Australasian Transport Research Forum 2022 Proceedings
28-30 September, Adelaide, Australia
Publication website: http://www.atrf.info

Considerations for Expediting Road Safety Benefits with the Deployment of Vehicle Communication Technologies

Neema Nassir[1,*], Jessica Tong[1], Patricia Lavieri[1], Stacey Ryan[2], Peter Sweatman[1], Susan Harris[2], and Majid Sarvi[1]

Abstract

Communication technologies are enabling the introduction of connected vehicles and have the potential to improve road safety outcomes at a global scale. This paper aims to deliver a systematic understanding, classification, and evaluation of available communication technologies for road safety that considers the current challenges, mindsets, and future direction for C-ITS technology implementation. This is achieved by combining the results of three lines of research inquiry: 1) literature review of existing communication technologies and worldwide pilot experiments and trial implementations, 2) assessment of the potential for selected connected vehicle safety applications to address motor vehicle crashes across different geographies and road conditions, and 3) expert panel interviews to investigate the challenges and opportunities for technology implementation, specifically in the Australian context, with supporting evidence from global literature sources. These investigations found that C-ITS deployment concerns identified by stakeholders are in line with those identified in literature; however, there are significant safety benefits to be reaped from C-ITS deployment. Policymakers can leverage the potential of this positive outcome and target efforts at addressing the identified challenges when considering pathways to the uptake of connectivity technologies.

1. Introduction

Co-operative intelligent transport systems (C-ITS) involve vehicle connectivity and communication 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, as well as in energy efficiency and emissions reduction; we focus specifically on the road safety benefits and the potential specific use cases have in varying road conditions. There are numerous use cases for connected vehicles which have been trialled and simulated by government-endorsed agencies, industry, and in academia. Safety benefits of C-ITS can be assessed by examining the proportion of crashes which each specific use cases have the potential to address (Asselin-Miller, et al.). The Victorian Road Safety database from Australia contains a comprehensive record of crashes over the last fifteen years, with attributes for each crash occurrence including severity of injury, geographic location, lighting

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[1] Department of Infrastructure Engineering, The University of Melbourne, Australia

[2] ITS Australia

* Corresponding: neema.nassir@unimelb.edu.au

conditions, and modes involved. Using these parameters, factors and variables that make certain crashes more common can be investigated. This investigation presents an opportunity to target the development and deployment of C-ITS use cases that have the ability to address the most common crashes. While this analysis uses state-level data, the results are applicable at a national and global level.

The deployment of connectivity technology requires several decisions to be made, including the type of technology and the method of deployment in vehicles; we present opinions from a panel of experts to support the identification of the challenges that C-ITS deployments face in the Australian environment that are broadly applicable at a global scale. Decisions for the technology are based on the framework presented in the European Roadmap to Deployment. Some of the challenges and opportunities in the deployment of C-ITS technology considered include the penetration rates required for the benefits to be realised, the use of aftermarket and original equipment manufacturer (OEM) hardware, and human-machine interaction factors.

The rest of the paper is organised as follows: Section 2 provides a short literature review of existing communication technologies and implementations. In Section 3, the details of specific road safety use cases and their expected effectiveness are discussed along with a connected vehicle deployment roadmap in Section 4. We analyse Road Safety data from Victoria, Australia, in Section 5 to understand the expected potential for safety benefits to be delivered from specific C-ITS use cases. We conclude our study in Section 6, noting that while our data analysis has been focused on Australia, the insights and advice provided are relevant in the global context.

2. C-ITS background

C-ITS refers to three levels of cooperation between vehicles and infrastructure: 1) equipped vehicles with Advanced Driver Assistance Systems (ADAS), 2) information exchange with the infrastructure, and 3) vehicle-to-vehicle communication (Guériau, et al., 2016). This paper focuses on the benefits which C-ITS communication technologies can bring in addition to ADAS. The integration of C-ITS technologies with other automation features will contribute to increasing the safety and efficiency of transportation networks.

Connected Vehicles (CV) supported by C-ITS technology are expected to augment existing ADAS; ADAS provide warnings to vehicles during driving or parking activities and are designed with a safe human-machine interface that does not require a communication method with other road users. ADAS can be enhanced with connectivity technology to improve overall network safety; C-ITS platforms are being developed in an effort to deliver cross-cutting benefits, including safety and traffic efficiency, to road users and the wider transport network in countries and regions such as Europe, the USA, and Asia (Kotsi, Mitsakis, & Tzanis). We define and review the status of the two technologies, DSRC and C-V2X in the market, provide an understanding of how C-ITS supports connected and automated vehicles, and highlight trials and specific use cases which have been assessed for road safety purposes.

C-ITS technologies offer short-range and long-range communications, where the nature of the application governs the type of communication employed. Two dominant communication technologies exist (Dedicated Short Range Communication, DSRC; and Cellular Vehicle-to-Everything, C-V2X) which have enabled three types of C-ITS implementation:

1. ***DSRC short-range direct communication:*** There have been a significant number of large-scale and real-world trials that test the capability of DSRC for C-ITS communication use cases.
2. ***C-V2X short-range direct communication (PC5) and long-range cellular communication (Uu):*** This implementation method is a proposed alternative to short-range communication

provided by DSRC. This technology is relatively new compared to DSRC and currently has few large-scale and real-world testing to support its deployment but is supported by a number of industries.

3. ***Hybrid – DSRC short-range direct communication with cellular long-range communication:*** A hybrid combination of DSRC and cellular technologies has also proven effective in multiple trials around the world. In the hybrid implementation method, direct and short range communication is delivered by DSRC, and cellular connectivity delivers the V2N connectivity for longer range communications.

These implementation methods provide the following main functionalities:

- ***Device-to-device connections***: V2V, V2I, and V2P direct communication without the need for reliance on network involvement for scheduling. Both DSRC and C-V2X (PC5) enable this method of communication.
- ***Device-to-network connections***: V2N solution using traditional cellular links to enable cloud services for an end-to-end solution. This communication is provided by either C-V2X Uu or a hybrid technology implementation.

3. Road Safety Applications and Use Cases

Planners and policy makers are placing a greater emphasis on understanding the potential of connected technology to act as a new solution to modern safety issues, alongside a multitude of more traditional approaches. This has led to a surge in research efforts which aim to estimate the benefits of existing and emerging C-ITS use cases in an attempt to measure the impacts of wider adoption and deployment of connected technologies.

While safety has been the main driver of the deployment of connected technologies, four types of Connected Vehicle Applications: Safety, Environmental, Mobility, and Support have been classified by USDOT *Connected Vehicle Reference Implementation Architecture* (2016), where each type is comprised of application fields that further contain specific use cases. The list of use cases presented in this review is not exhaustive and will focus predominantly on the application field of safety (Table 2). This section summarises estimated benefits of the use cases presented in Table 1 from pilots and trials, as well as simulations in academic experiments and scientific papers.

In urban environments, increased connectivity of vehicles could enable improved network productivity and offer safety benefits for all road users (Talebpour & Mahmassani, 2016). Connected vehicle (CV) applications promise to reduce crashes that cause fatalities and serious injuries, primarily by minimising the occurrence of driver errors, a predominant factor in 94% of traffic crashes (Yue, Abdel-Aty, Wu, & Wang, 2018). NHTSA (2010) demonstrates this capability through the analysis of its IntelliDrive safety systems program, which consisted of various connected vehicle applications. By sourcing crash data from the 2005-2008 General Estimates System, NHTSA estimated that connected vehicle applications have the potential to address over 4.5 million or 81% of all police reported vehicle crashes in the United States. Assessment of C-ITS should include comparing and identifying the efficacy of individual use cases (shown in Table 1). In this review, use cases in the safety application fields are classified according to their proximity to the crash, as follows.

- ***Safety awareness messages***: noncritical communications which act to provide an increased knowledge of the driver's surrounding infrastructure and environment. Generally, these awareness messages convey a static hazard, for example, upcoming work zones or red-light signals. Depending on the latency requirements of the use case, cellular long-range communication methods are expected to be able to provide the necessary communication.

- ***Safety warning messages***: time-critical communications where the driver is warned of an imminent threat and reactions to messages are time-sensitive. This involves situations where other road users may be moving and require an additional level of prediction based on the driver's movements and the movements of the other road user, for example, warnings for potential collision paths with another vehicle or a vulnerable road user.

Table 1: Application fields and use cases for Road Safety Applications

Message	Application Field	Use Case
Warning	Warnings for conflicts between vehicles (all modes including cars, trucks, and motorcycles)	Red Light Violator Warning Do Not Pass Warning (DNPW) Approaching Emergency Vehicle Warning (AEVW) Blind Spot Warning (BSW) Lane Change Warning (LCW) Cooperative Forward Collision Warning (CFCW) Right Turn Assist (RTA)/Left Turn Assist (LTA) Intersection Movement Assist (IMA)
	Warnings for conflicts involving vulnerable road users (e.g. pedestrians)	Detecting vulnerable road users Alerting vulnerable road users
Awareness	Infrastructure and environment awareness	Curve Speed Warning (CSW) Intersection Awareness Hazard Awareness In-Vehicle Signage

a. Warnings for conflicts between vehicles

i. Intersection Movement Assist (IMA)

Some accidents occur because drivers, cyclists, and pedestrians do not have the information they need to avoid decisions resulting in conflict. Intersection Movement Assist (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.

The efficacy of IMA has been identified for heavy vehicles in simulations conducted by Chang (2016) for the NHTSA. The experiment involved 40 simulations of two heavy trucks approaching an intersection at identical speeds and at the same time, half of which had a heavy truck equipped with IMA and the other half without. While only approximately half the trucks equipped with IMA managed to avoid a collision, they also found that the trucks without IMA collided in every scenario. This study concluded that IMA has a 43-56% effectiveness for crash avoidance.

ii. Red Light Violator Warning

Another intersection specific warning, red light violator warning, is used to communicate to the driver that a vehicle travelling in the opposite direction (an oncoming vehicle) is at risk of running a red light at the intersection ahead. This message can be communicated either by another cooperative vehicle (V2V), or by the intersection (V2I) and has the potential to be coupled with traffic signal logic and used to extend the red-light phase at the intersection if a potential collision is detected. There are currently no published quantitative results to demonstrate the effectiveness of this case.

iii. Right Turn Assist (RTA)/ Left Turn Assist (LTA)

Right Turn Assist (RTA) for left-driving countries and Left Turn Assist (LTA) for right-driving countries, is another intersection-specific collision avoidance warning that alerts the driver of a potential collision with an oncoming vehicle from the opposing direction while making a turn at both signalised and unsignalised intersections using V2V communication. This use case is expected to provide the highest benefit in situations where the driver's line of sight (LOS) is obscured by other vehicles, road curvature, or road infrastructure.

iv. Cooperative Forward Collision Warning (CFCW)

Cooperative Forward Collision Warning (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 the following vehicles (V2V communication), mitigating or reducing the outcome of rear-end collisions for vehicles travelling in the same lane. Austroads' research report (Logan, Young, Allen, & Horberry, 2017) 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.

A specific CFCW case, Emergency Electronic Brake Light (EEBL), warns the driver that the vehicle ahead (potentially not in the driver's LOS) is decelerating rapidly. This communication is provided by the decelerating vehicles, with the warning increasing the amount of time for the driver to respond. This use case was tested by the SPMD and was found to provide a relatively frequent value from the driver's perspective; however, no quantitative results are currently available for any of these specific use cases trialled.

v. Cooperative Blind Spot Warning (BSW) and Lane Change Warning (LCW)

Blind Spot Warning (BSW) and Lane Change Warning (LCW) are ADAS functions that 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 LCWs to operate at greater ranges, eliminating a key drawback and allowing for the development of similar applications like Overtake Assistance. Cooperative BSW/LCW removes the need for sensors within the vehicle to detect the lane change movement, instead, the vehicles performing these manoeuvres are able to broadcast their movements to surrounding vehicles (V2V communication).

vi. Do Not Pass Warning (DNPW)

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. The Texas Department of Transportation supported research by Motro et al. (2016; 2019) who simulated DSRC-based V2V warnings for overtaking manoeuvres on two-lane rural highways; these trials and simulations found that an overtaking warning was successfully sent and received in 77-96% of trials depending on the configurations and parameters tested.

vii. Approaching Emergency Vehicle Warning (AEVW)

Approaching Emergency Vehicle Warning (AEVW) is a time-critical use case where drivers are alerted to the presence of an approaching emergency vehicle. This warning aims to provide drivers with additional time to pull over and stop – as required under US traffic law – and generally allow the emergency vehicle to reach its target destination as soon as possible. This warning also acts to reduce the potential for collisions with emergency vehicles. Drive C2X (2014) estimated that AEVW would contribute to a reduction of at least 0.8% of all fatalities with a high penetration rate. The authors also note that this very practical use case may be particularly attractive for user acceptance of connected technology.

b. Warnings for conflicts involving vulnerable road users

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 fatalities 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 Towards Zero CAV, are currently investigating these use cases.

i. Detection of vulnerable road users

A trial conducted by AIMES (Benjamin, Young, & Sarvi, 2019) assessed the ability to detect and warn a driver on a collision course with a VRU at an intersection. This detection method passively locates the VRU mobile wi-fi signal and presents a significant benefit as minimal roadside infrastructure is required to provide this road safety enhancement.

ii. Alerting vulnerable road users

An application of V2P communication at the forefront of discussion is a smart phone application which alerts vulnerable road users when crossing an intersection. Tahmasbi-Sarvestani et al. (2017) developed and analysed a DSRC-enabled smart phone application which acted to alert vehicles when a potential collision may occur. The application functioned effectively as a beacon, communicating the location, direction, and speed of the vulnerable road user to the vehicle, and warning the driver if a collision was likely. Their evaluation found that While the technology theoretically functioned correctly, there were many challenges and drawbacks that may hinder the overall effectiveness of the application, such as network congestion, energy (battery) use, and security.

c. Infrastructure and Environment Awareness

i. Road Geometry Awareness

Curve Speed Warning (CSW) aims to address *single vehicle crashes* associated with excessive speed in the negotiation of highway 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 (Logan, Young, Allen, & Horberry, 2017) provided an estimated 19-29% effectiveness range for the use of CSW with human intervention.

ii. Intersection Awareness

Signalised crosswalk awareness messages alert drivers of the potential presence of a pedestrian at an upcoming intersection/crosswalk. Such awareness has the potential to reduce the number of road safety incidents involving vulnerable road users at crossings. The Towards Zero CAV trials conducted by

Telstra successfully demonstrated the ability for road infrastructure to communicate with vehicles concerning the presence of crossing pedestrians or bicycles at an upcoming intersection.

iii. Hazard Awareness

Hazard awareness messages are targeted at increasing the information available to the driver about their surroundings, including static factors which have the potential to cause road safety incidents. Examples of this include roadwork ahead warnings, level crossing ahead warnings, and weather warnings, communicated by surrounding infrastructure or other vehicles to the driver.

iv. In-Vehicle Signage

An additional capability for C-ITS communications is the enhancement to existing driver assist in-vehicle signage. Traditionally, in-vehicle signage relies on in-vehicle database and GPS to inform drivers about excessive speed or upcoming hazards (see 3.c.iii Hazard Awareness above). With vehicle connectivity, this function can be enhanced by providing drivers with real-time and up to date information about active, static, and variable speed limits as well as an alert if they are exceeding the limit.

4. Roadmap to Deployment

For this study, we considered the European Roadmap to Deployment (Car 2 Car Communication Consortium, 2019), which assists in considering C-ITS deployment stages despite the differing policy environments worldwide. A summarised version of this framework is shown Table 2; this deployment roadmap demonstrates a potential model for achieving cooperative automated driving with the objective of accident-free road transport; possible applications and references to potential use cases have been given in section 3.

The two types of safety messages, awareness and warnings, are reflected in the timeframe of the deployment model (Table 3), where the types of potential use cases on “Day 1” are expected to be for awareness purposes, while the use cases in “Days 2 and 3+” provide more time-critical and safety-specific warnings. The roadmap 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), 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.

Table 2: European Roadmap to Deployment: Expected Services and Use Cases (Car 2 Car Communication Consortium, 2019)

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
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; Coordination/negotiation; and VRU active advertisement	Manoeuvre Coordination Message (MCM); and Platooning Control Message (PCM)	• Vulnerable Road User protection/ Pedestrian Safety Messages

5. Victorian Road Safety Data Analysis

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 on the crash record open source database from the Victorian Government (Vicroads, 2020). 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. We analysed basic statistics for crashes in the state of Victoria, including crash severity by different crash types, modes, and regions. Selecting a set of dominant C-ITS communication technologies use cases that have been trialled for crash reduction benefits, both nationally and internationally, we estimated the addressable market for each use case to understand the scale of potential impacts associated with each use case of the technology.

a. Overview of Victorian Crash Data

VicRoads (2013) 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 subcategories based on VicRoads' DCA coding (Vicroads, 2013).

Table 3: Crash types by classification and severity of injury (Victoria, 2006-2019)

DCA Code	Crash Type	Fatal	Serious Injury	Other Injury	Total
110	Cross traffic	161	4,042	8,631	*12,834*
120	Head on - not overtaking	518	2,980	2,583	*6,081*
150-159	Head on - overtaking	101	820	1,115	*2,036*
180-184	Off path on curve	532	5,930	6,961	*13,423*
170-179	Off path on straight	927	15,357	18,660	*34,944*
100-109	Pedestrian	554	7,454	9,821	*17,829*
130-132	Rear end	151	7,615	27,107	*34,873*
121	Right turn against	128	5,609	10,487	*16,224*
113	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**

Table 3 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 category. Out of the total 186,546 crashes between 2006 to 2019, 3,528 were fatal, 64,904 lead to serious injuries, and another 118,114 crashes lead to other injuries.

Further investigation was conducted into crash variables including road lighting conditions, geometry, geographic region, speed zone, and the types of vehicles involved in crashes. Data suggested that each type of road user is prone to a certain set of crash classifications which were not necessarily similar across the modes of transport involved and geographic location. We expect that a diverse set of C-ITS communication use cases can potentially lead to most extensive crash reductions with distributed benefits over all transport modes and both in Melbourne Metropolitan area and rural/remote regions.

b. C-ITS Applications

We investigated eight of the use cases presented in the European Roadmap to Deployment (Table 2). The selection of connected applications is an important consideration; the deployment of applications that avoid crashes is critically important for safety improvement, but crash warnings will be rare events. The first use cases assessed was Lane Keep Assist; this is an ADAS-only application – all the following use cases are an improvement on ADAS functionality 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. The other seven cases considered are: 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

(PSMs). Table 4 details the specific Victorian road safety incident classifications (DCA codes) that we expect these use cases can address and notes the expected timeframe for deployment.

Table 4: Types of incidents (DCA codes) that can be addressed by road safety use cases

Deployment and Use Case		**Type of crash addressed (DCA codes)**
ADAS	Lane Keep Assist (LKA)	133, 170, 171, 172, 173
Day 1	Curve Speed Warning (CSW)	180, 181, 182, 183, 184, 189
2	Cooperative Forward Collision Warning	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)	134, 135, 136, 137, 142, 147, 154
3+	Pedestrian Safety Messages (PSMs)	100, 101, 102, 103, 104, 105, 106, 107, 108, 109

Assuming the crashes classified above could potentially be addressed by the use cases presented, we examined the expected proportion of road safety incidents that could be addressed (i.e. reduced) based on several factors including the severity of injury, geographic region, and type of vehicle involved.

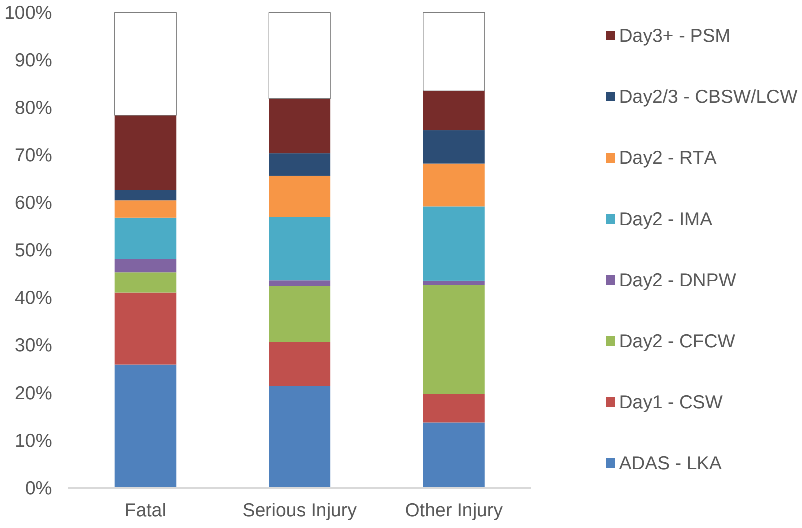

Figure 1. Proportion of crashes that specific use cases can address by severity

Under a 100% market penetration scenario, and assuming all necessary infrastructure is available for C-ITS, we identify the following. Approximately 80% of all crashes, for all levels of injury can be addressed by the eight use cases presented; specifically, 78% of fatal crashes, 82% of serious injury crashes, and 84% of other injury crashes can be addressed (Figure 1). 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, LKA functions have the potential to prevent the highest proportion of fatal incidents.

When C-ITS deployment reaches Day 2, more than 60% of all incidents have the potential to be addressed from the use cases considered. The ability for vehicles to provide IMA and CFCW could assist in reducing a significant portion of serious and other injury crashes on Victorian roads.

Meanwhile, the Day 1 use case, curve speed warning, is expected to have the potential to address 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 at 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. PSMs 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. Fatal pedestrian injuries were observed to be most prevalent in higher density metropolitan areas, thus, use cases addressing crashes involving pedestrians are an important avenue of investigation.

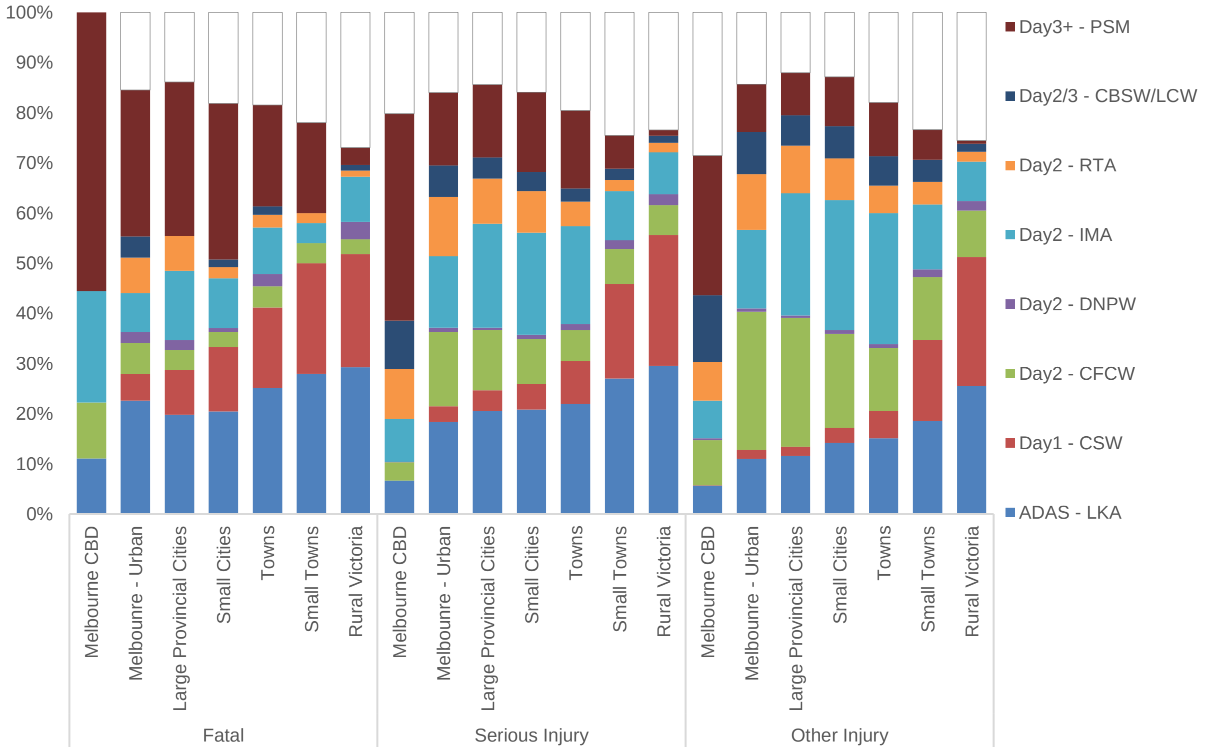

Figure 2 Proportion of crashes that specific use cases can address by severity and geographic region

The uptake of ADAS-only technology, specifically LKA functions, has significant potential in addressing road incidents across all areas; this potential increases with decreasing urban density for all injury types (Figure 2). That is, high density areas like Melbourne Central Business District (CBD) 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 CSW applications – locations with decreased urban density have the greatest potential to benefit from this use case.

We observe a reverse trend for the use of IMA (Day 2) and PSMs (Day 3+), with an increase in ability to address crashes in higher density urban environments. A significant proportion of fatal and serious injury crashes occur in increasingly dense and urban environments. Notably, PSMs 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 they have limited potential in addressing fatal crashes.

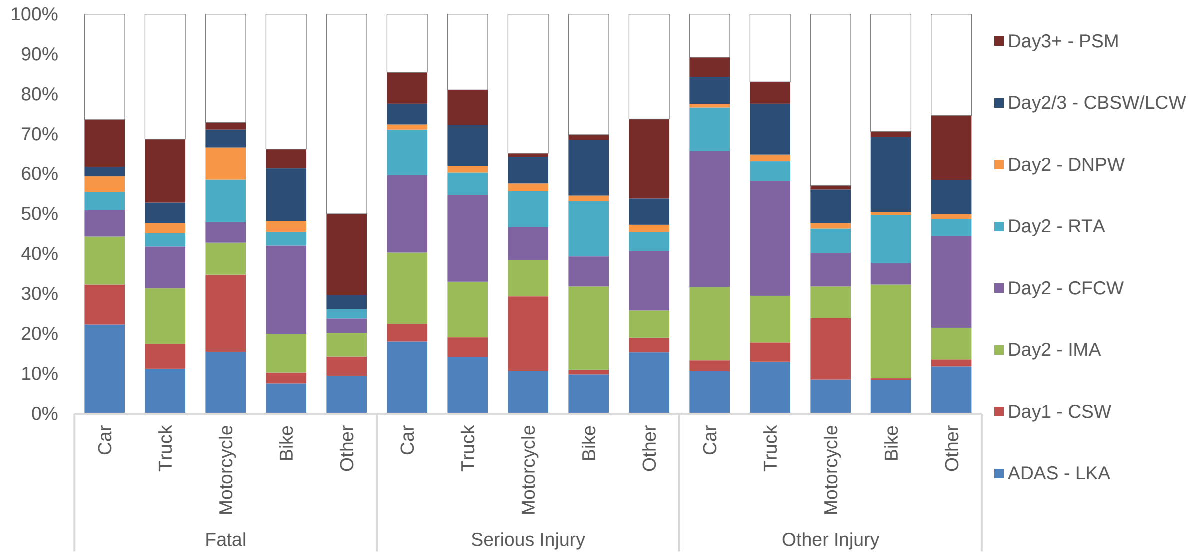

Figure 3 Proportion of vehicles involved in crashes that specific use cases can reduce by severity and vehicle type

As noted above, LKA has significant potential to address crashes in all geographic areas, particularly for incidents 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 except for PSMs. 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 the number of crashes that involve cars and trucks (Figure 3). However, approximately 20% of fatal incidents involving bikes could also be addressed by CFCW – this is consistent with a preliminary data analysis finding that the leading deadly crash type for bikes is rear-end crashes.

On Day 1, CSW is most applicable for motorcycle crashes for all severities. As the deployment timeline progresses to Day 2, we observe IMA to have a similar potential to CSW in reducing the number of crashes across all vehicle types and injury levels. A similar trend is also observed for RTA (LTA in left-driving countries), although for a smaller percentage of incidents. Day 2/3 CBSW/LCW is more relevant in addressing incidents involving bikes and trucks. For Day 3+ applications, PSMs are observed to have the greatest potential for incidents involving cars, trucks, and ‘other’ modes.

While there is a capability for ADAS-only LKA and Day 1 CSW to address a large proportion of crashes in Victoria, our analysis shows that these use cases are more applicable in 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 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. Overall, the eight use cases considered have also been studied in other literature, trials, and simulations. Under a 100% market penetration scenario, and assuming all necessary infrastructure is available, C-ITS has the potential to address approximately 80% of all crashes on Victorian roads. This result is likely applicable not only to other states and areas of Australia, but also to other countries.

6. Conclusion

This paper provides an overview of C-ITS communication technology and the state of development and deployment around the world. Connected applications, or use cases, represent a vast field; a useful classification scheme has been presented by the US DOT. In addition, the framework presented by the European Roadmap to Deployment presents a broader view of the field, with added information on likely sequencing and progression of the technologies. Both frameworks make an important distinction between use cases that 1) promote awareness of potential safety issues in the vicinity of the host vehicle and 2) generate warnings of specific crash-related risks. Under such schemes, awareness messaging benefits can be realised at low penetration rates, while sensing and cooperative driving applications require higher rates of penetration for benefits to be realised. Additional factors associated with technology deployment include network coverage, where rural and remote areas may require significant infrastructure investment in order to provide adequate coverage for cellular connectivity applications.

A comprehensive analysis of Victorian Road Safety data from Australia indicated that eight major connected safety use cases: Lane Keep Assist, Curve Speed Warning, Cooperative Forward Collision Warning, Do Not Pass Warning, Intersection Movement Assist, Right Turn Assist, Cooperative Blind Spot Warning, and Pedestrian Safety Messages have the capability to address approximately 80% of crashes on Victorian roads; specifically 78% of fatal crashes, 82% of serious injury crashes, and 84% of other injury crashes could be addressed. While these results are specific to Victoria, we expect similar outcomes both nationally and globally. Use case benefits were found to be unevenly distributed amongst different cohorts of road users and across different driving environments. While use cases at lower levels of connectivity and penetration (i.e. ADAS-only and Day 1) have the potential to address a significant share of crashes, there is clearly a need to consider pathways towards implementing Day 2 to 3+ use cases when benefits are expected to be seen across all geographic regions and modes.

This analysis assumed a 100% market penetration scenario, and that necessary infrastructure is available for C-ITS. Further work could be undertaken to determine the effectiveness of C-ITS technology at lower levels of penetration to determine if benefits exist earlier in deployment. Both stakeholders and the literature agree that there are many challenges that need to be addressed. Despite these issues, C-ITS technology, deployed in vehicles at both the OEM and aftermarket levels, presents an exciting opportunity to improve road safety outcomes, both in the state-level Victorian data investigated, as well as at a national and global scale.

Acknowledgements

This research was funded and supported by iMOVE CRC, an Australian Government initiative, as well as the Australian Department of Infrastructure, Transport, Regional Development and Communications (DITRDC), ITS Australia, and the University of Melbourne. We also recognise the support and expertise provided by Insurance Australia Group, Intelematics, and Transmax.

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