion of crashes that specific use cases can address by severity

A more detailed investigation into the types of crashes which C-ITS use cases have the potential to address is presented below; this includes an understanding of the geographic regions affected (Figure 2.2) and the type of vehicles involved (Figure 2.3).

The uptake of ADAS-only technology, specifically lane keep assist functions, has significant potential in addressing road crashes across all areas; this potential increases with decreasing density for all injury types. That is, high density areas like Melbourne CBD are recorded a small proportion of crash-types that could be addressed by LKA, while towns and rural Victoria are likely to see a greater impact. This trend is also observed in curve speed warning applications – locations with decreased urban density have the greatest potential to benefit from this use case.

We observe the reverse trend for the use of intersection movement assist (Day 2) and pedestrian safety messages (Day 3+), with an increasing in capability to address crashes in more urban environments. A significant proportion of fatal and serious injury crashes occur in increasingly dense and urban environments. Notably, pedestrian safety messages have the potential to address more than half of the fatal crashes that occur in Melbourne CBD, and approximately 30% to 40% of other and serious injury crashes in the same area. Additionally, CFCW is expected to have the greatest potential to address serious and other injury crashes in medium to sparse density environments, although have limited potential in addressing fatal crashes.

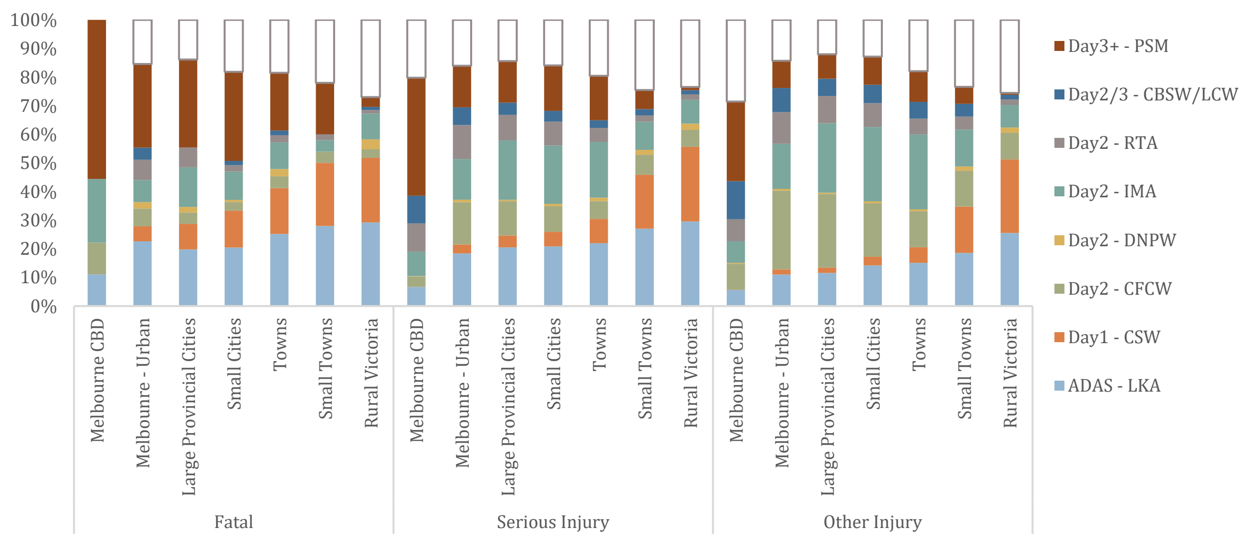


Figure 2.2 Proportion of crashes that specific use cases can address by severity and geographic region

Investigation of the crashes addressed by vehicle type and severity of injury is shown in Figure 2.3. As previously noted, Lane Keep Assist has significant potential to address crashes in all geographic areas, particularly for crashes involving cars. This use case has diminished potential in addressing crashes involving bikes or other vehicles. In fact, all used cases considered have a greater potential in addressing crashes involving cars and trucks than other modes with the exception of pedestrian safety messages. CFCW is still expected to have the greatest potential in addressing serious and other injury crashes; this use case is also considered more likely to reduce crashes that involve cars and trucks. However, approximately 20% of fatal crashes involving bikes could also be addressed by cooperative forward collision warning – this is consistent with the previous finding where the leading deadly crash type for bikes is "Rear end" (Section 1.3).

On Day 1, curve speed warning is most applicable for motorcycle crashes for all severities. As the deployment timeline progresses to Day 2, we observe intersection movement assist to have a similar potential as curve speed warning to reduce crashes across all vehicle types and injury levels. A similar trend is also observed for right turn assist, although for a smaller percentage of crashes. Day 2/3 cooperative blind spot warning and lane change warning is more relevant in addressing crashes involving bikes and trucks. For Day 3+ applications, pedestrian safety messages are observed to have the greatest potential for crashes involving cars, trucks and "other" vehicles.

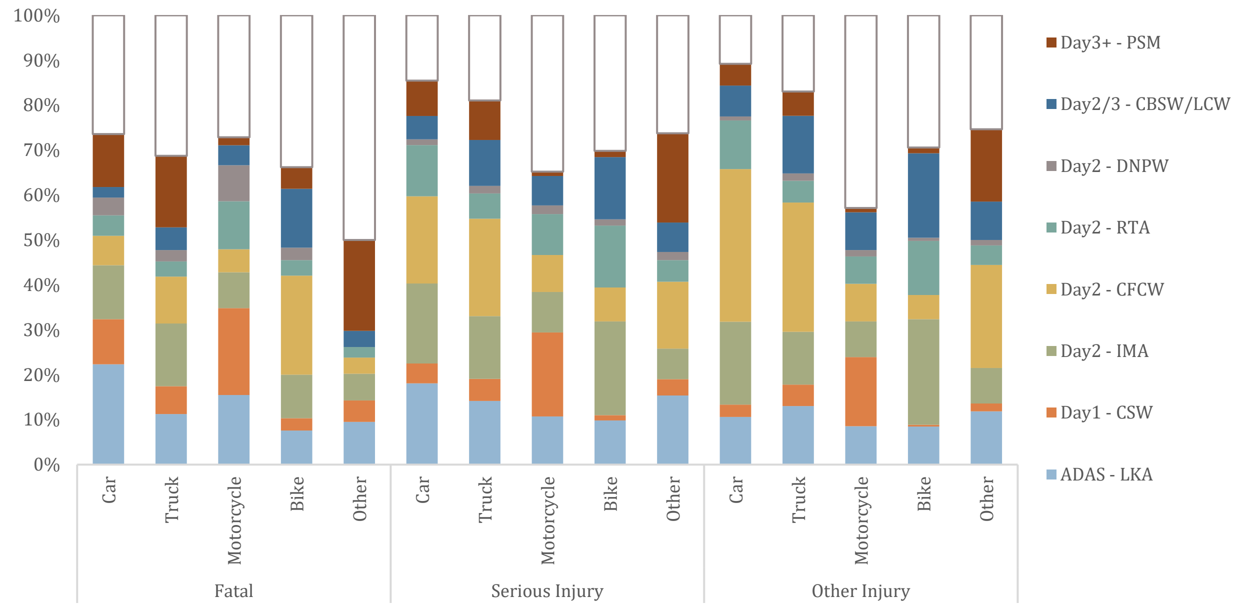


Figure 2.3 Proportion of vehicles involved in crashes that specific use cases can reduce by severity and vehicle type

3 Conclusions and Recommendations

This report presents an analysis of Victorian motor vehicle crashes, covering a fifteen-year period. Eight use cases have been studied: Lane Keep Assist (LKA), Curve Speed Warning (CSW), Cooperative Forward Collision Warning (CFCW), Do Not Pass Warning (DNPW), Intersection Movement Assist (IMA), Right Turn Assist (RTA), Cooperative Blind Spot Warning (CBSW/LCW), and Pedestrian Safety Messages (PSM). These use cases were found to have the capability to address approximately 80% of all crashes on Victorian roads (78% of fatal crashes, 82% of serious injury crashes, and 84% of other injury crashes) and have also been studied in other literature, trials, and simulations.

Table 3.1 Addressable crashes by severity and use case

Deployment Timeline Severity	ADAS	Day 1	Day 2	Day 2/3	Day 3+	NA	Total
Fatal	917	533	684	79	554	761	3,528
Serious Injury	13,923	6,038	22,686	3,048	7,454	11,755	64,904
Other Injury	16,245	7,140	57,209	8,264	9,821	19,435	118,114
Total	**31,085**	**13,711**	**80,579**	**11,391**	**17,829**	**31,951**	**186,546**

With regards to the types of vehicles involved in crashes, we expect that the arrival and ability to effectively use Day 2 applications will have the most significant impact in addressing crashes for all severities (see Figure 3.1). Notably, Day 2 applications have the greatest potential to address "other injuries" for all vehicle types. This is significant given that "other injuries" account for approximately 60% of all crashes (Table 1.1). Meanwhile, Day 1 applications are expected to have the greatest potential in reducing motorcycle-related crashes. This potential is decreases for other vehicle types, particularly bikes. Day 3+ applications are expected to have the greatest effect in reducing crashes involving "other" vehicles (i.e. pedestrians).

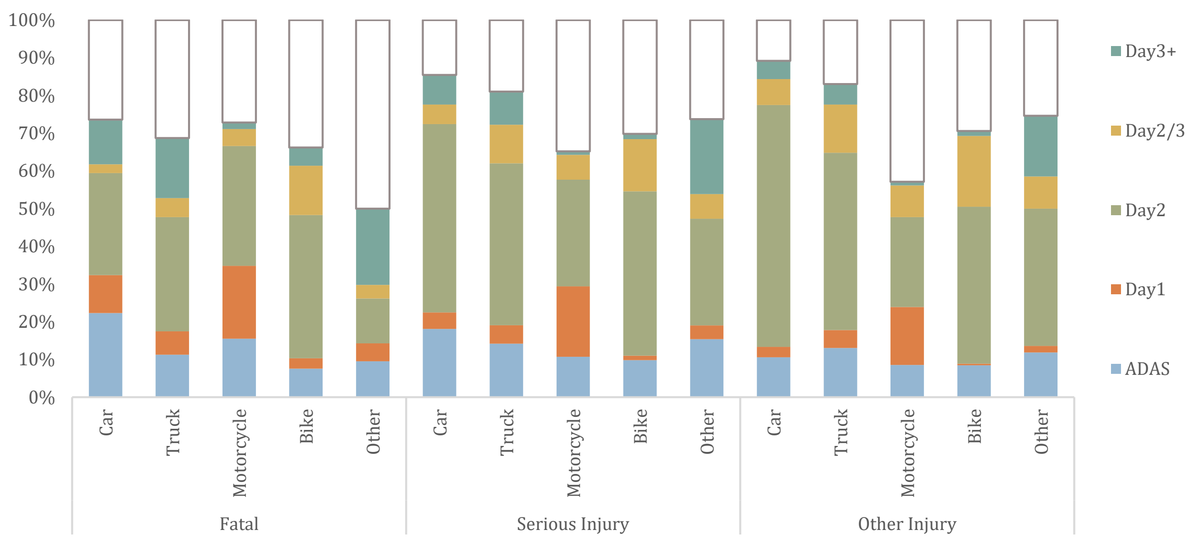


Figure 3.1 Proportion of vehicles involved in crashes by severity and vehicle type that can be addressed by C-ITS deployment timeframe

When expanded to consider the location of fatal and serious injury crashes (Figure 3.2), the potential for each application changes. Lane keep assist, an ADAS-only function, has increasing relevance in sparse environments such as towns and rural Victoria, particularly for crashes involving cars. This trend is more evident in the Day 1 application of curve speed warning for cars, trucks, and more significantly, motorcycles. For the use cases studied, Day 2 will likely have the greatest impact across all geographic locations for crashes involving cars, trucks, motorcycles, and bikes. However, the applications on Day 3+ will have the most significant effect in high density environments like Melbourne CBD and have the potential to address many crashes involving "other" vehicles (i.e. pedestrians).

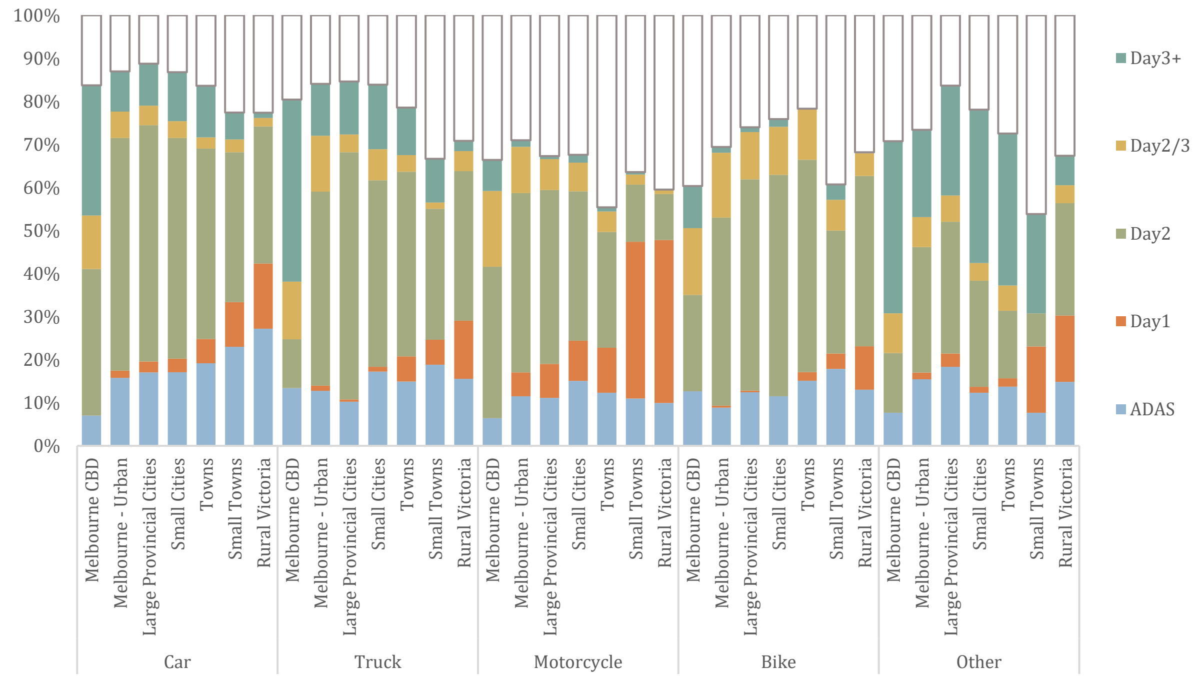


Figure 3.2 Proportion of vehicles involved in crashes by geographic region and vehicle type that can be addressed by C-ITS deployment timeframe (fatal and serious injury crashes only)

We provide a summary of each of the eight use cases investigated below; this considers the number of unique crash classifications addressed, the potential for the use case to reduce injuries by severity and location, and the ease of implementation relative to the required uptake and complexity of communications.

Lane Keep Assist (LKA)

- Six crash classifications can be addressed with this function;
- ADAS-only function that does not require connectivity technology and instead relies on sensing hardware, thus, considered to have the highest ease of implementation;
- Significant percentage of fatal injury crashes could be addressed; and
- Increasing potential for addressing crashes in less-dense regions; and
- Most applicable to crashes involving cars, trucks, and some fatal crashes for motorcyclists.

Curve Speed Warning (CSW)

- Six crash classifications can be addressed with this function;
- Day 1 awareness safety use case with communications that are not time-sensitive;
- Potential to have the greatest impact in small towns and rural locations; and
- Addresses a significant proportion of crashes involving motorcycles.

Cooperative Forward Collision Warning (CFCW)

- Three crash classifications can be addressed with this function;
- Day 2 function requiring improved cooperative awareness;
- Highly relevant to medium-density areas i.e. urban areas and small/large cities; and

- Addresses a significant proportion of "other" injury crashes which are the most common injury type.

Right Turn Assist (RTA)

- Three crash classifications can be addressed with this function;
- Day 2 function requiring improved cooperative awareness; and
- Greatest potential in reducing fatal motorcycle crashes, although broadly applicable to all vehicle types and geographic locations.

Do Not Pass Warning (DNPW)

- Five crash classifications can be addressed with this function;
- Day 2 function requiring improved cooperative awareness;
- Greatest potential in reducing fatal motorcycle crashes, although less so than RTA; and
- Broadly applicable to all vehicle types and geographic locations.

Intersection Movement Assist (IMA)

- Ten crash classifications can be addressed with this function;
- Day 2 function requiring improved cooperative awareness; and
- Greatest relevance to fatal crashes in Melbourne CBD and larger cities in Victoria.

Cooperative Blind Spot Warning/Lane Change Warning (CBSW/LCW)

- Seven crash classifications can be addressed with this function;
- Day 2/3 function requiring improved cooperative awareness and trajectory/manoeuvre sharing;
- Greatest potential in addressing crashes in Melbourne CBD; and
- Applicable to all vehicle types with significant potential regarding crashes involving bicycles and trucks.

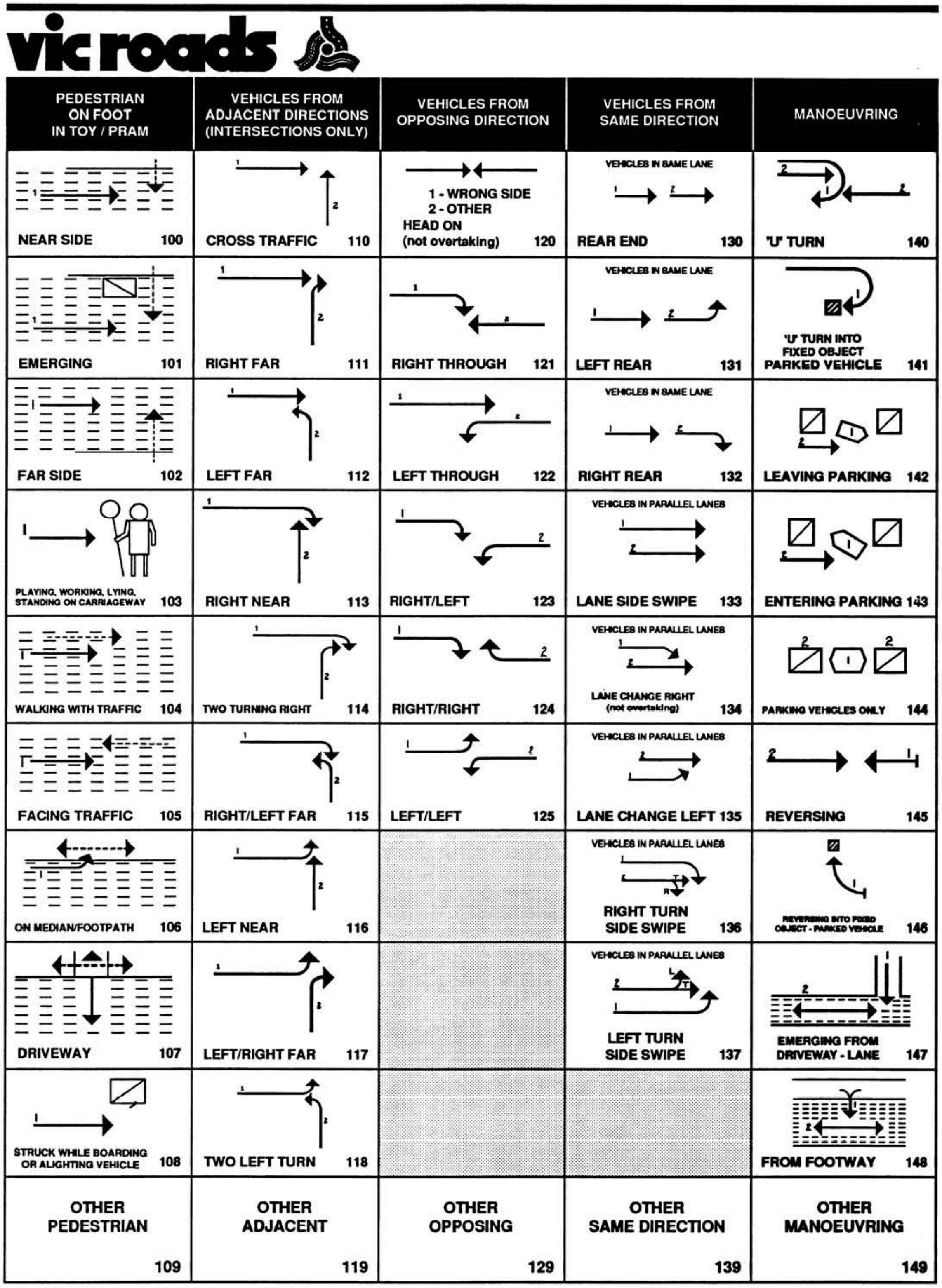
Pedestrian Safety Messages (PSM)

- Ten crash classifications can be addressed with this function;
- Critical use case given the vulnerability of pedestrians compared to other road users (e.g. cars);
- Highest degree of difficulty in implementation requiring a high level of coordination; and
- Potential to addressing a significant percentage of crashes in high density areas, specifically Melbourne CBD (more than 50% of fatal crashes);

While there is capability for ADAS-only lane keep assist and Day 1 curve speed warning to address a large proportion of crashes in Victoria, our analysis shows that these use cases are more applicable to medium to sparse environments such as small towns and rural regions. Given most of the population lives in denser and more urban regions, there is a need to consider pathways towards to implementing Day 2 to 3+ use cases as they are more likely to provide benefits across all geographic regions and vehicle types. Perhaps most importantly, these cases will address road safety cases involving the most vulnerable road users.

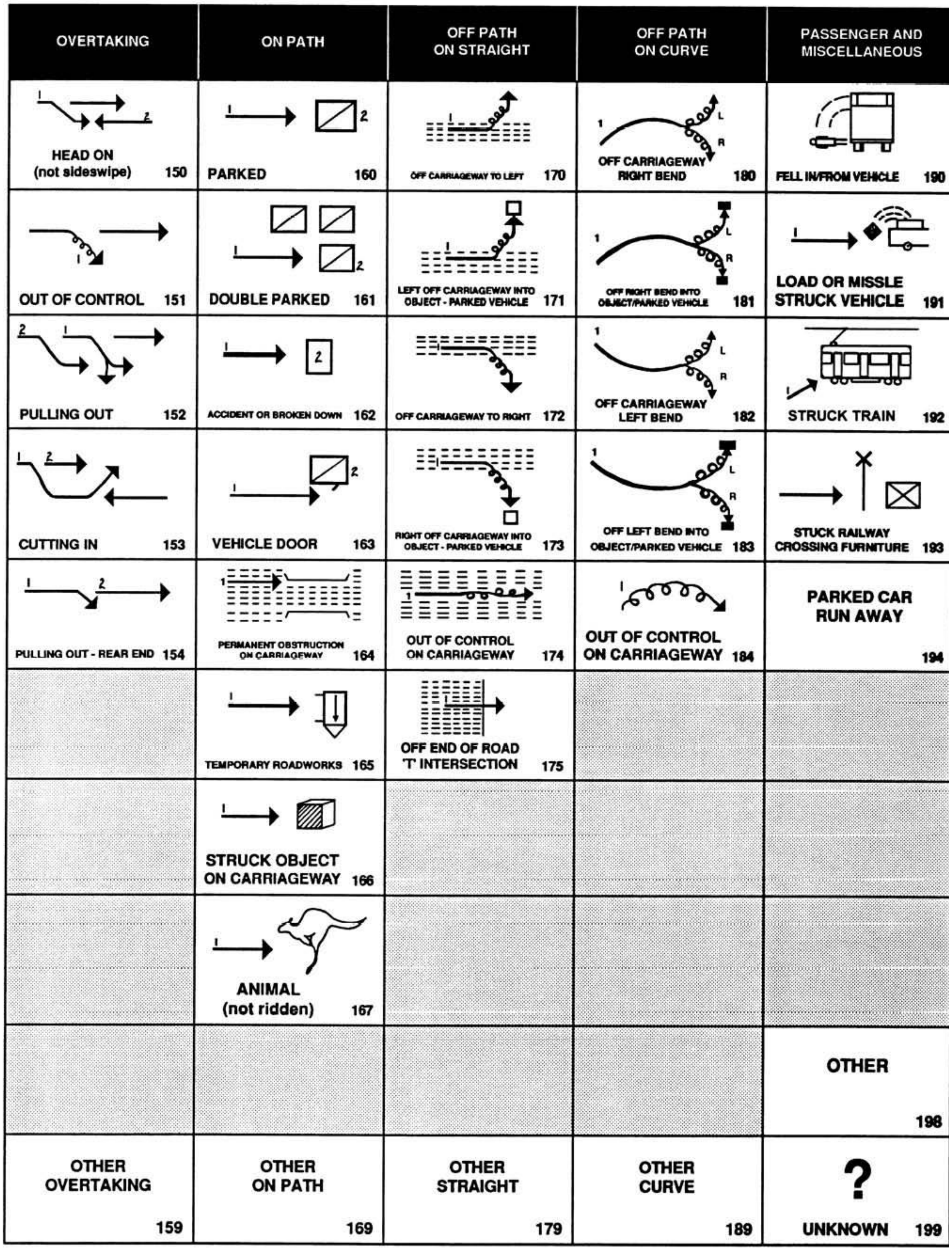
In this report we have provided a summary of trends for Victorian crashes over the last fifteen years. By considering some of the major C-ITS safety use cases that have been investigated globally and nationally, we present an estimate for the proportion of crashes that can be addressed considering the severity, location, and types of vehicles involved in each crash; approximately 80% of all crashes can be addressed by the eight use cases investigated. We note that the analysis provided only indicates a proportion of crashes that could potentially be addressed, and the measures provided are only indicative of the scale to which C-ITS applications can improve safety across the network. Further investigation into the effectiveness of the applications in addressing the specific crash types would be required to estimate the proportion of crashes that could be effectively addressed with the use cases presented.

Appendix A: VicRoads Crash Classifications



1. Definition for classifying accidents (DCA) should be determined by first selecting a column using the text above & then by diagrammatic sub-division.
2. The sub-division chosen should describe the general movement of vehicles involved in the initial event. It does not assign a cause to the accident.
3. Supplementary codes have been defined for most sub-divisions. These codes give further detail of the initial event.

DEFINITIONS FOR CLASSIFYING ACCIDENTS



4. The number 1,2 identify individual vehicles involved when the DCA is linked with other vehicle/driver information.
5. These codes were used for 1987 accidents and replace the Road User Movement (RUM) code.

Appendix B: Victorian Road Safety Data Summary

Crashes 2006-2019		GEOGRAPHIC REGION							
	Crash Type	**Melbourne CBD**	**Melbourne - Urban**	**Large Provincial Cities**	**Small Cities**	**Towns**	**Small Towns**	**Rural Victoria**	**Total**
FATAL INJURY CRASHES	Cross traffic	2	35	7	8	8	2	99	*161*
	Head on - not overtaking	0	92	5	11	11	10	389	*518*
	Head on - overtaking	0	29	2	2	3	0	65	*101*
	Off path on curve	0	69	9	17	19	11	407	*532*
	Off path on straight	0	272	22	31	31	14	557	*927*
	Pedestrian	5	382	31	41	24	9	62	*554*
	Rear end	1	81	4	4	5	2	54	*151*
	Right turn against	0	93	7	2	3	1	22	*128*
	Right turn near	0	51	2	3	2	0	47	*105*
	Other	1	204	12	13	13	1	107	*351*
	Total	*9*	*1,308*	*101*	*132*	*119*	*50*	*1,809*	*3,528*
SERIOUS INJURY CRASHES	Cross traffic	55	2,315	367	312	244	39	706	*4,038*
	Head on - not overtaking	2	1,393	74	82	84	45	1,288	*2,968*
	Head on - overtaking	1	366	19	25	27	11	369	*818*
	Off path on curve	0	1,204	123	135	164	118	4,136	*5,880*
	Off path on straight	62	7,301	634	605	514	211	5,920	*15,247*
	Pedestrian	308	5,722	446	428	307	42	185	*7,438*
	Rear end	27	5,842	370	240	123	44	957	*7,603*
	Right turn against	74	4,621	274	223	94	14	304	*5,604*
	Right turn near	5	2,158	159	137	97	14	444	*3,014*
	Other	213	8,470	601	505	320	94	1,836	*12,039*
	Total	*747*	*39,392*	*3,067*	*2,692*	*1,974*	*632*	*16,145*	*64,649*
OTHER INJURY CRASHES	Cross traffic	120	4,909	1,114	1,005	679	72	723	*8,622*
	Head on - not overtaking	0	1,266	87	86	99	52	980	*2,570*
	Head on - overtaking	8	586	35	48	30	17	387	*1,111*
	Off path on curve	1	1,339	126	197	205	147	4,833	*6,848*
	Off path on straight	165	8,904	866	982	691	231	6,639	*18,478*
	Pedestrian	570	7,386	601	655	413	55	124	*9,804*
	Rear end	185	21,397	1,814	1,251	483	116	1,786	*27,032*
	Right turn against	158	8,496	658	543	210	42	368	*10,475*
	Right turn near	13	4,197	328	423	185	27	470	*5,643*
	Other	827	19,231	1,426	1,490	859	168	2,955	*26,956*
	Total	*2,047*	*77,711*	*7,055*	*6,680*	*3,854*	*927*	*19,265*	*117,539*

Crashes 2006-2019		VEHICLES INVOVLED														
	Crash Type	**Bike**	**Bike-Car**	**Bike-Car-Motorcycle**	**Bike-Car-Truck**	**Bike-Motorcycle**	**Bike-Truck**	**Car**	**Car-Motorcycle**	**Car-Motorcycle-Truck**	**Car-Truck**	**Motorcycle**	**Motorcycle-Truck**	**Truck**	**Other**	**Total**
FATAL INJURY CRASHES	Cross traffic	0	7	0	0	0	2	94	15	0	40	0	1	1	1	*161*
	Head on - not overtaking	0	4	1	0	0	4	276	76	0	131	6	9	5	6	*518*
	Head on - overtaking	1	1	0	0	0	2	43	33	1	14	5	1	0	0	*101*
	Off path on curve	3	1	0	0	0	0	366	10	1	1	104	0	42	4	*532*
	Off path on straight	18	0	0	0	0	0	770	11	0	5	80	1	31	11	*927*
	Pedestrian	5	1	0	0	0	0	411	1	0	18	10	0	92	16	*554*
	Rear end	0	24	0	0	0	5	44	21	2	45	2	3	2	3	*151*
	Right turn against	0	4	0	1	0	0	48	50	1	12	0	10	0	2	*128*
	Right turn near	0	1	0	0	0	0	41	22	0	34	0	3	2	2	*105*
	Other	4	14	0	2	1	23	109	55	1	51	13	24	16	38	*351*
	Total	*31*	*57*	*1*	*3*	*1*	*36*	*2,202*	*294*	*6*	*351*	*220*	*52*	*191*	*83*	*3,528*
SERIOUS INJURY CRASHES	Cross traffic	0	524	0	0	1	13	2,783	329	0	290	2	12	14	74	*4,042*
	Head on - not overtaking	2	58	0	2	2	12	2,096	322	0	352	52	20	10	52	*2,980*
	Head on - overtaking	4	43	0	1	0	5	419	171	3	70	41	12	5	46	*820*
	Off path on curve	46	10	0	0	2	0	3,461	59	2	13	2,014	6	240	77	*5,930*
	Off path on straight	299	161	0	0	1	9	10,709	248	1	80	3,034	11	354	450	*15,357*
	Pedestrian	70	8	0	0	0	1	6,353	7	0	45	103	0	426	441	*7,454*
	Rear end	14	305	0	2	5	11	5,172	724	12	895	69	35	61	310	*7,615*
	Right turn against	0	710	3	1	2	18	3,513	987	1	224	0	39	6	105	*5,609*
	Right turn near	0	246	0	0	2	11	2,024	456	3	215	1	14	6	42	*3,020*
	Other	73	2,202	1	16	19	164	5,420	1,509	16	1,012	783	97	181	584	*12,077*
	Total	*508*	*4,267*	*4*	*22*	*34*	*244*	*41,950*	*4,812*	*38*	*3,196*	*6,099*	*246*	*1,303*	*2,181*	*64,904*
OTHER INJURY CRASHES	Cross traffic	1	1,369	0	0	4	27	6,260	383	0	394	0	7	16	170	*8,631*
	Head on - not overtaking	5	64	0	0	7	3	1,965	139	0	261	32	2	22	83	*2,583*
	Head on - overtaking	5	86	0	0	0	6	615	144	1	132	38	8	10	70	*1,115*
	Off path on curve	28	10	0	0	0	2	4,423	51	0	30	1,942	6	383	86	*6,961*
	Off path on straight	472	359	0	0	2	29	11,321	573	1	106	4,258	38	569	932	*18,660*
	Pedestrian	166	12	0	0	0	0	8,170	12	0	46	119	2	451	843	*9,821*
	Rear end	22	534	0	4	5	16	22,072	935	13	2,157	53	28	131	1,137	*27,107*
	Right turn against	1	1,561	1	1	5	20	7,498	777	1	374	0	20	9	219	*10,487*
	Right turn near	1	557	0	0	1	12	4,324	371	2	271	1	7	11	90	*5,648*
	Other	108	6,803	4	19	35	270	12,531	2,140	11	2,105	1,054	109	409	1,503	*27,101*
	Total	*809*	*11,355*	*5*	*24*	*59*	*385*	*79,179*	*5,525*	*29*	*5,876*	*7,497*	*227*	*2,011*	*5,133*	*118,114*

	Crashes 2006-2019	**ROAD GEOMETRY**								
	Crash Type	**Cross intersection**	**Dead end**	**Multiple intersection**	**Not at intersection**	**Private property**	**Road closure**	**T intersection**	**Y intersection**	**Total**
FATAL INJURY CRASHES	Cross traffic	159	0	2	0	0	0	0	0	*161*
	Head on - not overtaking	8	0	0	469	0	0	41	0	*518*
	Head on - overtaking	2	0	0	82	0	0	16	0	*100*
	Off path on curve	2	0	4	486	0	0	37	2	*531*
	Off path on straight	43	2	7	777	0	0	98	0	*927*
	Pedestrian	108	0	9	330	0	0	107	0	*554*
	Rear end	15	0	3	112	0	0	21	0	*151*
	Right turn against	36	0	10	14	0	0	68	0	*128*
	Right turn near	27	0	2	0	0	0	76	0	*105*
	Other	28	0	10	232	0	0	80	0	*350*
	Total	*428*	*2*	*47*	*2,502*	*0*	*0*	*544*	*2*	*3,525*
SERIOUS INJURY CRASHES	Cross traffic	3,931	0	95	4	0	0	2	2	*4,034*
	Head on - not overtaking	122	1	11	2,468	0	0	363	7	*2,972*
	Head on - overtaking	57	0	4	590	0	0	168	1	*820*
	Off path on curve	48	2	43	5,306	0	0	505	17	*5,921*
	Off path on straight	1,379	30	191	10,985	0	1	2,688	38	*15,312*
	Pedestrian	1,864	8	83	3,833	1	0	1,643	9	*7,441*
	Rear end	1,270	0	148	4,373	0	0	1,803	16	*7,610*
	Right turn against	2,370	0	298	562	0	0	2,358	17	*5,605*
	Right turn near	570	0	141	2	0	0	2,293	14	*3,020*
	Other	1,458	15	224	7,562	2	1	2,752	39	*12,053*
	Total	*13,069*	*56*	*1,238*	*35,685*	*3*	*2*	*14,575*	*160*	*64,788*
OTHER INJURY CRASHES	Cross traffic	8,377	0	206	25	0	0	8	1	*8,617*
	Head on - not overtaking	113	0	14	2,104	0	0	344	4	*2,579*
	Head on - overtaking	110	0	8	704	0	0	291	1	*1,114*
	Off path on curve	73	0	65	6,202	1	0	573	25	*6,939*
	Off path on straight	2,209	33	282	12,503	0	1	3,510	58	*18,596*
	Pedestrian	2,705	15	127	4,670	2	1	2,270	15	*9,805*
	Rear end	6,372	6	722	13,278	0	0	6,629	66	*27,073*
	Right turn against	4,659	0	476	1,024	0	0	4,305	20	*10,484*
	Right turn near	992	0	225	2	0	0	4,386	34	*5,639*
	Other	4,013	28	472	15,646	3	0	6,806	72	*27,040*
	Total	*29,623*	*82*	*2,597*	*56,158*	*6*	*2*	*29,122*	*296*	*117,886*