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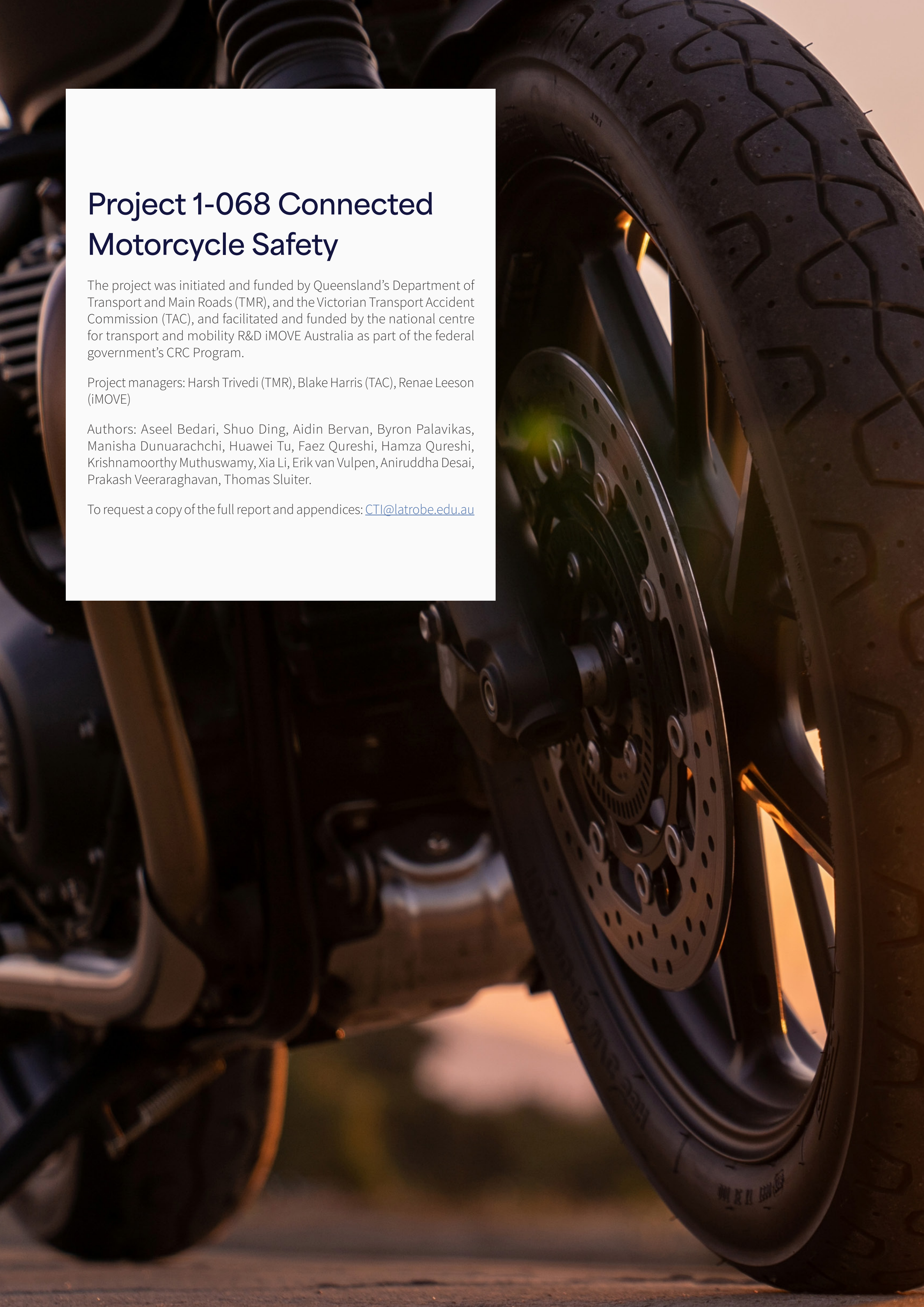

Project 1-068 Connected Motorcycle Safety

The project was initiated and funded by Queensland's Department of Transport and Main Roads (TMR), and the Victorian Transport Accident Commission (TAC), and facilitated and funded by the national centre for transport and mobility R&D iMOVE Australia as part of the federal government's CRC Program.

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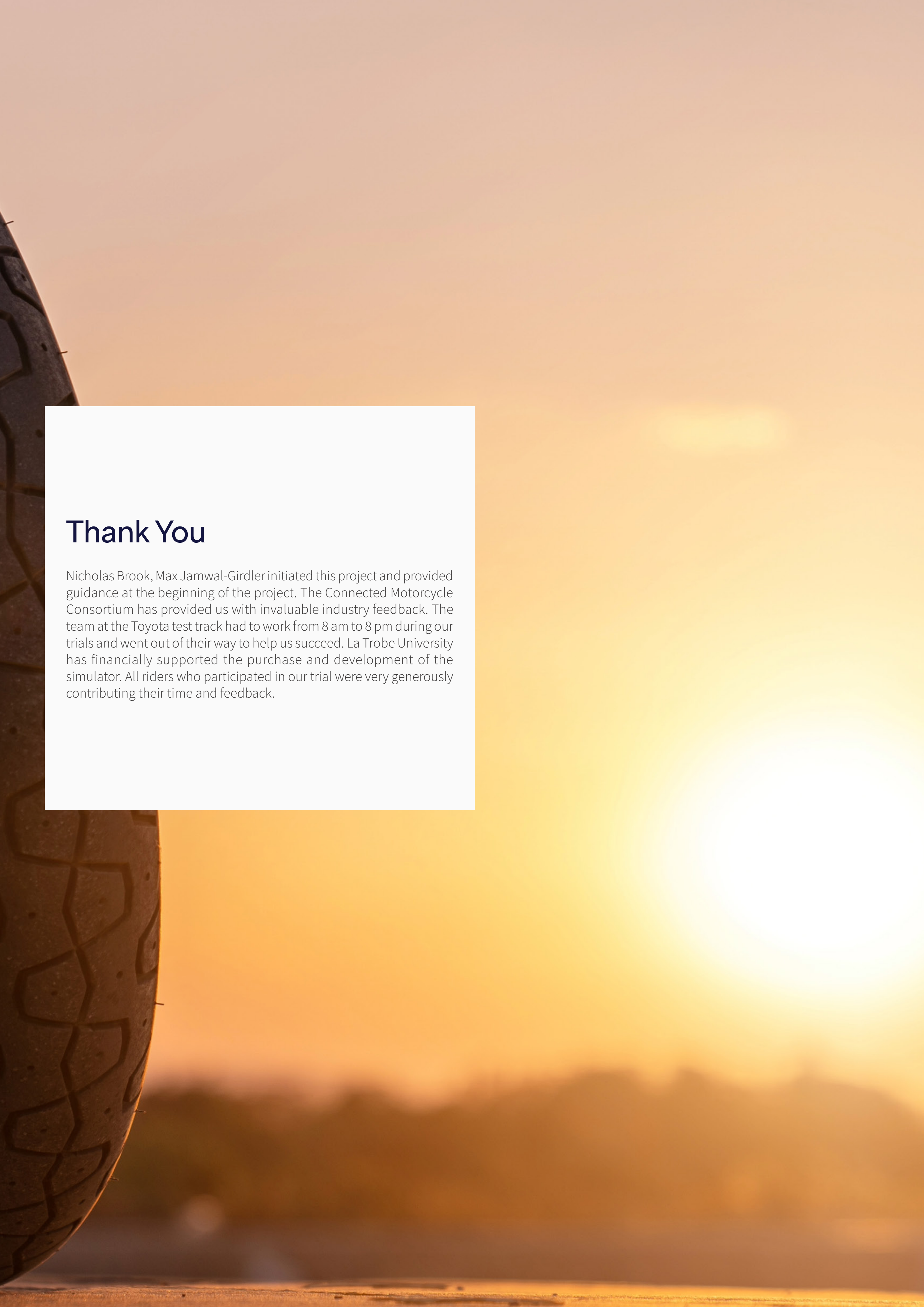


Thank You

Nicholas Brook, Max Jamwal-Girdler initiated this project and provided guidance at the beginning of the project. The Connected Motorcycle Consortium has provided us with invaluable industry feedback. The team at the Toyota test track had to work from 8 am to 8 pm during our trials and went out of their way to help us succeed. La Trobe University has financially supported the purchase and development of the simulator. All riders who participated in our trial were very generously contributing their time and feedback.

Executive Summary

Motorcyclists face the highest fatality rate of any motorised road user group in Australia, representing 20% of road deaths[1] despite accounting for just 0.7% of kilometres travelled[2] . In 2024, 278 riders lost their lives, making it the deadliest year since 1989[3].

Despite major advances in vehicle safety and intelligent transport systems (ITS), motorcycle safety has largely been left behind. For example, while the Ipswich Connected Vehicle Pilot has demonstrated the safety benefits of C-ITS for cars, heavy vehicles and infrastructure, motorcycles were not included (Department of Transport and Main Roads [Queensland], 2024). This project set out to answer three critical questions:

1. Is Cooperative Intelligent Transport Systems (C-ITS) for motorcycles technically feasible?
2. Do riders want it?
3. Is it effective: does it help riders react earlier?

We worked with the rider community from the outset, co-designing and testing how best to deliver warnings to riders. We co-developed warnings for smart glasses, smart-helmet sound and visual alerts, haptic wristbands, a dashboard design and LEDs on mirrors. Riders were clear: alerts must be intuitive and not distract from the riding experience. As many participants said: "Just tell me where the danger is, then I'll deal with it."

To test safely, we developed a motorcycle simulator designed for riding on the left-hand side of the road, integrating CARLA open-source software, a Simumak mechanical motorcycle simulator, and Cohda MK6 hardware. We used it for prototyping and trials with 150 riders. We then equipped real motorcycles with C-ITS and conducted live track testing at Toyota's proving ground with close to 100 riders.

Our findings show strong potential for low-effort, high-impact safety warnings, such as road surface alerts, work zone notifications, and other Infrastructure-to-Vehicle (I2V) messages. Riders started reacting to a dangerous curve 16 meters earlier when warned about it.

Vehicle to Vehicle (V2V) use cases, such as intersection assist warnings equally show significant potential to improve safety. At intersections where hazards such as oncoming cars were blocked from vision, reaction distances improved from just 15 metres without warnings to over 30 metres with them. In forward collision scenarios at 50 km/h, C-ITS extended the reaction distance by 8.5 metres, which is almost two car lengths.

Rider acceptance improved significantly throughout the trials. Initially sceptical, riders became more supportive after experiencing the technology firsthand. Even risk-tolerant riders, who are typically less interested in safety tech, identified specific use cases (e.g. intersection assist, rough surface alerts) as helpful.

Based on these insights, our recommendations include:

1. Given the elevated risk and demonstrated benefits to riders, motorcycles should be considered in all C-ITS ecosystem developments.
2. Governments can accelerate impact by establishing a nationally accessible database of known hazards—such as dangerous curves, roadworks, and black spots—that navigation apps and connected vehicle systems can draw from to deliver consistent warnings to riders.
3. Motorcycle manufacturers can accelerate the integration of collision avoidance technologies and support Bluetooth-based interoperability with third-party wearable Human Machine Interfaces (HMIs). These steps lay a practical foundation for broader C-ITS adoption.
4. Collaboration with the car industry could establish the added value of C-ITS in collision avoidance of motorcycles compared to other technologies (and raise motorcycle awareness among drivers at the same time).
5. Standardised Application Programming Interfaces (APIs) and open communication protocols should be adopted to support compatibility between factory-fitted systems, aftermarket solutions, and rider-preferred devices, enabling a diverse but connected ecosystem.
6. Smart algorithms using AI and edge computing can be co-developed across the industry, in line with the current collaboration on standards. This can ensure a shared understanding of complex traffic scenarios, reduce duplicated effort, and support consistent warning logic across different platforms for the greater good.

The rider community is ready, especially when included as partners in development. With collaborative design and smart deployment of existing technologies, the future of motorcycle safety can begin today.

Hear from the riders themselves:

[1] Australian Road Deaths Database
[2] ABS Statistics
[3] Australian Automobile Association

Contents

1.

Introduction

1.1 Background

Motorcyclists are among the most vulnerable road users, with significantly higher fatality and injury rates per kilometre travelled than car occupants—the highest risk among all motorised vehicle users. Motorcyclists face the highest fatality rate of any motorised road user group in Australia, representing 20% of road deaths[4] despite accounting for just 0.7% of kilometres travelled[5]. In 2024, 278 riders lost their lives, a 10.3% increase from 252 deaths in 2023, making it the deadliest year since 1989[6].

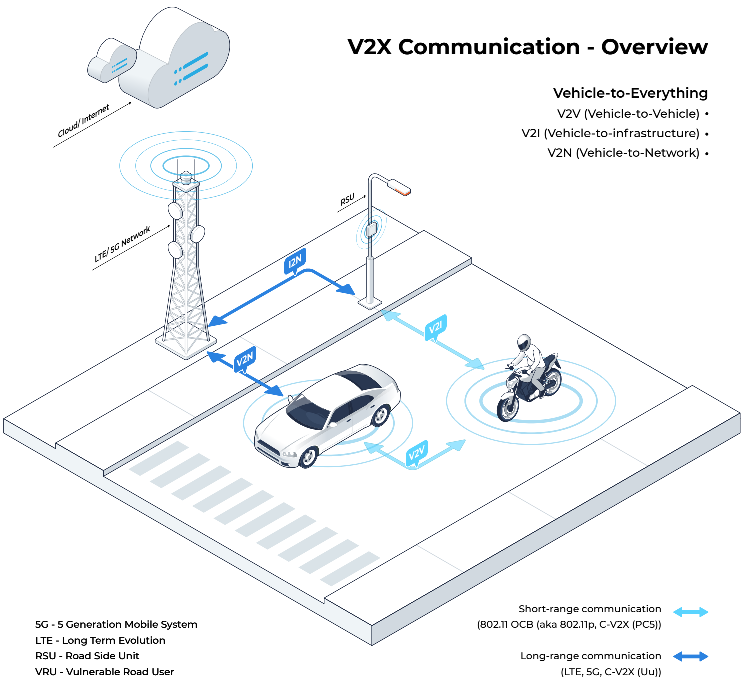
Motorcyclists are overrepresented in fatal crashes yet rarely included in connected vehicle research. With this project, we set out to change that.

This project builds on the success of the Ipswich Connected Vehicle Pilot (ICVP), which tested C-ITS in 355 cars. It showed that connected technology could improve road safety in real-world conditions.

The Queensland Department of Transport and Main Roads (TMR) decided to extend this work to motorcycles, which face very different risks and require different solutions. TMR launched this Connected Motorcycle project in collaboration with the Transport Accident Commission (TAC), the Centre for Technology Infusion at La Trobe University, and iMOVE CRC.

[4] Australian Road Deaths Database
[5] ABS Statistics
[6] Australian Automobile Association

Figure 1. C-ITS basic concepts



1.2 What is C-ITS?

Cooperative Intelligent Transport Systems (C-ITS) uses wireless technology to connect vehicles with each other and with roadside infrastructure. It allows real-time sharing of safety-critical data, enabling drivers and riders to detect hazards that might be outside their line of sight, such as a car running a red light, or a crash ahead around a bend.

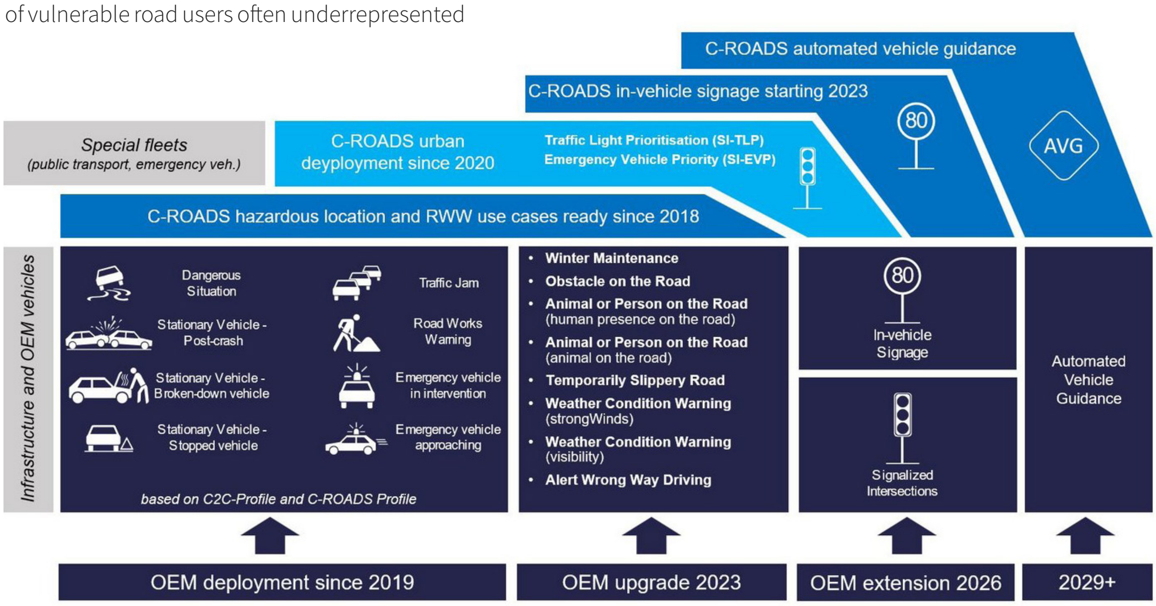
There are two types of C-ITS messages: short-range communication (for immediate safety alerts) and long-range communication (for broader efficiency and service improvements). Unlike onboard cameras or Light Detection and Ranging (LiDAR), C-ITS can detect dangers that are hidden from view.

For a deep dive into the technology please see [this report] which we created for the Australian Government.

C-ITS can increase rider safety in two ways: by alerting riders about road hazards and by making nearby road users aware of the presence of motorcycles.

Our connected motorcycle project builds on the foundational work of the Car2Car consortium. As an example, we leveraged algorithms and standards from the European C-Roads Platform, which aims to harmonise C-ITS deployment across Europe. While C-Roads has primarily focused on passenger vehicles, our initiative extends these efforts by adapting C-ITS technologies specifically for motorcycles, a group of vulnerable road users often underrepresented in such programs.

Figure 2. C-Roads roadmap
Source: Adapted from V2X on Europe's roads: The future or already a reality? by Vector, n.d. Retrieved from https://www.vector.com/cn/zh/news/news/v2x-on-europes-roads-the-future-or-already-a-reality/



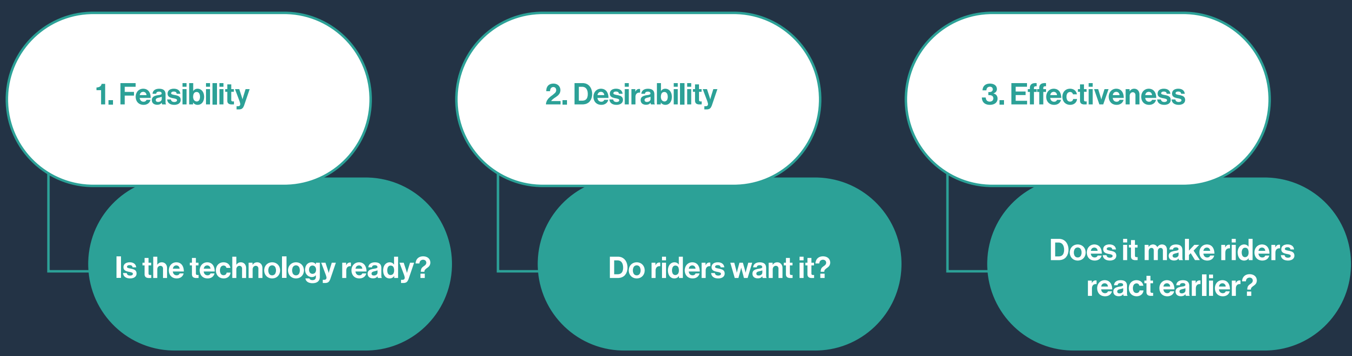
2. Objectives

While carmakers have been trialling C-ITS for almost two decades, most of that work has not included motorcycles. Even the Connected Motorcycle Consortium (CMC), a collaboration between manufacturers including BMW, Honda, Ducati, Suzuki, KTM, and Yamaha, only began in 2016.

Our project was the first globally to apply C-ITS at this scale to motorcycle-specific safety challenges and test it with regular motorcycle riders. We wanted to:

- Test whether the technology works for motorcycles.
- Understand if riders want these warning, and if yes, what kind of warnings riders want and how they prefer them to be delivered.
- Test whether the technology improves rider safety. Does it enable riders to make earlier decisions in reaction to potential hazards?

Figure 3. Project objectives



Learning from the prolonged adoption of Anti-lock Braking Systems (ABS) in Australia, our project team aimed to accelerate the integration of C-ITS for motorcycles. ABS technology was extended to motorcycles in 1988 when BMW introduced it on the K100 model, enhancing rider safety by preventing wheel lock-up during braking. But only in November 2019 did ABS become mandatory for new motorcycles over 125cc, and widespread adoption took many years, leaving many riders without this critical safety feature.

This project pro-actively engaged with riders, industry partners, and regulators to ensure that life-saving C-ITS technologies are embraced without similar delays.

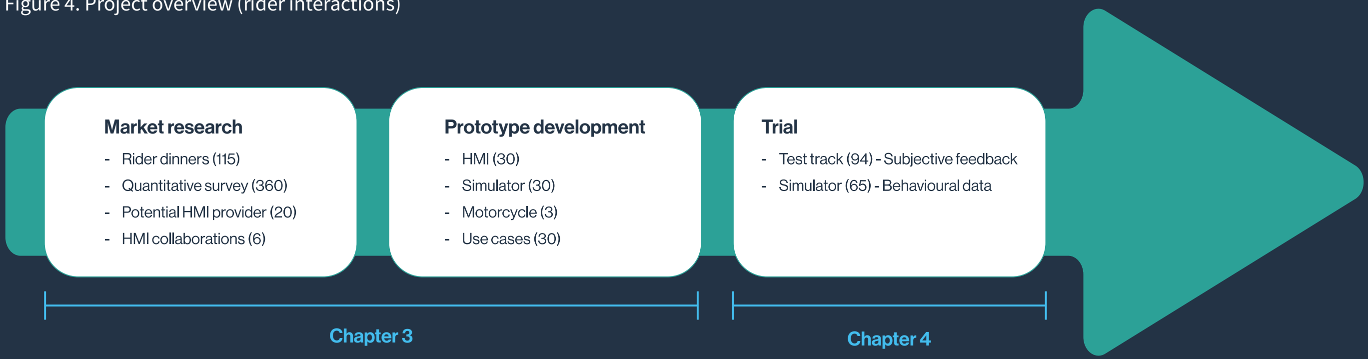
3. Project design

We designed this project in three phases. We first conducted market research to understand baseline perceptions of riders and the industry landscape. In the second phase we collaborated with riders and industry to develop prototypes and our test methods. These prototypes were trialled on the Toyota test track, and our simulator, in the third phase.

The test track focused on the real riding experience and riders' subjective feedback: does the system integrate into the riding experience? The simulator trials focused on the behaviour of the riders: Do riders have more time to react to a hazard because of the C-ITS warnings?

This chapter covers the market research and prototype development. The trial Feasibility, Desirability and Effectiveness will be discussed in chapter 4.

Figure 4. Project overview (rider interactions)

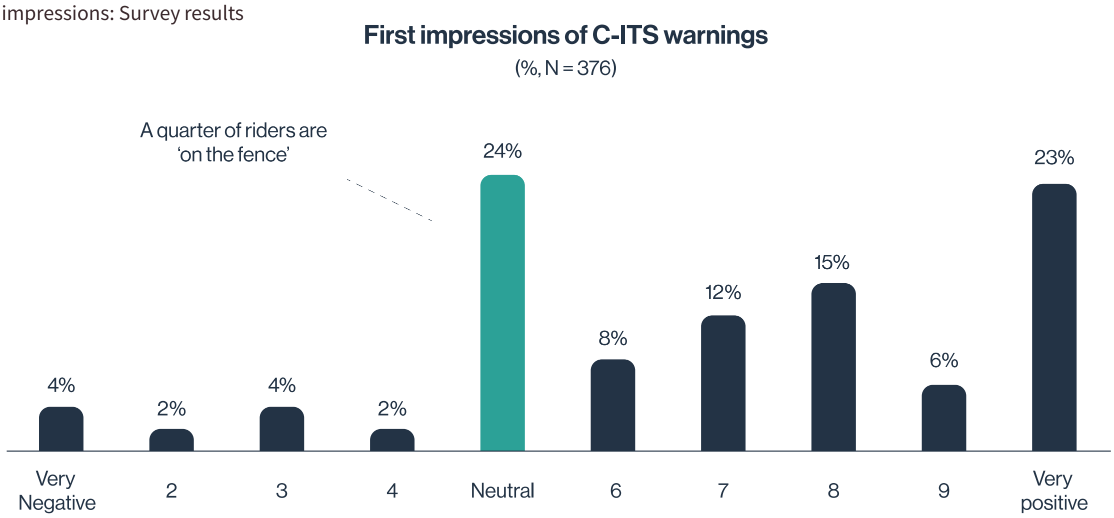


3.1 Rider engagement: Establishing a baseline

We knew that rider collaboration was going to be the key to success, so we started by engaging riders. We hosted dinners for riding groups in Queensland and Victoria. The informal gatherings gave us a clear picture of how riders think about safety, what makes them feel vulnerable, and how they respond to external alerts. We asked how they thought warnings should be delivered. We listened carefully to their preferences around audio, visual, and tactile feedback, as well as how much information is too much when you are balancing, shifting, and scanning traffic simultaneously. Riders told us not just what they feared, but what helped them stay focused and what they thought of the concept of C-ITS. This helped us verify assumptions and ensure that the solutions were rider-driven from day one.

We also conducted an online survey, distributed with the help of the TAC's newsletter 'Spokes', that generated 376 responses from all kinds of riders. Figure 5 shows that most riders were open to the concept of C-ITS, but a quarter of riders was 'on the fence' when they were first introduced to it.

Figure 5. First impressions: Survey results



Concerns

We wanted to understand why riders were neutral or negative and to see how we might change their mindset. The reasons for being neutral or negative could be grouped into seven themes as shown in Table 1. We decided to focus on the first three reasons in the subsequent co-development of the use cases and warning delivery.

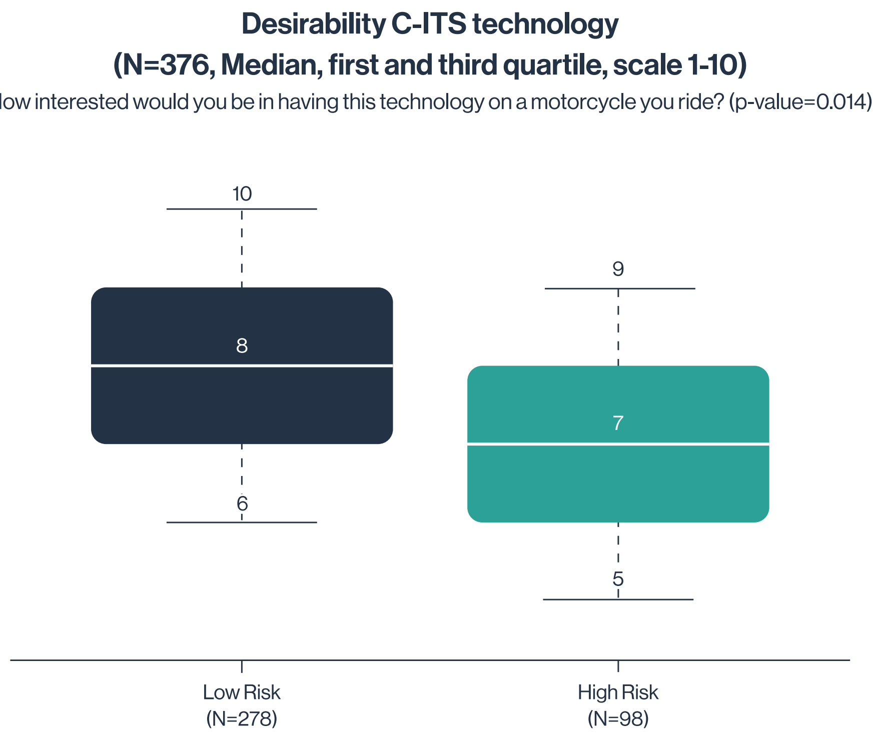
Table 1. Factors that influence C-ITS adoption

Theme	Concerns
1. Reliability of warnings	• Riders were concerned about false alarms or missed hazards. • Some questioned whether alerts would arrive early enough to be useful. • Worries about technical or connectivity issues affecting warning reliability.
2. Usefulness of Warning	• Warnings for obvious or routine situations (e.g. known bends, slow traffic) were seen as unnecessary.
3. Integration with Riding Experience: Distraction	• Riders were wary of anything that disrupted focus or added unwanted hardware. • Alerts should blend seamlessly into the riding experience.
4. Customisation	• Riders wanted warnings that adapt to their riding style or preferences (e.g. 'conservative' vs 'aggressive'). • Control over which warnings were active and how they were delivered (e.g. brightness, sound, vibration).
5. Dependency and Skill Erosion	• Some feared over-reliance could reduce situational awareness. • Long-term use might erode core riding skills.
6. Cost and Accessibility	• Cost was a concern, especially for non-premium or older bikes.
7. Privacy and Data Use	• Concerns about how data might be stored or used, particularly when connected to government systems.

Segments

From the start, self-proclaimed risky riders were less interested in the technology, scoring significantly lower on the question if they wanted the technology on their bike when it would become available.

Figure 6. Desirability: Risky riders vs. the rest

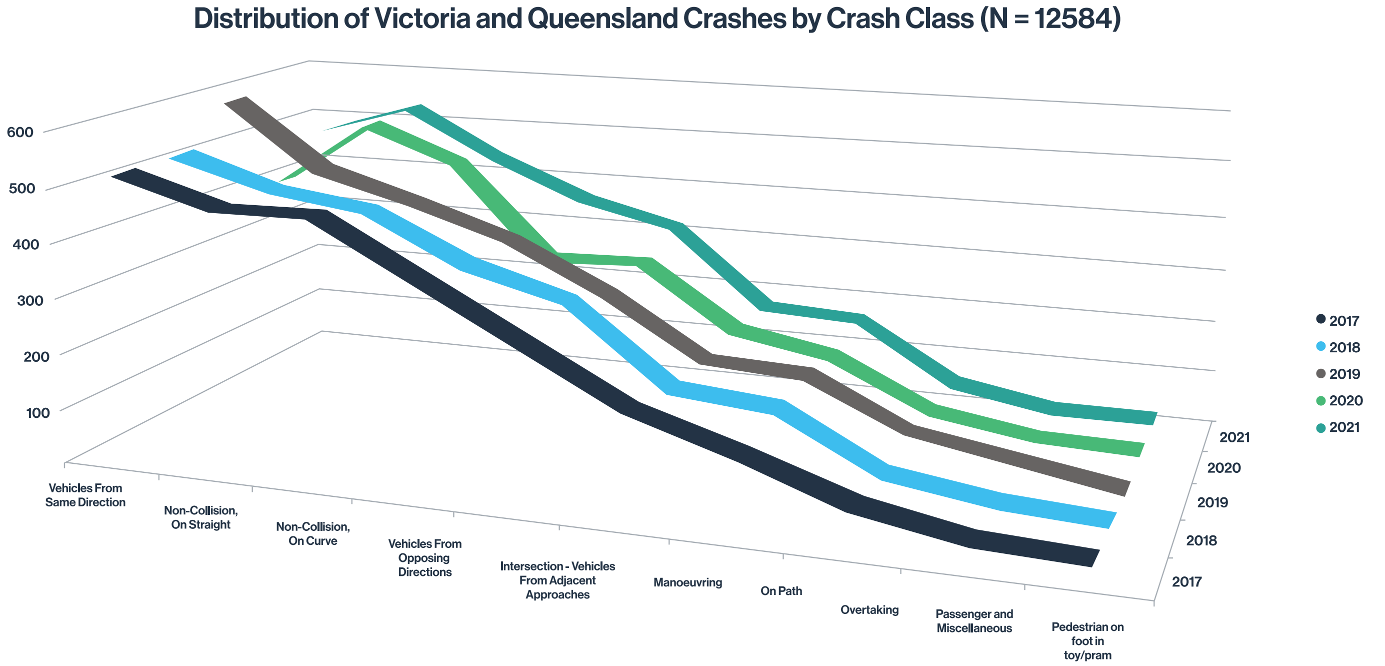


Over the course of the project, we maintained focus on these 'risky' riders: If we could address the concerns of the most critical riders, we would also meet the needs of the other riders. These insights helped improve the prototypes and understand the potential barriers we could face in our upcoming trials.

3.2 Prioritizing use cases: Accidentology

We analysed five years of motorcycle crash data in Victoria and ten years in Queensland; this data is collected by the police for the purpose of the RoadCrash database and reporting. Figure 7 shows a consistent pattern in crash types over time, indicating that the same classes of crashes recur year after year. This consistency suggests that if C-ITS technologies can reduce the incidence of these specific crash types, the impact is likely to be sustained over the long term.

Figure 7. Queensland and Victorian Crash Data (Crashes causing fatal and serious injury only) 2017 - 2021



Causation

In Queensland, the cause of a crash is recorded. A vehicle involved in a road traffic crash is considered "at fault" when determined as "most at fault" through a police assessment. We looked at 10 years of Queensland crash data (Figure 8). A high number of Motorcycles crashes do not involve other vehicles. But at intersections, this is not the case. It is more likely that crashes are caused by cars not seeing the rider. Figure 8 shows motorcycle crash categories and the administered causation. C-ITS can help both ways: by helping riders to see and to be seen by other road users.

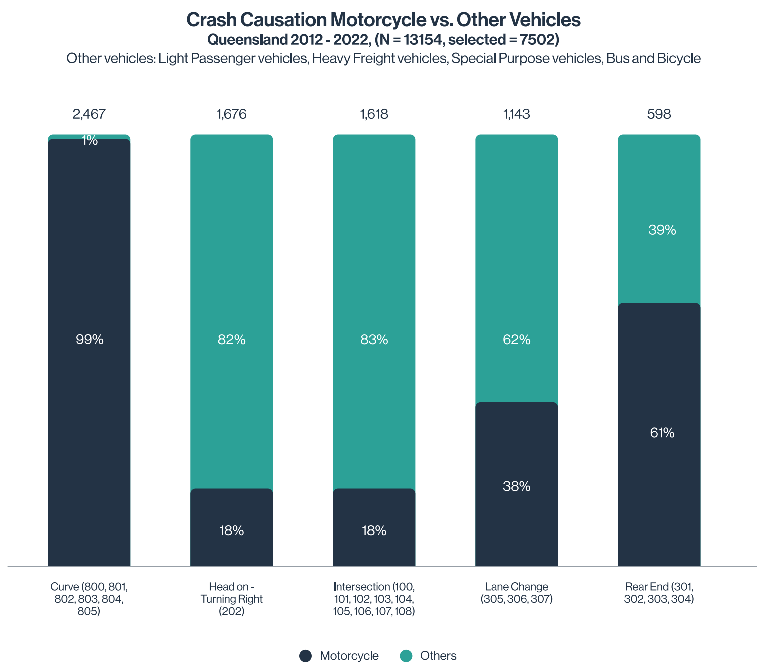
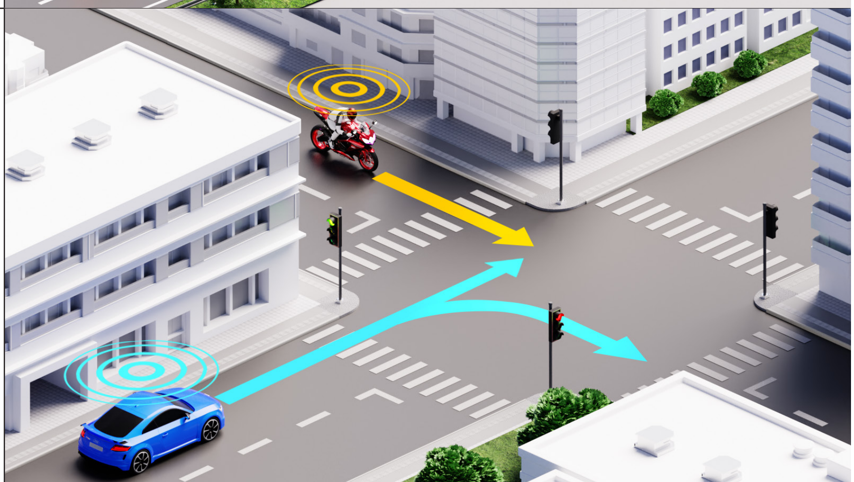


Figure 8. Crash causation (selected Definitions for Classifying Accidents Codes)

Use Cases

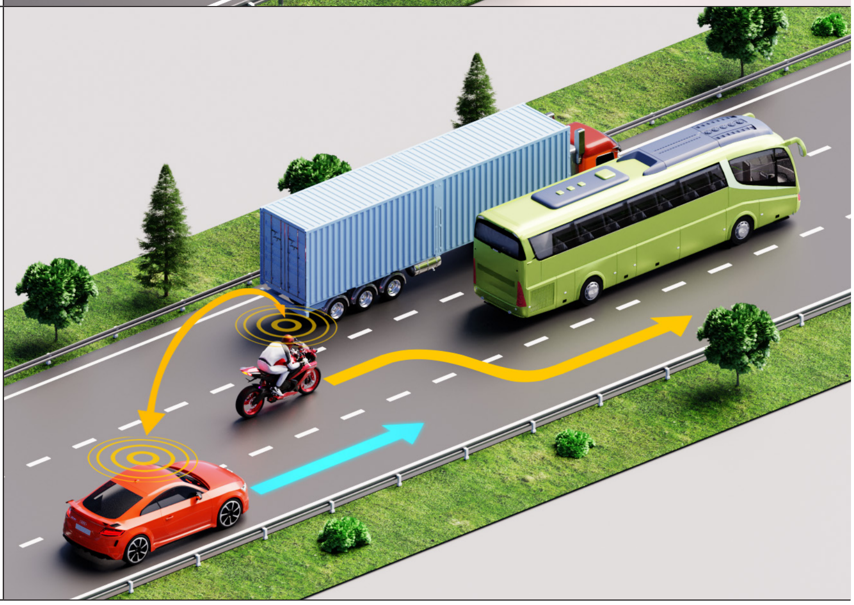
Based on these crash data, the engagements with riders and the survey results, we focused on five use cases (see Table 2):

Table 2. Priority Use Cases

Priority Use Cases	
Forward Collision Warning (FCW) *Frequent cause of crashes*	
Intersection Movement Assist (IMA) *Frequent cause of crashes*	
Dangerous Curve Warning (DCW) *Frequent cause of crashes*	

Change of Road Surface warning (CRSW)
High appeal with riders

Lane Change Assistance (LCA) / Blind Spot Warning (BCW)
Testing technical feasibility



These use cases represented not only the high frequency causes of crashes but also use cases we knew would appeal to riders (road surface) and would enable us to test the technological readiness (lane change).

3.3 Exploring warning delivery options

To create an intuitive experience and to integrate warnings with the riding experience, we invested significant effort in market research, industry engagement and the development of HMIs. We engaged with more than 20 global and Australian vendors of potential HMI devices. We collaborated with six to have their products deliver C-ITS warnings. We prototyped smart helmets, smartphone apps, LED mirrors, audio alerts, a dashboard alert, smart glasses and haptic wristbands (see Figure 9).

Figure 9. Prototyped HMIs

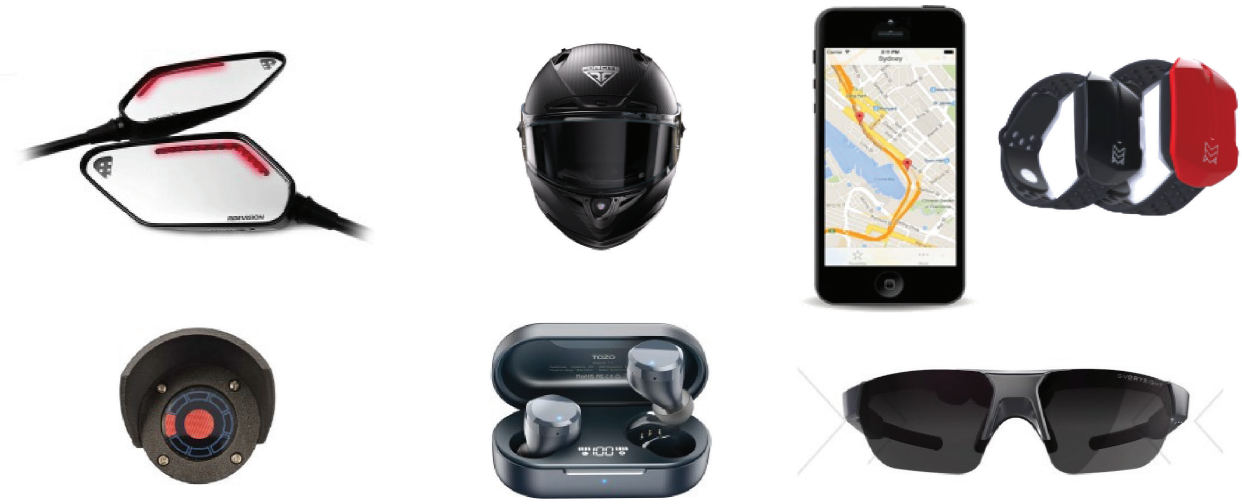


Table 3 shows the HMI devices tested in this project and their function.

Table 3 HMIs

Device	Function
Standard LEDs	LEDs on top of the dashboard indicated danger (left or right) ahead; LEDs on the mirrors alerted the rider about hazards approaching from the rear of the rider.
Dashboard Visuals	Displayed eight directional cues with urgency indication, helping riders assess hazard location and severity.
Smart Helmet Display	LED beneath the visor delivered warnings in the rider's lower peripheral vision.
Audio Warnings	Beep followed by a short voice message to capture attention and convey the location and hazard type.
Smartphone Display	Presented directional and distance-based warnings similar to the dashboard warnings.
Haptic Wristband	Delivered vibrations as tactile alerts. Mild vibration indicated caution; strong vibration indicated immediate danger.
Smart Glasses	Projected the same eight directional cues as the dashboard visuals in the corner of the view.

These devices provided us with a variety options for riders to choose from to suit individual preferences, representing key emerging technologies.

3.4 Prototyping: Warning design

Following the establishment of collaboration agreements with HMI vendors, we began working with riders to design warnings and warning icons that would fit well within the riding experience. From our rider dinners we knew that riders want to keep their eyes on the road as they need to process a lot of information. This was further emphasised when riders tried the HMIs and the initial warning designs on our simulator.

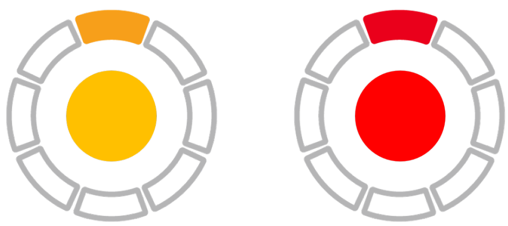
Riders highlighted several features that make a warning clear:

- **It shows where the danger is coming from.**
- **It avoids blinking or moving patterns that can be distracting.**
- **It keeps the mental effort low so riders can stay focused.**
- **It shows how urgent the warning is when needed.**

Based on this feedback, we followed one design principle for all our HMIs: Show me where the danger is, then I will solve it.

For instance, we changed our icons from being informative about the type of hazard (e.g., a symbol of a car crashing from the side) to icons that indicated the location of the hazard. The icons in Figure 10 were implemented in the dashboard, smart glasses and navigation apps in favour of informative icons. Only the auditory warnings still contained information about the hazard, like, 'vehicle from the left'.

Figure 10. C-ITS directional warning design: cautionary and imminent



This collaboration with riders helped us refine prototypes and test C-ITS warnings effectively, having credible options to evaluate.

3.5 Engaging with industry

Throughout the project, we have worked closely with the CMC, meeting fortnightly and regularly sharing insights. Their support significantly contributed to the project.

The Original Equipment Manufacturers (OEMs) have high interest in this technology which is demonstrated by active involvement in the CMC. Highlights included Ducati visits to Melbourne (Figure at the bottom); and our team visit to a global CMC workshop in Bologna in 2025 (Figure 11 Right). These in-person visits helped build relationships and sharing of insights.

Figure 11. CMC highlights

Connected Motorcycle Consortium

3.6 Creating a simulated test environment

To test dangerous road situations safely, we built a simulator. We created a motorcycle model in CARLA and integrated it with a Simumak mechanical motorcycle simulator which provides a similar experience to a normal motorcycle (see Figure 12). The Simumak simulator was chosen after a careful review of several options. Riders helped us improve the simulation experience and the use cases.

Figure 12. Simumak Carla simulation set up

In CARLA we created a virtual replica of the Toyota test track so that we would be able to make comparisons if required. But, using the CARLA simulation platform, we added buildings, fences, and parked vehicles to obscure lines of sight, intentionally hiding hazards that would otherwise be visible on the open track. This allowed us to simulate more critical scenarios compared to the test track, such as a car emerging from a blind intersection or a vehicle stopped just beyond a curve. The use cases were deliberately designed to result in a collision unless the rider took timely evasive action, enabling us to evaluate whether C-ITS warnings prompted faster, more accurate responses when riders could not rely on vision alone.

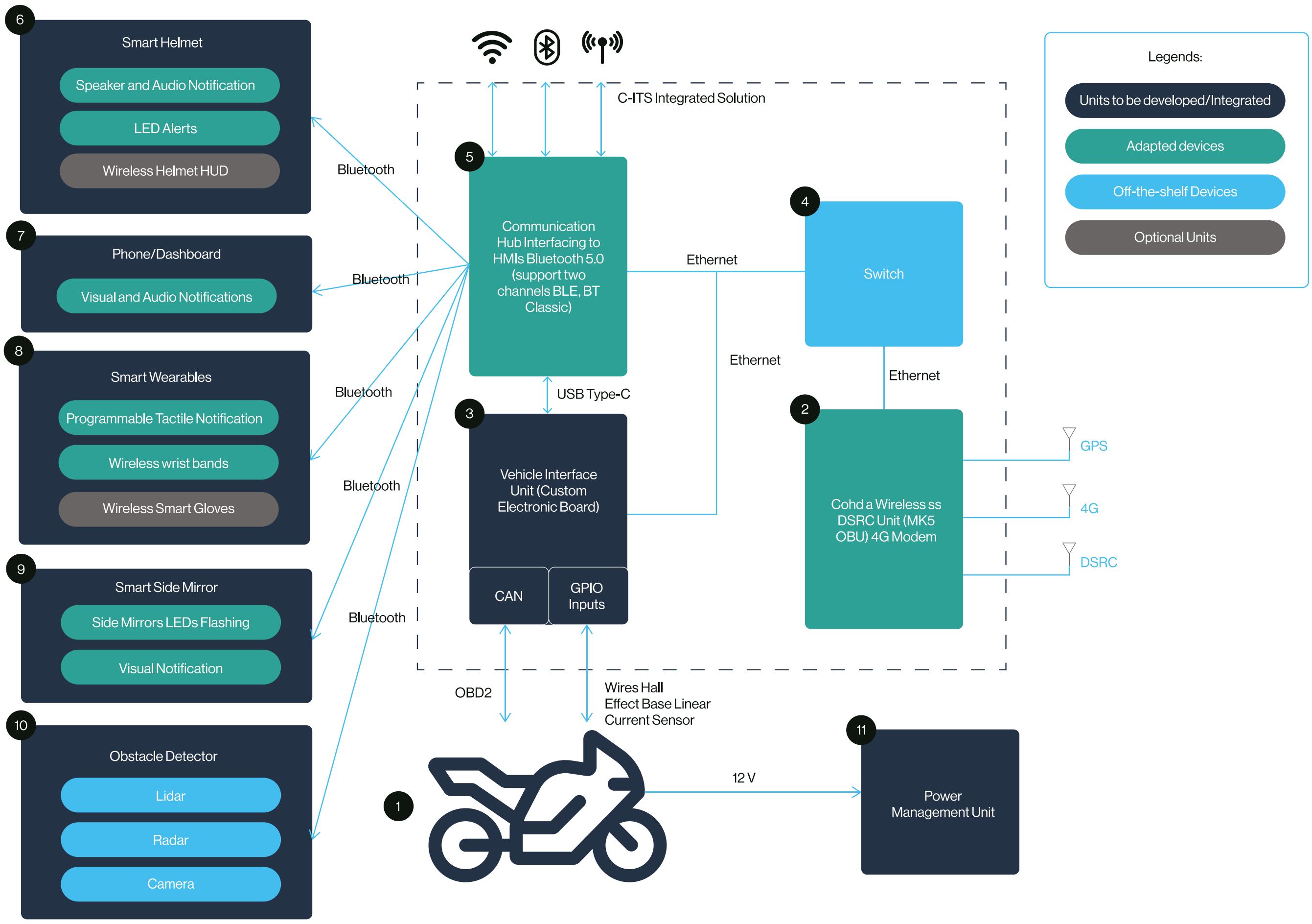
Figure 13. Use Cases in Carla simulation (note: 3rd person view, tests were in 1st person view)

3.7 Integrating C-ITS in motorcycles

To enable test-track testing, we integrated C-ITS equipment (Cohda MK6) into three motorcycles and connected the On-Board Diagnostics 2 (OBD2), which is a standardised system in vehicles that allows access to the vehicle's computer for diagnostic information and troubleshooting. We connected to the OBD2 to monitor key riding inputs such as throttle, clutch, braking, lane indication, and speed.

We built a complete C-ITS hardware system tailored specifically for motorcycles (Figure 14). The setup was compact, self-contained, and fully integrated into three test bikes.

Figure 14. Motorcycle schematic: C-ITS Integration



At the heart of the system was the Cohda Wireless MK6 On-Board Unit (OBU), which enabled communication with nearby vehicles and infrastructure (see Figure 14). This OBU ran Cohda's safety algorithms and processed both vehicle data and external messages.

When a risk was detected, the OBU triggered a warning that was sent via Ethernet to a custom Android app. This app acted as the control hub for rider alerts, activating the HMIs to show the correct warning with the relevant urgency.

We connected the unit to each motorcycle using a mix of OBD2 ports and direct wiring, so we could collect critical data like throttle position, speed, brake light status, and turn indicators, all updated ten times per second (See Figure 15). The MK6 OBU continuously fused this local data with incoming C-ITS messages like Cooperative Awareness Messages (CAM) and Decentralised Environmental Notification Messages (DENM).

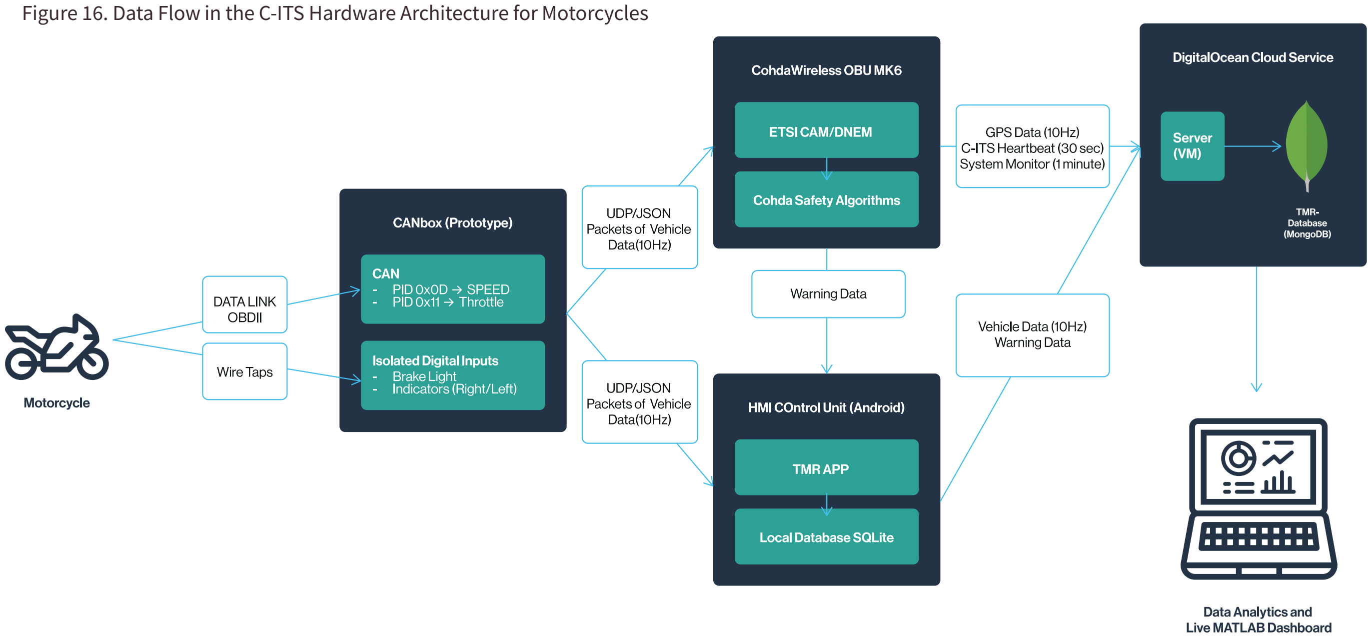
Figure 15. One of our 3 C-ITS enabled motorcycles

The system was fully self-powered and isolated from the core bike electronics, making it safe to retrofit. It proved highly modular, robust, and practical for trial deployment.

Data Flow

The data flow begins with the Motorcycle, which sends speed, throttle, indicator, and brake signals to the prototype CANbox. The CANbox packages this data into Java Script Object Notation (JSON) and broadcasts it via User Datagram Protocol (UDP). Both the Cohda MK6 OBU and Android device receive this data. The Cohda unit processes it alongside CAM, DENM, and GPS data to generate hazard warnings, which are then sent to the Android device. The Android device timestamps and forwards all received data, including Cohda warnings, to a MongoDB database service for storage, while also keeping a local backup.

Figure 16. Data Flow in the C-ITS Hardware Architecture for Motorcycles



4. Trials: Feasibility, Desirability and Effectiveness

The co-design, prototyping, and system integration stages culminated in two large-scale trials: one at the Toyota test track near Melbourne, and one using our custom-built motorcycle simulator. In February 2025, we invited 94 riders to test these bikes on the Toyota test track, and 65 riders came to Bundoora to participate in our simulator trial.

While both trials followed the same procedure and used identical tracks and scenarios, their objectives differed:

- The test track trial focused on desirability and feasibility, assessing how well the warnings integrated with real-world riding and how riders subjectively experienced the system.
- The simulator trial focused on effectiveness, using the same use cases as the test track but with increased simulated risk. Hazards were partially or fully obscured, unlike on the open test track. This allowed us to safely test hazardous scenarios, such as vehicles appearing from behind buildings, when riders could not rely on direct line-of-sight.

To measure the effect of C-ITS warnings, we asked respondents to complete three rounds. Each round consisted of three laps:

1. One round without C-ITS warning
2. One round with C-ITS warnings, using the LEDs on the bike and the mirrors
3. On round with C-ITS warning, using an HMI of their choice

Each round introduced 2 road situations. To avoid anticipation, the actual use case and the lap in which it occurred were both unknown to the rider.

For both trials, rider behaviour was recorded in real time. This included; speed, brake light status, throttle position, and turn indicators. We also monitored system performance, connectivity, and the success rate of warnings real time centrally from the test track. The track is sub-urban, but has no buildings, which means that the test conditions for the Global Navigation Satellite System (GNSS) and connectivity are very good. Subjective feedback was gathered through structured surveys before, during, and after each trial session (See Figure 17).

Figure 17. Rider Interview

4.1 Feasibility:
How well did the technology perform?
4.1.1 System performance

To assess the performance of our C-ITS system, we compared its performance against the European Telecommunications Standards Institute (ETSI) standards. ETSI develops global standards for ITS, including C-ITS. The standards stipulate the technical requirements for key Vehicle to Everything (V2X) safety applications[7] .

To ensure these warnings are effective and delivered in time, the standards define communication performance requirements. The required metrics are summarised in Table 4.

Table 4. ETSI metrics

Metric	Requirement/Threshold
Accuracy	< 1 m
Latency	≤ 300 ms total; safety-critical systems: ≤ 150 ms
Range	≥ 300 meters (line-of-sight, uncongested); ≥ 200 meters in line-of-sight, but congested channel load
Transmit Power	≥ 18 dBm (measured at antenna in relaxed channel load conditions)

Data Collection

We measured the metrics while riders were conducting their trials. We wanted to know the performance in normal usage, so we did not systematically change speeds from low to high or push the limits.

The u-blox GPS data was collected within approximately 498.6 accumulated hours for all five Cohda OBUs running from 24 February 2025, at 8 AM, to 8 March 2025, at 8 PM. The data was obtained using the u-blox GPS sensor, providing output in a standardised GPS log format widely recognised and supported by major GPS manufacturers.

The Dedicated Short Range Communication (DSRC) communication test was conducted on 24 February 2025, from 9:00 AM to 4:00 PM, covering approximately seven continuous hours of end-to-end transmission. During this period, the five OBUs and one Road Side Unit (RSU) were actively transmitting DSRC packets, forming a small-scale vehicular communication network to simulate real-world V2X interactions. Only periods of valid communication were considered, specifically, when both the sender and receiver were actively operating on the DSRC channel. Packet loss during this period was attributed solely to collision or weak signal conditions. The packet count reflects actual transmitted packets, each of which was logged and traceable from sender to receiver, ensuring accurate and reliable measurement of communication performance.

Findings: Accuracy, Latency, Packet Delivery Ratio (PDR)

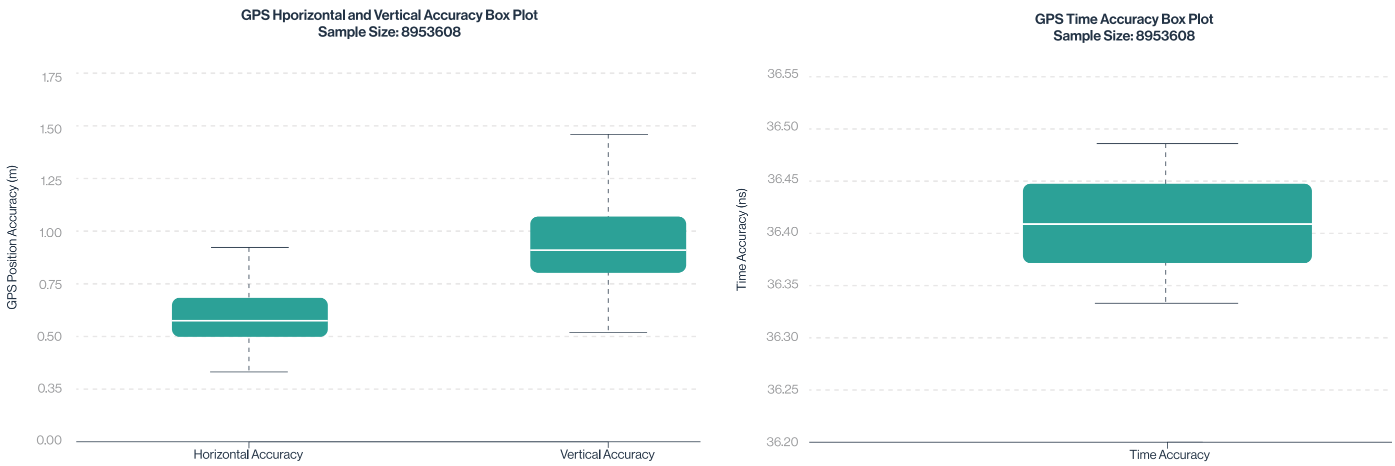
The GNSS sensor used in the Cohda MK6, a u-blox unit, performed well. C-ITS standards and deployments require relatively high precision; for example, lane-level applications such as accurate lane identification, overtaking detection, or blind spot monitoring typically require positioning accuracy of ≤1 metre. The u-blox GNSS modules compute and log accuracy by analysing satellite signal timing and quality, such as arrival time, signal strength, and geometry, to estimate the uncertainty in their location and time measurements. Figure 19 shows the findings:

- GNSS Accuracy: The u-blox module achieved 0.62 m horizontal and 0.98 m vertical accuracy (mean), well within the ≤1 m lane-level precision required.
- Time Accuracy: GPS time accuracy is the maximum deviation between the time calculated by a GPS receiver and the actual system time maintained by the GPS satellite constellation. Our measurements indicate ~36 ns, supporting time-critical safety applications .

Our system performed satisfactorily for real-time safety applications on motorcycles, without advanced corrections like Real Time Kinematic (RTK) positioning.

[7] TS 101 539-1 V1.1.1 (2013-08), ETSI TS 101 539-3 V1.1.1 (2013-11), and ETSI TS 101 539-2 V1.1.1 (2018-06)

Figure 18. GPS Accuracy



Alongside GPS performance, we evaluated the DSRC latency, range, and signal strength under test conditions.

Figure 19 illustrates the relationship between communication latency and distance. It is evident that DSRC maintains latency below three milliseconds within a range of up to 150 meters. Even at distances exceeding 300 meters, latency remains low at approximately five milliseconds.

Figure 20 presents Received Signal Strength Indicator (RSSI) values as a function of communication distance, with the transmit power fixed at 23 dBm. Based on the Australian Communication and Media Authority's (ACMA's) Radiocommunications (Intelligent Transport Systems) Class Licence 2017, the Effective Isotropic Radiated Power (EIRP) limit for DSRC transmissions in the 5.855–5.925 GHz band is typically 23 dBm per MHz, which allows for a total EIRP of up to approximately 33 dBm over a 10 MHz channel. Our DSRC OBU transmits at 23 dBm and is connected to a Mobile Mark SMWG-313 antenna, which provides seven dBi gain on the 5.8–6.0 GHz band. This results in a total EIRP of 30 dBm, which is within the permitted limit, confirming that the transmission setup is compliant with ACMA regulations.

As expected, RSSI decreases progressively with increasing distance. At approximately 350 meters, the lowest observed RSSI reaches –95 dBm, which effectively provides sufficient communication range.

Figure 19. DSRC Latency vs Distance with 95% CI

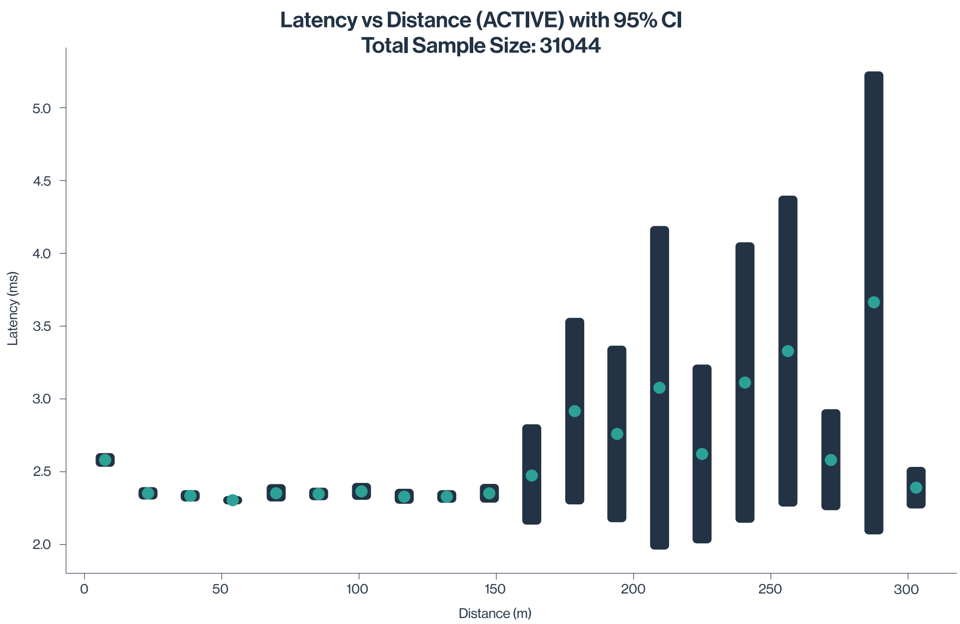


Figure 20. RSSI vs. distance

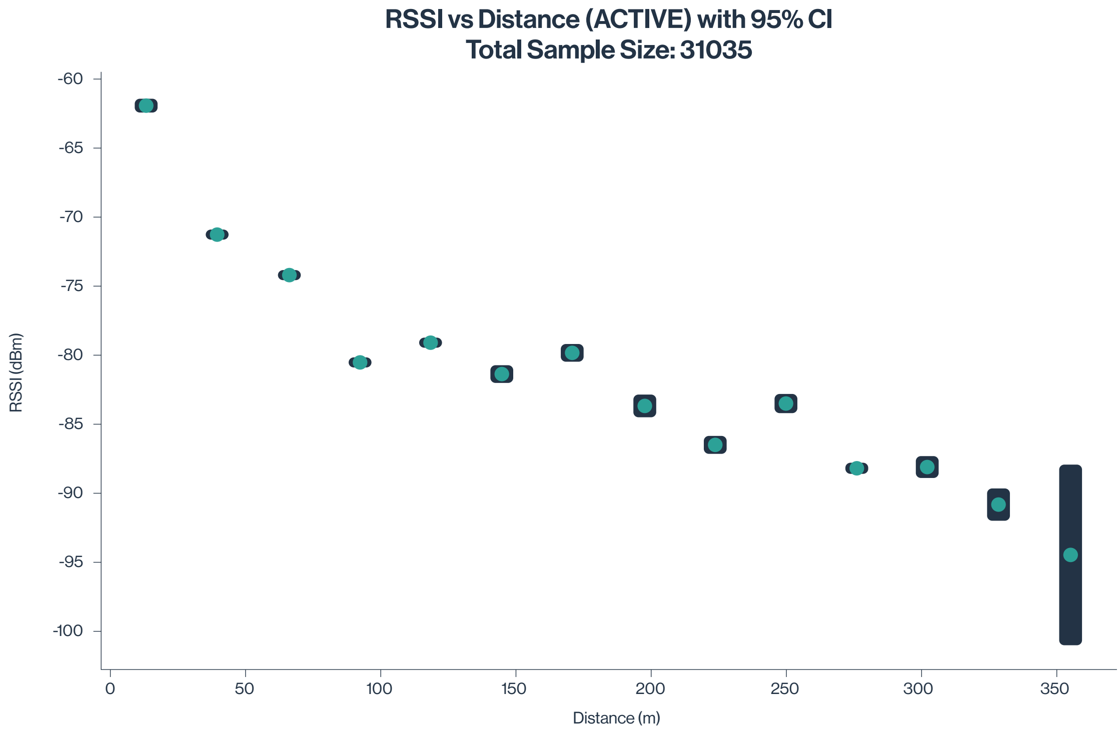
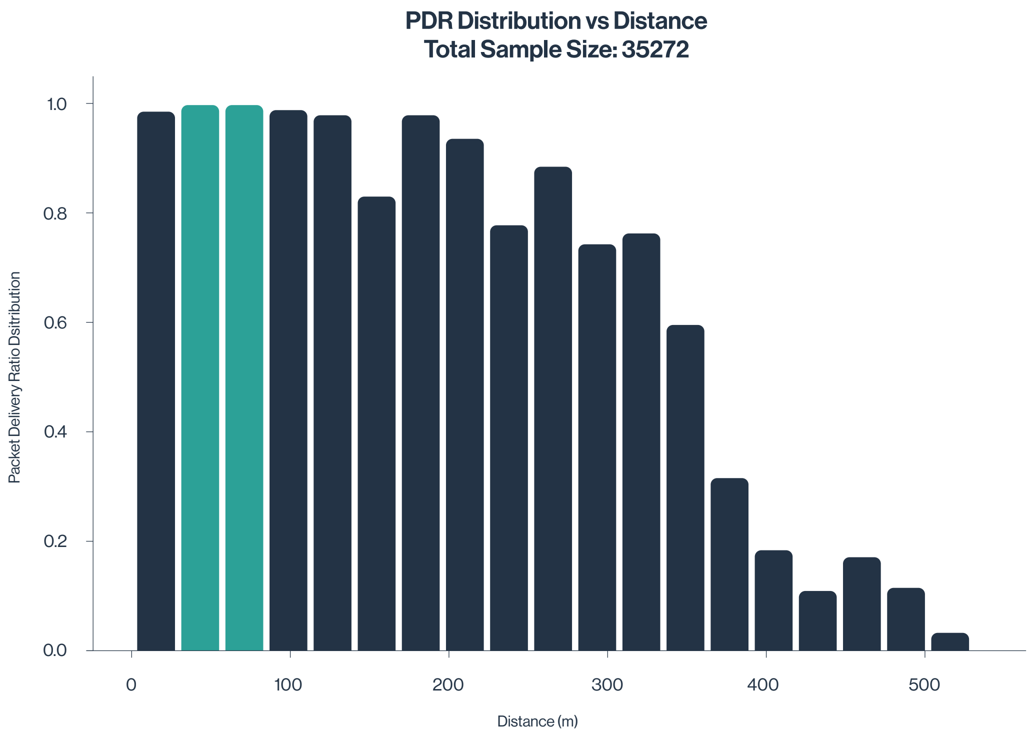


Figure 21 illustrates the PDR as a function of communication distance. The PDR remains consistently high, approximately 90% within 200 meters, and gradually decreases as the distance increases. Beyond 300 meters, a sharp decline in PDR is observed, indicating a significant reduction in communication reliability at extended ranges.

Figure 21. DSRC PDR vs Communication Distance with 95% CI



4.1.2 Software (the algorithm) performance

The warning logic used in these trials was a non-commercial test algorithm provided by Cohda Wireless. Our focus was not to evaluate Cohda's product, but to observe performance variability and identify areas of attention. OEMs see algorithm development as an area of competition, similarly to the algorithms of the various automated cars.

Findings: Reliability

To assess the reliability of the warnings, we compared the algorithm's performance on the test track with its performance in the simulator. Based on the trial plan, each participant was expected to encounter a predefined number of warnings for each use case. We then analysed the recorded data in our database to determine the actual occurrences of each warning type. Although the Cohda algorithms generate a burst of messages for each detected hazard, we grouped these bursts into single warning events for clarity and consistency in the analysis.

Table 5 shows that C-ITS performance in the simulator is consistently better than in the test track trials across all use cases. The controlled environment likely reduced latency, positional inaccuracies, and environmental noise. I2V warnings (e.g. Change of Road Surface, Dangerous Curve Warning) perform more reliably than V2V warnings (e.g. Forward Collision Warning, Intersection Movement Assist, Blind Spot Warning), as shown by lower missing rates across both simulator and test track trials. A 'missed' warning, is a warning that the C-ITS has not triggered. The reasons for missed warnings are situational and behavioural. For example, use cases triggered after sharp corners (especially FCW on the test track) exhibit a much higher rate of missed warnings—suggesting line-of-sight limitations or delayed recognition. In some cases, the rider changed lane or reduced speed, not following the instructions given. Missed warnings did not influence the rider research. When a warning was missed, we asked the rider to do that lap again so the rider could experience the warning.

Table 5. Warnings: Expected vs. received

		Simulation				Test Track Trial			
		Expected	Triggered	Missing (count)	Missing (%)	Expected	Triggered	Missing (count)	Missing (%)
V2V	FCW	260	252	8	4%	376	296	80	21%
V2V	IMA	260	243	17	7%	376	313	63	16%
I2V	DCW	455	449	6	2%	658	643	15	2%
V2V	BSW	130	122	8	6%	188	177	11	5%
I2V	CRS	65	64	1	1%	94	94	0	0%

Findings: Timing

To evaluate the reliability of the timing, the FCW warning algorithm was tested in both trials. For both the test track and the simulation environment, we created histogram plots for each test scenario to illustrate the repeatability of warnings.

Figure 22. Distribution of warning delivery timing (Test track vs. Simulator)

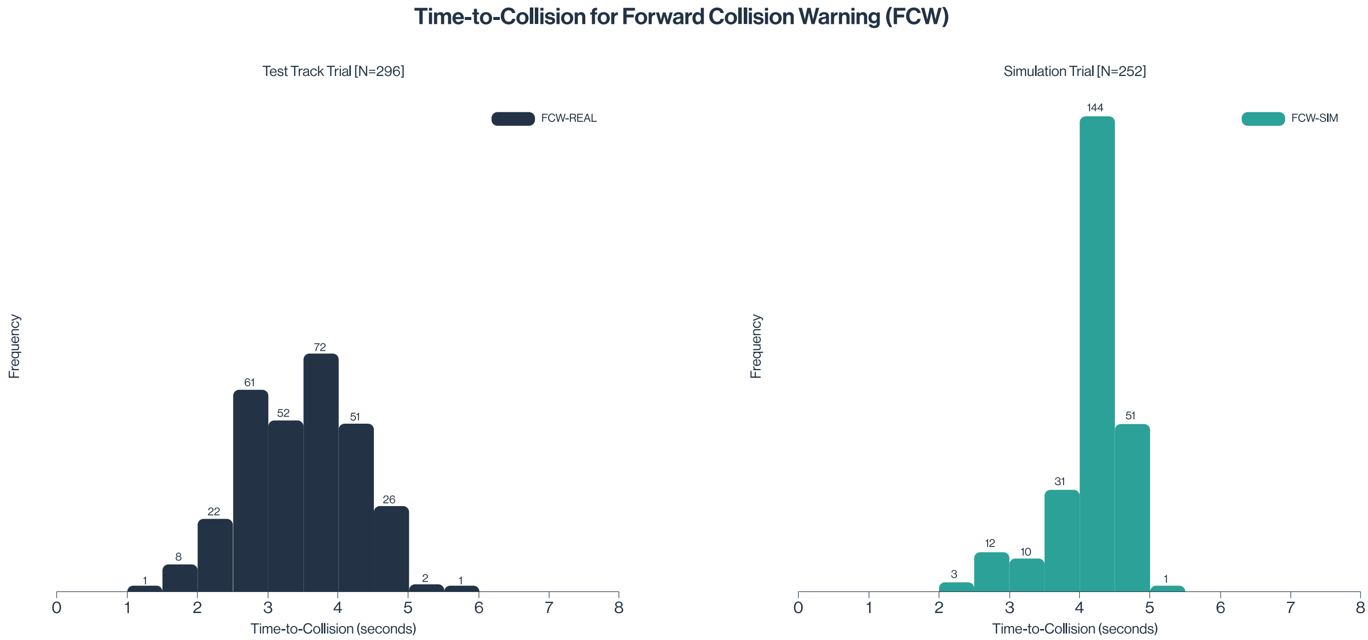
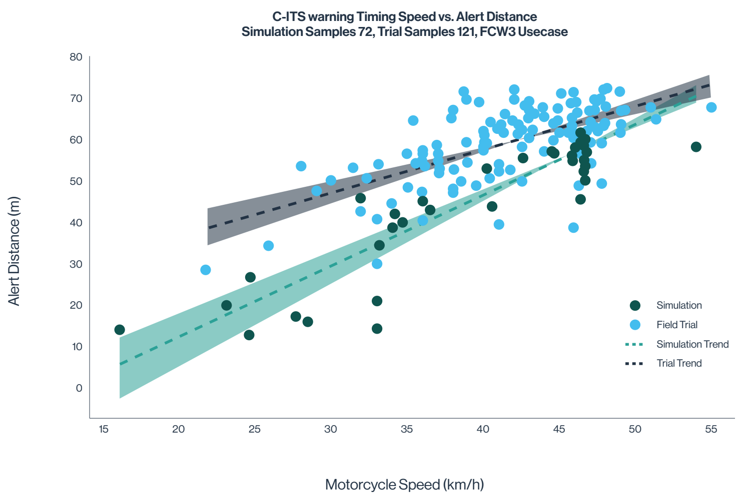


Figure 22 shows that in simulation trials, the warning Time To Collision (TTC) distribution is more tightly clustered, indicating high consistency in the timing delivery. The TTC is the time difference between the timing of the warning and the estimated time of the associated potential collision. In the test track trials, the distribution is more variable, reflecting external uncertainties like sensor noise, driver behaviour, and environment-induced delays.

As the location of the warning depends on the speed of the rider (the higher the speed, the further away from the hazard a warning is expected) we plotted speed and warning distance of the FCW (Figure 23). The performance on the track was not as good as in the ideal circumstances of the simulator, but still followed a relatively good pattern. R^2 values range from 0.702 to 0.862 (for more information, please refer to the appendix). Network strength, weather conditions, real movement, impact delivery of warnings.

Figure 23. Speed vs. warning distance delivery FCW



While real-world conditions introduced variability, most warnings were still delivered within acceptable timeframes for rider response, demonstrating feasibility even under less-than-ideal conditions. However, our use cases were simple. For more complex scenarios, there is a need for further development.

4.1.3 Feasibility: Commercial integration

A feasibility question of a different nature is how C-ITS can be brought to market. For new motorcycles, a wide range of chipsets and modules, are already available, enabling OEMs to integrate C-ITS directly into the bike. This allows for built-in warning systems and supports wireless connections to third-party HMI devices, giving riders flexibility in how alerts are received.

For riders seeking after-market solutions, compact devices like the Commsignia OBU LITE show real promise. Although designed for bicycles and e-scooters, its small form factor and support for CAN-FD and USB interfaces suggest it could be adapted for motorcycles. Preliminary tests at La Trobe University found the OBU LITE performed reliably within an effective range of 400 meters. While packet loss increased beyond that, the critical stopping distance for a motorcycle travelling at 70 km/h is under 40 meters—well within the device's effective range. This shows that even consumer-level OBUs can deliver meaningful safety benefits for key V2V scenarios.

4.1.4 Conclusion and considerations

The results of our feasibility analysis suggest that the core technology is ready for deployment in motorcycles. Location accuracy, latency, and connectivity all meet, or exceed, the technical requirements for real-time safety applications. What remains is further refinement of the algorithms that trigger warnings. While current test versions perform well in controlled environments, real-world variability still affects their consistency, particularly in more complex road and traffic scenarios.

With robust hardware already on the market, and AI-driven improvements to software within reach, now is the time to invest in maturing the algorithms and accelerating deployment.

4.2 Desirability: Do riders want it?

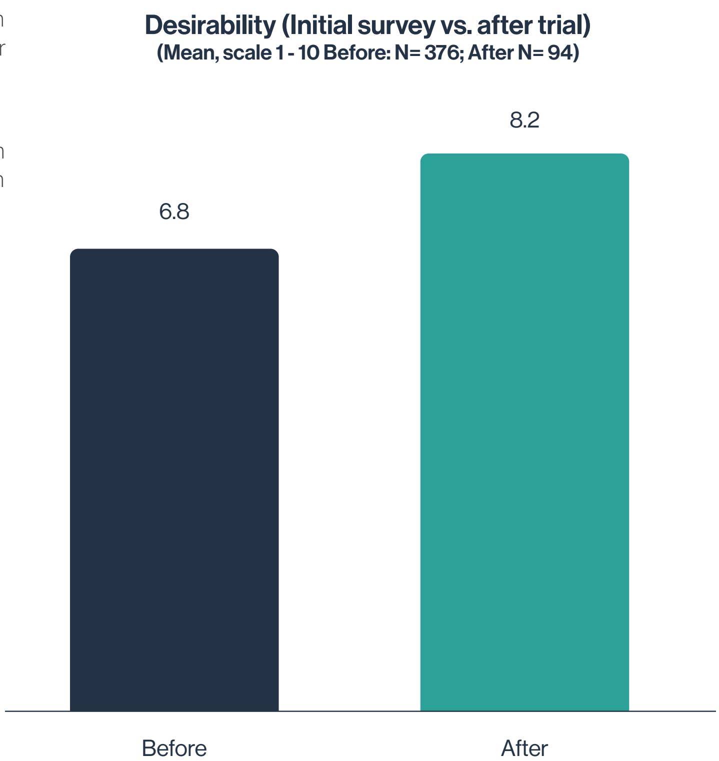
In February 2025, over two weeks of perfect riding weather, 94 riders joined us at the Toyota test track. Each participant spent a morning, afternoon, or evening riding several rounds on our connected motorcycles, experiencing five key C-ITS use cases multiple times at different locations of the track. Before, during, and after their rides, we engaged them to gather feedback on their experience with the technology.

4.2.1 Rider adoption

At the conclusion of the trial, we invited riders to reflect on a structured set of adoption-related questions, exploring not just whether they would want this technology on their own motorcycles, but under what conditions, and why.

Compared to their initial baseline responses, riders showed a marked shift toward more favourable views, see Figure 24, suggesting that direct experience with the system, in both simulated and real-world conditions, played a critical role in shaping acceptance.

Figure 24. Desirability (before and after the trial)



4.2.2 Segment profiles and attitudinal differences

Similar to the initial survey at the start of the project, self-identified risk-taking riders were generally less positive about C-ITS and more conservative riders appreciated the technology more. However, this time a third segment emerged: riders who also saw themselves as risk-takers yet still valued the safety benefits of the technology. This segment, the 'young sporty commuters', enjoyed pushing the limits but could also appreciate well-designed, non-intrusive safety support (see Figure 25).

Table 6 shows how the three rider segments differ from each other. The three segments showed significant differences in their perceptions of C-ITS warnings, riding experience, risk attitudes, and the types of motorcycles they ride.

Figure 25. Rider segmentation (desirability vs. risk appetite)

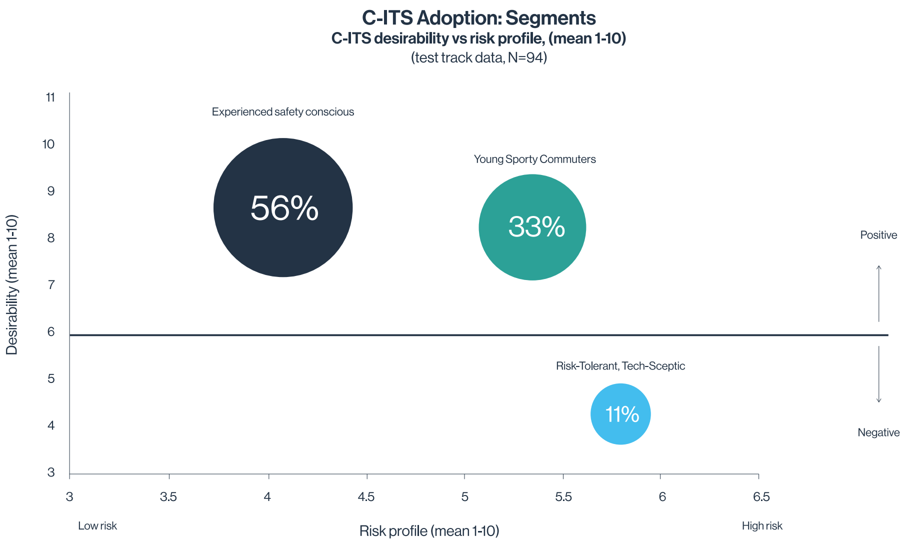


Table 6. Segment descriptions

Experienced safety conscious	Young Sporty Commuters	Risk-Tolerant, Tech-Sceptic
Social/adventure riders who appreciate safe riding and useful tech	Urban commuters who want tech that fits their fast-paced lifestyle	Thrill-seekers or 'pure-riders', less engaged with safety tech
• Highest desirability (8.83) • Longest riding experience and highest age • Ride diverse motorcycle types (cruisers, adventure, touring) • Value warning systems (high usefulness, early response, and integration) • Most open to standard and custom C-ITS	• High desirability (8.39) • Youngest and least experienced riders • Ride almost exclusively naked/sport bikes • High risk self-assessment and most frequent riders • Strong interest in integrated, custom warning tech	• Lowest desirability (4.30) • Moderate age, low precaution scores, and highest risk self-assessment. • Less likely to use or value warning systems • Least interested in standard or custom C-ITS warning delivery

Although the risk-tolerant, tech-sceptic segment made up a smaller portion of the sample (10 out of 94 riders), they likely represent a larger portion of the broader rider population. Given the nature of the trial, self-selection likely skewed representation toward riders already open to engagement with technology. We believe the sceptical segment is likely underrepresented, which may limit the extrapolation of adoption rates to the general rider population.

Our segmentation data is based on the test track data, because we wanted to base it on a near realistic experience. However, many riders acknowledged that the open visibility of the test track may have reduced the usefulness of the warnings.

That's why we compared the survey results obtained from the test track participants with the results obtained from the simulator. (Only 27 riders participated in both). Across both test track and simulator trials, the Experienced Safety-Conscious and Young Sporty Commuters consistently rated C-ITS warnings higher in desirability, usefulness, reaction time improvement, and integration than the Risk-Tolerant, Tech-Sceptic group.

While all segments rated the system more positively in the simulator, likely due to reduced visibility and hence a higher perceived danger level, the gap in attitudes remained: risk-tolerant riders continued to be the most sceptical. Age and self-assessed risk scores remained stable across environments and reflected the expected rider profiles: older and more cautious for the safety-conscious group, younger and higher risk for the others.

Table 7. Comparison of key evaluation metrics across rider segments during test track and simulator trials (N=94 (test track data) and N=65 (simulator trials))

Factors (Scale 1 = low, 10 = high)	Test track trials (N=94)			Simulator trials (N=65)		
	Experienced Safety Conscious (56%)	Young Sporty Commuters (33%)	Risk-Tolerant, Tech-Sceptic (11%)	Experienced Safety Conscious (47%)	Young Sporty Commuters (43%)	Risk-Tolerant, Tech-Sceptic (10%)
Desirability	8.8	8.4	4.3	8.9	9.0	6.4
Overall usefulness	7.9	8.2	4.7	8.7	8.8	6.3
Improve reaction time	6.3	6.9	2.8	8.5	8.8	7.0
Warning integration	7.7	8.4	4.4	8.9	8.3	5.3
Age	6.1	3.5	3.9	5.3	3.2	3.9
Risk: self assesment	4.1	5.4	5.8	4.9	4.7	5.0

The trial revealed clear rider segments with distinct attitudes toward C-ITS. Safety-conscious and young commuter riders consistently rated warnings as useful and well-integrated—across both real-world and simulator conditions. Risk-tolerant riders were less positive but still valued select use cases. Below we will examine the adoption factors in more detail.

4.2.3 What factors drive adoption?

We wanted to understand which factors influence riders' decisions to adopt technology, and which factors do not. Understanding this will inform future strategies aimed at reaching riders more effectively.

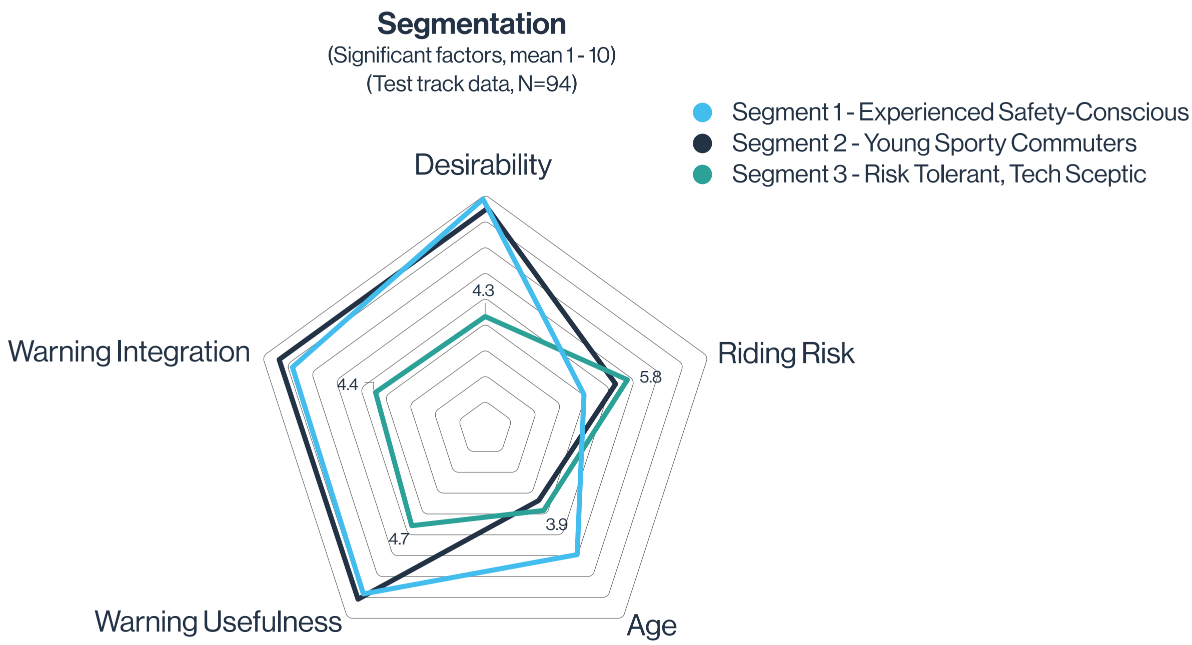
Gender and hours on the road did not make a difference, as can be seen in Table 8.

Table 8. Factors that do not influence adoption

Factors	Experienced safety conscious	Young Sporty Commuters	Risk-Tolerant, Tech-Sceptic
Gender (Male) (percentage)	91 %	77 %	80 %
Monthly riding hours (means)	4.87	5.39	5.40

Our analysis found that beyond desirability, risk appetite, and age, the most significant factors were warning integration and warning usefulness (Figure 26). The risk tolerant group, scored between four and five on a scale of ten on these factors, significantly lower than the other two segments. Which means that they thought the warnings were a distraction and not very useful.

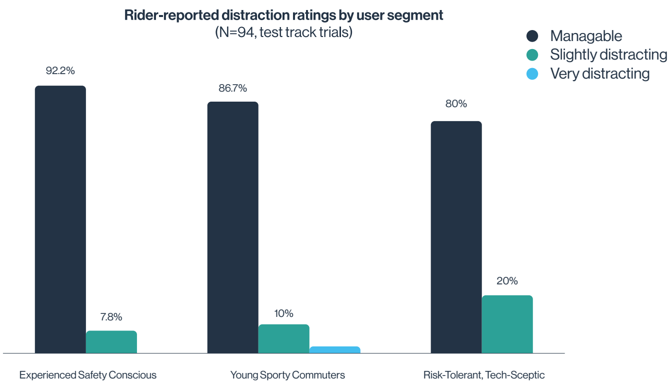
Figure 26. Key adoption factors



Warning integration

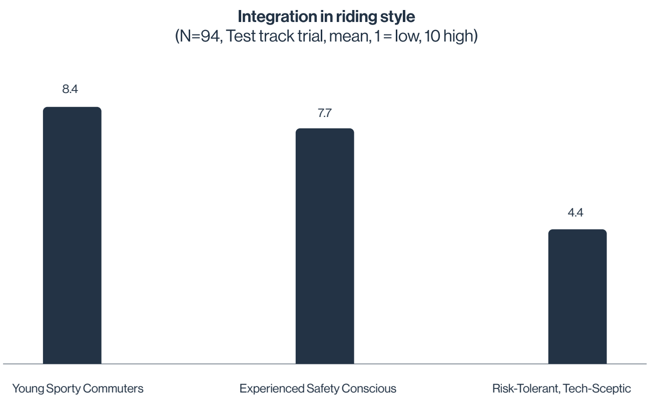
Overall, we were encouraged to see that the prototype warning devices, co-designed with riders, were well received during the trial. Most participants found the warnings unobtrusive (see Figure 27). As expected, the risk-tolerant segment appeared to have higher expectations around staying focused on the road.

Figure 27. Distraction ratings



Similarly, as shown in (Figure 28) the Experienced safety-conscious and the Young sporty commuters rated warning integration quite positively, with averages of 7.7 and 8.4 out of 10. However, the Risk-tolerant, Tech-sceptic thought that the warnings did not integrate well at all and rated it much lower, an average of 4.4.

Figure 28. Integration in riding experience



Qualitative feedback reinforced this. Three themes were reinforced by riders:

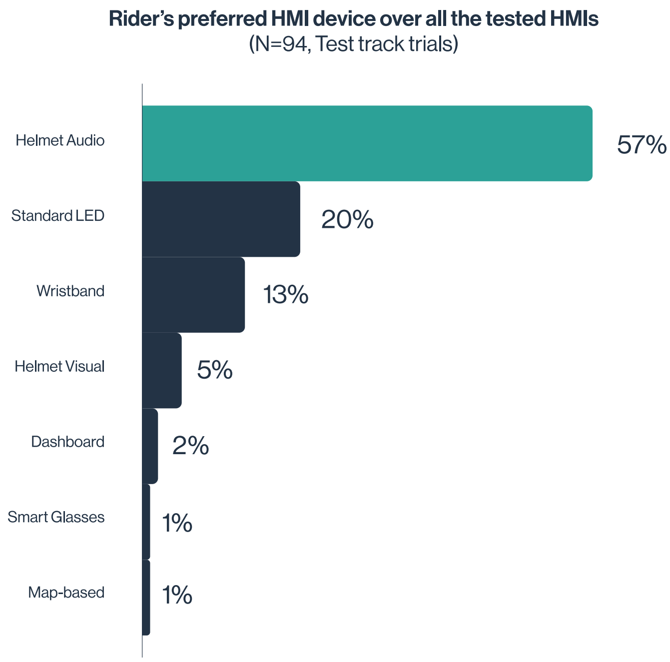
- Trust in technology vs. skills
  - "I made my decision by the time I received the warning."
  - "The lights reminded me to slow down. But I would do it anyway."
- Perceived redundancy vs. value-ad
  - "From glancing at the screen, you had to pay too much attention."
- Cognitive load and attention management
  - "The timing of it and the different senses—it takes you out of the situation rather than keeping you in it."

Most riders responded well to the alerts when they were timely, subtle, and easy to interpret. But if a warning duplicated the rider's instincts, came too late, or felt distracting, confidence dropped, especially among more risk-tolerant participants. The key message is that integration is critical. If warnings do not support a rider's natural flow and decision-making, they are unlikely to be trusted or used, regardless of technical performance.

Warning delivery

The warning delivery influences the integration of the warnings in the rider experience. After a first round with what we called 'standard' LED warnings, referring to the LEDs on the mirror and the dashboard, we explained the six HMI prototypes, and asked riders to choose one or two to try in the next round. We did not want to force riders to try anHMI that they would not consider in real life. Figure 29 shows which delivery methods were preferred.

Figure 29. HMI preferences



Note that this preference is focused on the warning delivery. It does not consider other influences, such as cost, need for charging, easily forgotten or lost, etc. Also, riders do expect their bikes to be equipped with C-ITS warning HMIs such as the LEDs on the mirrors and the dashboard. But riders appreciate the ability to customise how warnings are delivered with custom HMIs. Table 9 summarises the positive and negative aspects of the HMIs.

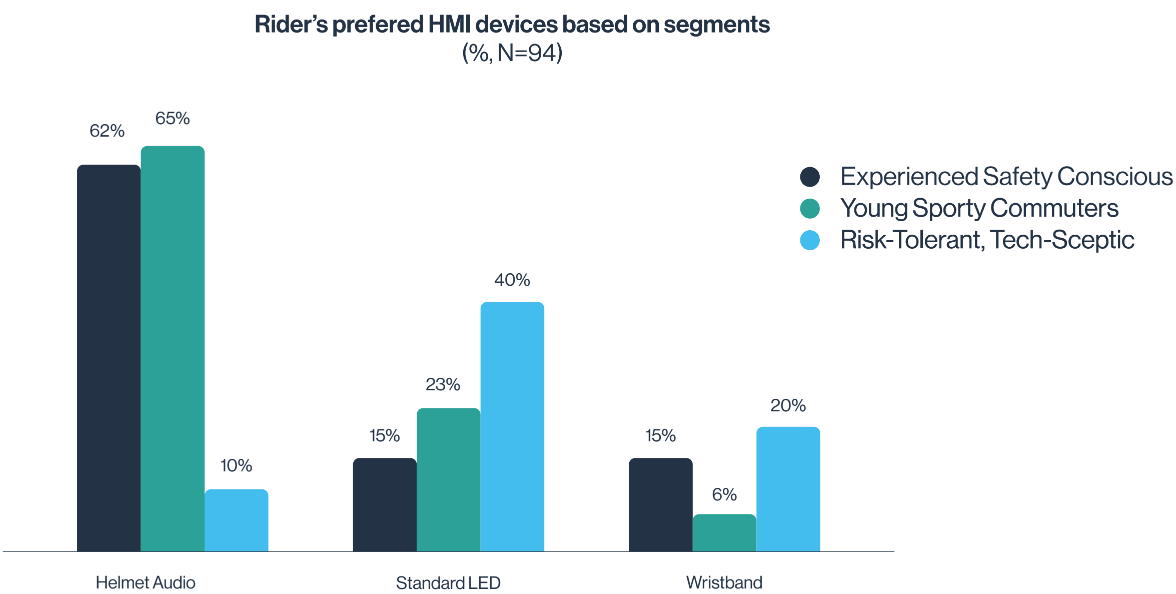
Table 9. Positive and negative aspects of the warning delivery HMI

HMI Type	Positive aspects	Negative aspects
Helmet Audio	Clear and immediate; doesn't require looking away; generally non-distracting.	Sometimes hard to hear in noisy environments. May interfere with music if there are too many.
LEDs on Bike	Easy to see at a glance; directionally informative.	Can be hard to see in bright sunlight; The LEDs on the dashboard can be out of the field of view.
Wristband	Quick and discreet; Particularly effective in combination with audio cues.	No indication about the direction of the hazard.
Helmet Visual	Occasionally useful when in rider's peripheral vision.	Below the field of view for some riders, easy to miss. Need to learn the 'code' to understand the meaning.
Dashboard	Familiar interface for some riders; helpful when stationary.	Requires glancing down or away; not ideal while riding due to divided attention.
Smart Glasses	Good in concept; potential for heads-up information without distraction.	Warnings went unnoticed; information was out of sight, not sufficiently salient or not intuitively placed.
Navigation app	Navigation apps are used by many riders.	Requires glancing down or away if not placed within line of sight.

Helmet audio and wristbands emerged as the least distracting, most preferred HMIs, offering non-intrusive yet informative alerts that riders could interpret quickly. However, looking by segment (Figure 30) the risk tolerant segment has a clear preference for the standard LEDs. Note that the sample is small, but intuitively, this fits with their attitudes that do not favour 'fancy' technology.

Overall, the results suggest clear design priorities: warnings should be ambient but salient, multimodal in delivery, and customisable to rider preferences. They should help point out the direction of the hazard. When riders could choose how to receive alerts, through audio, haptics, or lights, they consistently preferred systems that were intuitive, unobtrusive, and easy to interpret. While custom HMIs like helmet audio and wristbands were most popular overall, risk-tolerant riders leaned toward familiar options like LEDs. This suggests that a one-size-fits-all approach will not work: designing flexible, rider-led HMI options, anchored by standard systems on the bike, will be key to real-world uptake.

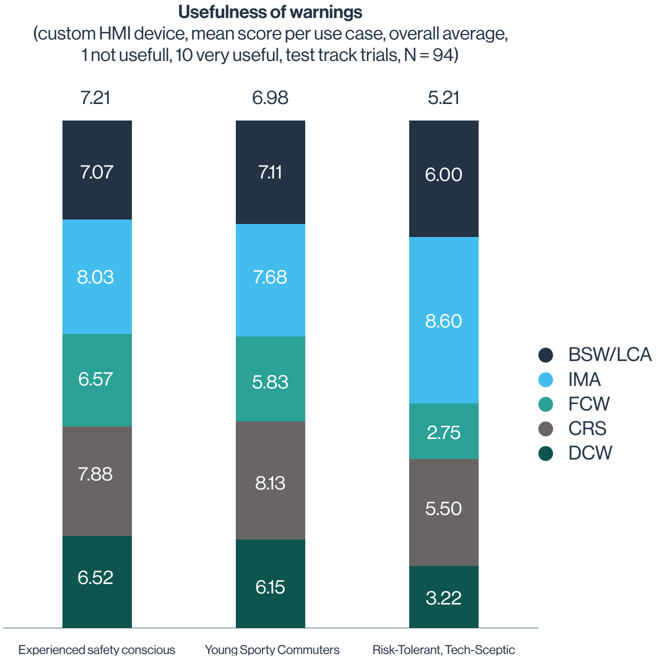
Figure 30. HMI preference by segment



Usefulness

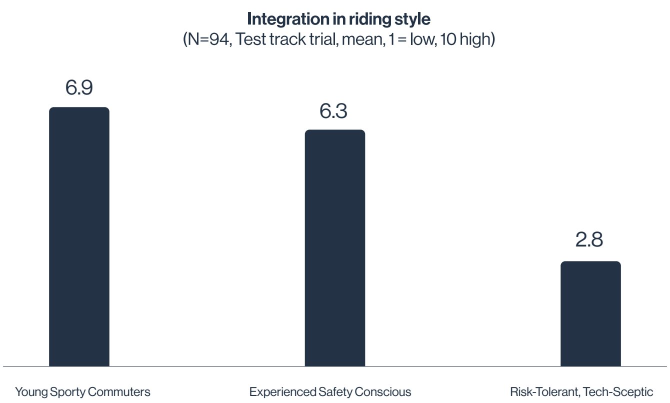
The usefulness of the warning, firstly depends on the use case. Figure 31 shows that the 'Risk tolerant, tech-sceptic' have lower overall appreciation of the usefulness, but they do have use cases that appeal to them, particularly the IMA use case, but also the LCA and the CRS warning were favoured.

Figure 31. Warning usefulness by use-case



Rider feedback suggested that the warnings were generally seen as helpful in improving reaction time, especially in situations where visibility or situational awareness was reduced. As shown in Figure 32 , the Experienced Safety-Conscious and Young Sporty Commuters segments rated the warnings as moderately to highly effective, with mean scores of 6.31 and 6.94, respectively.

Figure 32. Subjective reaction improvement



In contrast, the Risk-Tolerant, Tech-Sceptics segment rated the warnings significantly lower (mean = 2.80), reflecting a more sceptical attitude or a lower perceived benefit.

Qualitative feedback reinforced these results. Riders in the first two segments described instances where the warnings helped them prepare for hazards in time. One commented, "Especially for the intersection… I was more prepared for it than the first time around [without a warning]," while another noted, "For the blind spot, that car was out of my focus, so the warning really helped." Riders reported adjusting their speed, planning evasive actions, and mentally preparing for risks more effectively.

Even the most sceptical segment saw value in alerts like intersection assist, lane change assist, and rough surface warnings. Highlighting these in communication and rollout strategies may improve early acceptance, while still ensuring that the full range of risk scenarios is addressed across all rider types.

4.2.3 Conclusion and considerations

The trial confirmed that most riders responded positively to C-ITS technology after experiencing it under realistic riding conditions.

Three distinct rider segments emerged: Experienced Safety-Conscious Riders, Young Sporty Commuters, And Risk-Tolerant Tech-Sceptics. The first two groups showed strong interest in adopting the technology, while the third remained more reserved, though even among these sceptics, several recognised value in specific use cases such as intersection assist and lane change warnings.

A clear preference emerged for customisable, intuitive warning delivery systems. Helmet audio and haptic wristbands were considered the least distracting and most useful, while integrated LEDs on mirrors or dashboards were viewed as essential baseline features. However, adoption varied significantly across rider types, with perceived usefulness and the quality of system integration proving more influential than demographic factors like gender or riding hours.

Importantly, riders did not just report preferences, they actively selected and tested different warning devices while riding, offering deeper behavioural insights into what works. Across the board, warnings were generally seen as helpful in improving hazard response, especially in situations with limited visibility. Still, concerns were raised around potential distraction, false alarms, and over-reliance on technology.

To accelerate adoption of C-ITS among motorcyclists, systems must be both trusted and tailored. Riders responded most positively when warnings felt integrated into their riding experience, not imposed on it. This means systems must strike a careful balance: providing ambient, non-intrusive awareness most of the time, while ensuring critical alerts cut through when needed.

Integration and perceived usefulness are key drivers of adoption. Poorly timed or distracting warnings—especially those that misread deliberate actions like lane filtering, risk eroding rider confidence. Instead, smart algorithms must accurately classify real threats, and user-friendly interfaces must deliver those alerts in a way that supports focus, not fragment it.

Importantly, all safety scenarios need to be covered, but adoption can be strengthened by leading with the use cases that resonate most with harder-to-reach riders. Even the most sceptical group in our trial saw value in warnings like intersection assist, lane change assist, and rough surface alerts. Emphasising these use cases in messaging and early rollout strategies can help build credibility, while still ensuring broader safety coverage for all rider types.

Emerging user experience technologies, such as directional audio, adaptive LEDs, and lightweight Augmented Reality, offer promising ways to deliver this nuanced experience. Thoughtful design, customisation, and communication will be critical to transforming C-ITS from technical feasibility into rider-endorsed reality.

4.3 Effectiveness: Does it help riders react earlier?

The aim of C-ITS warnings is to give riders a ‘heads up’ about potential dangers—especially those not yet visible or outside the rider’s line of sight. To assess whether this makes riders react earlier, compared to when they do not get a warning, we measured reaction distance: the space between the moment a rider first responds and the point where a collision could have occurred.

4.3.1 Data collection and analysis

A total of 65 riders participated in the simulator trial. We collected the following data in real time to calculate the reaction distance:

- **Motorcycle speed**
- **Throttle percentage**
- **Brake light indicator**
- **Steering and the lane Ids**
- **Time of the first warning**
- **Location data of the rider and the hazard**

Data from 65 riders who participated in the simulator trial was used in the following effectiveness analysis. The developed algorithm used a combination of telemetry data, including speed, throttle, braking input, and lateral movement (lane change), to detect the first behavioural deviations which indicated their reaction and response (see Figure 33 and Figure 34).

A threshold-based decision logic was applied to identify the earliest instance of such deviation following the warning onset (Figure 33). For additional robustness, a dedicated lane-change detection component was incorporated to identify swerving or positional adjustments (manoeuvring) typically associated with hazard avoidance. Lane change algorithm was used only for FCW and IMA as lane change is not used as a behavioural marker for reaction in curves, since lateral movement in curves doesn't consistently represent an evasive action (refer to Figure 34).

Figure 33. Detection of first response using Speed, Throttle and Brake indicator data

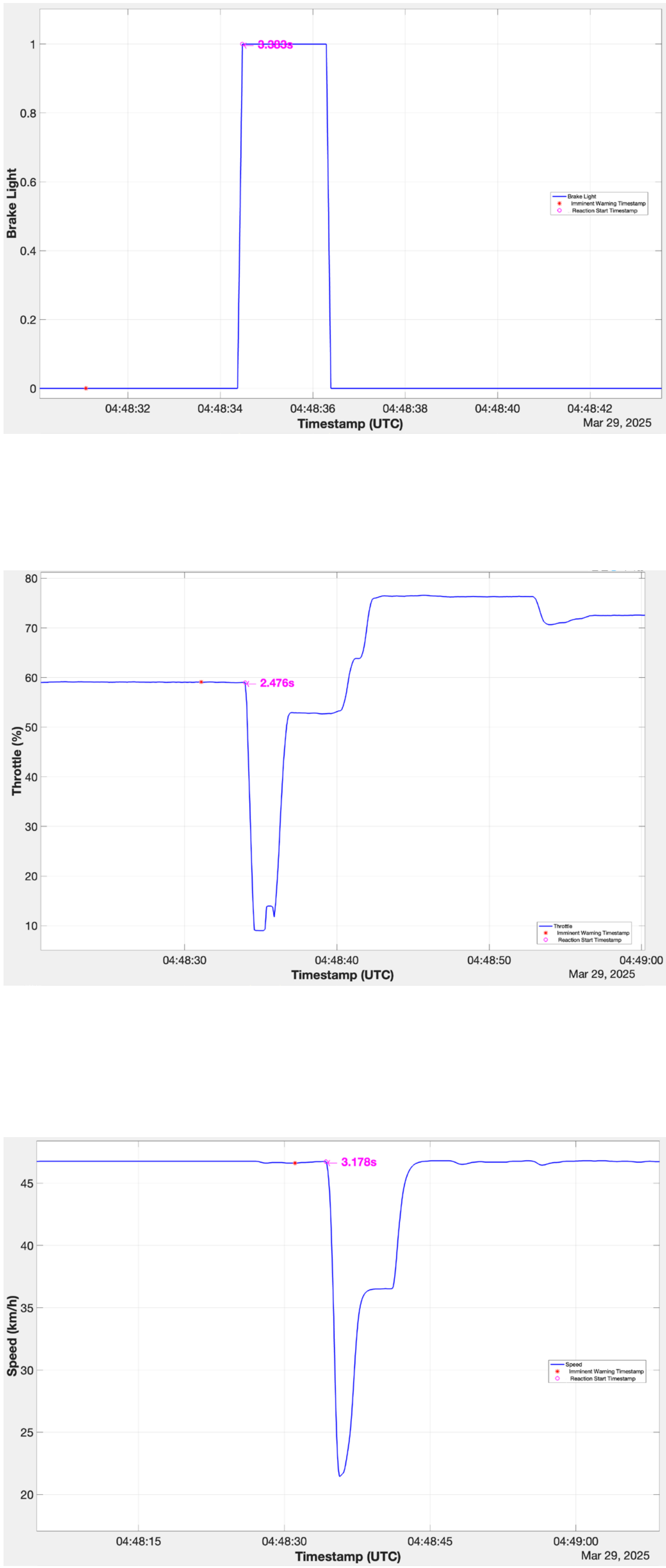
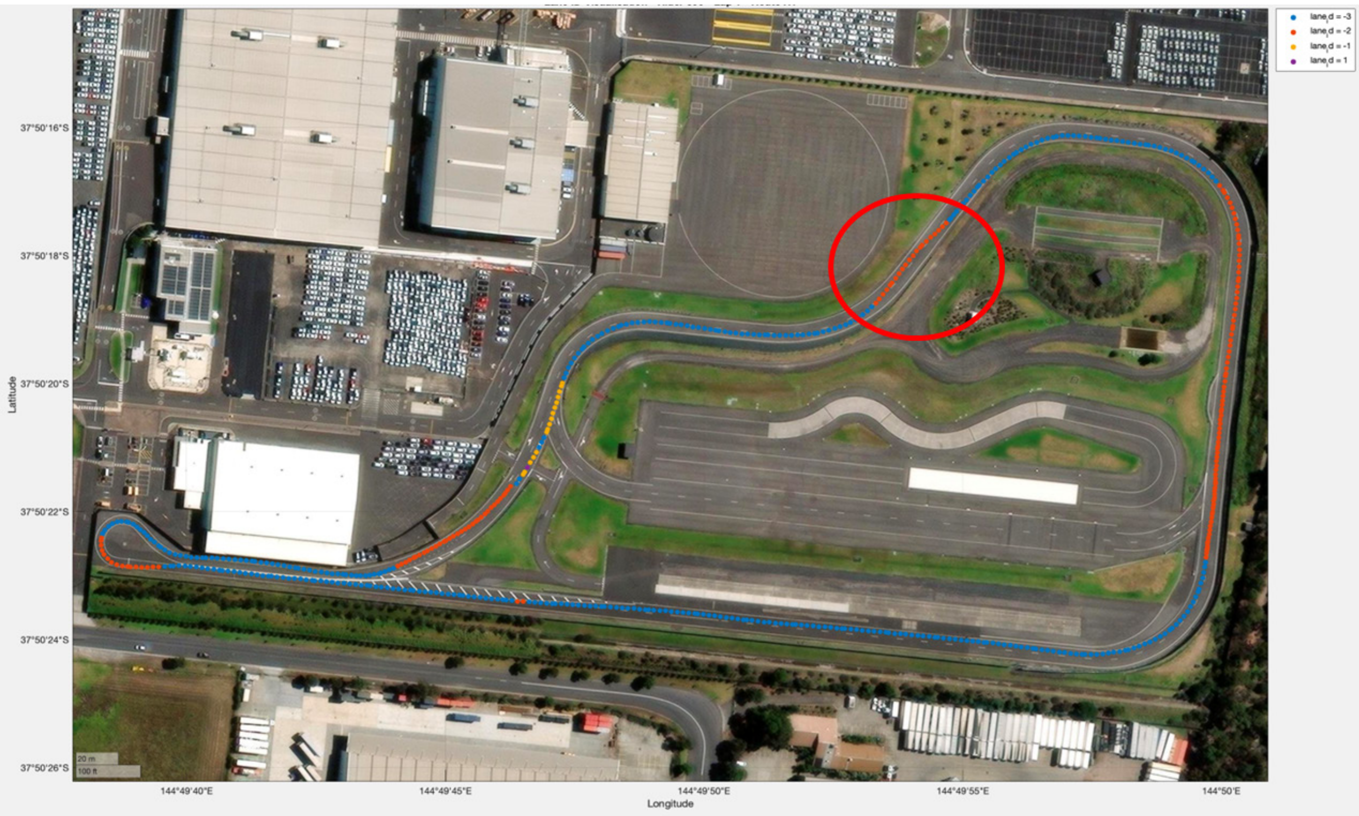


Figure 34. Detection of lane change as a reaction to a warning



We excluded data points where the rider reacted before receiving the warning. This happened often on the test track, where the rider had clear visibility of the hazard. On the simulator, visual obstructions like buildings and fog limited anticipation, although some early reactions still occurred.

4.3.2 Controlling the 'learning effect'

A significant factor in this study was the 'learning effect'. When measuring 'effectiveness' in terms of 'reaction distance', riders should not be able to anticipate test scenarios.

We managed this by asking the rider to complete three rounds where each round consisted of three laps. In each round, we varied in which lap the test scenarios occurred. We did not inform the rider which use cases were to be expected nor did we inform the rider in which of the three laps the use case would occur. This approach minimised the likelihood that riders could anticipate the hazard.

4.3.3 Results

Did C-ITS provide the rider with more time to react? Yes, in all three tested use cases (Forward Collision Warning, Intersection Movement Assist, and Dangerous Curve Warning), riders who received C-ITS warnings reacted significantly earlier[8] compared to when they did not receive a warning. It improved their 'Time to Collision' which is the estimated time remaining before impact.

Forward collision warning

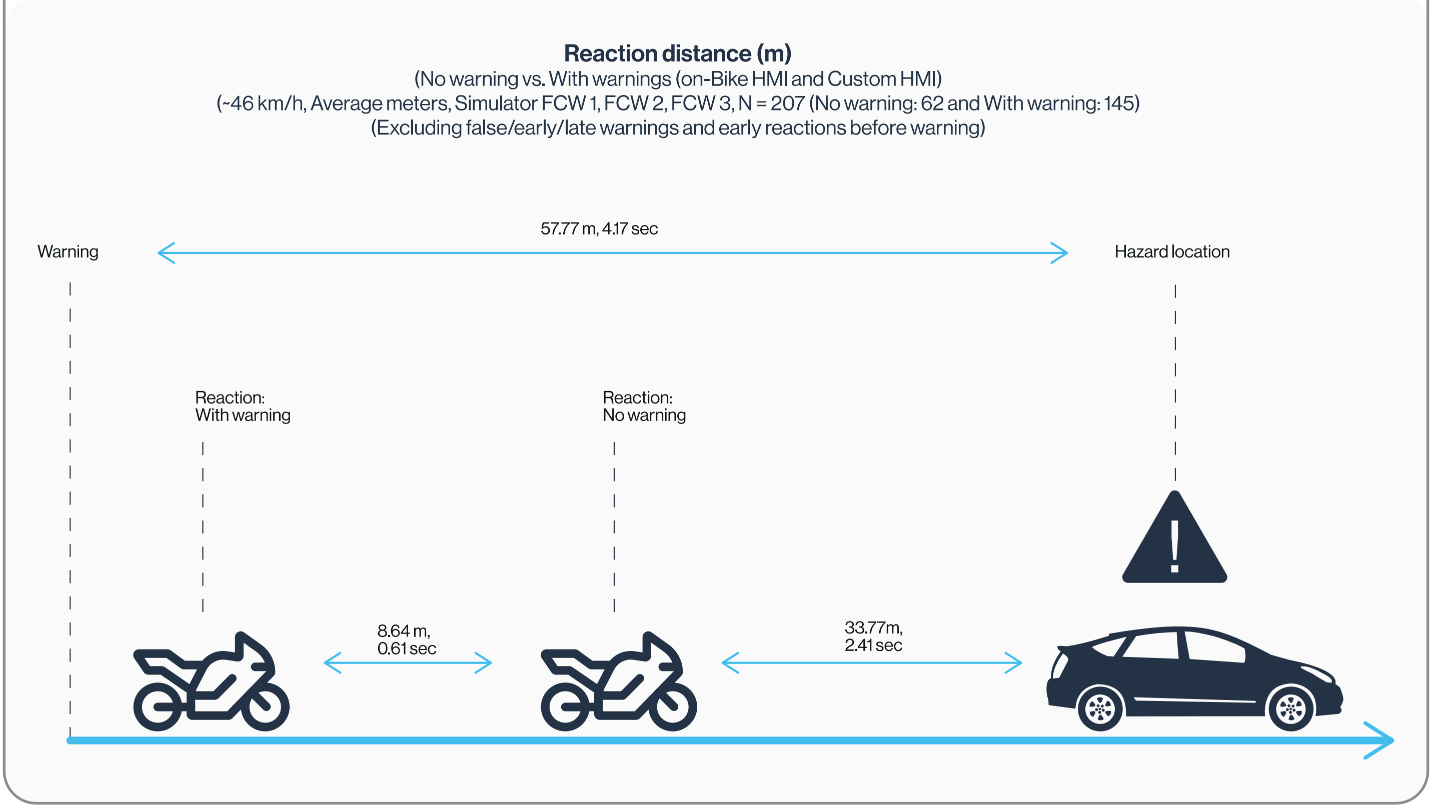
Table 10 and Figure 35 shows how the forward collision warning added almost two car lengths to the reaction distance:

- **Reaction Distance increased by nearly 8.64 meters, allowing significantly more space for braking or swerving.**
- **Time to Collision was extended by 0.61 seconds, giving riders additional critical time to avoid impact.**

Table 10. Rider behaviour in FCW Scenarios (With vs. Without Warning), $p < 0.05$

Metric	No Warning	With Warning	Improvement Direction
Reaction Distance (m)	33.77	42.40	↑ Increased safety buffer
Time to Collision (s)	2.41	3.02	↑ More time to act

Figure 35. Reaction distance FCW



[8] A non-parametric Mann–Whitney U test (since reaction distance is not normally distributed in With and No warning groups) confirmed that the difference between the two groups was statistically significant ($p < 0.05$).

Intersection Movement Assist

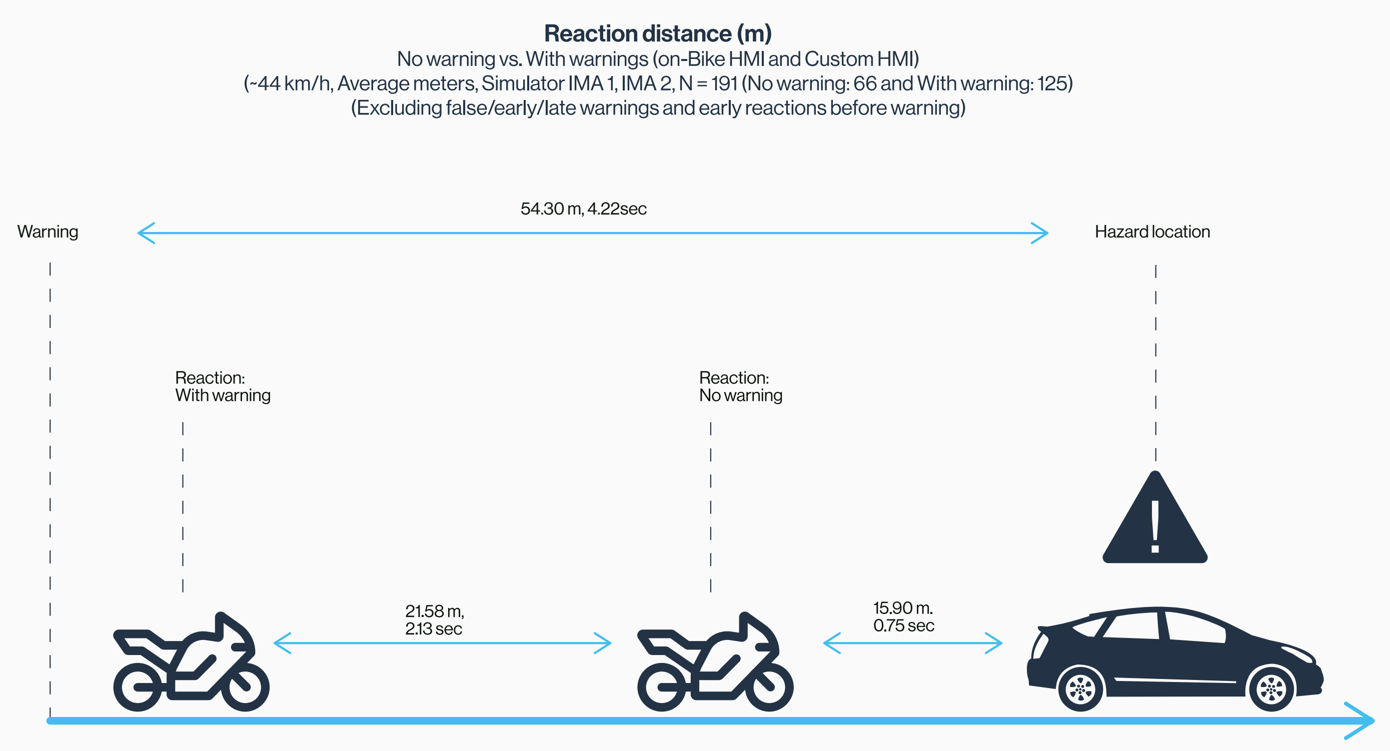
The intersection use case was tricky. As shown in Table 11 and Figure 36, the rider could not see the car coming from the left until the very last moment, hence the very short reaction distance without warnings. C-ITS made a huge difference in this use case; riders started to react 22 meters earlier.

- **Reaction Distance improved by more than 21.58 meters, providing much-needed space to respond.**
- **Time to Collision nearly quadrupled, rising from 0.75 to 2.88 seconds—suggesting improved situational awareness.**

Table 11. Rider behaviour in IMA Scenarios (With vs. Without Warning) , $p < 0.05$

Metric	No Warning	With Warning	Improvement Direction
Reaction Distance (m)	15.90	37.48	↑ Increased safety buffer
Time to Collision (s)	0.75	2.88	↑ More time to act

Figure 36. Intersection Movement Assist: Reaction distance



Dangerous Curve Warning

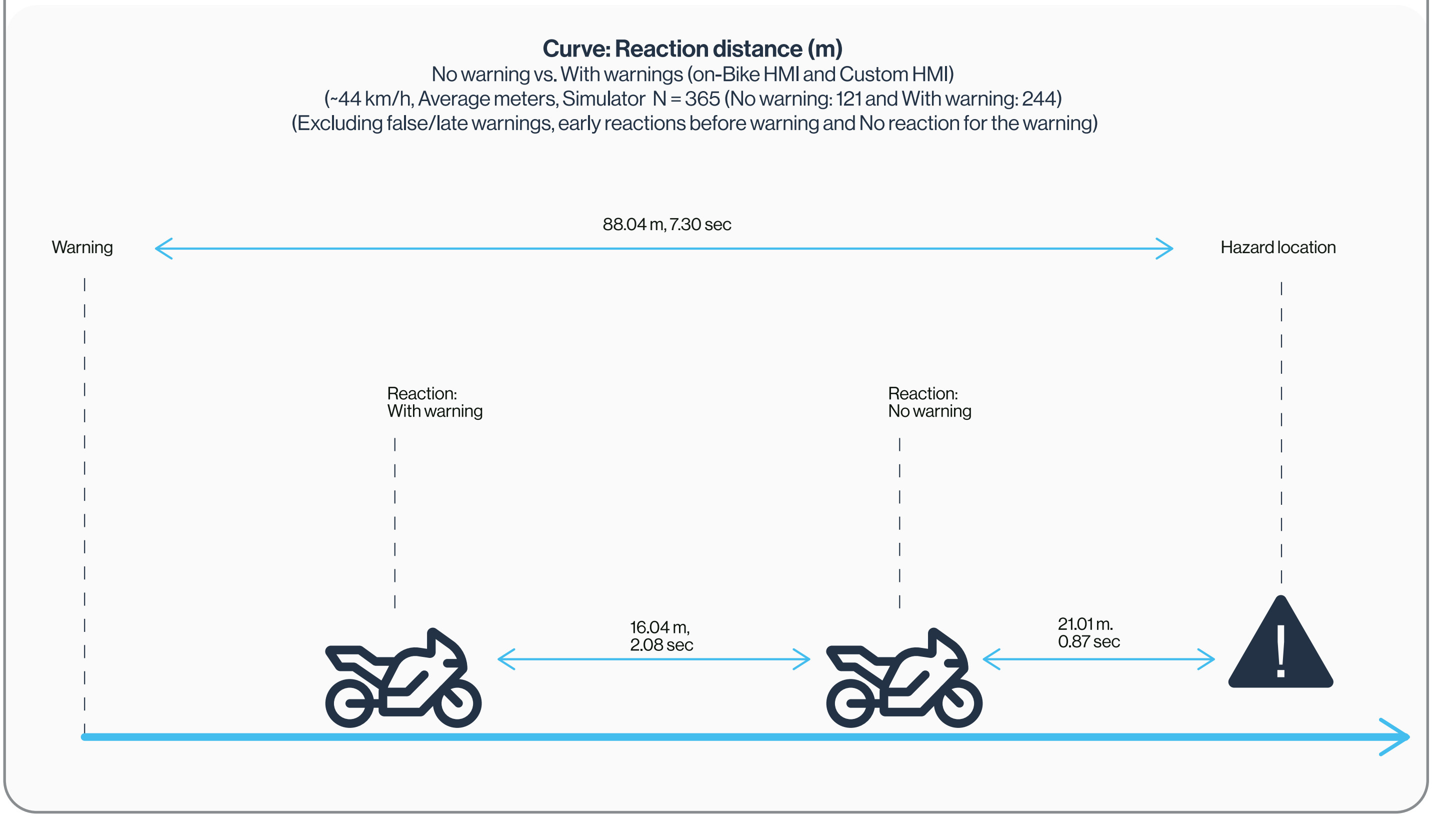
The dangerous curve warning (DCW) was provided as an I2V warning when the rider approached a fixed location (like a roadside sign). The warning was triggered three seconds earlier compared to the above scenarios, based on our previous research with riders. Unlike other use cases, riders received this warning each time they passed that location. Even though riders became familiar with the hairpin curve and its associated warning, the warnings still led to improved behaviour as show in Table 12 and Figure 37).

- **Reaction distances increased by ~16 meters, despite the fixed nature of the warning trigger.**
- **Riders in the warning condition had over 3× more time to collision than those without.**

Table 12. Rider behaviour in Curve Scenarios (With vs. Without Warning), $p < 0.05$

Metric	No Warning	With Warning	Improvement Direction
Reaction Distance (m)	21.01	37.06	↑ Increased safety buffer
Time to Collision (s)	0.87	2.96	↑ More time to act

Figure 37. Dangerous curve warning: Reaction distance

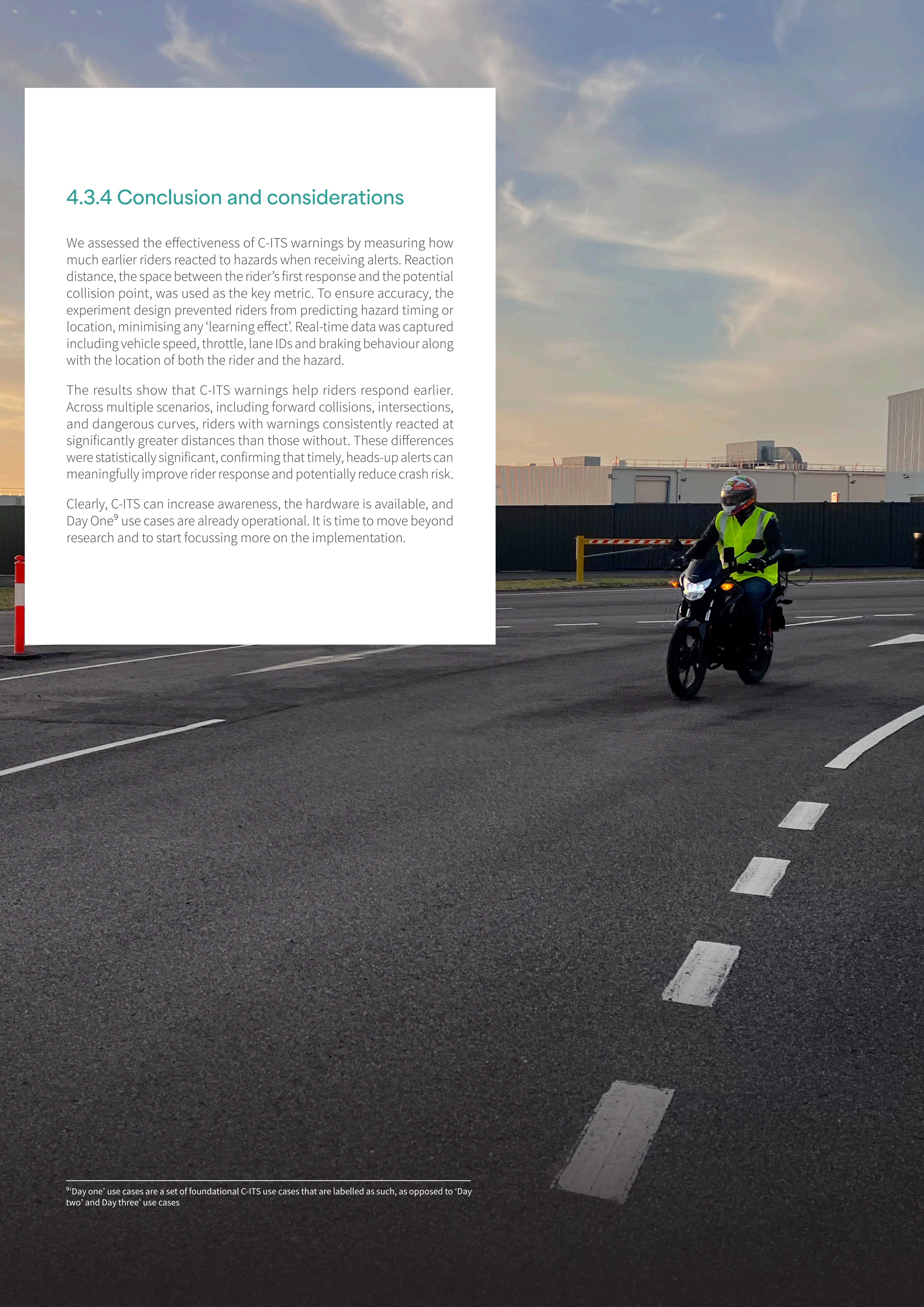


4.3.4 Conclusion and considerations

We assessed the effectiveness of C-ITS warnings by measuring how much earlier riders reacted to hazards when receiving alerts. Reaction distance, the space between the rider's first response and the potential collision point, was used as the key metric. To ensure accuracy, the experiment design prevented riders from predicting hazard timing or location, minimising any 'learning effect'. Real-time data was captured including vehicle speed, throttle, lane IDs and braking behaviour along with the location of both the rider and the hazard.

The results show that C-ITS warnings help riders respond earlier. Across multiple scenarios, including forward collisions, intersections, and dangerous curves, riders with warnings consistently reacted at significantly greater distances than those without. These differences were statistically significant, confirming that timely, heads-up alerts can meaningfully improve rider response and potentially reduce crash risk.

Clearly, C-ITS can increase awareness, the hardware is available, and Day One[9] use cases are already operational. It is time to move beyond research and to start focussing more on the implementation.

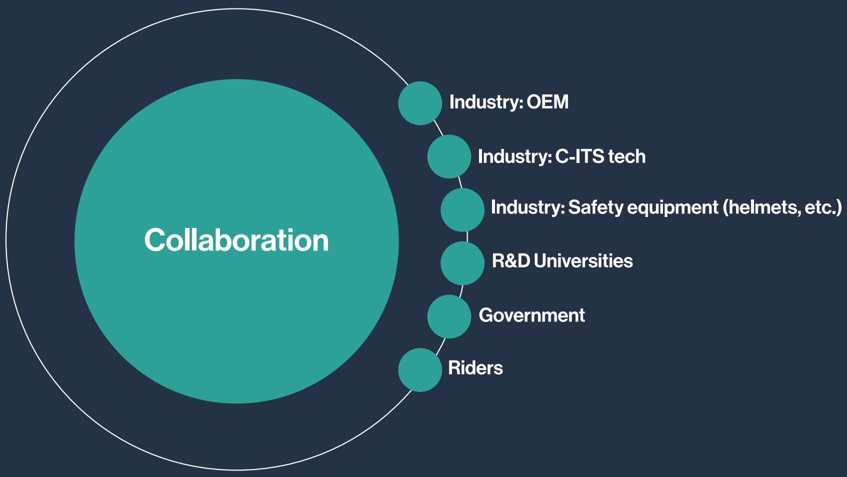


[9]'Day one' use cases are a set of foundational C-ITS use cases that are labelled as such, as opposed to 'Day two' and Day three' use cases

5. Where to from here?

We started this project to explore whether applying C-ITS to motorcycles was feasible, desirable, and effective. Through extensive rider engagement, simulations, and real-world testing, we found that not only is the technology ready, but riders also welcome it. The trial delivered convincing evidence that C-ITS can reduce crash risks.

We achieved these results using commercially available, off-the-shelf hardware, and simple test algorithms, indicating that the necessary components and basic scenarios are ready for deployment. Still, significant collaboration efforts are required. From a policy perspective, C-ITS on motorcycles offers a compelling case for public investment: it targets a high-risk user group, shows strong rider acceptance, and has the potential to significantly reduce crash-related injuries and fatalities, a major cost driver in national health and transport budgets. Governments need not wait for a full-scale rollout. Initial collaboration efforts, such as building the digital infrastructure for hazard warnings, would already yield benefits and catalyse industry collaboration. This incremental approach lowers cost barriers and accelerates the path to connected rider safety.



5.1 Governments

Governments are well-positioned to drive progress. By publishing existing road hazard data, such as surface defects, dangerous curves, and planned works, through National Access Points, they can enable immediate safety gains via warnings in navigation apps. This offers a low-cost, scalable first step toward a broader C-ITS ecosystem.

In parallel, public agencies can foster public–private partnerships to advance standards development and support pilot programs. Their leadership is especially important in promoting open architectures and ensuring interoperability across systems, laying the groundwork for connected safety technologies that benefit all road users.

Moreover, governments are expected to build the C-ITS ecosystem in the near future. Until that happens, there remains significant scope for governments to undertake broader foundational efforts. These include developing data-sharing frameworks, implementing security credential management systems, and designing interoperable digital infrastructure. Together, these elements will form the backbone of a scalable and future-ready C-ITS ecosystem that can evolve alongside emerging technologies.

5.2 OEMS and aftermarket device manufacturers

Motorcycle manufacturers can accelerate adoption by embedding warning systems into new bikes and enabling connectivity with rider-preferred HMIs, such as smart helmets, smart glasses, or haptic wristbands. Importantly, they can provide access to OBUs, allowing third-party apps and devices to connect securely and innovate.

Many bikes and rider apps already collect performance and behaviour data. When warnings become available, this data can be used to personalise warning timing, alert types, and formats to match individual riding styles and preferences. Interoperability can be supported through open standards like Bluetooth, enabling seamless integration between factory-fitted and aftermarket solutions. Manufacturers need to align with emerging standards for connected warnings, particularly when using Bluetooth or similar wireless technologies to communicate with third-party devices.

Adding technologies like LIDAR and radar can also help advance C-ITS capabilities, as it creates a market for situational awareness and eventually can be used for co-operative warnings.

For effective warning delivery, the challenge lies in balance: providing ambient awareness for general surroundings and cautionary alerts, while ensuring salient, high-priority alerts stand out. Innovations in sound design, augmented displays, and tactile feedback can help create intuitive, non-distracting rider experiences.

As the complexity of road situations increases, manufacturers will need to invest in more advanced algorithms. While our trial dealt with relatively simple use cases, real-world deployment will require advanced AI and edge computing, technologies already used in autonomous vehicles, to interpret traffic situations and make timely decisions. Given the collective benefit, the industry could consider collaborating on algorithm development rather than duplicating efforts.

Lastly, riders expressed interest in after-market solutions for their own bikes. OEMs or third-party suppliers can meet this demand by developing modular C-ITS kits that connect via OBD ports or external sensors—extending safety innovations to older motorcycle models.

5.3 Universities

Universities can play a role in bridging innovation and implementation. As neutral partners, we can test emerging technologies in real-world conditions, evaluate rider behaviour, and help shape evidence-based standards.

Looking ahead, universities can continue to lead collaborative trials, train the next generation of transport engineers, and explore the broader implications of connected mobility, across ethics, equity, and infrastructure design. By partnering with industry, government, and riders, we help ensure that motorcycle safety technologies are not only effective, but trusted and inclusive.

5.4 Riders

Riders themselves have a powerful role to play. By asking for these technologies and providing feedback, they drive demand. The same connected safety solutions being developed for cars should be available for motorcycles too, but tailored for the riding experience. Riders should continue to expect more, and ask for better.

Figure 38. A perfect example of public-private partnership. Representatives from Cohda wireless, Toyota, La Trobe, TAC, iMOVE and TMR

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