

Connected Motorcycle Safety

Start today, prepare for tomorrow

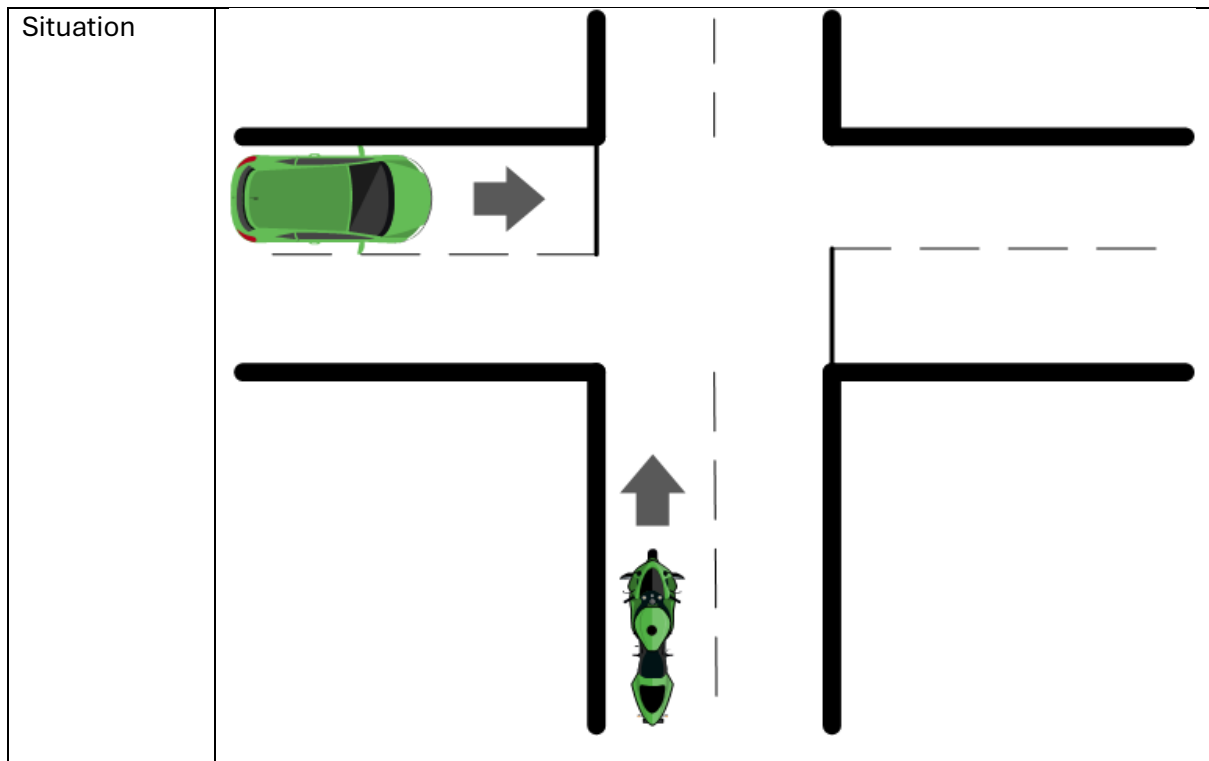
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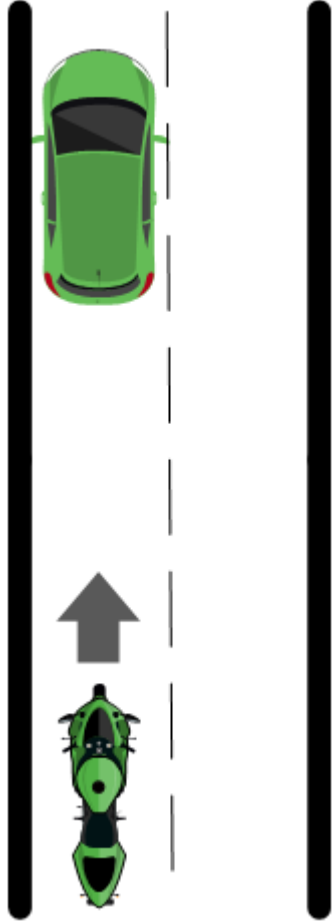
Use cases

This document refers to the following use cases:

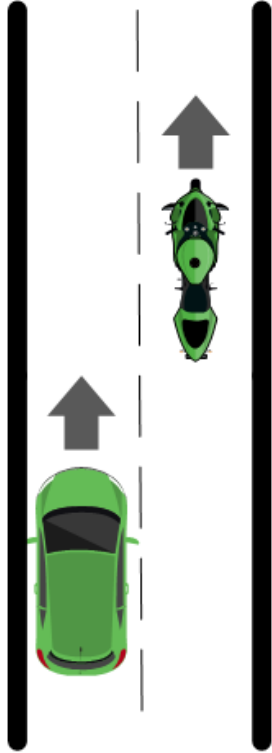
Intersection Movement Assist (IMA)	
Type of road network	TOYOTA Autodrome
Type of motorcycle	Honda CB 125F
Use case introduction	
Summary	This use case warns a rider about a vehicle approaching an intersection that's expected to continue straight through. The rider receives the warning with enough time to change their behaviour and avoid a potential collision. The use case will take place at two separate locations on the autodrome. At both locations, the vehicle will approach from the left, with the motorcycle on the road that has the right of way, in accordance with Australian traffic laws. The vehicle's speed will vary depending on the rider's speed and riding behaviour. This ensures the TTC for the Cohda algorithm is triggered while the vehicle still comes to a controlled stop before the intersection's threshold. Riders are instructed to ride at a maximum speed of 50 km/h when possible.
Objective	• Warn the motorcycle of the potential collision from a vehicle approaching the intersection. • The trajectory of both vehicles entering the intersection triggers the Cohda algorithm for a TTC. • The rider will change their behaviour to avoid the potential collision.
Desired behaviour	The rider will react to the delivered warning, changing their behaviour to prevent a collision with a vehicle approaching from the left of the intersection.
Use case description	



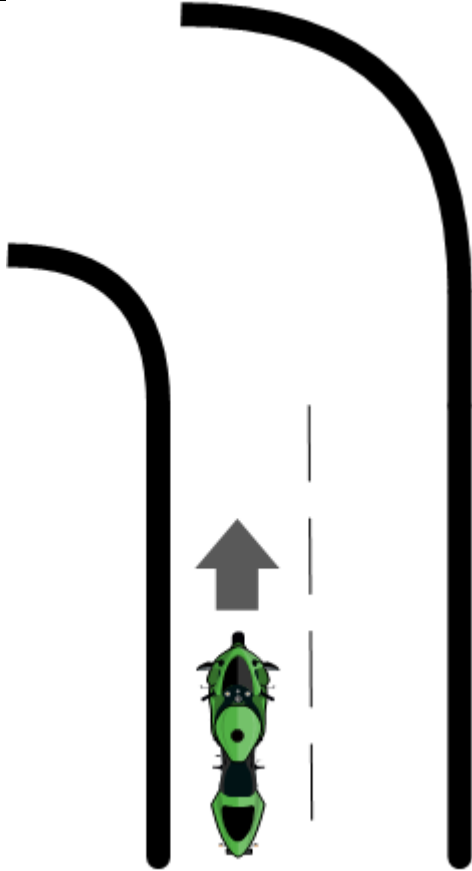
Forward Collision Warning (FCW)	
Type of road network	TOYOTA Autodrome
Type of motorcycle	Honda CB 125F
Use case introduction	
Summary	This use case warns a rider about a stationary vehicle in the same lane as their motorcycle. A warning triggers once the rider crosses a threshold, which the Cohda algorithm determines based on the distance to the vehicle and the motorcycle's speed. The use case will be conducted at three different locations at the autodrome. In each scenario, the vehicle will already be in a stationary position in the motorcycle's presumed path. Riders are instructed to ride in the left lane unless overtaking, so all stationary vehicles will be in the left lane. There will be two levels of warnings sent to the rider. The first is a cautionary warning, issued when the Cohda warning is initially sent. If the rider's behaviour doesn't change, a second, imminent warning will then be provided.
Objective	- Warn the motorcycle of the potential collision with a stationary vehicle in its path. - The rider will change their behaviour to avoid the potential collision.

Desired behaviour	The rider will react to the delivered warning, changing their behaviour to prevent a collision with a vehicle by coming to a complete stop or slowing their speed before moving around the stationary vehicle.
Use case description	
Situation	

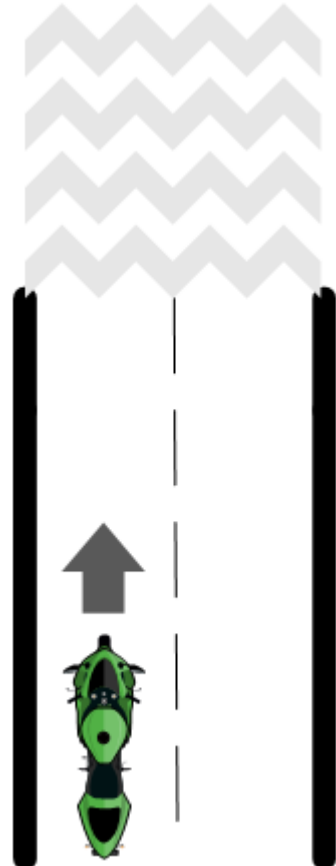
Blind Side Warning / Lane Change Warning (BSW / LCW)	
Type of road network	TOYOTA Autodrome
Type of motorcycle	Honda CB 125F
Use case introduction	
Summary	This use case warns a rider about a vehicle located in a potential blind spot, either to the rear left or rear right side of the rider. A warning will be triggered once the vehicle enters a critical zone, as determined by the Cohda algorithm, provided both the motorcycle and the vehicle are travelling at speeds greater than 40 km/h.

	This use case provides two different warnings: a blind spot warning and a lane change warning. The Cohda OBU on the motorcycle will scan the indicator information provided by the vehicle. If the conditions for a blind spot warning are met and the motorcycle's indicator has been activated for the same lane the vehicle is currently in, the cautionary warning will be upgraded to an imminent warning, signifying that the lane change warning conditions have been met.
Objective	- Warn the motorcycle of a vehicle in their blind spot. - Upgrade the warning to a lane change if the rider turns on their indicator for the corresponding lane of the vehicle's position.
Desired behaviour	The rider will not change lanes to move into the path of the vehicle.
Use case description	
Situation	

Dangerous Curve Warning (DCW)	
Type of road network	TOYOTA Autodrome
Type of motorcycle	Honda CB 125F

Use case introduction	
Summary	This use case warns a rider that they are approaching a dangerous curve. The warning is sent from an RSU and triggers once the rider crosses the threshold of a GPS coordinate set within the RSU. The warning is delivered in advance of the curve, giving the rider ample time to focus and adjust their speed to safely navigate the curve.
Objective	Warn the motorcycle that they are approaching a dangerous curve.
Desired behaviour	The rider will react to the delivered warning by reducing their speed to anticipate and then safely navigate the curve.
Use case description	
Situation	

Change Road Surface (CRS) Warning	
Type of road network	TOYOTA Autodrome
Type of motorcycle	Honda CB 125F
Use case introduction	

Summary	This use case warns a rider that they are approaching a change in the road's surface condition. The warning is sent from an RSU and triggers once the rider crosses a GPS coordinate threshold set within the RSU. The warning is delivered in advance of the change in road condition, giving the rider ample time to focus their attention on the different conditions they will encounter.
Objective	Warn the motorcycle that they are approaching a change in road surface condition.
Desired behaviour	The rider will react to the delivered warning by reducing their speed and navigating the change in road conditions.
Use case description	
Situation	 The diagram illustrates a motorcycle (green and black) traveling upwards on a road. The road is flanked by two thick black vertical bars representing lane boundaries. A dashed vertical line runs down the center of the road. Above the motorcycle, a grey arrow points upwards, indicating the direction of travel. Further ahead, a series of grey chevron patterns (pointing upwards) represent a change in road surface condition, such as a speed bump or a different pavement type.

1. Feasibility

Main Research Question:

How well did the C-ITS technology perform?

Project outcome:

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 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.

1.1 C-ITS System Performance

Table 1: Cohda MK6 Performance Measurement Metrics

Category	Performance Measurement
Cohda MK6 U-Blox High Accuracy GPS Sensor	GPS Accuracy – Horizontal and vertical position error in meters. GPS Time Accuracy- How close the GPS receiver’s internal clock is synchronized to true GPS time.
EU ITS-G5 DSRC Communication	DSRC Communication End-to-End Latency: <10ms for safety-critical messages.
	DSRC Packet Delivery Ratio (PDR): defined as the percentage of successfully received packets compared to the total number of packets sent.
	Packet Reception Signal Strength: Reception reliability in varying conditions, communication range, speed, Line-of-Sight.
	Communication Range: Maximum distance for effective message exchange, Range > 200m is expected.

To assess the performance of our C-ITS system, we compared its performance against ETSI standards. ETSI is the European Telecommunications Standards Institute, which develops global standards for ICT, including C-ITS. The standards stipulate the technical requirements for key V2X safety applications in Cooperative Intelligent Transport Systems (C-ITS)¹.

To ensure these warnings are effective and delivered in time, the standards define communication performance requirements. The required KPI elements are summarised in Table 2.

¹ 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)

Table 2: 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)

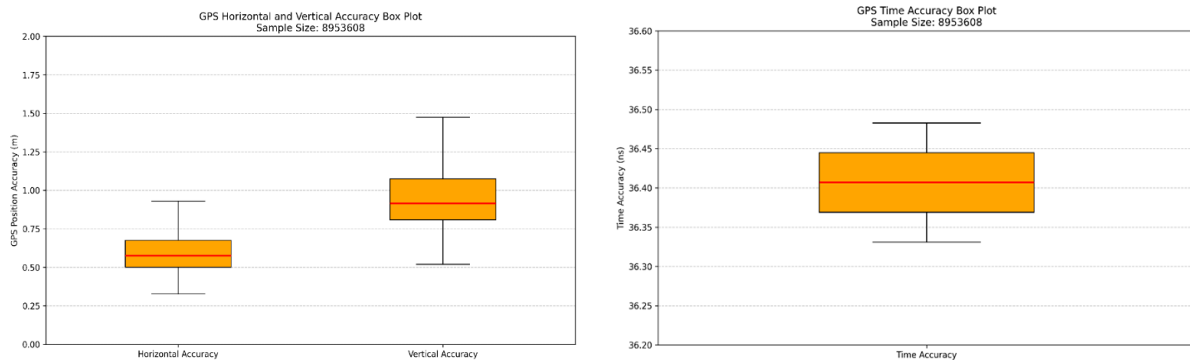
The GPS sensor that the Cohda MK6 used, a U-blox unit, performed well. C-ITS standards and deployments require much high precision. For instance, lane-level accuracy of ≤ 1 meter is necessary for correct lane identification, overtaking detection, or blind spot monitoring.

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 1 shows the findings:

- GPS 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: Maintained ~ 36 ns, supporting time-critical safety applications.

Our system performs satisfactory for real-time safety applications on motorcycles, without advanced corrections like RTK.

Figure 1: GPS Accuracy



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

Figure 2 illustrates the relationship between communication latency and distance. It is evident that DSRC direct communication maintains latency below 2.5 milliseconds within a range of up to 150 meters. Even at distances exceeding 300 meters, latency remains low at approximately 5 milliseconds.

Figure 2: DSRC Communication Latency vs Distance with 95% CI

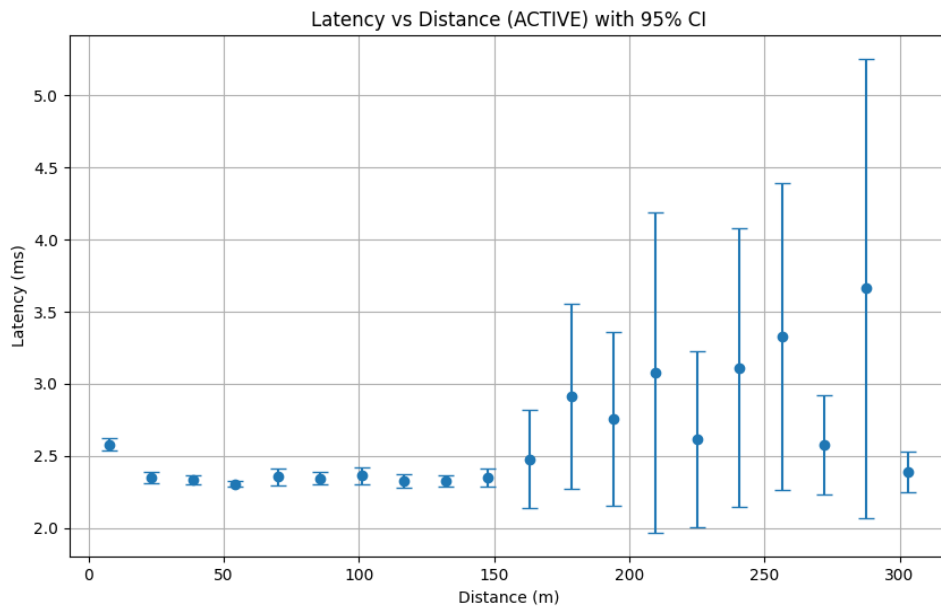


Figure 3 presents received RSSI values as a function of communication distance, with the transmit power fixed at 23 dBm. As expected, RSSI decreases progressively with increasing distance. At approximately 350 meters, the lowest observed RSSI reaches -95 dBm, which effectively defines the practical communication range achievable at the Toyota Autodrome site under the given test conditions.

Figure 3: RSSI vs. Distance

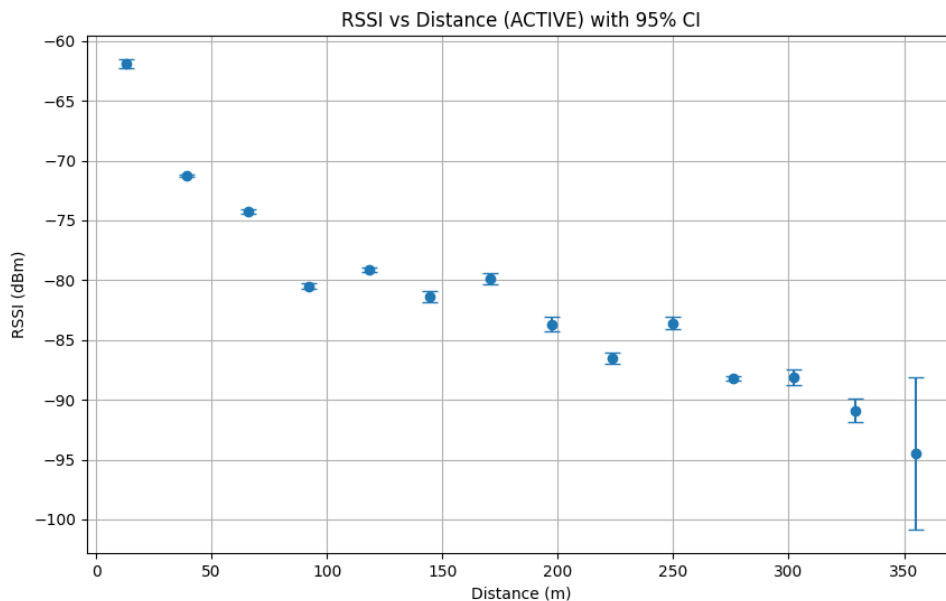
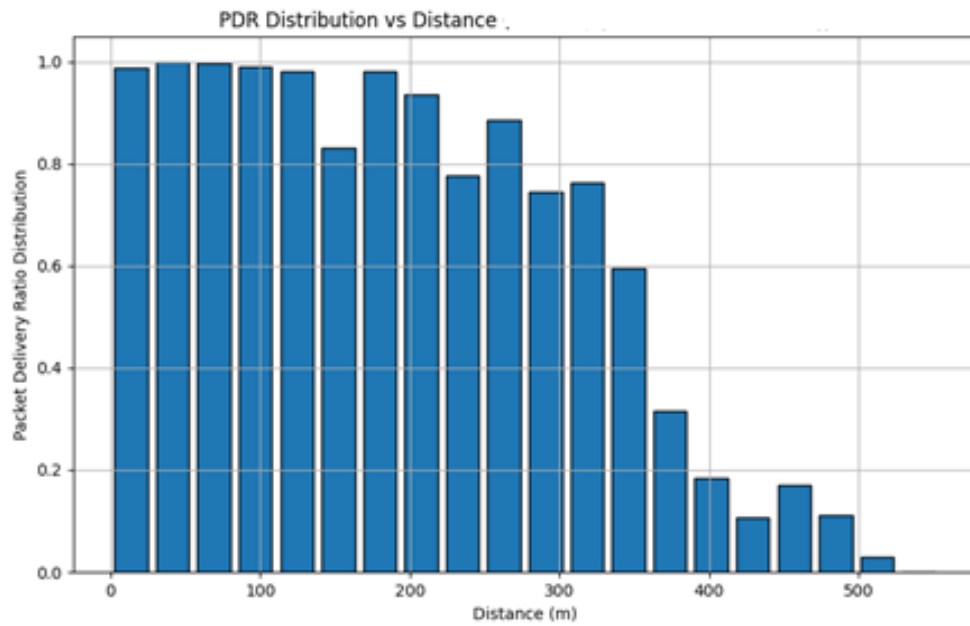


Figure 4 illustrates the Packet Delivery Ratio (PDR) as a function of communication distance. The PDR remains consistently high—approximately 90% within 200 meters—and gradually decreases as the distance increases. Beyond 300 meters, a sharp decline in PDR is observed, indicating a significant reduction in communication reliability at extended ranges.

Figure 4: DSRC RSSI vs. Communication Distance with 95% CI



1.2 C-ITS Algorithm Performance

In this section, we present the performance evaluation of the C-ITS safety algorithms tested at designated locations on the Toyota test track. Developed by Cohda Wireless, these algorithms were integrated into the Cohda software stack on OBU MK6 devices, which were also used in the simulation trials. Table 3 summarises the missing warning rates for each warning type, based on test scenarios ranging from simple to moderately complex, as outlined in the trial plan.

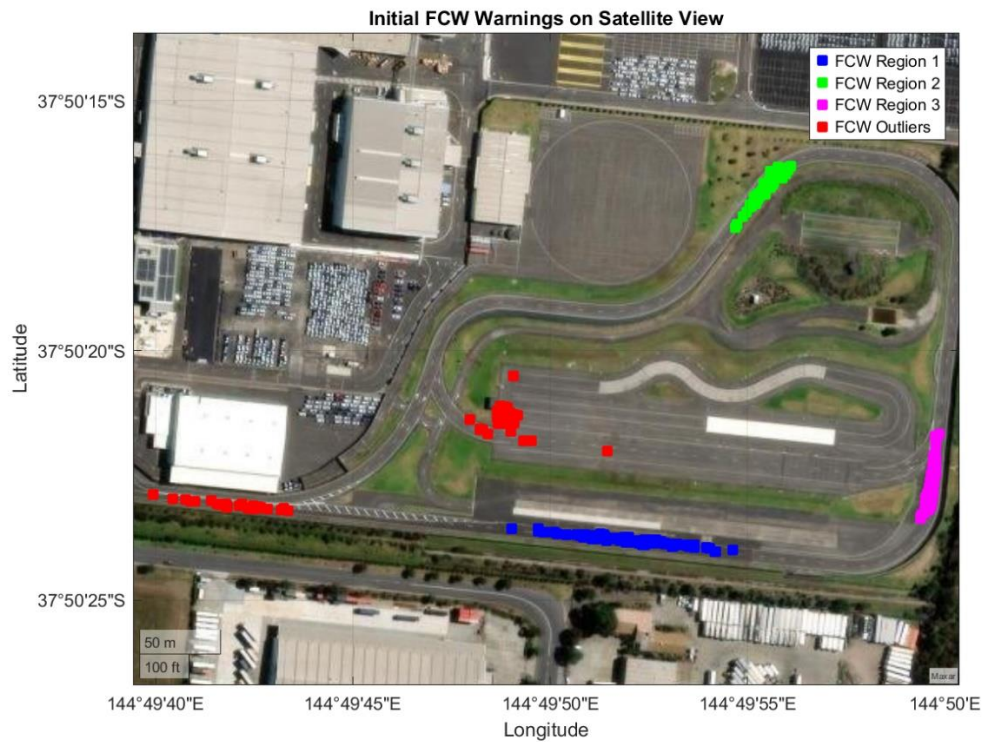
Table 3: Summary of Missing Rate of C-ITS Algorithms

	Simulation				Test Track Trial			
Warning Type	Expected number of warnings	Number of received warnings	Number of missing warnings	Missing Rate	Expected number of warnings	Number of received warnings	Number of missing warnings	Missing Rate
FCW	260	252	8	4%	376	296	80	21%
IMA	260	243	17	7%	376	313	63	17%
DCW	455	449	6	2%	658	643	15	2%
BSW	130	122	8	6%	188	177	11	6%
CRS	65	64	1	1%	94	94	0	0%

Forward Collision Warning (FCW)

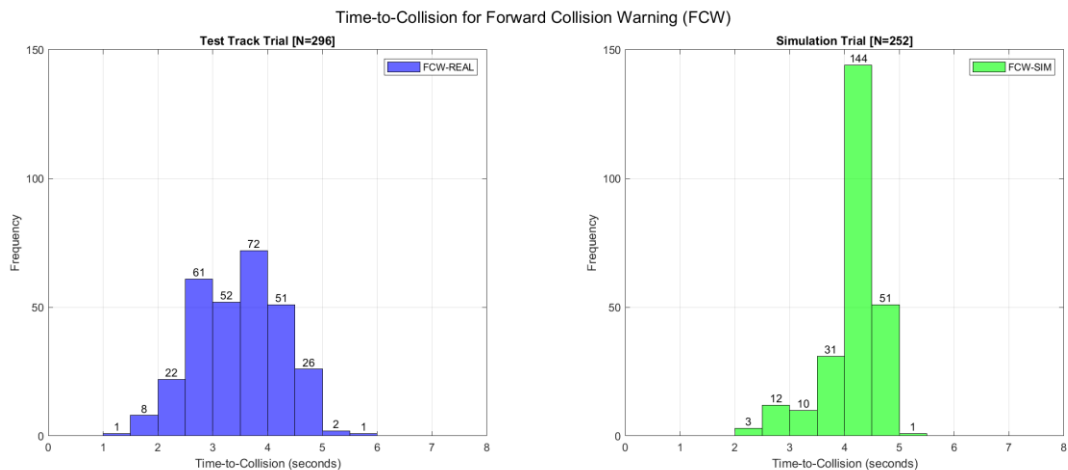
Figure 5 shows the starting points of FCW warnings. The La Trobe team designated three regions for this use case, shown in blue, green, and magenta. We removed unwanted outliers (red points); these are not false warnings but simply fall outside the designated regions.

Figure 5: Initial FCW Warnings on Satellite View



The next two histograms in Figure 6 illustrate the repeatability of the FCW algorithm between the real-world Toyota test track trials and the simulation trial. The simulation histogram shows better grouping and less spreads of data points, indicating better repeatability. In contrast, on the Toyota test track, the grouping of data points is less pronounced compared to the simulation.

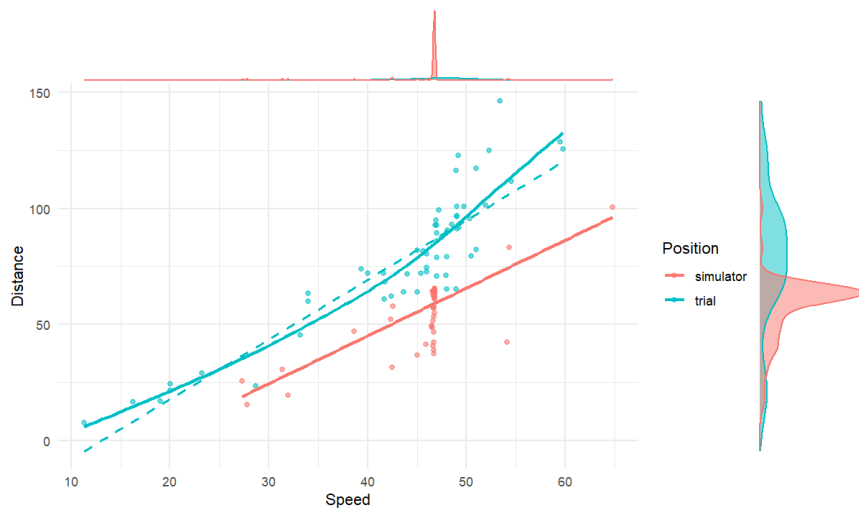
Figure 6: The repeatability of FCW algorithm



Since the distribution of warnings is related to speed, we plotted speed and warning delivery against each other for both the test track trial and the simulator trial. In ideal circumstances the warning distribution is much clearer clustered. In real circumstances there is more variability.

Figure 7: FCW1 Analysis - Trial and Simulation Comparison

GAM (Solid) and Linear (Dashed) Fits with Marginal Distributions



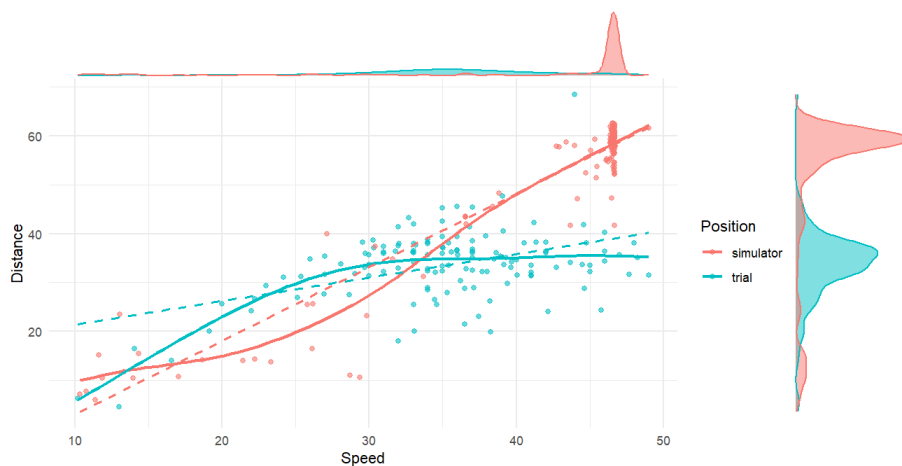
Use Case Distance to RV

Predictors	Estimates	CI	p
(Intercept)	-55.6	-67.31 – -43.89	<0.001
useCase HV speed	2.46	2.21 – 2.71	<0.001
group [trial]	26.89	22.96 – 30.83	<0.001
Observations	127		
R ² / R ² adjusted	0.803 / 0.800		

This regression model examines Distance to RV as a function of vehicle speed and group (trial vs. simulator). Vehicle speed is a strong positive predictor ($\beta = 2.46$, $p < 0.001$), and participants in the trial group exhibited significantly longer distances ($\beta = 26.89$, $p < 0.001$). With 127 observations, the model explains 80.0% of the variance (adjusted $R^2 = 0.800$), indicating a strong model fit. No interaction term was detected.

Figure 8: FCW2 Analysis - Trial and Simulation Comparison

GAM (Solid) and Linear (Dashed) Fits with Marginal Distributions

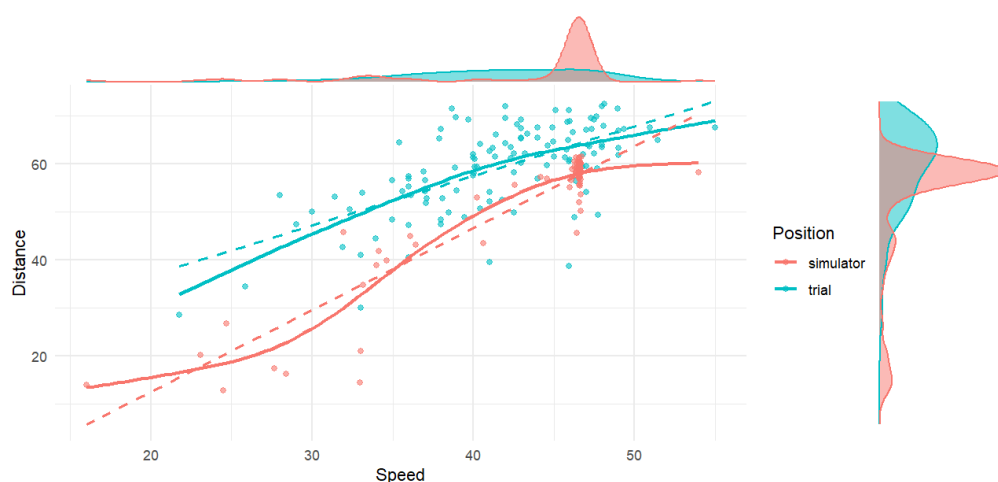


use Case Distance to RV			
Predictors	Estimates	CI	p
(Intercept)	-12.13	-16.13 – -8.13	<0.001
useCase HV speed	1.51	1.42 – 1.60	<0.001
group [trial]	28.68	22.37 – 34.99	<0.001
useCase HV speed × group[trial]	-1.03	-1.19 – -0.86	<0.001
Observations	285		
R ² / R ² adjusted	0.862 / 0.861		

This regression model examines Distance to RV as a function of vehicle speed, group (trial vs. simulator), and their interaction. Vehicle speed is a strong positive predictor ($\beta = 1.51$, $p < 0.001$), and participants in the trial group showed significantly longer distances ($\beta = 28.68$, $p < 0.001$). However, the interaction term indicates that the effect of speed on distance is significantly reduced in the trial group ($\beta = -1.03$, $p < 0.001$). Based on 285 observations, the model explains 86.1% of the variance (adjusted $R^2 = 0.861$), indicating a very good model fit.

Figure 9: FCW3 Analysis - Trial and Simulation Comparison

GAM (Solid) and Linear (Dashed) Fits with Marginal Distributions



use Case Distance to RV			
Predictors	Estimates	CI	p
(Intercept)	-21.68	-30.53 – -12.83	<0.001
useCase HV speed	1.71	1.50 – 1.91	<0.001
group [trial]	37.82	25.64 – 50.00	<0.001
useCase HV speed × group[trial]	-0.67	-0.96 – -0.39	<0.001
Observations	193		
R ² / R ² adjusted	0.702 / 0.697		

This regression model examines Distance to RV as a function of vehicle speed, group (trial vs. simulator), and their interaction. Vehicle speed is a strong positive predictor ($\beta = 1.71$, $p < 0.001$), and participants in the trial group exhibited significantly longer distances ($\beta = 37.82$, $p < 0.001$). The interaction term shows that the effect of speed on distance is significantly weaker in the trial group ($\beta = -0.67$, $p < 0.001$). Based on 193 observations, the model explains 69.7% of the variance (adjusted $R^2 = 0.697$), indicating a good model fit.

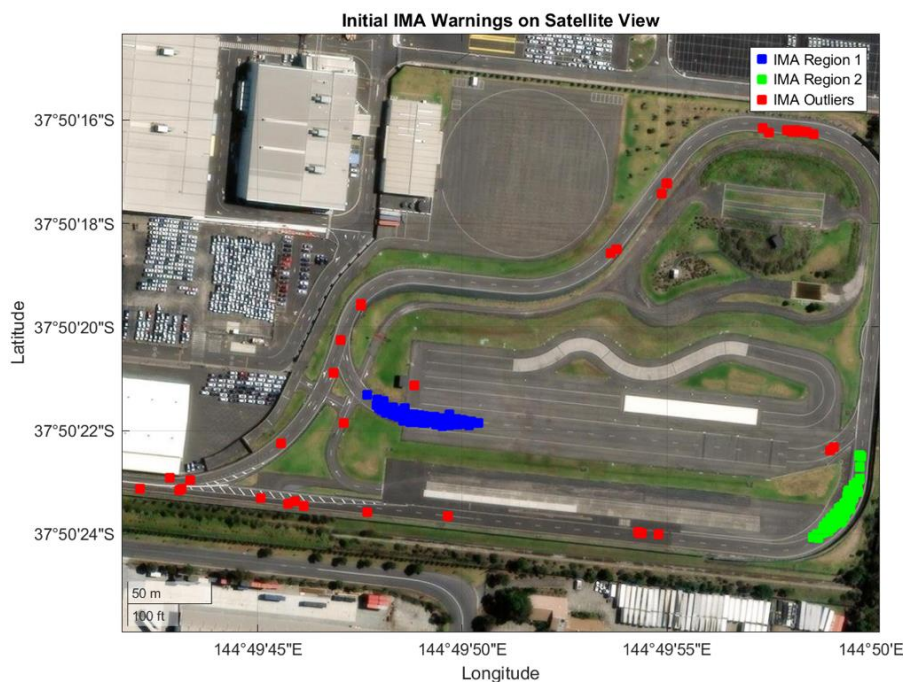
Across all three FCW scenarios(1-3), the following trends are consistent:

1. Vehicle speed is a key determinant of safe following distance.
2. Real-world warnings are delivered more spread out and further away than those in simulator environments.
3. The effect of speed is slightly weaker in real-world conditions
4. All models show strong predictive validity, with R^2 values above 0.7.

Intersection Movement Assist (IMA) or Intersection Collision Warning (ICW):

As shown in Figure 10, La Trobe University designated two regions specifically for the IMA scenarios. IMA can have different types, but for this study, we used only the ICW algorithm. The starting points of ICW warnings are shown in blue for the IMA1 location and in green for the IMA2 location. The red points on the map represent outliers. These outliers may have occurred due to repositioning the vehicles between test scenarios during the trials, which resulted in unintended data points. Additionally, some outliers may be false warnings, indicating room for improvement in further fine-tuning of the algorithms.

Figure 10: Initial ICW Warnings on Satellite View

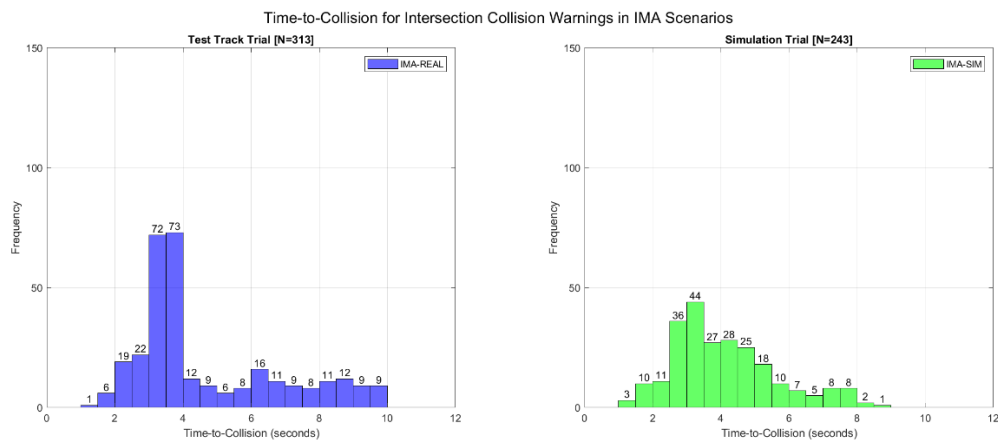


The ICW warning histogram (Figure 11) shows that the real-world test track data points are more repeatable between 2.5 and 4 seconds of time-to-collision; however, this could be slightly late

for ICW. In contrast, the simulation trial data shows less grouping but generates more early warnings than the test track data.

In conclusion, the IMA1 and IMA2 scenarios were moderately complex, especially when there was a curve for either the motorcycle or the vehicle. The ICW algorithm proved to perform reasonably well for our scenarios. Additionally, it performed slightly better in the simulation by issuing more early warnings to riders.

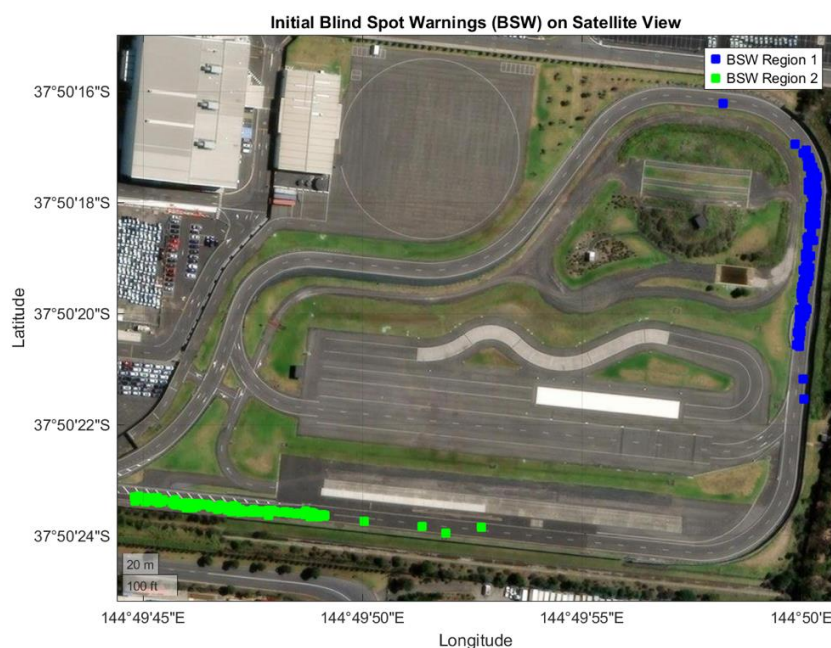
Figure 11: The repeatability of the IMA algorithm



Blind Spot Warnings (BSW):

We implemented the Blind Spot Warning (BSW) algorithms available in the Cohda software stack to deliver meaningful and directional blind spot alerts, as well as to identify potential lane change hazards. Figure 12 illustrates the BSW warnings, within Region 1 shown in blue and Region 2 shown in green. Additionally, we planned for a safe and simple BSW scenario using only one car, and the result was consistent, with no outliers observed for this specific use case.

Figure 12: Initial BSW Warnings on Satellite View



Dangerous Curve Warning (DCW):

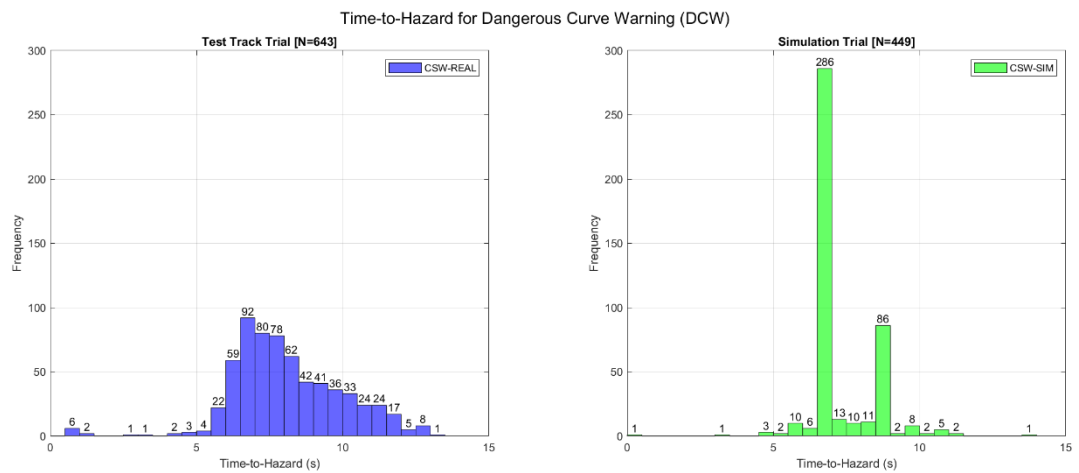
For the dangerous curve use case, we utilized only the Curve Speed Warning (CSW) algorithm provided within the Cohda software stack. The CSW algorithm operates based on the rider's location, posted speed limits, and the rider's actual speed. It generates two types of warnings: one indicating an upcoming curve based on the rider's approach, and another indicating over speeding while already within the curve. For this analysis, we considered the over speeding warnings as outliers and excluded them from the performance evaluation. We focused exclusively on the initiation points of the curve-ahead warnings, as illustrated in Figure 13. In this figure, the blue points represent Dangerous Curve Warnings (DCWs) recorded during the Toyota Autodrome test track trial, the green points are DCWs generated in simulation, trial and the red points indicate overspeeding warnings, which have been excluded from the analysis.

Figure 13: Initial Dangerous Curve Warnings on Satellite View



The histograms in Figure 14 illustrate the distribution of time-to-curve warnings for both the test track trials and the simulation trials. On the test track, the majority of warnings were triggered after 5.5 seconds of time-to-hazard (TTH) and extended up to 12 seconds, with most occurring sufficiently in advance to allow safe rider response. In contrast, the simulation data demonstrates high repeatability, with warning lead times consistently ranging from 6.0 to 6.5 seconds and likewise providing adequate early warnings.

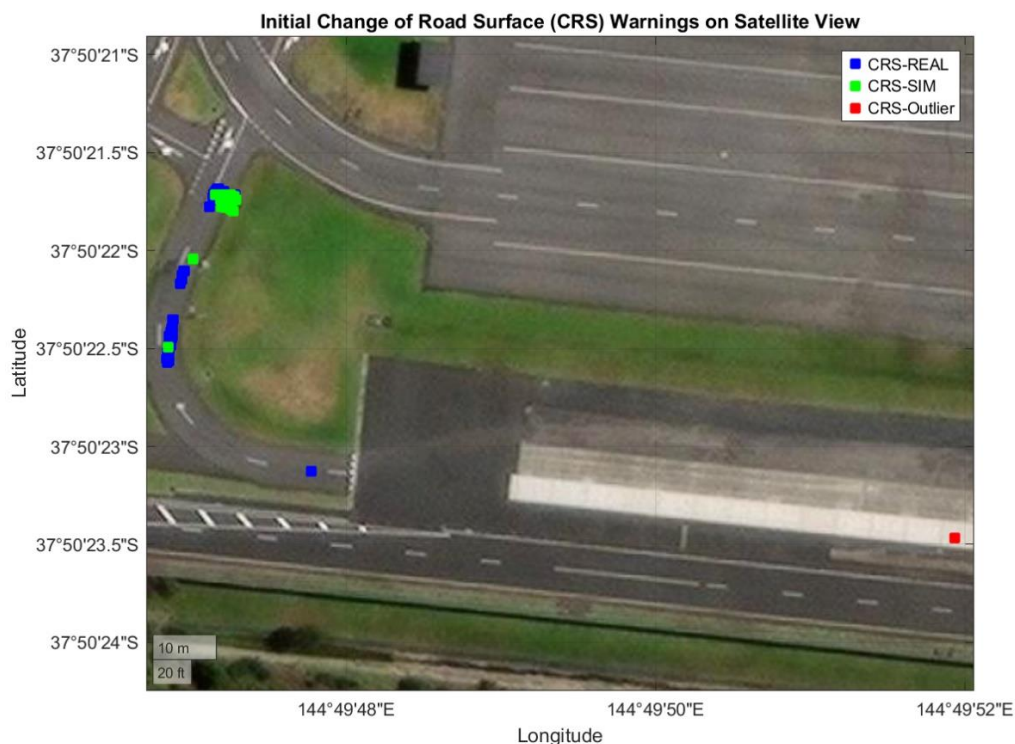
Figure 14: Performance of DCW Algorithms



Change Road Surface (CRS) Warning (rough surface):

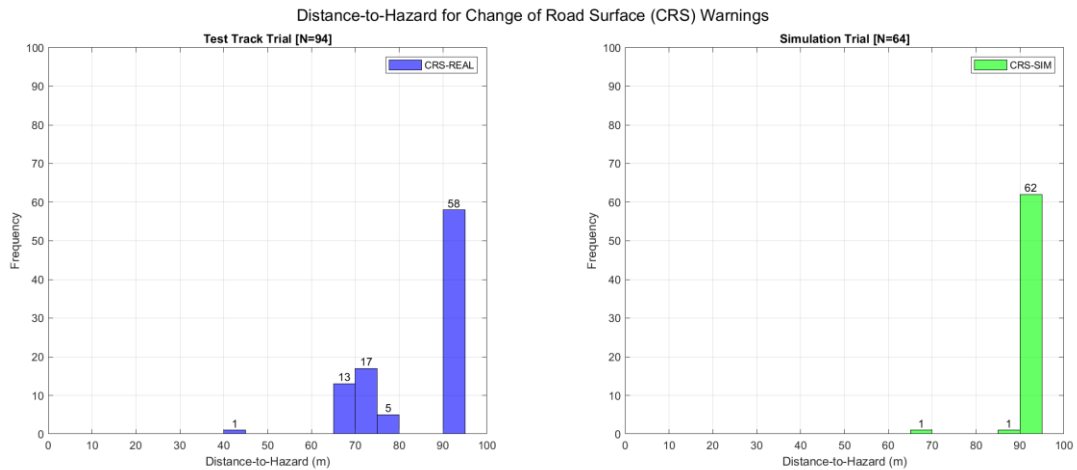
For the Change of Road Surface use case, we utilised TSR warnings delivered through C-ITS DENM messages. This warning is purely location-based, providing alerts to riders about upcoming rough surface conditions. Similar to the Dangerous Curve Warning (DCW), the TSR algorithm demonstrated strong performance in terms of both repeatability and reliability. Figure 15 shows the starting points of the CRS warnings (or TSR warnings for rough surfaces). It is evident from the map that the simulation data points are more tightly grouped than those from the test track trials, likely due to the near-ideal GPS accuracy inherent in the simulation environment.

Figure 15: Initial TSR Warnings on Satellite View



As shown in Figure 16, the Change of Road Surface (CRS) warnings are purely location-based and therefore exhibit very high repeatability when analysed by distance rather than by time-to-hazard (TTH). In the simulation, nearly all CRS warnings were triggered 90 meters before the hazard. Similarly, on the test track, most CRS warnings occurred at approximately 90 meters, with a few occurring between 65 and 75 meters, likely due to variations in GPS accuracy during the trials. Although the Cohda TSR algorithm provides the distance to hazard, for more accurate measurement on curved road segments, we separately calculated the distance to the hazard along the actual road path.

Figure 16: Distribution of distance to hazard of CRS warnings



1.3 Hardware Commercial Integration

The integration of C-ITS into motorcycles must be examined from three perspectives:

- Integration by manufacturers into new motorcycles.
- The ability to retrofit the technology onto older motorcycles.
- Off-the-shelf options for consumers to install themselves or have installed by their bike shop.

For new motorcycles, the primary limitation is the level of adoption by OEM motorcycle manufacturers. While C-ITS DSRC chipsets are readily available from companies such as Qualcomm and Autotalks, the decision to integrate the technology lies with the manufacturers.

This presents a classic catch-22: C-ITS requires a critical mass of connected vehicles to be effective, yet manufacturers are hesitant to invest without a proven return, especially when the technology depends on widespread adoption to function effectively. Both manufacturers and consumers may need incentives, potentially through government support, as public infrastructure will also play a critical role in the broader ecosystem.

One concern raised by riders during trials was how they could integrate this technology into their own bikes. Their only point of reference was the prototype used in the trial, a large black box mounted on a luggage rack, which is not a practical solution for most riders. A key challenge in retrofitting is access to CAN bus or OBD ports. However, many OBUs can still operate without this

data. For example, in the case of the Cohda MK6, all algorithms in the trial could generate warnings using only GPS data, except for the Lane Change/Merge Alert (LCMA). The “merge” component of this alert requires knowledge of the host vehicle's indicator status to distinguish it from a simple lane change. In our case, this information wasn't accessible via the OBD CAN bus, so we had to tap the indicator signal manually and relay it to the OBU using a custom vehicle interface.

Such workarounds may be required when retrofitting motorcycles, depending on whether the bike has CAN bus access. This leaves room for OEMs or third-party suppliers to develop installation kits. A tiered approach may be suitable, as not all warnings and algorithms will be feasible under all circumstances. Additionally, the capabilities of a system are limited by the software stack provided by the OBU manufacturer, most of which are still in the research and pilot phases, with many warnings still under development and testing.

For off-the-shelf options that riders can purchase and install themselves, products such as the Commsigna OBU LITE show promise for motorcycles due to their small form factor. The OBU LITE, in particular, is designed for bicycles, e-bikes, and e-scooters, and features CAN-FD and USB interfaces, suggesting it could be adapted for motorcycles.

A preliminary evaluation conducted at La Trobe University for the Commsigna OBU LITE found that it performed well within a 400-meter range. Beyond that range, packet loss increased to approximately 60%. However, for a motorcycle travelling at 70 km/h with an assumed deceleration rate of 5 m/s^2 , the stopping distance is under 40 meters—well within the device's effective range. This provides sufficient time to generate and respond to alerts, demonstrating that the OBU LITE can support key V2V applications.

This suggests a promising future for consumer-level, off-the-shelf C-ITS solutions.

After generating a warning, the next key element is delivering it effectively to the rider. During the trials, a bespoke application was developed to facilitate this. The application included debugging features for the development team and supported connections to multiple commercial and in-house devices. It also logged trial data to a database for each rider. While such features are unnecessary in a commercial context, this setup highlights the importance of having universal access to the OBU to allow integration with third-party systems.

On-bike warning systems and Human-Machine Interfaces (HMIs) can be readily manufactured for new motorcycles. However, based on feedback from over 100 riders, HMIs that are worn by the riders offering minimal obstruction while riding, were consistently preferred over fixed, motorcycle-mounted devices.

This suggests a need for standardisation to support third-party application developers in creating interoperable solutions within the broader C-ITS ecosystem. Most HMI devices already offer a companion mobile application to facilitate message relay. For new motorcycles, Bluetooth or other wireless technologies can be used to connect the onboard C-ITS system to a rider's mobile device, which in turn would display warnings via the preferred Human-Machine Interface (HMI). For retrofitted or off-the-shelf solutions, standardised protocols will be necessary to allow seamless integration of a wide range of hardware and software options.

A strong theme in rider feedback was the desire for control over the warning system. Riders expressed a preference for adjustable warning levels and timing to suit individual riding styles. Many also wanted the ability to select which warnings were active. For instance, a high percentage of riders found the curve warning unhelpful and would choose to disable it.

Riders also emphasised the importance of customisation in how warnings are presented. This includes options to adjust the brightness and colour of illuminated indicators, with some noting that certain colours, like red, can conflict with existing dashboard alerts, such as redlining indicators on the rev counter. Riders further suggested the need for control over audio alerts, including options for tones or spoken messages, as well as vibration patterns via haptic devices.

1.4 Conclusions

The C-ITS system demonstrated strong performance against ETSI benchmarks. The GPS module consistently met sub-meter accuracy, while DSRC communication maintained low latency and a high packet delivery rate within 200 meters. These results confirm that the system can reliably support real-time safety applications for motorcycles under trial conditions.

Algorithm performance varied across use cases. While lane-based and location-triggered warnings such as CRS and DCW were highly reliable, algorithms like FCW and IMA showed more variability, especially in real-world trials. Simulation environments yielded higher consistency, but all tested warnings achieved meaningful detection rates, validating the algorithm stack's core effectiveness.

Commercial integration of C-ITS on motorcycles remains limited by OEM adoption and retrofit complexity. However, the trial showed that consumer-level OBUs and wearable HMIs can support key use cases. Riders preferred customisable, wearable warning systems, underscoring the need for open standards to support future third-party innovations and scalable deployment.

2. Desirability

Main Research Question:

What factors influence the adoption of C-ITS technology by riders?

Project outcome:

Most riders are very interested in having a C-ITS warning system on their motorbike to support their own observations. Having a system that can help them “look” ahead further and detect risks they cannot see allows for a safer riding experience.

However, adoption is conditional: warnings must be useful, customisable and personalised, and delivered in a way that integrates well with the riding experience.

2.1 Introduction

C-ITS technology could have a potential to improve traffic safety by reducing road crashes resulting from human errors. Research on the safety impact of different vehicle automation technologies (e.g., ADAS, ICV, and Connected and Automated Vehicles (CAVs)) indeed suggests a substantial decrease in the frequency and severity of crashes due to optimised hazard sensing and detection capabilities of these technologies (e.g., Shannon et al., 2021; Sheehan et al., 2017). Australia is developing infrastructure and policy to support connected and automated vehicles (CAV), for example, Queensland's Ipswich Connected Vehicle Pilot and Bruce Highway deployment, and Victoria's Australian Integrated Multimodal Ecosystems (AIMES). Road safety is a critical component of the C-ITS standards and use cases, with a growing focus on developing data and interfaces. C-ITS presents an emerging opportunity to improve motorcycle rider safety and is being investigated internationally, for example, by the Connected Motorcycle Consortium (CMC).

To realise the potential safety benefits of motorcycle² connected technologies, it is essential to identify barriers that may prevent system uptake and use. That is, researchers need to understand whether these connected technologies are currently, or could become, acceptable to motorcycle riders. It is counterproductive, both financially and from a safety perspective, to invest in developing new technologies if the systems are never purchased or if they are purchased but never used (Van Der Laan et al., 1997).

User acceptance is a multifaceted and highly context-dependent construct. Although the concept is broadly recognised, multiple attempts have been made to define, model, and measure acceptance of safety technologies among road users. In the context of this study, user acceptance of C-ITS is understood in line with the definition provided by Adell (2009), namely as “*the degree to which an individual incorporates the system in his/her riding, or, if the system is not available, intends to use it*” (Adell, 2009, p. 31). This distinction captures both actual behavioural integration and future willingness to adopt the technology. Furthermore, as outlined by Pianelli et al. (2007), acceptance can be divided into *a priori acceptability*, the perceptions

² Motorcycle includes motor-scooters (e.g. vespa-style), motor-trikes and moped.

formed before using the system, and a *posteriori acceptability*, the opinions shaped after direct exposure.

This report explores user desirability by evaluating their acceptance to different C-ITS warning modalities across multiple road scenarios. By analysing both quantitative data and qualitative feedback from riders mainly in test track trials, the findings offer critical insights into how C-ITS systems can be designed and deployed in ways that we can increase adoptions of these emerging technologies.

2.2 Research objectives:

- To evaluate the desirability of receiving C-ITS warning for various use cases
- To identify the most desirable method to communicate warnings
- To identify the factors influencing adoption among different rider segments, with a focus on the resistant group.

2.3 Conceptual Model

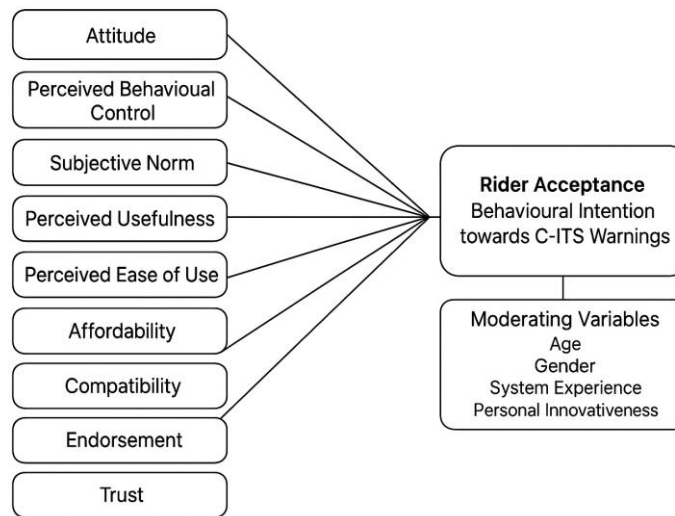
This study was guided by the conceptual Model of Driver Acceptance developed by Rahman et al. (2018), which provides a structured framework for evaluating user acceptance of C-ITS technologies (see Figure 17). The model identifies nine core factors that influence system acceptance: attitude, perceived usefulness, perceived ease of use, subjective norm, perceived behavioural control, compatibility, trust, endorsement, and affordability.

The model also recognises the influence of socio-demographic characteristics—such as age, gender, rider experience, which may moderate the relationship between the nine independent variables and system acceptance. Additionally, attitude is proposed as a partial mediator of the effect of the other eight variables on acceptance outcomes.

Although initially developed for car drivers, this model was adapted in our study to assess rider acceptance of C-ITS warnings. It offered a strong foundation for interpreting data gathered through simulator and test track trials.

Importantly, the Model of Driver Acceptance aligns conceptually with the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) (Alalwan et al., 2015), which also considers constructs such as performance expectancy, effort expectancy, social influence, and facilitating conditions, along with moderating factors like age, gender, and experience. This theoretical alignment strengthens the validity of using Rahman et al.'s model within the context of our research on emerging C-ITS technologies for motorcyclists.

Figure 17: Full Conceptual Model of Driver Acceptance as proposed by Rahman et al. (2018)



2.4 Research design

Before the trial commenced, riders were asked to complete a pre-trial survey to collect demographic information. This data was used to build detailed rider profiles, helping to interpret results based on individual differences in age, experience, and riding behaviour.

Each participant then completed three rounds of three laps around the Toyota test track, under the following conditions:

- Round 1 No C-ITS warnings (baseline condition)
- Round 2: C-ITS warnings delivered through a standard LEDS warning device
- Round 3: C-ITS warnings delivered through a device of the rider's choice

In each round, three road scenarios were introduced during one of the three laps (1st, 2nd, or 3rd), without riders knowing when or where they would occur. This ensured natural responses and reduced expectancy bias.

After each round, a structured face-to-face interview was conducted. These interviews, together with a post-trial survey completed at the end of the final lap, explored the following key themes:

- Rider perspective on improving their reaction: riders will be asked for their perspective on how the warnings influenced their reaction. This subjective data will provide insights into whether riders believe the warnings helped them to react more quickly and effectively in hazardous situations.
- Usefulness: Feedback focused on whether riders perceive the warnings as beneficial. Riders reflected on whether the system helped them anticipate or avoid dangerous situations.
- System Acceptability: Riders rated how well they accept the C-ITS system as a useful tool in real-world scenarios. The focus will be on the system's perceived value, whether they would be willing to use it regularly, and how much they trust its functionality.
- Cognitive Impact: An essential part of the assessment was to determine if the warnings overload the rider's cognitive capacity or contribute to unnecessary stress. Riders

reflected on whether the warnings caused distraction, whether they disrupted the riding experience, or if they seamlessly integrated into their decision-making process.

- Comparison Between Different warning devices: Riders were asked to compare the usability and clarity of warnings across various warning devices used in the trial.
- Ease of Use: riders were asked to assess how easily riders can understand, process, and react to the C-ITS warnings. Riders were asked how intuitive the system felt whether they required additional mental effort to interpret the warnings, and how quickly they could respond after receiving the warnings.

Qualitative feedback: Open Questions: Riders had the opportunity to express their thoughts freely, providing qualitative data on their overall experience with the warnings and how they felt while interacting with the system.

2.5 Data collection and analysis methodology

We conducted both simulator and test track trials, with 94 riders participating in the test track trials and 65 in the simulator trials. Riders completed a training session followed by three rounds of trials. As outlined in the previous section, each rider was asked to complete a pre-trial survey and take part in structured interviews during and after the trials.

All data were collected using the QuestionPro platform. The datasets were downloaded and linked using each rider's unique UserID.

To measure desirability, we focused on analysing the test track data, as it reflects conditions that closely resemble real-world riding experiences.

A multi-method quantitative analysis approach was used to investigate the relationship between rider characteristics and their perception of C-ITS warnings, as well as the perceived usefulness and desirability of different HMI configurations. The following statistical techniques were applied:

2.5.1 Structural Equation Modelling (SEM)

Structural Equation Modelling (SEM) is a statistical method used to understand complex relationships between different variables in a study. It helps researchers go beyond basic analysis by looking at how multiple factors interact with one another, both directly and indirectly.

In our study, SEM allowed us to examine how different rider-related factors (such as age, gender, and riding experience), system factors (such as warning quality and usefulness), and perceived danger influence how desirable riders found the C-ITS warnings.

What makes SEM useful in this context is that it can:

- Analyse multiple relationships at the same time (e.g., how warning quality affects desirability while also influencing ease of use)
- Include both measured data and abstract ideas (called latent variables) like "trust" or "perceived usefulness," which cannot be measured directly but are reflected in survey responses
- Estimate the strength and direction of relationships using a standardised value called β (beta coefficient), which makes it easy to compare which factors are more influential

In short, SEM helps provide a complete picture of what drives rider acceptance and allows us to test whether our assumptions, based on theory, match what we see in the real-world data.

2.5.2 Descriptive Analysis

Descriptive statistics, including cross-tabulations was used to provide a general overview of the demographic and behavioural variables. This includes:

- Rider profiles (e.g., age, gender, years of experience, type of rider, type of motorcycle)
- Preferred HMI device
- Mean scores on variables such as perceived usefulness, reaction time improvement, and system desirability

This helped identify general trends and highlight variations across rider groups.

2.5.3 Regression Tree Analysis

Regression tree analysis was conducted to identify the most influential variables affecting desirability. This method enabled the segmentation of participants based on combinations of factors (e.g., type of rider, experience level, and preferred HMI) and showed how different characteristics led to varying perceptions of C-ITS warnings.

2.5.4 Correlation Analysis

Pearson correlation coefficients were calculated to examine the relationships between continuous variables such as:

- Reaction time improvement
- Ease of use
- Overall usefulness
- Desirability

These correlations provide insight into which aspects of the system co-vary, helping to understand whether, for example, perceiving the warnings as useful also aligns with perceiving them as desirable.

2.5.5 Linear Regression

Multiple linear regression models were applied to predict key outcomes (e.g., overall usefulness, reaction time improvement) based on independent variables such as risk profile, gender, age, riding experience, and HMI preferences. This method was used to isolate the individual effect of each predictor on the dependent variables, while controlling for the influence of others.

2.5.6 Cluster Analysis

Cluster analysis was conducted to classify riders into meaningful groups based on their post-trial feedback. The clustering algorithm grouped participants according to similar patterns in their responses related to usefulness, desirability, ease of use, and system trust. This segmentation provided valuable insights into differing acceptance profiles and their potential implications for system design and targeting strategies.

2.5.7 Qualitative Analysis

Open-ended responses were coded and analysed thematically to complement the quantitative findings. Rider feedback was reviewed to identify patterns related to:

- Perceived usefulness of each warning type
- Impact on rider reaction time
- Clarity and timing of the warnings
- Preferences for different HMI devices
- Overall system acceptability

Common themes were grouped to illustrate how different types of warnings were experienced across varied use cases and rider segments. This thematic analysis helped explain some of the variation in quantitative results and provided deeper insight into the real-world implications of using C-ITS warnings on motorcycles.

2.6 Analysis Results

2.6.1 SEM analysis results

Figure 18 shows the model we used to understand what makes riders find C-ITS warnings desirable. This model tested how different factors, like how useful the warnings were, how well they were integrated, how dangerous the use cases were, and individual rider characteristics, influence a rider's overall impression of the system.

We analysed feedback from 159 riders by combining both simulator and test track trials datasets using SEM. This method helps us understand not just which factors are important, but how strongly they influence rider opinions.

Each arrow in Figure 18 represents a relationship between two factors. For example, one arrow shows how “Warning Quality” affects “Desirability.”

The number next to each arrow is called a standardised regression coefficient (shown as β). You can think of β to show:

- Whether the relationship is positive or negative
- How strong that relationship is (higher values mean stronger influence)
- All β values are on the same scale, so you can compare them directly

Figure 18: SEM analysis results (combined test track and simulator trials)

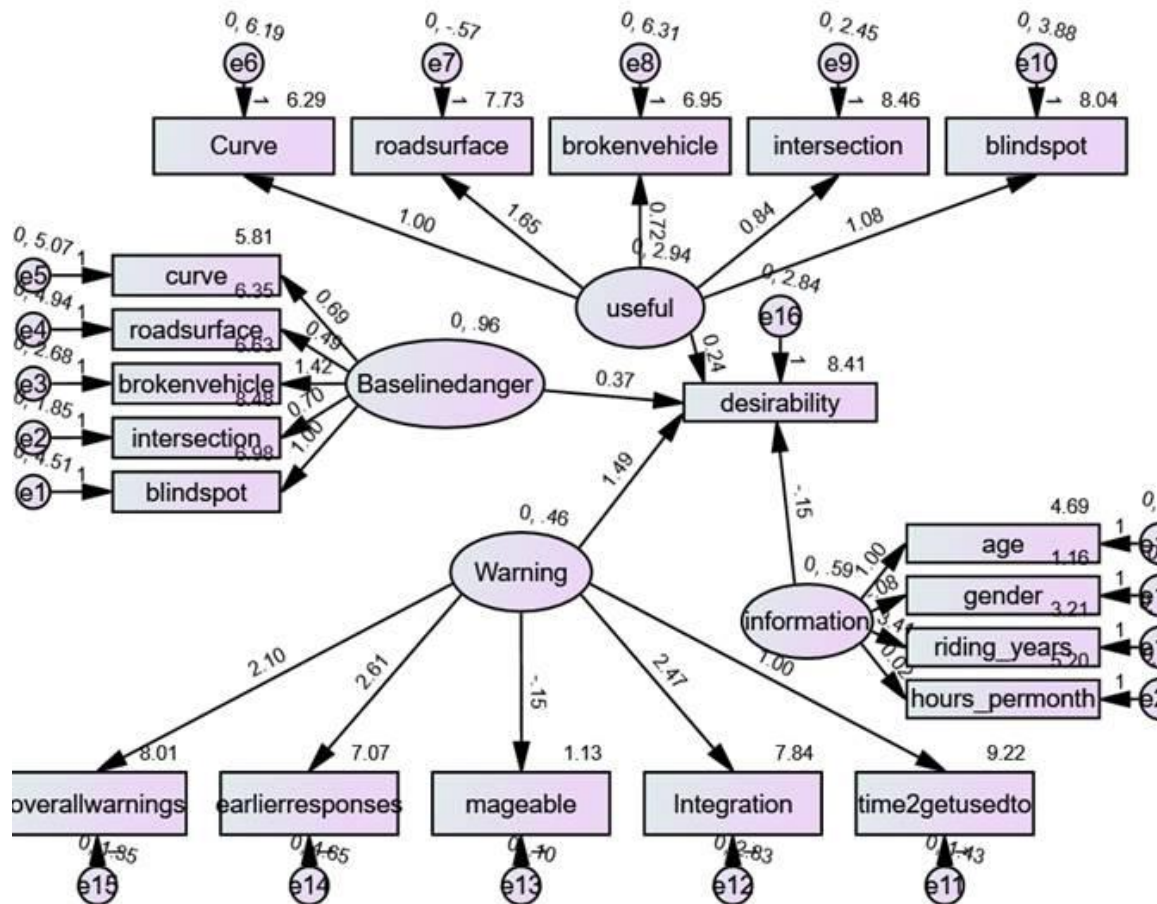


Table 4 below summarises the results, highlighting which factors made the system desirable to riders.

Table 4: What influenced riders' desirability ratings of the warning system?

What was tested?	Does it affect how desirable the system is?	What does the number mean (β)?	What does this tell us?
Warning Quality	Yes, strongly	$\beta = 1.49$	Riders who found the warnings clear, timely, and manageable were more likely to like the system.
Perceived Usefulness	Yes, moderately	$\beta = 0.24$	If riders thought the warnings were helpful for real hazards, they found them more appealing.
Perceived Danger on the Road	Slightly	$\beta = 0.37$	Riders who felt a situation was risky were more open to having a warning system.

Demographics (e.g., age, gender)	Not overall, but some small effects	$\beta = -0.15$	Gender showed a small difference ($\beta = -0.168$), but most demographic factors had little effect.
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- Riders rated warning quality highly when the warnings helped them respond earlier, were easy to understand, and did not cause stress or distraction.
- Warnings were seen as most useful when they related to real-world risks like blind spots, intersections, and broken-down vehicles.
- The model showed that we can explain 32% of the variation in how desirable riders found the system. In research, this is considered a solid result.

These results tell us that good warning design matters most. If a warning system is clear, not overwhelming, and genuinely useful in helping riders spot danger, people are far more likely to want to use it. While factors like gender had a small impact, what really drives desirability is whether the system works smoothly and helps riders stay safer.

2.6.2 Descriptive results

The descriptive analysis provided a comprehensive profile of the 94 trial participants. Most were male (85%), middle-aged, and highly experienced, with nearly half having over 20 years of riding experience. Riders generally reported high safety practices, such as wearing helmets and maintaining safe following distances. Across all segments, intersection scenarios were seen as the most dangerous. Desirability and perceived usefulness of warnings varied by age, experience, and rider type, revealing distinct segment-level trends that informed later analyses.

Rider profile:

Table 5: Rider profile

Toyota track trials	Overall (N = 94)
Q7: Gender	
1 Males	80 (85.11%)
2 Females	12 (12.77 %)
3 Other	2 (2.12%)
Q8: age	
2 18-25	6 (6.38%)
3 26-35	13 (13.83%)
4 36-45	21 (22.34%)
5 46-55	14 (14.89%)
6 56-65	18 (19.15%)
7 66-75	20 (21.28%)
8 76-85	2 (2.13%)
Q20: Motorcycle type	
1 Cruiser	10 (10.6%)
2 Touring/Riser	8 (8.5%)

3 Naked/Sport	52 (55.3%)
4 Adventure	17 (18.1%)
blank)	7 (7.4%)
Q14: Riding experience	
1 0 - 5 years	17 (18.09%)
2 6 - 10 years	16 (17.02%)
3 11 - 15 years	7 (7.45%)
4 16 - 20 years	9 (9.57%)
5 more than 20 years	45 (47.87%)
Q15: Hours ride per month	
3: 10 hours	10 (10.6%)
4: 15 hours	23 (24.5%)
5: 25 hours	28 (29.8%)
6: 50 hours	21 (22.3%)
7: 75 hours	5 (5.3%)
8: 100 or more hours	7 (7.4%)
Q23: A1 Wear a helmet	
0	0 (0%)
1	94 (100%)
Q23: A2 Wear protective clothing	
0	0 (0%)
1	94 (100%)
Q23: A3 Use hand signals when turning	
0	85 (90.4%)
1	9 (9.6%)
Q23: A4 Wear reflective clothing to increase visibility	
0	61 (65%)
1	33 (35%)
Q23: A5 Maintain a safe following distance	
0	3 (3.19%)
1	91 (96.8%)
Q23: A6 Ride sober	
0	3 (3.19%)
1	91(96.81%)
Q23: A7 Maintain a safe buffer from another road user	
0	3 (3.19%)
1	91(96.81%)
Q23: A8 Only ride in favorable weather conditions	
0	55 (58.5%)
1	39 (41.5%)

Q23: A9 Don't ride when tired	
0	26 (27.66%)
1	68 (72.34%)
Q20: Rider type	
1 Commuter	18 (19.1%)
2 Professional rider	4 (4.3%)
3 Social riders	29 (30.9%)
4 Thrill seeker	6 (6.4%)
5 Adventure rider	11 (11.7%)
6 Motorcycle enthusiast	14 (14.9%)
7 Me-driver	12 (12.8%)
Q27: Self risk evaluation	
Mean (SD)	4.68 (1.93)
Median [Min, Max]	5 [1, 10]

Risk profile Vs Danger level: How would you describe your own riding style? Vs How would you rate the following road situations in terms of potential danger?

Table 6: Risk profile vs danger level

Risk profile	DCW	CRS	FCW	IMA	BSW
1	7.4	5.4	5.6	8.6	7.8
2	5.8	6.8	8.1	8.6	8.7
3	5.7	6.9	5.9	8.1	7.4
4	5.1	7.1	7.2	7.9	7.2
5	4.8	6.6	6.8	8.4	6.6
6	5.7	6.4	6.0	8.3	6.4
7	5.2	6.0	6.9	8.5	7.2
8	1	3.0	7.0	10.0	8.0
10	7.5	5.5	5.0	8.0	4.0

Risk profile VS Usefulness per use case (standard HMI): How would you describe your own riding style? Vs How useful did you find the warnings delivered during each road traffic scenario using the standard HMI?

Table 7: Risk vs. usefulness

Risk profile	DCW	CRS	FCW	IMA	BSW
1	3.5		4.8	8.0	6.0
2	4.8	8.0	7.8	8.3	6.0
3	4.0	10.0	6.0	7.3	7.5
4	3.4	6.0	5.3	6.8	7.0

5	5.3	6.7	5.9	8.1	8.0
6	3.9	2.8	5.0	8.2	7.8
7	5.3	7.0	2.5	5.7	6.3
8	4.0	2.0	8.0		
10	3.0	2.0	8.0		

Risk profile VS Usefulness per use case (Custom HMI): How would you describe your own riding style? Vs How useful did you find the warnings delivered during each road traffic scenario using your chosen custom HMI?

Table 8: risk vs usefulness per use case (custom HMI)

Risk profile	DCW	CRS	FCW	IMA	BSW
1	5.4	7.0	4.0	7.8	6.3
2	8.1	5.0	8.0	7.7	9.5
3	5.8	6.8	5.5	8.1	8.7
4	6.5	9.3	6.8	7.4	5.4
5	7.1	9.1	6.6	8.5	7.0
6	4.2	4.0	5.4	8.3	6.8
7	5.5	8.0	6.1	8.3	7.0
8	9.0		7.0	7.0	
10	4.5		3.0	7.0	2.0

Risk profile vs Post-Trial survey questions:

Table 9: Risk vs post trial questions

Risk profile	Overall usefulness	Improve reaction time	Integration to decision making process	Time to get used to it	Overall desirability
1	9.0	8.0	8.5	10.0	9.6
2	8.9	7.3	8.0	8.9	8.7
3	6.9	5.1	7.5	9.0	8.6
4	7.5	6.0	7.2	9.1	9.2

5	7.9	6.7	7.5	9.6	8.4
6	7.4	6.4	7.6	9.4	7.1
7	7.8	6.0	7.6	9.5	7.6
8	8.0	5.0	10.0	10.0	10.0
10	6.5	1.5	5.5	10.0	4.5

Gender:

Table 10: Gender vs. usefulness

Gender	Overall usefulness	Improve reaction time	Integration to decision making process	Time to get used to it	Overall desirability
Male	7.6	6.0	7.5	9.3	8.3
Female	8.0	6.4	7.6	9.6	8.1

Age:

Table 11: Age vs. post trial questions

Age	Overall usefulness	Improve reaction time	Integration to decision making process	Time to get used to it	Overall desirability
18-25	7.5	5.5	7.3	9.0	7.5
26-35	6.5	5.9	7.2	8.5	7.2
36-45	7.7	6.1	7.6	9.4	7.7
46-55	8.2	6.7	8.2	9.9	9.4
56-65	8.1	5.9	7.7	9.7	8.4
66-75	8.0	6.5	7.6	9.2	8.5
76-85	4.5	5.0	1.0	10.0	10.0

Years of experience:

Table 12: experience vs. post trial questions

Year of experience	Overall usefulness	Improve reaction time	Integration to decision making process	Time to get used to it	Overall desirability
0 - 5 years	7.8	6.6	7.9	9.2	8.5
6 - 10 years	7.3	6.1	7.3	8.9	7.3
11 - 15 years	7.9	5.7	7.4	9.7	8.9
16 - 20 years	8.4	7.6	8.9	9.3	8.4
more than 20 years	7.6	5.7	7.3	9.5	8.3

Type of rider:*Table 13: Rider type vs post trial questions*

Type of rider	Overall usefulness	Improve reaction time	Integration to decision making process	Time to get used to it	Overall desirability
Commuter	7.6	6.8	6.9	9.3	7.7
Professional rider	6.3	3.0	6.5	7.8	7.5
Social rider	8.5	7.0	8.1	9.4	8.8
Thrill seeker	7.8	6.2	7.8	9.5	8.7
Adventure rider	7.6	5.0	7.5	9.9	8.2
Motorcycle enthusiast	6.4	5.2	7.6	9.2	7.5
Me-driver	7.8	6.1	7.3	9.5	8.3

Type of motorcycle:*Table 14: Motorcycle type vs post trial questions*

Type of motorcycle	Overall usefulness	Improve reaction time	Integration to decision making process	Time to get used to it	Overall desirability
Cruiser	7.8	6.9	7.9	9.8	8.0
Touring/Riser	7.6	6.5	9.4	9.9	9.5
Naked/Sport	7.9	6.5	7.4	9.2	8.0
Adventure	7.6	5.4	7.9	9.4	8.4

2.6.3 Results of Combining both simulator and test track trials

This section provides analysis results of riders who find C-ITS not (so) desirable (scored 1-5 for overall desirability). We have used the combined datasets (Simulator and test track trials) to perform this analysis. The analysis focus on qualitative analysis of why riders score 1-5 for desirability.

Why some riders have low interest in C-ITS technology?

23 out of 159 participants score between 1-5 on desirability, with the majority being somewhat neutral. See the distribution below:

Self-reported reasons why?

The open-ended reasons given are manifold, a qualitative analysis showed 16 reasons why (some had multiple reasons). Please find the reasons below in order of mentions:

- N=4 have more trust in their own abilities / feel they don't need it
- N=3 do find it a good feature (despite a lower score)
- N=3 are concerned about costs
- N=3 find it a good solution for others / beginners
- N=3 find it potentially distracting
- N=2 fear false alerts
- N=2 are indifferent about it
- N=1 mentioned they detected the risks before the warnings
- N=1 mentioned they ride off-road mostly
- N=1 had privacy issues with the technology
- N=1 feared tech issues when retrofitted to bike
- N=1 sees only limited value in 1-2 use cases
- N=1 mentioned it could be overbearing (would switch it off)
- N=1 was concerned about changes in bike design
- N=1 mentioned they ride many different bikes (portable option would be great)
- N=1 needed the technology to be proven first

2.6.4 Regression tree results

The regression tree identified key variables that influenced rider perceptions of C-ITS desirability. It showed that riders with higher safety awareness and lower self-rated risk were more likely to rate the warnings positively. Device preference, age, and riding style also influenced outcomes. This method effectively segmented riders based on combinations of traits, highlighting that a one-size-fits-all approach may not work for promoting C-ITS technology.

Figure 19: Regression Tree results

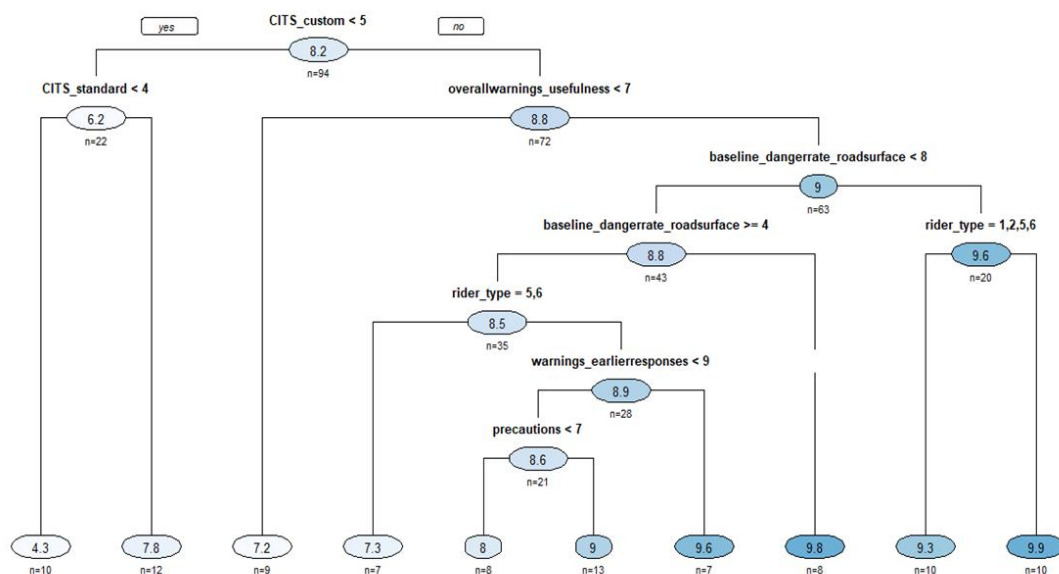
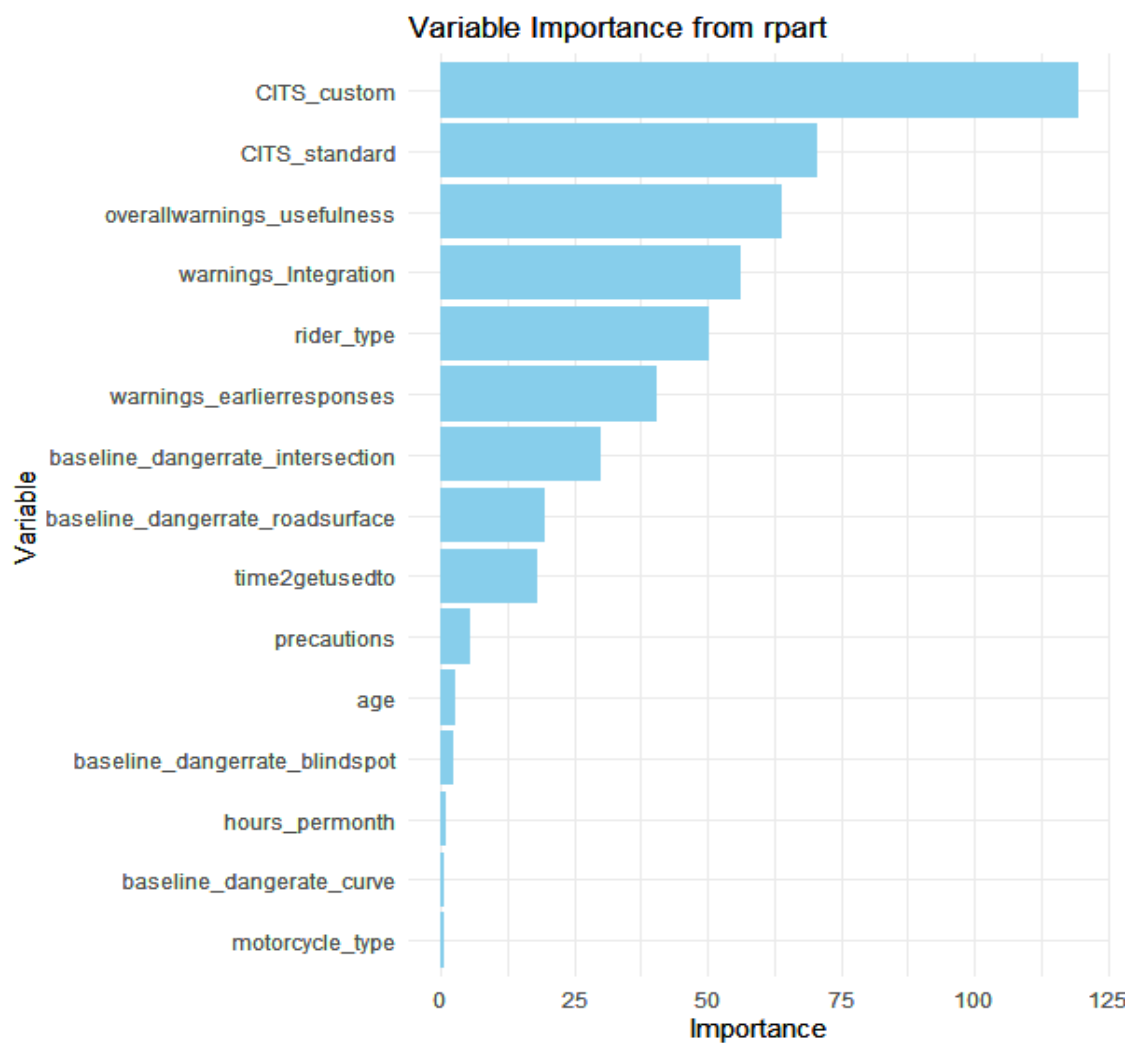


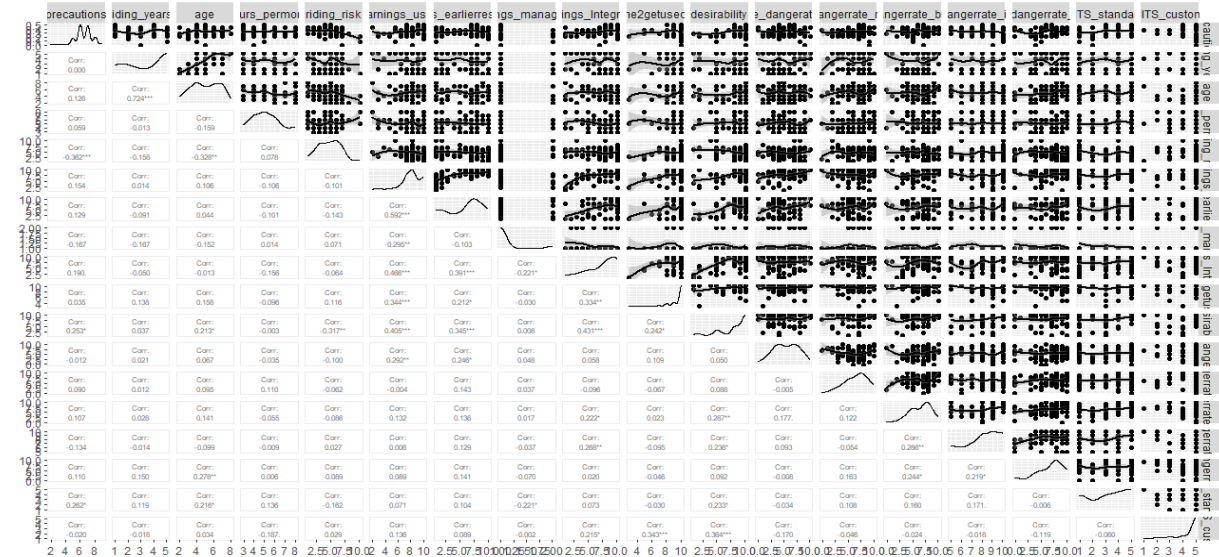
Figure 20: Variable importance based on the regression tree results



2.6.5 Correlation analysis results

Correlation analysis revealed strong links between perceived usefulness, desirability, and ease of use. Riders who found the warnings useful were also more likely to see them as desirable and felt they improved reaction time. This indicates that usefulness is a strong driver of overall acceptance. Weak or no correlation was found between factors like warning timing and overall desirability, suggesting that perceived benefit carries more weight than delivery timing alone.

Figure 21: Correlation Analysis results



2.6.6 Linear regression results

Linear regression models showed that riders with higher self-rated risk-taking behaviour were significantly less likely to find the system desirable ($p < 0.05$). Conversely, perceived usefulness and baseline danger perception (e.g., intersection danger) were positively associated with desirability. Gender and age were not significant predictors. Importantly, custom HMI warnings were a strong positive predictor of desirability ($p < 0.001$), reinforcing the importance of adaptive warning delivery methods.

Table 15: Linear regression results

	Desirability			Desirability		
Predictors	Estimates	CI	p	Estimates	CI	p
(Intercept)	-4.33	- 9.30 – 0.64	0.087	-0.18	- 3.29 – 2.93	0.907
age	0.06	- 0.20 – 0.32	0.665			
precautions	0.13	- 0.23 – 0.49	0.477			
riding risk	-0.26	-0.48 – - 0.05	0.016	-0.34	-0.52 – - 0.15	0.001
Overall warnings usefulness	0.29	0.04 – 0.54	0.026	0.35	0.14 – 0.57	0.001
warnings earlier responses	0	- 0.15 – 0.15	0.986			
warnings Integration	0.13	- 0.06 – 0.31	0.187	0.17	- 0.01 – 0.34	0.065

time2getusedto	0.2	- 0.15 – 0.55	0.266			
baseline danger rate	0.09	- 0.09 – 0.28	0.321			
Broken vehicle						
baseline danger rate	0.33	0.06 – 0.61	0.018	0.31	0.06 – 0.56	0.016
intersection						
CITS standard	0.15	- 0.10 – 0.40	0.234			
CITS custom	0.82	0.40 – 1.24	<0.001	0.75	0.34 – 1.16	0.001
Observations	90			91		
R ² / R ² adjusted	0.519 / 0.452			0.451 / 0.418		

2.6.7 Clustering analysis results

Cluster analysis grouped riders into three distinct segments:

- Segment 1 (Experienced Safety-Conscious): Older riders, longer experience, lowest risk-taking, and highest desirability (mean = 8.83).
- Segment 2 (Young Sporty Commuters): Young, high-risk riders, high riding frequency, but still showed high desirability (mean = 8.39).
- Segment 3 (Risk-Tolerant Tech-Sceptics): Mid-age, moderate experience, highest risk-taking, and lowest desirability (mean = 4.30).

This segmentation offered practical insight into how different rider profiles relate to technology acceptance and where communication or design changes may be needed.

Table 16: Cluster Analysis results for the test track

Test track trials	1 (N=53)	2 (N=31)	3 (N=10)	Overall (N=94)	P-value
precautions					
Mean±SD	6.72 ± 0.885	6.39 ± 1.45	5.60 ± 1.17	6.49 ± 1.17	0.069
Median (IQR)	7 (1)	7 (1.5)	6 (1)	6.5 (1)	
gender					
1	48 (91 %)	24 (77 %)	8 (80 %)	80 (85 %)	0.465
2	5 (9 %)	5 (16 %)	2 (20 %)	12 (13 %)	
3	0 (0 %)	2 (6 %)	0 (0 %)	2 (2 %)	
motorcycle_type					
Cruiser	9 (17 %)	0 (0 %)	1 (10 %)	10 (11 %)	<0.001
Touring/Riser	8 (15 %)	0 (0 %)	0 (0 %)	8 (9 %)	

Naked/Sport	16 (30 %)	29 (94 %)	7 (70 %)	52 (55 %)	
Adventure	14 (26 %)	2 (6 %)	1 (10 %)	17 (18 %)	
Missing	6 (11.3%)	0 (0%)	1 (10.0%)	7 (7.4%)	
rider_type					
commuter	4 (8 %)	11 (35 %)	3 (30 %)	18 (19 %)	0.009
professional	2 (4 %)	0 (0 %)	2 (20 %)	4 (4 %)	
social rider,enjoy	22 (42 %)	7 (23 %)	0 (0 %)	29 (31 %)	
thrill seeker	1 (2 %)	3 (10 %)	2 (20 %)	6 (6 %)	
Adventure	9 (17 %)	2 (6 %)	0 (0 %)	11 (12 %)	
enthusiast	6 (11 %)	7 (23 %)	1 (10 %)	14 (15 %)	
me-time	9 (17 %)	1 (3 %)	2 (20 %)	12 (13 %)	
riding_years					
Mean±SD	4.49 ± 1.12	2.00 ± 1.13	3.10 ± 1.52	3.52 ± 1.63	<0.001
Median (IQR)	5 (0)	2 (1.5)	2.5 (2.75)	4 (3)	
age					
Mean±SD	6.08 ± 1.05	3.48 ± 0.926	3.90 ± 1.29	4.99 ± 1.62	<0.001
Median (IQR)	6 (2)	4 (1)	4 (0.75)	5 (2)	
hours_permonth					
Mean±SD	4.87 ± 1.30	5.39 ± 1.38	5.40 ± 1.26	5.10 ± 1.34	0.307
Median (IQR)	5 (2)	5 (2)	5.5 (1.75)	5 (2)	
riding_risk					
Mean±SD	4.08 ± 1.66	5.35 ± 2.03	5.80 ± 1.99	4.68 ± 1.94	0.007
Median (IQR)	4 (2)	6 (3)	6 (0.75)	5 (3)	
overallwarnings_usefulness					
Mean±SD	7.92 ± 1.82	8.19 ± 1.35	4.70 ± 2.06	7.67 ± 1.98	<0.001
Median (IQR)	8 (2)	8 (2)	4.5 (2.75)	8 (2)	
warnings_earlierresponses					
Mean±SD	6.31 ± 2.80	6.94 ± 2.57	2.80 ± 3.08	6.14 ± 2.98	0.014
Median (IQR)	7 (3.25)	7 (1.5)	1 (1.75)	7 (4)	
Missing	1 (1.9%)	0 (0%)	0 (0%)	1 (1.1%)	

warnings_manageable					
Mean±SD	1.04 ± 0.196	1.10 ± 0.301	1.40 ± 0.516	1.10 ± 0.299	0.007
Median (IQR)	1 (0)	1 (0)	1 (1)	1 (0)	
Missing	2 (3.8%)	0 (0%)	0 (0%)	2 (2.1%)	
warnings_Integration					
Mean±SD	7.71 ± 2.26	8.35 ± 1.91	4.40 ± 3.17	7.57 ± 2.51	0.006
Median (IQR)	8 (4)	9 (3)	3.5 (4.75)	8 (4)	
Missing	1 (1.9%)	0 (0%)	0 (0%)	1 (1.1%)	
time2getusedto					
Mean±SD	9.55 ± 1.12	9.42 ± 0.992	8.10 ± 2.08	9.35 ± 1.28	0.004
Median (IQR)	10 (0)	10 (1)	9 (1.75)	10 (1)	
desirability					
Mean±SD	8.83 ± 1.83	8.39 ± 1.76	4.30 ± 2.83	8.20 ± 2.35	<0.001
Median (IQR)	10 (2)	9 (2)	5 (3.75)	9 (2)	
baseline_dangerate_curve					
Mean±SD	5.36 ± 2.39	5.84 ± 2.48	4.20 ± 1.99	5.39 ± 2.41	0.329
Median (IQR)	5 (3)	6 (3.5)	4 (1.75)	5 (3)	
baseline_dangerrate_roadsurface					
Mean±SD	6.58 ± 2.34	6.16 ± 2.33	6.40 ± 1.90	6.43 ± 2.28	0.934
Median (IQR)	7 (3)	7 (3)	7 (2.5)	7 (3)	
baseline_dangerrate_brokenvehicle					
Mean±SD	6.79 ± 2.15	6.52 ± 1.81	4.80 ± 2.04	6.49 ± 2.10	0.059
Median (IQR)	7 (3)	7 (3)	5 (3.5)	7 (3)	
baseline_dangerrate_intersection					
Mean±SD	8.17 ± 1.65	8.58 ± 1.26	8.20 ± 1.55	8.31 ± 1.52	0.824
Median (IQR)	9 (2)	9 (2)	8.5 (1.75)	9 (1.75)	
baseline_dangerrate_blindspot					
Mean±SD	7.11 ± 2.49	5.97 ± 2.56	6.50 ± 3.10	6.67 ± 2.60	0.153
Median (IQR)	8 (3)	7 (4)	7 (3.75)	7 (3)	
CITS_standard					
Mean±SD	3.68 ± 1.37	2.94 ± 1.59	2.00 ± 1.15	3.26 ± 1.52	0.007
Median (IQR)	4 (2)	3 (3)	1.5 (2)	3.5 (3)	

CITS_custom					
Mean±SD	4.62 ± 0.867	4.74 ± 0.631	3.67 ± 1.32	4.57 ± 0.893	0.015
Median (IQR)	5 (0)	5 (0)	4 (3)	5 (0)	
Missing	1 (1.9%)	0 (0%)	1 (10.0%)	2 (2.1%)	

We did the same clustering analysis for the simulator data as well and the results can be seen in the table below:

Table 17: Cluster Analysis Results for the Simulator

Simulator trials	1	2	3	P-value
	(N=30)	(N=28)	(N=7)	
precautions				
Mean±SD	6.67 ± 1.06	6.57 ± 1.53	6.29 ± 0.488	0.857
Median (IQR)	7 (1)	7 (3)	6 (0.5)	
gender				
1	26 (87 %)	18 (64 %)	7 (100 %)	0.336
2	4 (13 %)	9 (32 %)	0 (0 %)	
3	0 (0 %)	1 (4 %)	0 (0 %)	
motorcycle_type				
1	1 (3 %)	5 (18 %)	1 (14 %)	0.057
2	4 (13 %)	0 (0 %)	0 (0 %)	
3	18 (60 %)	22 (79 %)	2 (29 %)	
4	6 (20 %)	0 (0 %)	2 (29 %)	
Missing	1 (3.3%)	1 (3.6%)	2 (28.6%)	
rider_type				
1	4 (13 %)	11 (39 %)	0 (0 %)	0.090
2	2 (7 %)	0 (0 %)	0 (0 %)	
3	9 (30 %)	8 (29 %)	0 (0 %)	
4	3 (10 %)	0 (0 %)	1 (14 %)	
5	4 (13 %)	1 (4 %)	4 (57 %)	
6	5 (17 %)	6 (21 %)	2 (29 %)	
7	3 (10 %)	2 (7 %)	0 (0 %)	
riding_years				
Mean±SD	3.87 ± 1.53	1.39 ± 0.916	3.43 ± 1.13	<0.001
Median (IQR)	5 (2)	1 (0)	3 (1)	
age				
Mean±SD	5.30 ± 1.39	3.21 ± 1.13	3.86 ± 0.690	<0.001
Median (IQR)	5 (2.75)	3 (2)	4 (0.5)	

hours_permonth				
Mean±SD	5.27 ± 1.60	5.39 ± 1.52	5.57 ± 1.51	0.982
Median (IQR)	5 (2)	5 (2)	5 (2)	
riding_risk				
Mean±SD	4.93 ± 1.95	4.68 ± 2.04	5.00 ± 2.16	0.893
Median (IQR)	5 (2)	4 (3)	6 (2.5)	
Mean±SD	8.70 ± 1.44	8.82 ± 0.983	6.29 ± 1.89	0.031
Median (IQR)	9 (2)	9 (2)	5 (2.5)	
warnings_earlierresponses				
Mean±SD	8.47 ± 2.11	8.75 ± 1.21	7.00 ± 2.00	0.188
Median (IQR)	10 (2.75)	8.5 (2)	7 (2)	
warnings_manageable				
Mean±SD	1.00 ± 0	1.14 ± 0.356	2.00 ± 0	<0.001
Median (IQR)	1 (0)	1 (0)	2 (0)	
warnings_Integration				
Mean±SD	8.87 ± 1.87	8.25 ± 1.80	5.29 ± 2.50	0.002
Median (IQR)	10 (2)	9 (1.5)	7 (4)	
time2getusedto				
Mean±SD	9.37 ± 1.38	9.14 ± 1.24	7.14 ± 1.86	0.002
Median (IQR)	10 (0)	10 (2)	8 (0.5)	
desirability				
Mean±SD	8.93 ± 1.62	9.04 ± 1.60	6.43 ± 2.15	0.010
Median (IQR)	10 (2)	10 (2)	6 (2.5)	
baseline_dangerate_curve				
Mean±SD	7.03 ± 2.16	5.82 ± 2.23	6.14 ± 1.21	0.092
Median (IQR)	8 (1.75)	6.5 (3)	6 (2)	
Mean±SD	6.67 ± 2.28	6.29 ± 2.24	4.14 ± 1.57	0.063
Median (IQR)	7 (2.75)	6 (3)	4 (1)	
Mean±SD	7.60 ± 2.16	6.21 ± 2.02	6.00 ± 2.58	0.047
Median (IQR)	8 (3)	7 (3)	6 (3.5)	
Mean±SD	9.17 ± 1.02	8.61 ± 1.71	7.43 ± 1.90	0.134
Median (IQR)	9.5 (1.75)	9 (2)	7 (3)	
Mean±SD	8.30 ± 1.56	6.54 ± 1.75	7.29 ± 1.70	0.002
Median (IQR)	8 (2)	7 (2.25)	8 (2)	
CITS_standard				
Mean±SD	3.03 ± 1.52	3.82 ± 1.28	2.86 ± 1.35	0.152

Median (IQR)	3 (2)	4 (2)	3 (1.5)	
CITS_custom				
Mean±SD	4.63 ± 0.890	4.71 ± 0.659	3.29 ± 1.70	0.021
Median (IQR)	5 (0)	5 (0)	4 (2.5)	

2.6.8 Qualitative analysis results

Thematic analysis of rider comments revealed both support and scepticism. Riders appreciated warnings in blind spots and intersections but raised concerns about late alerts, distraction, and relevance. Helmet audio and wristbands were praised for their subtlety and clarity, while LED and visual-only cues were often missed. Segment 3 riders expressed concerns about privacy, over-reliance on tech, and disruption to the riding experience. These qualitative insights helped explain why certain rider types were less receptive, supplementing the statistical models with context and nuance.

Perceived Risk and Usefulness

1. Dangerous Curve warnings

Thematic analysis of participant responses highlighted mixed perceptions regarding the danger associated with curves and the usefulness of related warnings. While some riders recognised the inherent risk posed by sharp bends and poor visibility, others expressed confidence in their ability to handle such scenarios without technological assistance.

One participant noted:

"Curve – if the road is unknown by me, the danger level is higher, but otherwise no."

This divergence in perception highlights the influence of rider familiarity, confidence, and personal risk calibration. Timing was a recurrent subtheme. Several participants noted that warnings were delivered too late to be actionable:

"It could help me. Only the curve 8 out of 10. The warning was late."

2. Intersection movement assist (IMA) warnings received more consistent concern regarding danger. Participants cited unpredictability at junctions and the presence of other vehicles as contributing factors:

"IMA: More likely to assume that they stop at a stop sign – not always true."

"IMA – very hard to see the warnings. I am very much focused on what's around me."

However, riders also voiced doubts about the warning's clarity and delivery. Some indicated that the intersection warning felt redundant or hard to interpret in real-time, especially when mental workload was already high.

3. Forward collision warnings (FCW), participants appeared to appreciate their presence but again stressed timing and modality. A few indicated that the alerts added value, especially in high-speed or low-visibility contexts:

"FCW: In traffic scenarios where there are trucks or large vehicles, it's hard to see."

This supports the idea that forward collision warnings are most valued when they augment the rider's limited line of sight. Yet, concerns about false positives and situational misfit persisted.

4. Blind Spot and Lane Change Alerts: they were often positively received, with riders highlighting their utility during overtaking or merging:

"LCA: The potential for blind spots is high. I appreciated the alert."

"Having something to help with the blind spot, especially on a multi-lane road, is very useful."

Nevertheless, visual-only warnings (e.g., LEDs) were frequently criticised as being difficult to notice or too subtle during dynamic riding conditions:

"The LEDs might be a distraction. I prefer audio or haptic cues."

This illustrates that modality matters: riders preferred multimodal warnings that allowed them to maintain focus without unnecessary eye movement.

Qualitative analysis based on the three segments:

Table 18: Qualitative analysis based on the three segments

Segment	Theme	Quotes
Segment 1	Other / General Doubts	I like it especially on the blind spot.
Segment 1	Other / General Doubts	to prevent injury or accident to avoid collision.
Segment 1	Other / General Doubts	I like the advance warning as an extra feature.
Segment 1	Other / General Doubts	I think it would be good feature.
Segment 1	Other / General Doubts	I can see it will be helpful for new riders like my kids and my wife.
Segment 1	Distraction / Cognitive Overload	I don't need it. I've been riding for a while, and I am used to doing things my own sort of way. And having something tell me there is a curve coming or there is something beside me, may be a bit too much.
Segment 1	Distraction / Cognitive Overload	10: because the audio works it is brilliant, it is useful, does not distract, it can only help you. anything that helps you on a motorcycle is a bonus.
Segment 1	Other / General Doubts	9: I think any further awareness is fantastic, anything that makes it safer on a bike.
Segment 1	Other / General Doubts	then be able to integrate my helmet with the audio meaning I am in the safest bike.
Segment 1	Other / General Doubts	I am impressed with the technology. the biggest danger of a motorcycle is other drivers on the road.
Segment 1	Other / General Doubts	I'm an experienced rider but I like these warnings

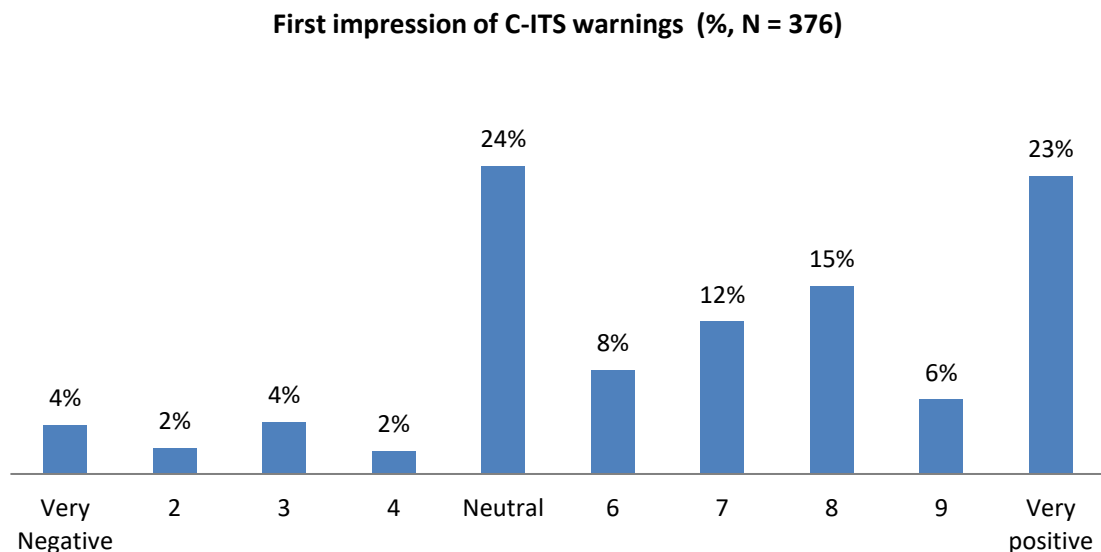
Segment 1	Cost / Value Concerns	Depend on the cost of product. Also, I don't like to get a new helmet but rather like to integrate into my current helmet.
Segment 1	Other / General Doubts	I like anything that helps me to keep my focus
Segment 1	Other / General Doubts	10: I think that the technology could be hugely valuable to deliver earlier warning of a danger before it becomes imminent. Would justify a premium. I could see BMW putting it on as an option.
Segment 1	Cost / Value Concerns	I would have to see how to work in a filtering situation. I do not want to go on for every car. essentially in the regional area, it is very helpful. it depends on the cost. I give it 10
Segment 1	Other / General Doubts	I cannot see how it is going to be appropriate in every situation.
Segment 1	Redundancy / Not Needed	The appeal is that there is an additional aid to the already risky situation. There is much more traffic and traffic behavior are much more different.
Segment 1	Other / General Doubts	It's a backup support to grab attention. Once you're familiar it will be very useful.
Segment 1	Other / General Doubts	It needs to be seamlessly integrated into the bike without wiring and all. Also, the warnings need to be consistence.
Segment 2	Other / General Doubts	I would for sure get the helmet audio, but I did not like the LEDs
Segment 2	Other / General Doubts	Interesting to see how it would work when commuting or out and about on country roads.
Segment 2	Cost / Value Concerns	It is clearly very useful tools but mainly will be cost and how much reliable the technology to give me warnings for each of the use cases.
Segment 2	Cost / Value Concerns	At a reasonable cost I would do it. I would like to see it being able to retrofit onto my bike, I ride older bikes. And for it to be adjustable to sensitivity levels. Don't want to be overloaded for any situation that are non-threatening
Segment 2	Other / General Doubts	10: There are a few times it would have been nice to know there is a sharp turn or there is a car coming. You never know what is coming, so it is nice to have a help that is not in your face.
Segment 2	Other / General Doubts	Helmet is good but not LEDs
Segment 2	Other / General Doubts	9: I see a use case for it; in nearly any situation there is a benefit. And as it is developed further it only is going to be better.

Segment 2	Other / General Doubts	I am very interested, and I do not mind paying extra to get the dashboard on my bike now.
Segment 2	Other / General Doubts	my concerns are privacy and tracking your movements and privacy.
Segment 3	Timing of warnings	“I am picking up and reacting before the warning lights.” “The warning was late. I already anticipated the hazard.”
Segment 2	Other / General Doubts	I'm not the safest rider I guess I ride faster. I ride daily now. but I just have around 8 months experience as a rider.
Segment 3	Other / General Doubts	I only want to focus on the road, and I use it as a therapy. So, I don't like interruptions.
Segment 3	Other / General Doubts	My motorcycle is primarily used in an off-road situation where traffic hazards dont exist. For my adventure bike, this would be much more useful.
Segment 3	Other / General Doubts	Not something I'd consider. The CF Moto 800 MT has a rear end warning. It does not affect my decision at all.
Segment 3	Other / General Doubts	Because of the privacy issues I dislike this warning system. Data collection through this is something I don't like to have it on my motorcycle

2.7 Results evaluation and discussion

In order to determine what factors, influence adoptions and to better understand rider’s perceptions to C-ITS technology, at the starting point of the project we conducted qualitative research through rider dinners in both Victoria and Queensland and a large quantitative survey. The results from this research found that most riders were cautiously optimistic about the introduction of connected technology in motorcycles but did show reservations.

Figure 22: First Impression for C-ITS warnings



Concerns raised by riders early in the trial

1. **Alerts for Obvious Situations** – Riders questioned the value of warnings for scenarios they could already anticipate, such as clearly visible curves or expected lane changes.
2. **Inaccurate Alerts** – There were worries about false positives (warnings with no real threat) and false negatives (failing to alert when a hazard exists).
3. **System Reliability** – Riders expressed concerns about potential hardware failures, sensor malfunctions, or inconsistent connectivity affecting performance.
4. **Overdependence** – Some riders feared that relying too much on technology could reduce their own awareness and judgment on the road.
5. **Erosion of Riding Skills** – There was concern that continuous assistance might cause riders to become less sharp or reactive over time.
6. **Cost Barriers** – The high potential cost of C-ITS add-ons were flagged as a key obstacle to adoption, especially among everyday riders.
7. **Annoying or Repetitive Alerts** – Riders were concerned that alerts could become irritating or disruptive if not well calibrated.
8. **Lack of User Control** – Many riders wanted the ability to tailor alert types, timing, and delivery methods to their personal preferences.
9. **Warnings Arriving Too Late** – Some doubted the system's ability to deliver alerts with enough lead time to allow for safe response.

How desirable is C-ITS technology?

Based on the survey responses and the cluster analysis results, the riders were grouped into three segments as shown in Table 19. These segments showed significant differences in their perceptions of C-ITS warnings, riding experience, risk attitudes, and the types of motorcycles they ride.

Table 19: Rider segmentation based on cluster analysis (N=94)

Experience safety conscious	Young Sporty Commuters	Risk-Tolerant, Tech-Skeptic
Social/adventure riders who appreciate safe riding and useful tech	Urban commuters who want tech that fits their fast-paced lifestyle	Thrill-seekers or professionals less engaged with safety tech
Highest desirability (8.83) Longest riding experience and highest age Ride diverse motorcycle types (cruisers, adventure, touring)	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

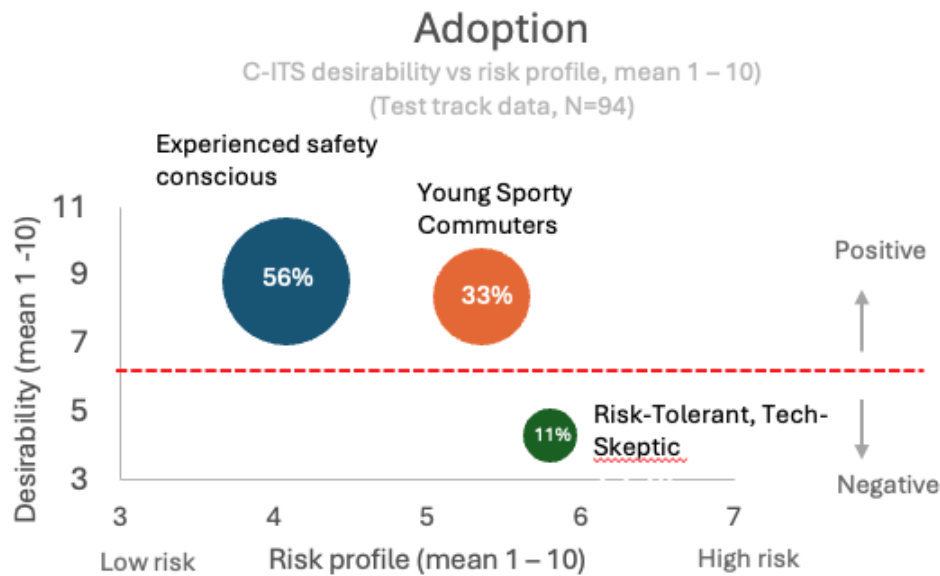
Value warning systems (high usefulness, early response, and integration) Most open to standard and custom C-ITS		Least interested in standard or custom C-ITS warning delivery
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Segment 1: Experienced Safety-Conscious Riders (N = 53) demonstrated the highest desirability score for C-ITS (Mean = 8.83). This group had the oldest average age (Mean = 6.08) and the longest riding experience (Mean years = 4.49). Most riders in this segment used a mix of cruisers, adventure, and touring bikes, and identified as social or recreational riders. They had the highest precaution scores (Mean = 6.72), lowest riding risk (Mean = 4.08), and showed strong agreement with importance of these warnings (Mean = 7.92).

Segment 2: Young Sporty Commuters (N = 31) also reported a high desirability score (Mean = 8.39). This group had the youngest riders (Mean age = 3.48) and least riding experience (Mean years = 2.00), and nearly all rode naked or sport motorcycles (94%). These riders identified mostly as commuters and enthusiasts. Despite higher self-reported riding risk (Mean = 5.35), they found C-ITS warnings to be highly useful (Mean = 8.19).

Segment 3: Risk-Tolerant, Tech-Sceptic Riders (N = 10) had the lowest desirability score (Mean = 4.30). They were of moderate age and experience (Mean age = 3.90; riding years = 3.10) but showed the lowest precaution scores (Mean = 5.60) and highest risk-taking self-assessments (Mean = 5.80). They were more likely to identify as thrill seekers or professionals and were less engaged with safety technology. This group gave low scores for warning usefulness (Mean = 4.70). They showed the least interest in both standard and custom HMIs, indicating low overall acceptance of C-ITS.

Figure 23: Three groups of riders, three different attitudes to C-ITS



While most participants in the trial responded positively to the C-ITS technology (Figure 23), it is important to acknowledge that the sample may reflect a self-selection bias, where riders who were already interested in advanced safety systems were more likely to participate. As a result, the trial likely underrepresents riders who are sceptical or indifferent toward such technology. Despite this, a clear segment emerged in segment 3 (risk-tolerant, tech-sceptic riders), who showed low desirability for C-ITS and limited engagement with warning systems. Although this group made up a smaller portion of the sample (10 out of 94 riders), they likely represent a larger portion of the wider rider population. For this reason, we now shift our attention to understanding which factors influence their adoption decisions and just as importantly, which factors do not. This will help government and decision-making bodies to inform future strategies aimed at reaching this group more effectively.

What factors do not affect non-adoption?

Based on the analysis, we found that one factor that did not affect non-adoptions segment was gender. It was similar across all segments, showing no clear impact on C-ITS adoption. Monthly riding hours were also fairly consistent, indicating that riding frequency alone does not predict desirability.

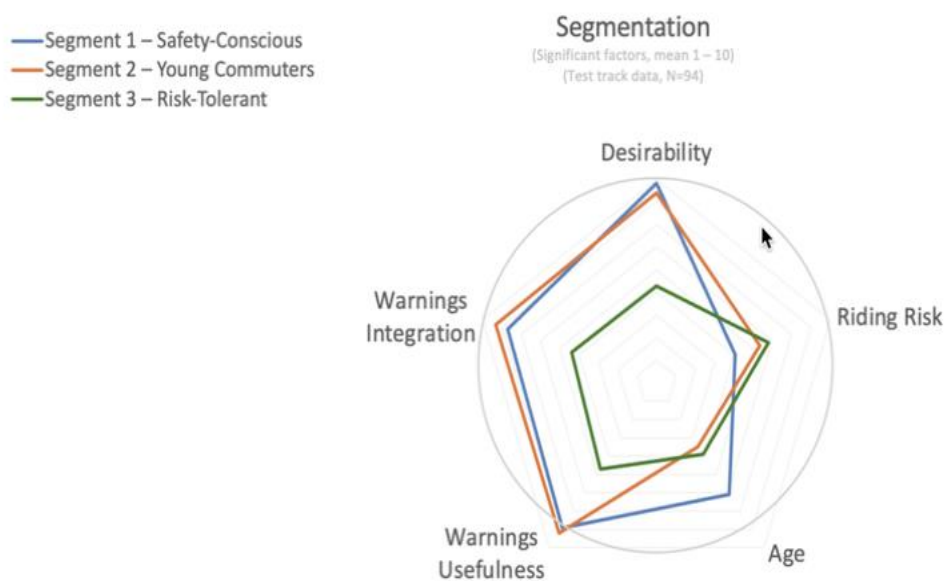
Table 20: Factors that do not influence adoption based on the three segment groups.

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

What are the main factors that influence non-adoptions?

We identified several key factors that differentiate rider segments and influence the desirability of C-ITS technology. These include age, risk perception, warning integration, and perceived usefulness. This aligns with the initial results from our quantitative research, which suggested that riders with a higher risk profile and more riding experience (often older riders) may be less likely to adopt the technology. We also expected that desirability increases when riders find the warnings useful and perceive them to be well-integrated into the riding experience.

Figure 24: Factors that influence adoptions per segment



As shown in Figure 24, both Segment 1 (experienced safety-conscious riders) and Segment 2 (young sporty commuters) reported high levels of desirability toward the technology. These groups also rated warning integration and usefulness positively, indicating that most initial concerns about the system being distracting or poorly implemented were largely addressed.

In contrast, Segment 3 (risk-tolerant, tech-sceptic riders) recorded the lowest desirability scores. This group also rated the system lowest on both warning integration and perceived usefulness, indicating that they did not find the warnings relevant or well-aligned with their riding style. Unlike Segments 1 and 2, they were less likely to recognise the value of C-ITS warnings, possibly due to their higher self-assessed riding confidence, greater risk tolerance, and lower precautionary behaviours. Given these results, the next sections will provide a detailed analysis of these two factors: warning integration and warning usefulness, to better understand the drivers behind non-adoption within this segment.

2.7.1 Warning integration

From the start of the project, it was important to study how to communicate C-ITS warnings in a way that works for riders. How the warnings are integrated into the Human-Machine Interface (HMI) devices can make a big difference. It affects how riders experience the system and whether they are likely to use it.

So, we looked closely at more than just whether riders noticed the warnings. We also considered how the warnings were delivered, whether they fit naturally into the riding experience, and which methods riders found helpful or distracting.

How can the warnings be designed?

To explore this, we ran a qualitative study with over 30 riders. We asked them about different ways of receiving warnings, including audio, visual, and haptic options.

The feedback was consistent. Riders said the warnings should help them scan the road and spot safe paths. The system should not pull their attention away or force them to look somewhere else. Instead, it should let them stay focused on the road ahead.

We also discussed different ways to design the warnings with the riders. Based on those conversations, they highlighted several features that make a warning clear:

- It clearly shows where the danger is coming from.
- It uses simple, familiar symbols.
- It avoids blinking or moving patterns that can be distracting.
- It keeps the mental effort low so riders can stay focused.
- It shows how serious the warning is when needed.
- These insights helped shape the design of the warning systems we tested later in the project. Each HMI was chosen based on how well it could support these design goals.

What were the final designs of each HMI device used in the trials?

In the final trials, we tested six different HMI devices. Each one was selected to deliver warnings in a way that supported rider awareness without causing distraction. The devices and their functions were:

1. LED mirrors: Showed directional warnings using lights on the mirrors. These indicated whether the risk was coming from the left, right, front, or back.
2. Dashboard visuals: Displayed eight directional cues along with real-time distance estimates. This gave riders a quick overview of where the hazard was and how far away it was.
3. Smart helmet display: Integrated visual alerts directly into the rider's field of vision inside the helmet. This allowed riders to receive warnings without moving their eyes away from the road.

4. Audio warnings: Played a beep followed by a short verbal message. The sound was used to grab attention and quickly explain the risk.
5. Smartphone display: Offered the same directional warnings and distance information as the dashboard. This acted as a secondary visual option for riders.
6. Haptic wristband: Provided optional tactile feedback through vibrations. This was designed for riders who preferred a silent or more discreet warning method.

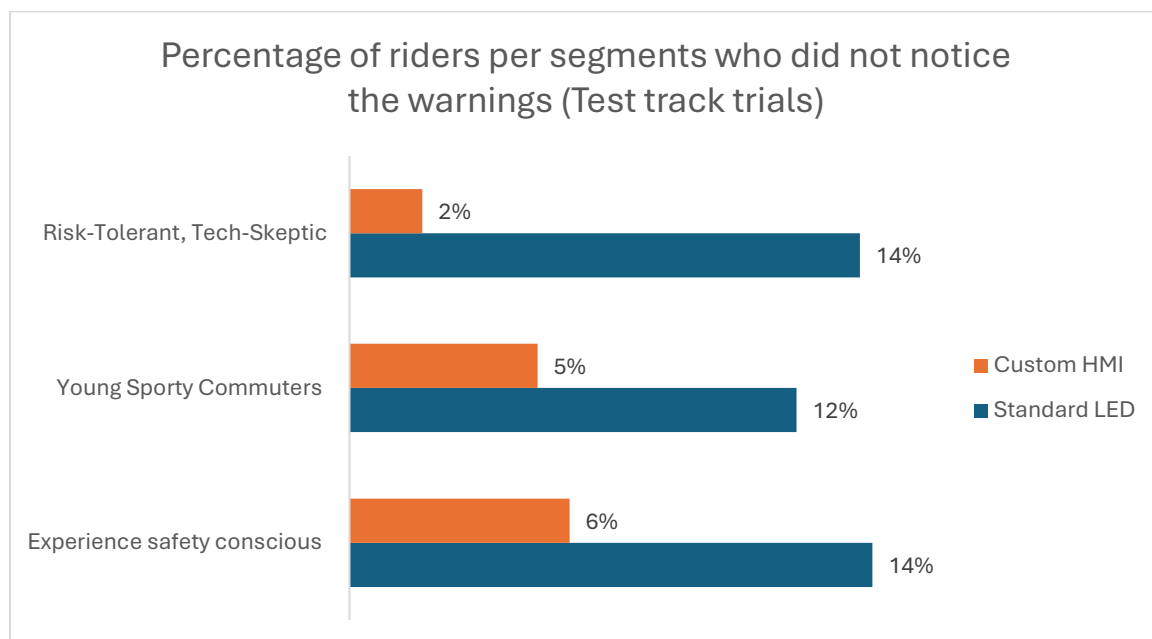
Evaluation of the warning integration

To evaluate how well the warnings were integrated and how the choice of HMI affected rider experience, we analysed the data across several key measures. These included whether riders noticed the warnings, whether the warnings helped improve reaction time, how useful the warnings were perceived to be, and whether the HMI was distracting. Our goal was to understand how HMI selection influenced these outcomes and to identify which device riders preferred most for receiving C-ITS warnings.

Did the rider notice or did not notice the warning per HMI by use case?

Figure 25 shows that across all rider segments, custom HMI devices were more effective at capturing rider attention than standard LED warnings. The percentage of riders who did not notice warnings delivered via standard LEDs was consistently higher, with 14% in both the Experienced Safety-Conscious and Risk-Tolerant, Tech-Sceptic groups, and 12% among Young Sporty Commuters. In contrast, only 6% of riders in the Experienced group, 5% of Young Sporty Commuters, and just 2% of Tech-Sceptics missed warnings delivered by custom HMIs.

Figure 25: Number of riders per segment who did not notice the warning given by the standard LEDs and the custom HMI devices



However, rider comments suggest that some warnings were missed not because they weren't delivered, but because riders were too focused on the road to notice them. Several participants said they were concentrating on handling the bike and navigating their surroundings. *One rider explained, "I have not noticed a warning. Maybe it came, but I was too focused on the road."* Another shared, *"I did not look for any warnings and I did not see them. I was not expecting them."* A third rider, referring to the map-based phone warning, noted, *"I was not looking at the phone, so did not see any of the warnings. I was focused on the road."* These insights highlight the need for warnings to fit naturally into the rider's line of sight and riding rhythm. These results suggest that timing, placement, and rider attention are critical for making warnings effective, especially in demanding or high-risk scenarios.

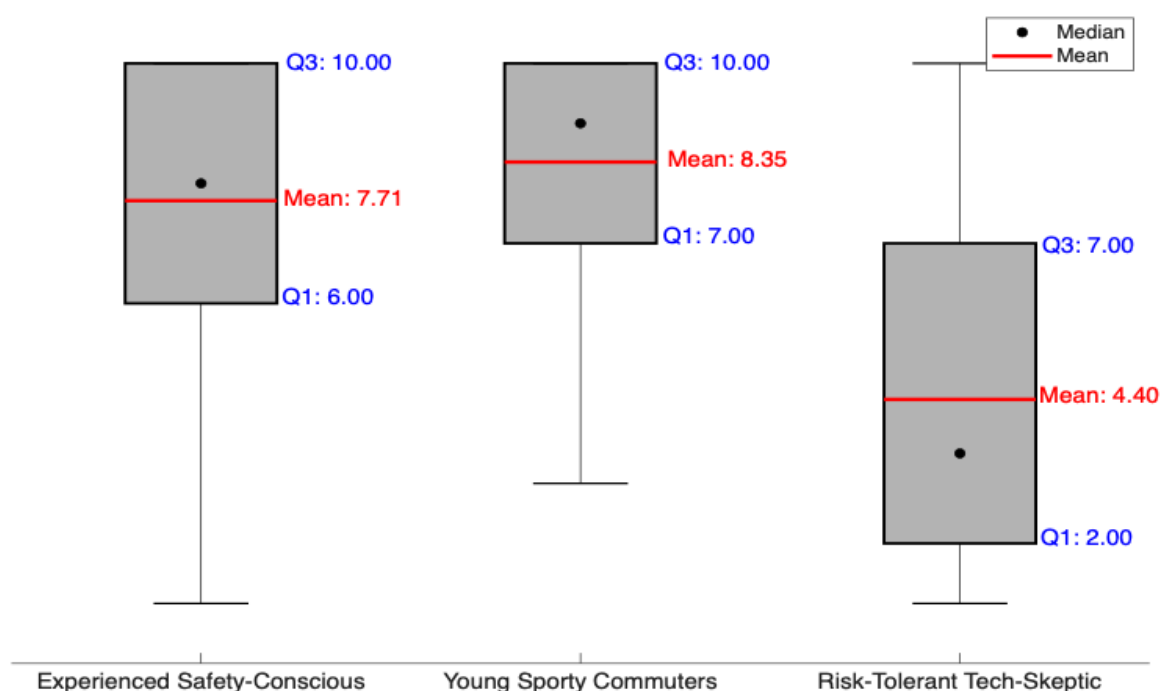
Do the warnings integrate into riders' behaviors?

Understanding how well riders felt the warnings were integrated into their decision making was a key point to know whether riders perceived the warnings as helpful in real-time riding, whether they added to or distracted from their judgment, and how this affected their willingness to adopt the technology.

As shown in Figure 26, there are clear differences between rider segments. Segment 1 (Experienced Safety-Conscious) and Segment 2 (Young Sporty Commuters) rated the integration of warnings relatively high, with average scores of 7.71 and 8.35 out of 10 respectively. However, Segment 3 (Risk-Tolerant, Tech-Sceptic) gave much lower ratings, with an average of 4.40, which was statistically significant ($p = 0.006$). This gap indicates that riders in Segment 3 generally felt the warnings were not well integrated into their riding behaviour or decision making.

Figure 26: Boxplot of warnings integrations of rider decision making process

Rider's perception of how the warnings integrate into their decision-making process
(Test track trials, N=94, $p = 0.006$)



Qualitative feedback supports this finding. Many riders in Segment 3 expressed that the warnings either came too late or did not provide information in a useful way. One rider said, *“I made my decision by the time I received the warning.”* Another noted, *“It alerted me to a situation but not where it was and what action to take.”* This suggests that even when warnings were noticed, they did not always align with the timing or format riders needed to act on them effectively.

Some riders found the system distracting or overly complicated. For example, one stated, *“From glancing at the screen, you had to pay too much attention,”* and another explained, *“The timing of it and the different senses, it takes you out of the situation rather than keeping you in it.”* Others described already relying on their own judgment: *“The lights reminded me to slow down. But I would do it anyway.”*

Interestingly, a few riders expressed a willingness to accept the system after becoming more familiar with it. As one put it, *“I want to get used to the system before I integrate it into my riding.”* This shows that some concerns may be addressed over time with better user training or repeated exposure.

In summary, while Segments 1 and 2 generally saw the warnings as a helpful addition to their riding decisions, Segment 3 remained unconvinced. Their feedback points to key issues with timing, clarity, and perceived redundancy of warnings. These concerns may be influenced by the specific HMI devices used, how the warnings were presented, or how well each device aligned with their riding style.

What HMI is the most favourable/ not favourable and why?

Understanding which HMI devices riders preferred, and why, helps pinpoint what makes warning delivery both effective and acceptable. Hence, we firstly asked riders which HMI best communicated warnings and then we compare how much the selected custom HMI was better or worse in communicating warnings than the standard LEDs device.

Figure 27 shows that across all rider groups, helmet audio emerged as the most preferred HMI device, selected by 57% of participants during the test track trials. To better understand these preferences, we need to look into rider preferences for HMI devices based on their segment.

Figure 28 illustrates that the rider preferences varied significantly across segments, reflecting different priorities and perceptions of warning effectiveness. Segments 1 (Experienced Safety-Conscious Riders) and 2 (Young Sporty Commuters) overwhelmingly preferred helmet audio, with 62% and 65% of riders in each group respectively selecting it as their top choice. These riders consistently valued the ability to receive clear, descriptive warnings without diverting attention from the road. Comments such as *“Audio is just talking to you such as corner, car ahead”* and *“You don’t have to look away from the road using audio warning”* reflected the appeal of audio-based alerts for maintaining situational awareness. The helmet audio was also seen as intuitive and reliable, especially in unfamiliar or high-risk scenarios. However, a few riders expressed concern over repetitiveness, noting that warnings sometimes repeated unnecessarily, potentially diminishing their effectiveness.

In addition to helmet audio, wristbands were moderately favoured among Segments 1 and 2 for their non-visual, non-intrusive feedback. Riders appreciated the simplicity of the haptic feedback, with one noting, *“You don’t need any concentration to receive it, it just lets you know there’s a threat.”* Standard LEDs also received moderate support, particularly when integrated onto the motorcycle where they were naturally within the rider’s field of view. For instance, a rider commented, *“LEDs on the bike were better, it was brighter and easier to see.”*

In contrast, Segment 3 (Risk-Tolerant, Tech-Sceptic Riders) showed markedly different preferences. This group was less enthusiastic about helmet audio, with only 10% identifying it as their preferred HMI. Instead, 40% favoured standard LEDs, citing their visibility and straightforward design. For these riders, the familiarity and clarity of visual indicators were seen as more trustworthy than newer, tech-heavy options. As one participant remarked, *“The LEDs on the bike were more visible. I didn’t have to change where I’m looking.”* Others were sceptical of more advanced interfaces like helmet visuals or audio, expressing that they either failed to notice them or found them distracting. One rider summarised this sentiment, saying, *“Too much audio is annoying. I turn off my Google Maps audio for anything other than alerts.”* Wristbands were also relatively well received (20%) in this segment, often because they were subtle and didn’t demand visual focus. However, even among those who used wristbands, there were comments about habituation over time, with some noting they eventually became easier to ignore.

Figure 27: Preferred HMI device over all the tested HMIs

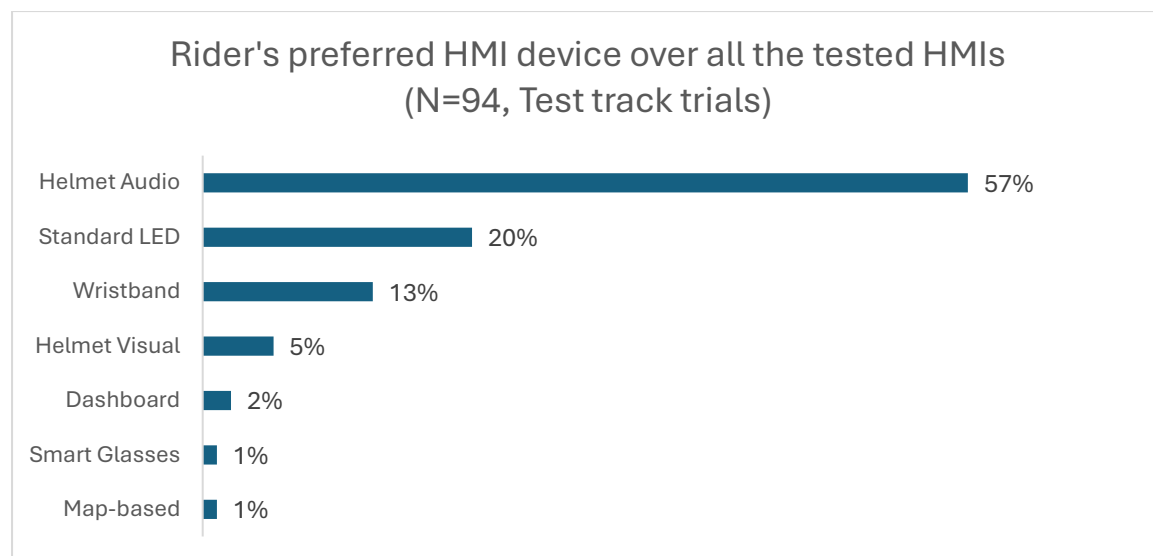
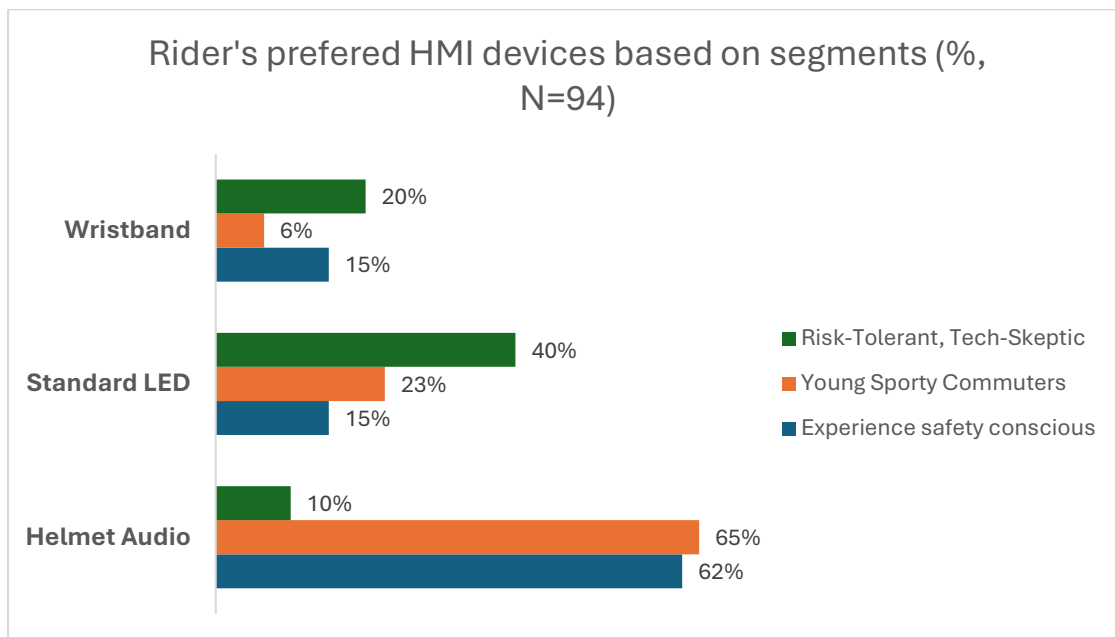


Figure 28: Rider's preferred HMI devices by segment (%), based on test track trial responses (N = 94)



These results align with the results from asking riders to compare between the custom and standards HMI devices. As shown in Figure 29, most riders in segments 1 and 2 found the custom devices better in communicating warnings comparing with the standard LEDs. However, Segment 3 was noticeably less convinced. Table 21 lists a summary of rider- reported strength and weakness associated with each HMI device

Overall, helmet audio was the most universally preferred HMI for Segments 1 and 2 due to its ability to deliver urgent information seamlessly. Meanwhile, Segment 3 riders gravitated toward simpler, more traditional warning mechanisms like LEDs and wristbands, emphasising the importance of visibility, non-intrusiveness, and familiarity. These findings underscore the need for customisable and rider-centric HMI solutions that match different rider profiles and expectations.

Figure 29: comparing the standard LEDs in terms of how much better/ worse the custom warning was in communicating warnings

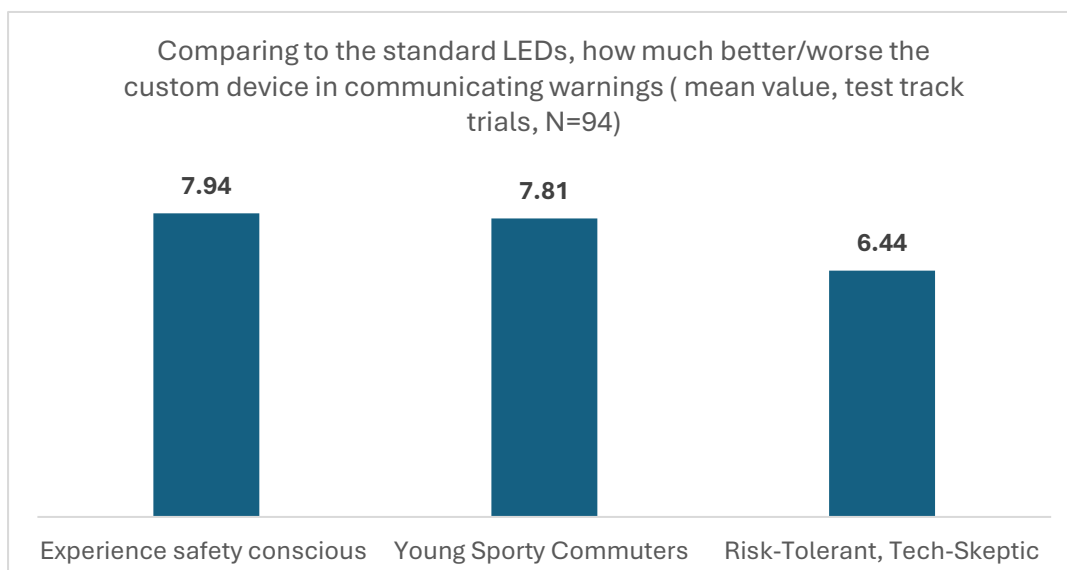


Table 21: Summary of rider-reported strengths and drawbacks associated with each HMI device during the test

HMI Type	Positive Themes	Negative Themes
Helmet Audio	Clear, immediate, non-distracting, informative	Can be repetitive, interfered by noise
Wristband	Instant, discreet, works with audio	Can be forgotten or desensitised
LEDs on Bike	Visible, directional	Confusion in bright light, lacks detail/context
Helmet Visual	Sometimes helpful in periphery	Poor visibility, hard to interpret
Smart Glasses	—	Nearly invisible, out of sight
Dashboard/Phone	Familiar (for some), good when stationary	Requires looking away, less suitable on the move

Does the choice of HMI impact the usefulness and the interest level of warnings?

Figure 30: Rider's rating of overall warning usefulness by preferred HMI device (N=94, Test track trials)

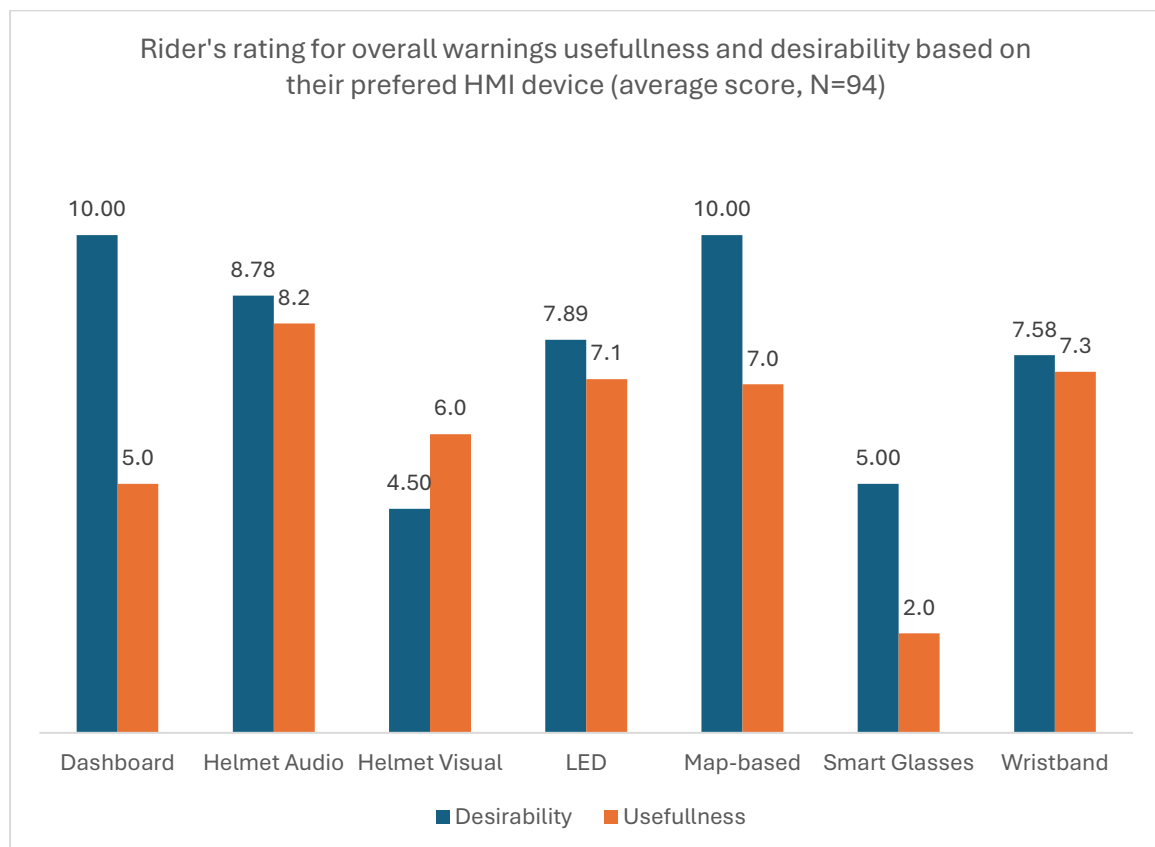


Figure 30 illustrates that the choice of HMI device significantly influences how riders' rate both the usefulness and desirability of C-ITS warnings. Helmet audio stands out as the top-performing

modality, with the highest average usefulness score (8.2) and the highest desirability rating (8.78). Riders appreciated its immediacy and clarity, with one noting, “It is always there, you can’t miss it... a missed warning is worse than no warning if you used to rely on it.” Others highlighted how it supports natural riding behaviour: “Because you are not looking at the dashboard at the right time, you are looking at the situation.”

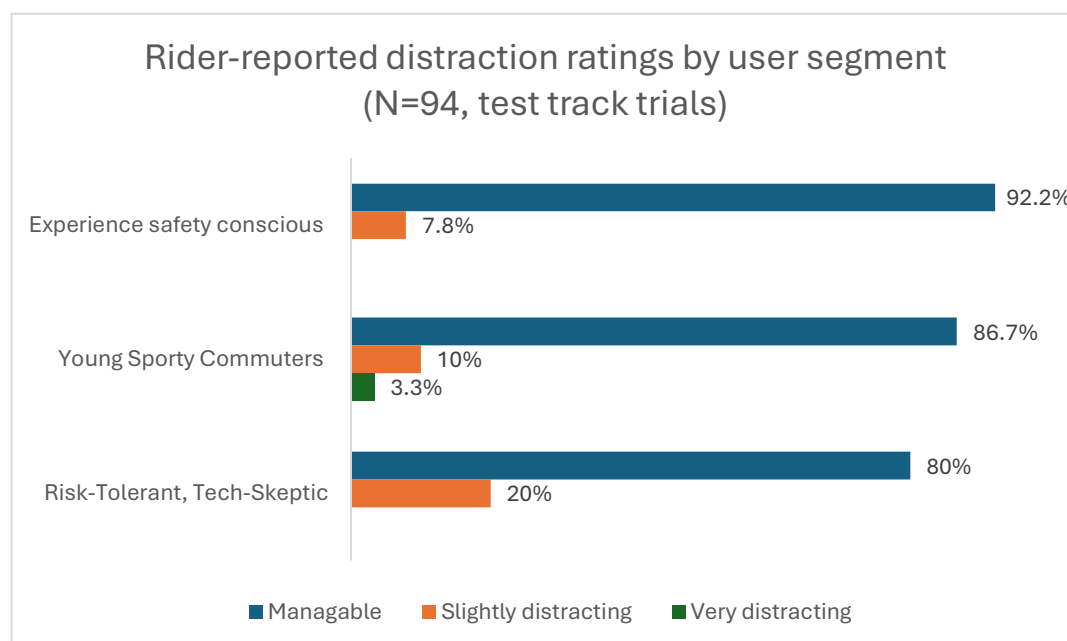
Wristbands (usefulness: 7.3; desirability: 7.58) and LEDs (usefulness: 7.1; desirability: 7.89) also scored well, especially for their non-intrusive delivery. As one rider put it, “The wristband does not interfere with my observations; it is not distracting,” while another stated, “The LEDs are aimed at your eyes—you will see it whether you are looking at it or not.”

In contrast, visual-only options received lower ratings. Helmet visuals scored 6.0 for usefulness and 4.5 for desirability, reflecting concerns about visibility and interpretation. Smart glasses had the lowest usefulness score (2.0) and a desirability rating of 5.0, often criticised for being out of the rider’s line of sight. Dashboards also scored poorly on usefulness (5.0), although their desirability rating was surprisingly high (10.0), suggesting some riders may still value familiar interfaces despite limited practical benefit.

These results show that audio and haptic HMIs are both more effective and more appealing to riders, particularly in dynamic environments. Devices requiring visual attention tend to be less useful and less desirable, highlighting the importance of designing alerts that align with real-world riding behaviour and cognitive load.

Which HMI is most/least distracting? And what cause distraction

Figure 31: Rider-reported distraction levels by user segment (N=94, test track trials)



The level of distraction reported by riders varied by rider segment, as shown in Figure 31. Experienced Safety-Conscious riders were the most tolerant of C-ITS warnings, with 92.2% rating them as manageable and only 7.8% finding them slightly distracting. Young Sporty Commuters

followed closely, with 86.7% rating warnings as manageable. However, this group also included the only riders (3.3%) who rated the warnings as very distracting, indicating that while generally accepting, some found the alerts intrusive. The Risk-Tolerant, Tech-Sceptic segment showed the highest sensitivity to distraction, with 20% finding the warnings slightly distracting and only 80% considering them manageable.

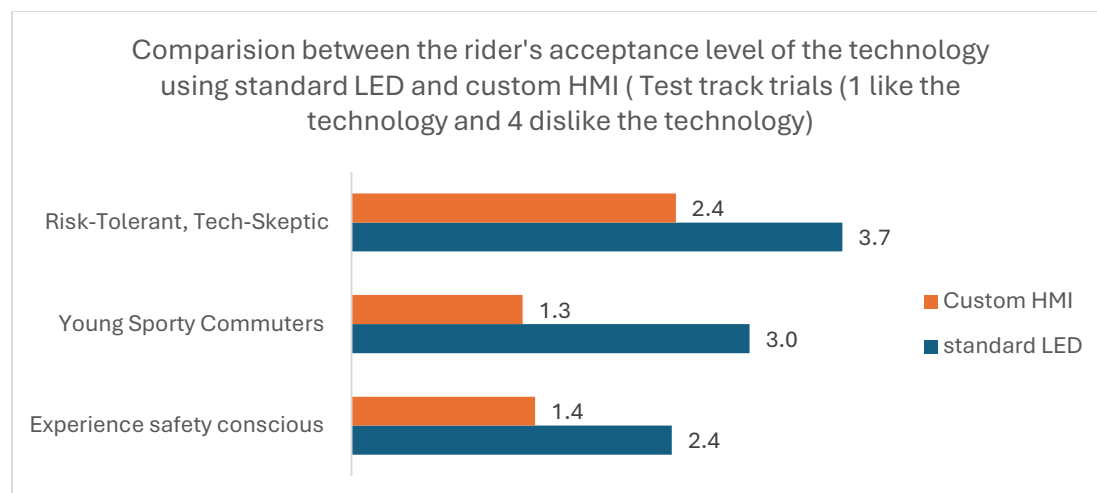
These findings suggest that distraction levels are influenced not only by HMI type but also by rider characteristics such as risk tolerance and familiarity with technology. Riders in Segment 1 were more accepting, likely due to their safety-focused attitudes and openness to support tools. In contrast, riders in Segment 3 may have found the warnings misaligned with their riding style, leading to lower tolerance.

Qualitative feedback supports this, with riders citing repetitive or poorly timed warnings as common causes of distraction, particularly with LEDs and dashboards. Conversely, helmet audio and wristbands were perceived as the least distracting, offering timely, intuitive alerts without requiring riders to divert attention. These results highlight the importance of customising warning modalities to rider profiles and avoiding information overload to promote safe and effective system use.

What the acceptance level of the system using the standard LEDs and the custom HMI device?

Overall, the effectiveness of warning integration was heavily influenced by both the HMI modality and the rider's segment characteristics. While Segments 1 and 2 generally perceived the warnings, particularly those delivered via helmet audio and wristbands, as well-integrated and supportive of their riding decisions, Segment 3 remained sceptical. The latter group frequently questioned the timing, clarity, and necessity of the alerts. Moreover, despite improved noticeability with custom HMIs, some riders still missed warnings due to attentional demands or poor placement. These findings highlight the need for adaptive, rider-centric HMI systems that align with different riding behaviours and risk attitudes. Tailoring warning modalities to specific rider profiles may enhance trust, reduce distraction, and increase the perceived usefulness of C-ITS technologies.

Figure 32: Comparison between the rider's acceptance level of the technology using standard LED and custom HMI



2.7.2 Warning usefulness

Another key factor influencing rider adoption of C-ITS warning technology is perceived usefulness. Regardless of how well-integrated or timely a warning may be, if riders do not believe it adds value to their decision-making or enhances their safety, they are unlikely to accept or want such a system on their motorcycle.

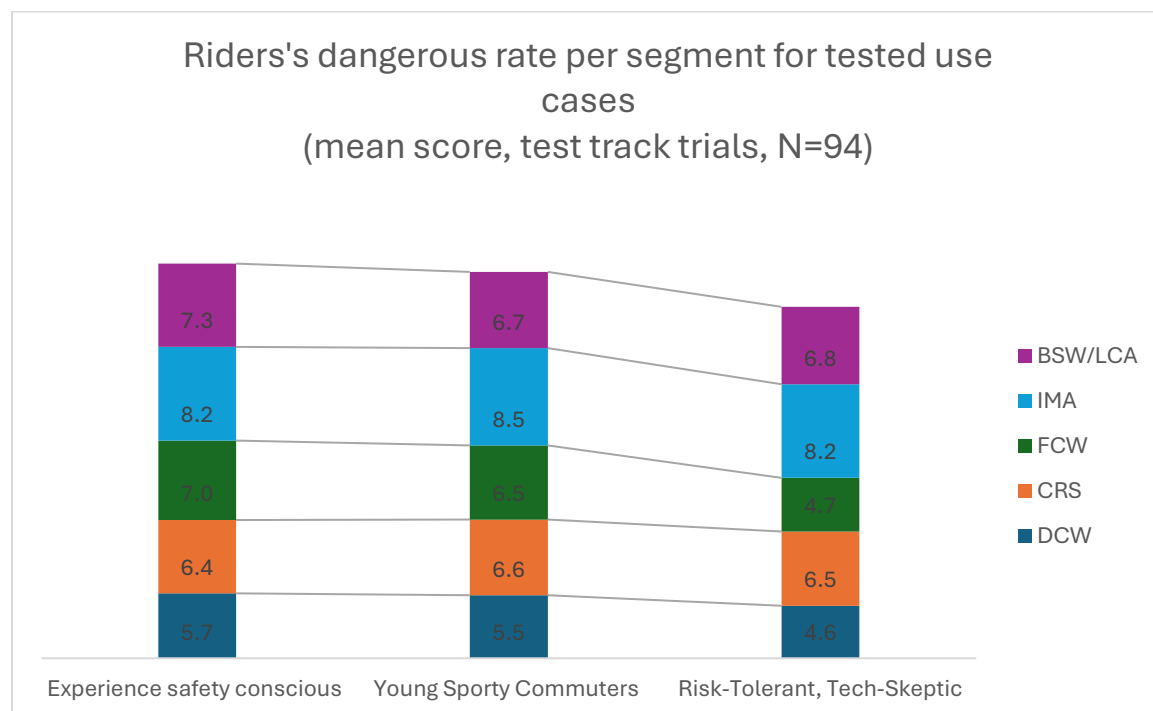
This section explores how riders assessed the usefulness of C-ITS warnings across several dimensions. To evaluate this, we compare responses from both the simulator and test track trials. The rationale behind this comparison is that the execution of use cases in the simulator trials involved more concealed and high-risk scenarios than those on the test track. Based on this, our hypothesis is that riders would perceive the warnings in the simulator trials as more useful.

To evaluate this, we address the following guiding questions:

Evaluation of warnings usefulness

How dangerous did riders perceive each use case scenario to be?

Figure 33: Rider's rating of the use cases dangerous level



Based on both the quantitative and qualitative data of test track trials, riders' perceptions of danger varied significantly across the different C-ITS use cases, and these perceptions directly influenced how useful they found the warnings. Figure 33 illustrates that across all segments, the IMA (Intersection Movement Assist) and BSW/LCA (Blind Spot Warning/Lane Change Assist) were rated as the most dangerous use cases, particularly among the Young Sporty Commuters and Experienced Safety-Conscious riders. This aligns with the strong qualitative sentiment that intersection and blind spot scenarios are highly unpredictable and potentially fatal due to limited visibility, poor communication with other drivers, and the high likelihood of human error. Riders

repeatedly described IMA as situations where “you don't know what [the driver] is going to do” or “you have no way of knowing if they saw you,” underlining the urgency for early warnings in such cases.

By contrast, Curve Speed Warnings (CRS) and Rough Surface (RS) were often rated as less dangerous, particularly among the Risk-Tolerant, Tech-Sceptic segment. Many in this group felt these situations were manageable with experience and visibility, with riders noting that “curves are part of riding” or that “rough surfaces are expected.” Still, others highlighted that these scenarios could become more dangerous when combined with poor weather or hidden obstacles, particularly if they appear mid-turn, reducing the rider’s margin for corrective action.

Forward Collision Warnings (FCW) scenarios received moderate danger scores. FCW was seen as more manageable when riders had good visibility but dangerous when the vehicle ahead was suddenly stationary. It was also considered highly context-dependent, less dangerous on open roads but riskier when obscured by traffic or situated just beyond a bend. Riders cited the challenge of “being rear-ended while trying to swerve around a broken vehicle” as a critical concern.

How useful did they find the warnings for each specific use case?

Figure 34: Rider's perceptions of warning usefulness for each use case using standard LEDS

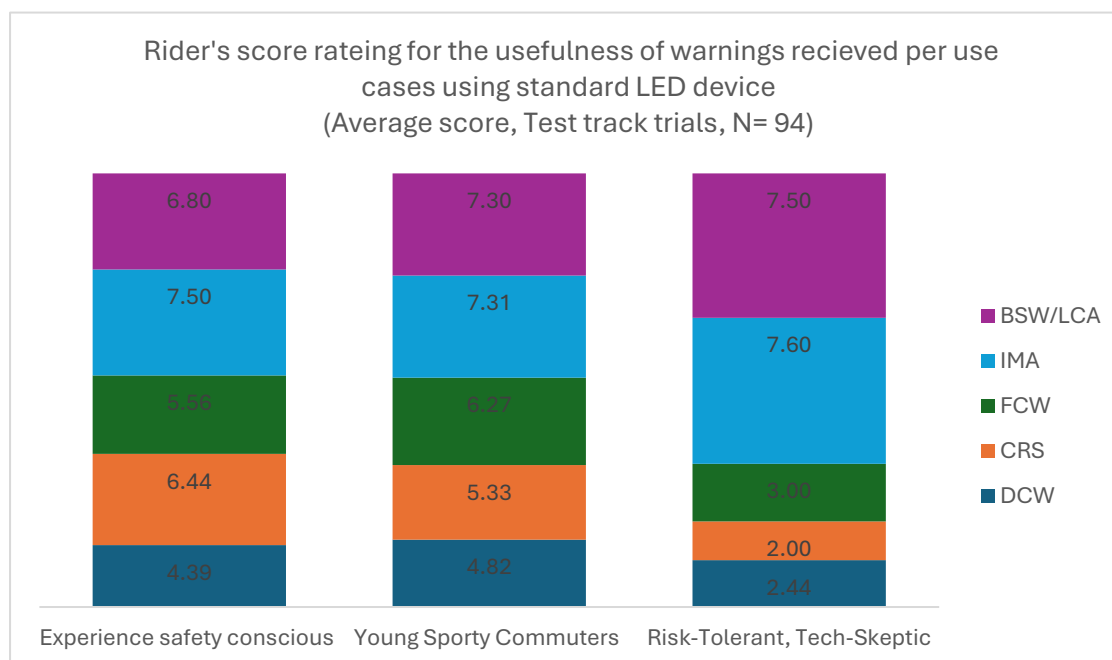
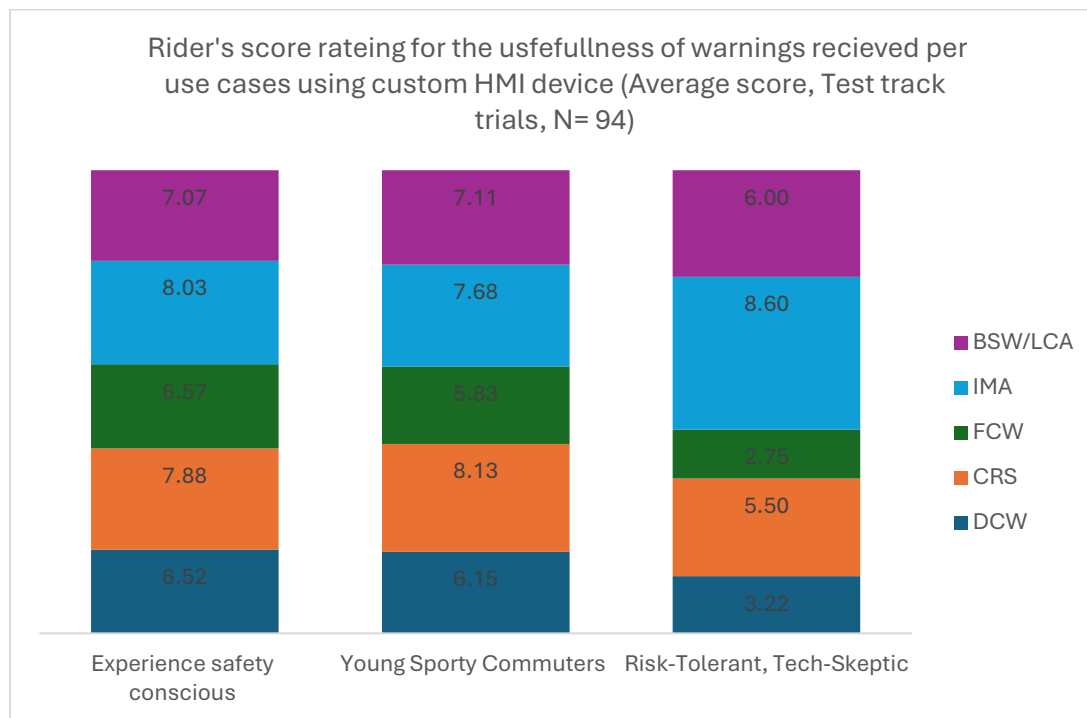


Figure 35: Rider's perceptions of warning usefulness for each use case using custom HMI



Riders perceived usefulness of C-ITS warnings closely aligned with their evaluation of how dangerous each scenario was. As illustrated in Figure 34 and Figure 35, warnings related to Intersection Movement Assist (IMA) and Blind Spot/Lane Change Assist (BSW/LCA) were rated the most useful across all segments. These scenarios were also consistently described as the most dangerous during interviews, primarily due to limited visibility, unpredictability of other road users, and the high likelihood of collision. One rider stated, “At intersections, you can’t always tell if the car sees you... having the red warning was a wake-up call.” Another commented, “That blind spot warning saved me. I would have just merged otherwise.”

In contrast, DCW and CRS received more mixed responses. Although some riders acknowledged their potential value, particularly in low-visibility or unfamiliar roads, many noted that the warnings were either too late or unnecessary when the hazard was already visible. For example, riders frequently reported seeing the curve or gravel ahead before the warning was triggered, reducing its perceived benefit. As one experienced rider noted, “I already knew the curve was there. The warning was distracting.”

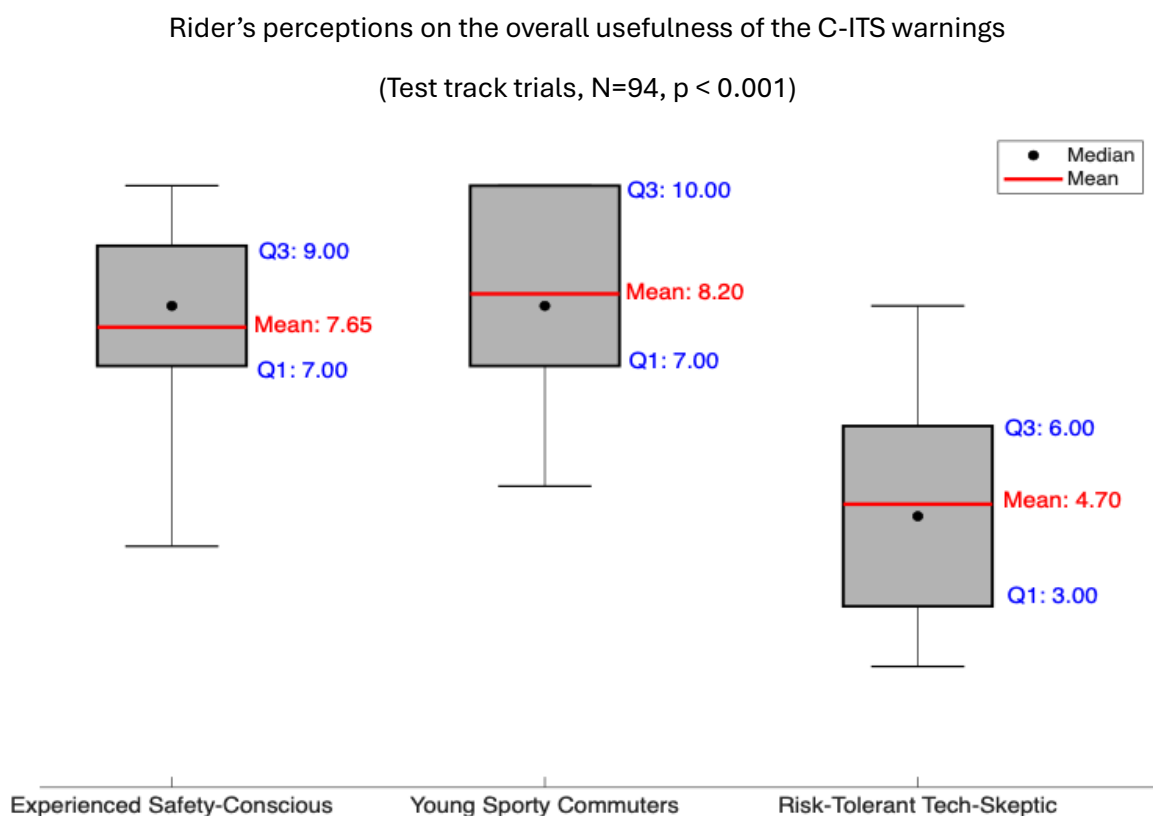
Forward Collision Warning (FCW) ratings were also polarised. Riders found FCW helpful when the vehicle ahead was partially obscured or stationary in an unexpected location, but its value diminished in scenarios where the hazard was clearly visible.

Segment-level analysis reinforces these trends. Segments 1 and 2 (Experienced Safety-Conscious and Young Sporty Commuters) generally gave higher usefulness ratings for IMA and BSW warnings, reflecting a clear appreciation for alerts that address blind spots and intersection threats. Segment 3 (Risk-Tolerant, Tech-Sceptics), however, continued to express doubt about the overall usefulness of most warnings, particularly when the warnings were either unclear or

delivered too late. This scepticism is evident in quotes such as, “I didn’t see the point of that warning. I was already braking.”

In summary, the perceived usefulness of warnings is strongly tied to how dangerous riders judged the situation to be. Warnings were considered most helpful in complex, low-visibility scenarios, especially intersections and blind spots where riders cannot easily anticipate hazards. The less predictable or visible the hazard, the greater the perceived value of receiving a timely and intelligible warning. Conversely, warnings for clearly visible, routine conditions such as standard curves or rough surfaces were often perceived as redundant, poorly timed, or even distracting.

Figure 36: Rider's rating on the overall usefulness



Beyond usefulness ratings for specific scenarios, we also examined riders' overall perceptions of the C-ITS warning system's usefulness (Figure 36). Results revealed statistically significant differences across the three rider segments ($p < 0.001$), highlighting how rider profiles influence their evaluation of the system. Young Sporty Commuters reported the highest overall usefulness, with an average score of 8.20, suggesting strong acceptance and positive engagement with the warnings. Experienced Safety-Conscious riders also rated the system positively, with a slightly lower average of 7.65, reflecting an appreciation for alerts that support safe riding behaviour.

In contrast, Risk-Tolerant, Tech-Sceptical riders gave considerably lower ratings, with an average score of 4.70. This group expressed doubt about the system's usefulness, particularly when warnings were perceived as unnecessary or poorly timed. The broader spread of responses in this group also indicates a less consistent or more critical view of the system. Despite that, some

riders in this group acknowledged the system's potential, especially in more dangerous or unpredictable situations. For example, one rider rated the system a "2" during the test but said it could be an "8" in real-world conditions. Another admitted, "I try to be an alert rider, but I do make mistakes. I get a lot of near misses... I am easily distracted," suggesting warnings might still serve as useful back-up, even for experienced riders.

Overall, these findings support the earlier scenario-based analysis: riders who are more focused on safety or performance tend to find value in the C-ITS system, while those who rely on their own judgment or have less trust in technology are less likely to view the warnings as useful.

Did riders feel that the warnings subjectively improved their reaction?

Table 22: 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	Test track trials (N=94)			Simulator trials (N=65)		
	Experience safety conscious (56%)	Young Sporty Commuters (33%)	Risk- Tolerant, Tech- Sceptic (11%)	Experience 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 factor	4.1	5.4	5.8	4.9	4.7	5.0

While most of the desirability analysis in this study focuses on test track trial data due to its closer resemblance to real-world riding, this specific question required a broader view. To assess whether riders felt that the warnings subjectively improved their reaction time, it was important to also consider data from the simulator trials. This is because the test track scenarios were designed with visible hazards for safety purposes, which may have reduced the perceived need for a warning. In contrast, the simulator environment allowed hazards to be concealed, and visibility reduced, offering a better opportunity to observe whether warnings helped riders respond more effectively in unpredictable conditions.

As shown in Table 22, across both trials, riders reported varying degrees of improvement in reaction time, with simulator participants generally giving higher ratings. In the simulator trials, the mean reaction improvement scores were 8.47 for Experienced Safety-Conscious riders, 8.75 for Young Sporty Commuters, and 7.00 for Risk-Tolerant, Tech-Sceptics. In contrast, the same

segments in the test track trials rated the warnings at 6.31, 6.94, and 2.80 respectively. These differences were statistically significant ($p = 0.014$), suggesting that riders perceived the warnings as more helpful when the hazard was less visible or more sudden conditions that were better replicated in the simulator.

Riders in Segments 1 and 2 consistently reported that warnings helped them anticipate and respond to hazards, particularly in blind spots and intersections. Comments included statements such as, “Especially for the intersection... I was more prepared for it than the first time around,” and “For the blind spot, that car was out of my focus, so the warning really helped.” These riders described the warnings as useful prompts that supported earlier speed adjustments, better hazard scanning, and improved mental readiness for evasive action. In contrast, riders in Segment 3 expressed ongoing scepticism, especially in the test track environment. With hazards clearly visible, many felt the warnings were unnecessary or even distracting. Their average score of 2.80 reflects a belief that the system did not add value when

What are the factors that need improvement?

As part of the evaluation, we asked riders, “What changes would help the warnings fit more naturally into your riding experience?” The following key points emerged from their feedback, highlighting specific areas for improvement to enhance the integration, clarity, and usability of C-ITS warnings.

One of the most consistent themes was the timing of warnings. Several participants suggested giving riders the ability to customise when warnings are delivered, with timing modes such as “early,” “standard,” or “minimal” based on personal preference or riding context.

Another recurring theme was the need for more specific and informative warnings. Riders wanted alerts that went beyond basic cues and included clearer descriptions. For example, differentiating between “sharp curve,” “gravel,” or “broken-down vehicle.” Directional audio and visual cues that clearly indicate the location and type of hazard were considered essential, especially if delivered with urgency tones or symbols that could help riders assess the seriousness of the warning.

Placement and visibility of devices were also frequently mentioned. Several riders found standard LEDs difficult to see in bright conditions or while riding at speed. Preferred placements included helmet-mounted lights (particularly at the top), mirrors, and positions within the rider’s peripheral vision. Some noted that LEDs should be brighter, colour-differentiated, and use distinctive flashing patterns to stand out from other visual cues on the motorcycle, such as factory gearshift indicators or turn signals.

In terms of modality preferences, many riders expressed a preference for combinations of audio and visual warnings, with some also valuing haptic feedback provided it was strong enough and positioned where it would not interfere with gear (e.g., not under gloves). Several also asked for configurable systems, allowing riders to turn off certain alerts, adjust volume or vibration strength, and select which device provides which type of feedback.

Finally, a number of riders highlighted the importance of familiarisation and adaptability. They noted that C-ITS warnings would become more effective once they had time to get used to them, suggesting that clear design, repeated exposure, and rider training could enhance their natural integration into the riding experience. As one rider commented, “It’s something I’d come to value once I got used to it.”

Overall, the feedback suggests that for C-ITS warnings to fit naturally into everyday riding, they must be timely, customisable, easily perceivable, and seamlessly integrated into existing riding behaviours

2.8 Conclusion

In conclusion, the findings demonstrate that overall desirability of C-ITS warnings is influenced by a combination of factors, including rider profile, perceived usefulness, warning design, and how well the system integrates into the natural riding experience. Riders from safety-conscious and performance-oriented segments consistently rated the system as more desirable, valuing the warnings for their ability to support decision-making in complex or unpredictable environments. In contrast, risk-tolerant and tech-sceptical riders were more critical, particularly when the warnings were seen as unnecessary or poorly timed.

Desirability was highest when warnings were perceived as clear, timely, and relevant to the context, especially in situations involving blind spots and intersections. Riders responded positively to systems that required minimal adjustment to their existing behaviour and offered a sense of control through customisation, such as adjustable timing, modality, and alert types.

Qualitative feedback reinforced that desirability grows with familiarity and trust. Riders expressed willingness to adopt the system if it could prove consistent, non-intrusive, and genuinely helpful in enhancing safety. Conversely, desirability declined when warnings were repetitive, vague, or arrived too late to prompt meaningful action.

3. Effectiveness

Main Research Question:

Are C-ITS warnings effective for riders?

Project outcome:

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 were 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 sooner. 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.

3.1 Introduction

A total of 65 riders participated in the trial, each interacting with diverse Human-Machine Interface (HMI) devices, such as LED dashboard and mirrors (on-Bike), smart helmets, smart glasses, and haptic wearables. These devices delivered C-ITS alerts in audio, visual, or tactile formats, providing early warnings about upcoming road hazards.

The primary aim of this research was to evaluate how different C-ITS warnings affect rider behaviour and reaction under three key use cases:

- Forward Collision Warning (FCW): Alerts riders of a rapidly approaching obstacle or vehicle ahead.
- Intersection Movement Assist (IMA): Warns riders of potential collisions with vehicles at intersections.
- Dangerous Curve Warning (DCW): Alerts riders if they are approaching a dangerous curve.

While real-world on-road trials were also conducted in parallel, only simulator trial data was used for measuring the effectiveness of the warnings. This decision was based on the unique capability of the simulator environment to introduce concealed hazards, creating genuine surprise elements. Such surprise scenarios are ethically challenging and unsafe to replicate in real traffic conditions, making the simulator a more valid environment for reaction-distance analysis.

3.2 Data Preprocessing and Cleaning

The raw real time timeseries data generated during the simulator trials spanned multiple sensors and control interfaces—resulting in large, high-frequency datasets for each participant. To

prepare the data for robust and accurate analysis, a comprehensive preprocessing pipeline was implemented. The following steps were undertaken:

- **Duplicate Removal:** Redundant entries arising from logging glitches or replay loops were identified and eliminated.
- **Missing Value Handling:** Any gaps due to dropped signals or hardware disconnects were interpolated using spline or nearest-neighbour methods, depending on the nature of the signal. The analysis used three key data sources: CanBus (vehicle data), warning data, and GPS data. If any one of these was completely missing for a round, that round was excluded, as all three were required for calculating the effectiveness matrix.
- **Outlier Detection and Filtering:** Speed, throttle and lane position readings were analysed for anomalies. Statistical techniques such as z-score filtering and interquartile range thresholds were applied to exclude biologically or physically implausible values.
- **Data Normalization:** To enable comparison across riders and sessions, data were normalized based on each rider's individual baseline riding profile to account for differences in riding styles and skill levels. Where necessary, normalization was performed using the Z-score method to standardize the data and ensure consistency across datasets.
- **Data Smoothing:** Continuous variables such as speed, throttle, and steering angle were subjected to smoothing techniques to reduce random fluctuations and transient noise. This step preserved the underlying behavioural trends while filtering out high-frequency jitter that could interfere with accurate modelling and interpretation of rider actions.
- **Segmentation of Events:** For each trial, a reasonable time window was selected to monitor rider behaviour—extending from a short duration prior to the warning onset to the point at which the rider passed the hazard. This window was chosen to ensure that the initial rider response, which typically occurs shortly after the warning, was fully captured. It allowed focused analysis of anticipatory, reactive, and post-response behaviours while ensuring alignment with the temporal dynamics of each use case.

These preprocessing steps ensured that the subsequent analysis was based on clean, consistent, and temporally accurate data, eliminating biases due to sensor errors or environmental inconsistencies.

3.3 Reaction Distance and Time to Collision Algorithm Development

To quantify how effectively riders responded to C-ITS warnings, a custom MATLAB-based algorithm was developed to estimate the reaction timestamp—defined as the point in time when the rider initiated the first measurable response following a warning (or baseline event). This estimate was not used to directly compare reaction times across conditions due to the absence of a consistent hazard visibility point in the baseline (no warning) scenario. In such cases, the moment when a rider visually detected a hazard could vary significantly between individuals and was thus excluded from comparative metrics.

The algorithm used a combination of telemetry data, including speed, throttle, braking input, and lateral movement (change in position within the lane or lane change), to detect behavioural

deviations indicative of a response. A threshold-based decision logic was applied to identify the earliest instance of such deviation following the warning onset. For additional robustness, a dedicated lane-change detection component was incorporated to identify swerving or positional adjustments (manoeuvring) typically associated with hazard avoidance.

Once the reaction timestamp was determined, it served as the anchor point for two key calculations:

- **Reaction Distance:** This was defined as the linear distance, derived from GPS coordinates, between the rider's position at the moment of reaction initiation and the location of the concealed hazard (if the hazard is stationary) or collision point (if the hazard is moving). Vincenty's formula was used to compute this distance, as it calculates geodesic distances on an ellipsoidal model of the Earth, offering higher accuracy than simpler models. This method is particularly reliable even for short distances (under 100 m), where precision is crucial. Unlike the Haversine formula—which assumes a spherical Earth and may introduce minor errors—Vincenty's approach provides more accurate results, making it well-suited for safety and reaction-time analysis.
- **Time to Collision (TTC):** This metric estimated the time remaining before the rider would reach the hazard, assuming they continued at their current speed from the reaction point. It quantifies the buffer available for a successful evasive or braking manoeuvre and is essential for assessing the practical value of different warning strategies.

This dual-metric approach—spatial (reaction distance) and temporal (TTC)—enabled a more robust and equitable assessment of rider response effectiveness, especially when comparing warning-enabled and baseline conditions, where direct reaction time alone would have been an unreliable indicator.

3.4 Experimental Design

The study employed a within-subjects experimental design, where each of the 65 riders participated in trials under both control and intervention conditions. This approach allowed for direct comparisons of behaviour with and without C-ITS warnings, enhancing the internal validity of the study and minimizing inter-subject variability. To further mitigate learning and anticipation effects, the same use case was implemented across multiple locations, and the order of exposure was randomized for each round. This randomization ensured that riders could not predict the occurrence or location of a hazard, preserving the naturalistic response patterns and minimizing adaptation over repeated exposures.

This combination of methodological rigor strengthened the reliability of observed effects, making the findings more robust for evaluating the real-world impact of C-ITS warning systems on rider behavior.

3.4.1 Trial Conditions:

- **Baseline Condition (No Warning):**
Riders encountered concealed hazards without any prior warning. These scenarios represented the natural, unassisted rider response to unexpected dangers and served as the control group for the analysis.

- **C-ITS Warning Enabled Condition (With Warnings):**

Riders received advance warnings several seconds before encountering a hidden hazard. These warnings were delivered via two channels:

1. On-bike HMI: All riders were exposed to warnings through an integrated on-bike interface, which included LED indicators on the mirrors and dashboard. This setup ensured a consistent baseline of HMI exposure across all participants.
2. Preferred HMI Devices: In addition to the on-bike system, each rider tested warnings delivered via one preferred HMI device of their choosing—such as smart glasses, smart helmets, smartwatches, or dashboard. This method introduced variation based on user preferences and was designed to explore the personalization and usability aspects of HMI effectiveness.

All warning-enabled trials were used to evaluate whether C-ITS interventions led to earlier and safer rider responses in comparison to the baseline condition.

3.4.2 Use Case Coverage and Trial Randomization:

Each participant completed multiple repetitions of five distinct use cases, randomized in order to reduce learning effects, habituation, and expectation bias:

1. Forward Collision Warning (FCW)
2. Intersection Movement Assist (IMA)
3. Dangerous Curve Warning (DCW)
4. Change of Road Surface Warning
5. Blind Spot Warning

To ensure comparability, environmental conditions such as lighting, road texture, weather conditions and curve geometry were held constant across both baseline and intervention trials. This controlled setup ensured that observed differences in rider behaviour could be confidently attributed to the presence or absence of C-ITS warnings.

3.4.3 Exclusion of Non-Quantifiable Use Cases:

Although all five use cases were tested, two were excluded from the final effectiveness analysis due to limitations in measurable behavioural data:

- **Change of Road Surface Warning:**
This scenario proved difficult to assess in a simulator context, as the lack of tactile feedback made it impossible to simulate the physical sensation of a changing road surface—an essential element for authentic rider perception and reaction.
- **Blind Spot Warning:**
In this case, the desired rider response was inaction—choosing not to change lanes or initiate a merge upon receiving a warning. As not reacting is itself the correct and safest response, traditional reaction-distance metrics were not applicable for effectiveness evaluation.

Consequently, only the remaining three use cases—FCW, IMA, and DCW—were used for the core analysis of C-ITS warning effectiveness, where rider reactions could be clearly measured and compared across conditions.

3.5 Use Case Effectiveness Summary

3.5.1 Forward Collision Warning (FCW)

Selection and Filtering of Valid FCW Instances:

Forward Collision Warning (FCW) was one of the core use cases analysed in detail to assess the effectiveness of C-ITS warnings. A total of 260 FCW scenarios were initially expected from the simulator trials (i.e., 4 FCW events per rider across 65 riders).

However, to maintain analytical rigor, only 215 events (83%) were retained for initial consideration. The remaining 45 cases were excluded due to missing or incomplete data, such as corrupted sensor logs or incomplete trial segments, which would otherwise compromise the validity of the results.

A secondary quality check was then applied to the 215 FCW warnings:

- **False Warnings (including premature alerts):**
6 cases (3%) were excluded where warnings were triggered too early or not aligned with a real hazard, which could mislead rider behaviour.
- **Late Warnings (Time-to-Event < 1.7 seconds):**
0 cases fell below this threshold. The 1.7-second cut-off is based on guidance from the Connected Motorcycle Consortium (CMC) white paper on rider reaction time [CMC, 2020], which recommends 1.7 seconds as the minimum time required for riders to perceive and respond to a hazard in real-world scenarios.
- **Abnormally Early Reactions (reaction time < -1 second):**
2 cases (1%) were identified where riders appeared to react even before the warning onset, possibly due to visual anticipation of the hazard or lack of familiarity with the simulator while trying to maintain control, or residual learning effects that persisted despite the use of randomization. These were also excluded, as the warning had no influence on the response.

After this cleaning process, a total of 207 FCW events (96% of considered warnings) were retained as valid for effectiveness analysis.

These 207 valid FCW events occurred across three predefined locations on the map, each designed to simulate a forward collision scenario. Of these, 53 events occurred at the first location (FCW1), 105 events at the second (FCW2), and 49 events at the third (FCW3). While the exact nature of the hazard varied slightly based on location, all events were analysed collectively to assess the overall impact of Forward Collision Warnings.

Using fixed locations for FCW testing helped maintain consistency across participants and reduced the learning curve, as riders gradually became familiar with the route layout while still encountering hazards in unpredictable ways. This stratification allowed the study to explore how

different types of forward collision scenarios influence rider response dynamics, both in baseline and warning conditions.

Rider Behaviour Analysis:

To evaluate the behavioural impact of C-ITS Forward Collision Warnings (FCW), we compared rider responses between two conditions: with warnings and without warnings.

The analysis was conducted using 207 validated FCW instances, with 62 cases under the baseline (no warning) condition and 145 cases where riders received warnings via either the on-bike HMI or their preferred custom HMI device.

Quantitative Findings:

Table 23: Quantitative Summary of Rider Behaviour in FCW Scenarios (With vs. Without Warning)

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

- **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.

These results are visually summarized in the Figure 37, which illustrates the distance and time gap between the warning onset, rider reaction, and hazard location in both test conditions. The figure demonstrates that riders receiving a C-ITS warning began reacting earlier, further away from the hazard, and had more time to prevent a collision.

At an average riding speed of approximately 46 km/h, the observed improvement in Time to Collision and reaction distance is substantial. As a reference point, according to IFZ (Institut für Zweiradsicherheit, Germany), the average full braking distance at 50 km/h is approximately 19.6 meters, while the swerving distance is about 29 meters. These benchmarks provide important context: the additional 8.64 meters gained in reaction distance through C-ITS warnings could be critical in enabling the rider to execute either braking or evasive manoeuvres in time to avoid a collision.

Figure 37: Impact of C-ITS Forward Collision Warnings on Rider Reaction Distance and Timing

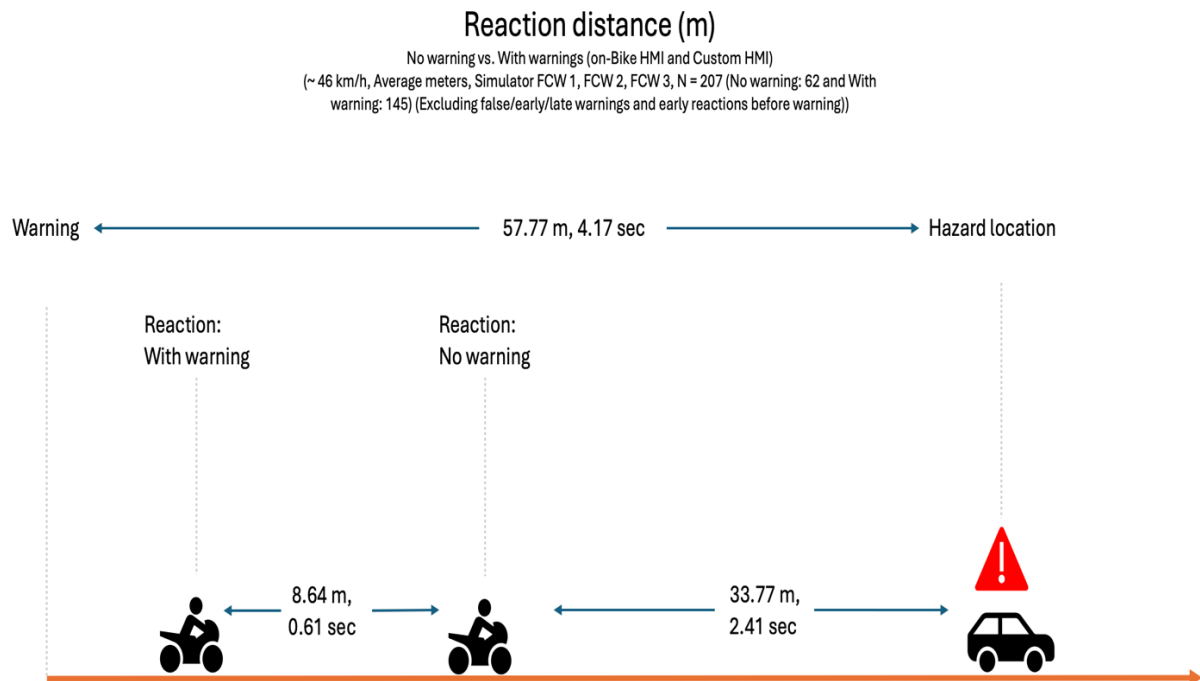
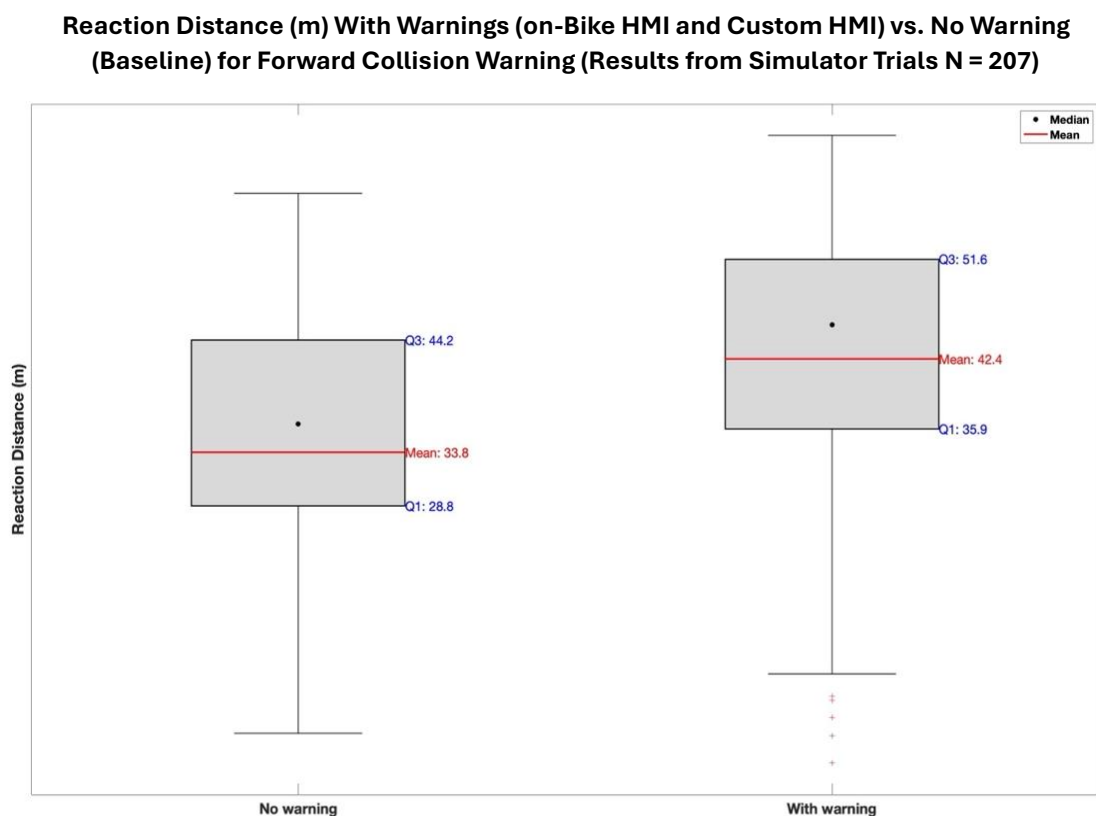


Figure 38: Effect of C-ITS FCW on Rider Reaction Distance: Simulator-Based Comparison



This effectiveness is further illustrated in the reaction distance boxplot (Figure 38), which compares the distribution of distances between the warning and no-warning groups. Riders who received warnings not only demonstrated higher mean and median reaction distances but also exhibited a noticeable rightward shift in the overall spread. A non-parametric Mann–Whitney U test (since reaction distance is not normally distributed in both groups) confirmed that the difference between the two groups was statistically significant ($p < 0.05$), validating that the improvements observed were not due to chance.

Overall, these results validate that Forward Collision Warnings significantly enhance rider response, reduce reaction latency, and create a safer buffer to mitigate potential impacts. These enhancements collectively contribute to improved rider safety and more time-critical decision-making in the face of forward collision hazards.

3.5.2 Intersection Movement Assist (IMA)

Selection and Filtering of Valid IMA Instances:

Intersection Movement Assist (IMA) was evaluated as the second core use case to determine the effectiveness of C-ITS warnings in improving rider safety at intersections. A total of 260 IMA scenarios were initially expected from the simulator trials similar to FCWs.

After excluding entries with missing or incomplete data, 218 IMA events (84%) were retained for preliminary review. A quality control check was then performed to remove unqualified events:

- **False or Premature Warnings:**
16 cases (7%) were discarded where warnings were issued too early or were not aligned with a valid hazard.
- **Late Warnings (Time-to-Event < 1.7 seconds):**
8 events (4%) were excluded based on the CMC-recommended threshold for minimum reaction time.
- **Early Reactions (Reaction Time < -1s):**
3 cases (1%) were removed, where riders reacted too early, potentially due to overcompensating or anticipatory behaviour unrelated to the warning.

After these exclusions, 191 valid IMA cases (88%) remained for analysis. These were split almost evenly between the two locations used in the trial: 91 instances in IMA1 (48%) and 100 instances in IMA2 (52%).

Rider Behavior Analysis:

To assess rider behavior, two indicators were analyzed: reaction distance, and time to collision, comparing those who received C-ITS warnings with those who did not. The potential collision point—specific to each use case location—was considered when calculating reaction distance in IMA warnings.

Out of the 191 valid trials:

- 66 riders were in the baseline condition (no warning)

- 125 riders received IMA warnings through either the on-bike HMI or their preferred HMI device

Quantitative Findings:

Table 24: Quantitative Summary of Rider Behavior in IMA Scenarios (With vs. Without Warning)

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

- **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.

The intersection scenario was designed such that a hazard vehicle approached unexpectedly from a side road—creating a genuine surprise element for the rider. This is clearly reflected in the data, where average reaction distances in the baseline (no warning) condition were approximately half those observed in the FCW scenario.

These results are illustrated in Figure 39, which compares rider reaction timing and distance in both test conditions. Riders who received IMA warnings began responding earlier and further from the point of hazard conflict, giving them more time to manoeuvre safely. At an average approach speed of ~44 km/h, the gains in both time and distance are particularly critical given the complexity of intersection navigation and side-impact collision risks.

Figure 39: Impact of C-ITS Intersection Movement Assist Warning on Rider Reaction Distance and Timing

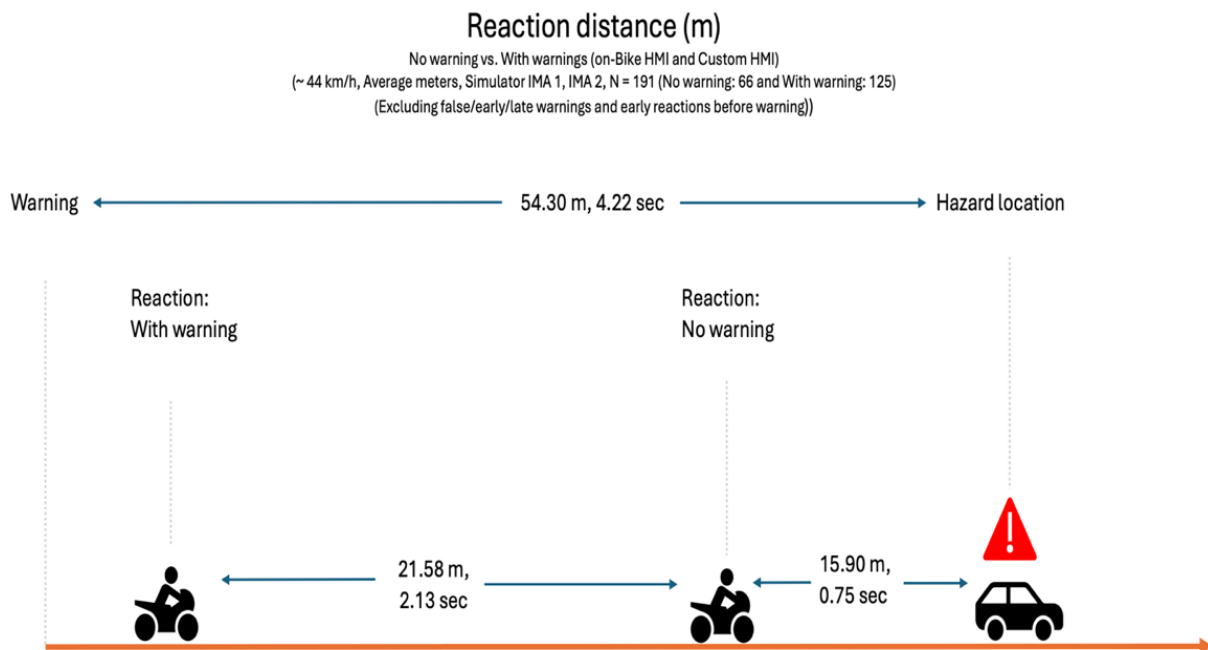
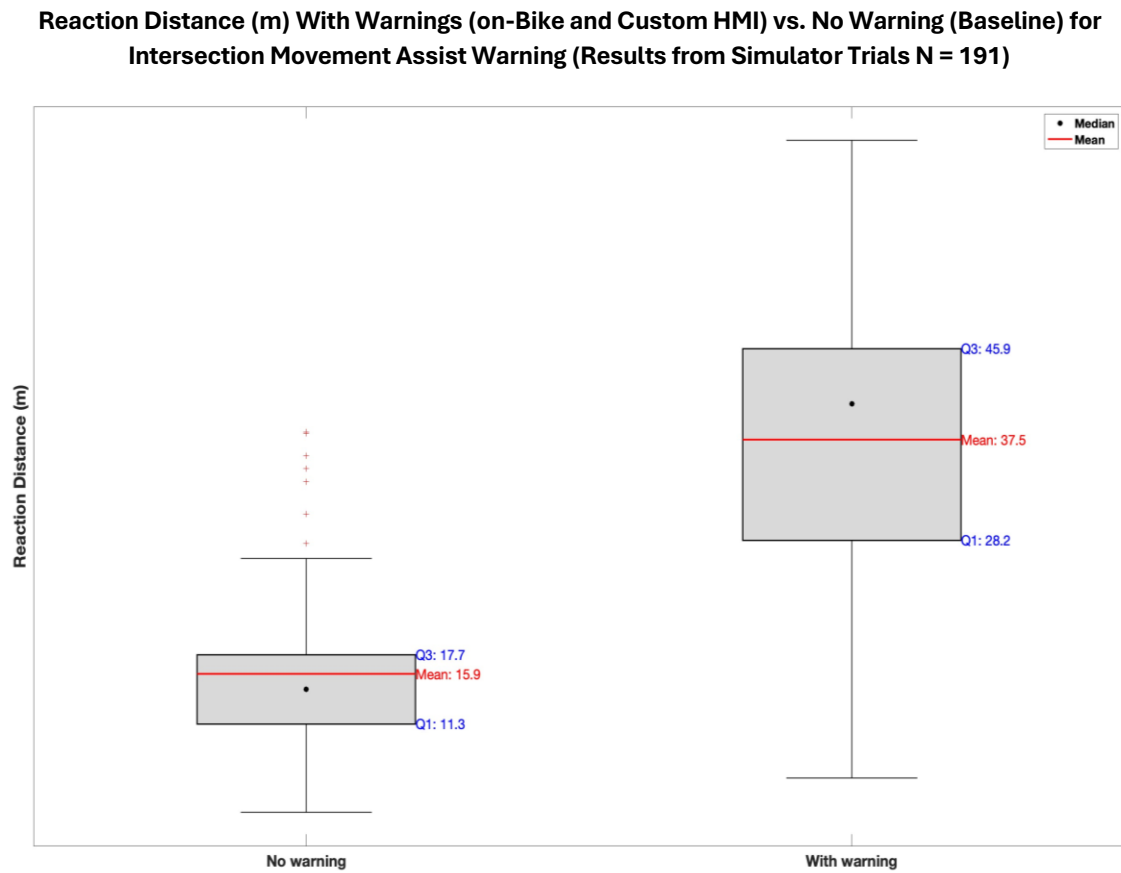


Figure 40: Effect of C-ITS IMA on Rider Reaction Distance: Simulator-Based Comparison



The reaction distance boxplot (Figure 40) further illustrates the shift in response behaviour. The warning group demonstrated a significantly higher median (40.8) and mean (37.5) reaction distance, with a broader interquartile range (17.7), indicating stronger and more consistent response patterns.

Normality tests (Kolmogorov–Smirnov with Lilliefors correction) confirmed that neither group followed a normal distribution, necessitating the use of a non-parametric Mann–Whitney U test. The test yielded a statistically significant difference ($p < 0.05$) between the warning and no-warning groups, validating that the observed improvements were meaningful and not due to chance.

Overall, the results confirm that Intersection Movement Assist warnings substantially enhance rider response at intersections, where hazards often arise with little to no warning. The warnings prompted significantly faster reactions, greater safety buffers, and increased time to collision, highlighting their critical role in improving rider awareness and reducing crash risk in high-conflict scenarios.

3.5.3 Dangerous Curve Warning (DCW)

Selection and Filtering of Valid Curve Warning Instances:

Dangerous Curve Warning differs from the previous two use cases in that it is based on Vehicle-to-Infrastructure (V2I) communication, where the warning is triggered by the motorcycle's position on the map, not by another vehicle. Riders received the warning every time they passed a predefined curve location but need to move towards the curve along the road. Unlike FCW and IMA, DCW was location-triggered and not avoidable, and as such, it was only tested at a single curve location in the simulator.

A total of 455 DCW events were expected across all riders (7 events per rider for 65 riders). Of these, 433 warnings (95%) were retained for initial analysis after excluding trials with missing or incomplete data.

Subsequent filtering of the 433 DCW warnings was based on the following:

- **False Warnings (e.g., late or misaligned with curve location):**
47 events (11%) were excluded where the warning triggered beyond the predefined activation zone.
- **Early Reactions (reaction time < -1 second):**
4 cases (1%) were excluded where the rider reacted before the warning was issued.
- **No Reaction:**
17 cases (4%) were excluded where riders showed no measurable response, likely due to learning effects as riders became accustomed to the simulator and pre-empted the curve without responding explicitly to the warning.

After applying these filters, 365 valid CSW trials (84%) were retained for effectiveness analysis.

Rider Behavior Analysis:

As with the other use cases, we examined reaction distance and time to collision. When calculating the reaction distance, the start of the curve or the end location of the predefined warning activation zone was considered as the hazard location. In total:

- 121 trials were from the no-warning condition
- 244 trials were from the warning condition

Unlike IMA and FCW, lane change was not used as a behavioural marker for reaction in curves, since lateral movement in curves doesn't consistently represent an evasive action.

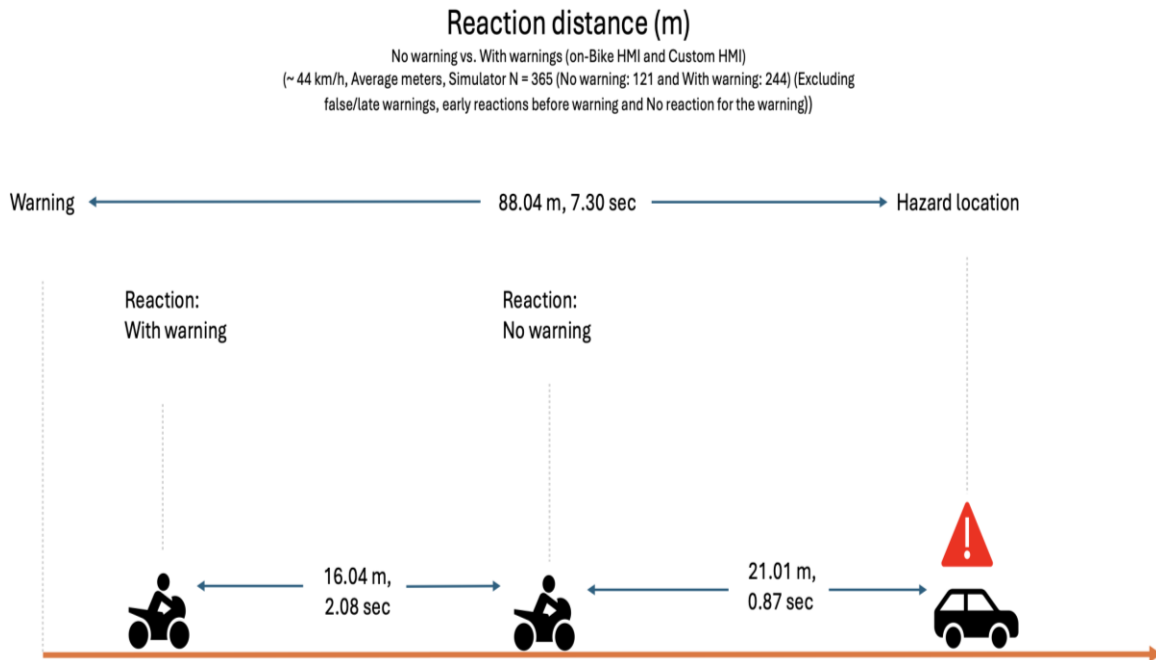
Quantitative Findings:

Table 25: Quantitative Summary of Rider Behavior in Dangerous Curve Scenarios (With vs. Without Warning)

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

- **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.

Figure 41: Impact of C-ITS Dangerous Curve warning on Rider Reaction Distance and Timing



These differences are visualized in Figure 41, which compares response behavior in both conditions. Even though the warning was always triggered around the same location, riders benefited significantly from the early alert in terms of preparation and smoother curve handling.

As with the previous use cases, we tested for normality and performed significance testing:

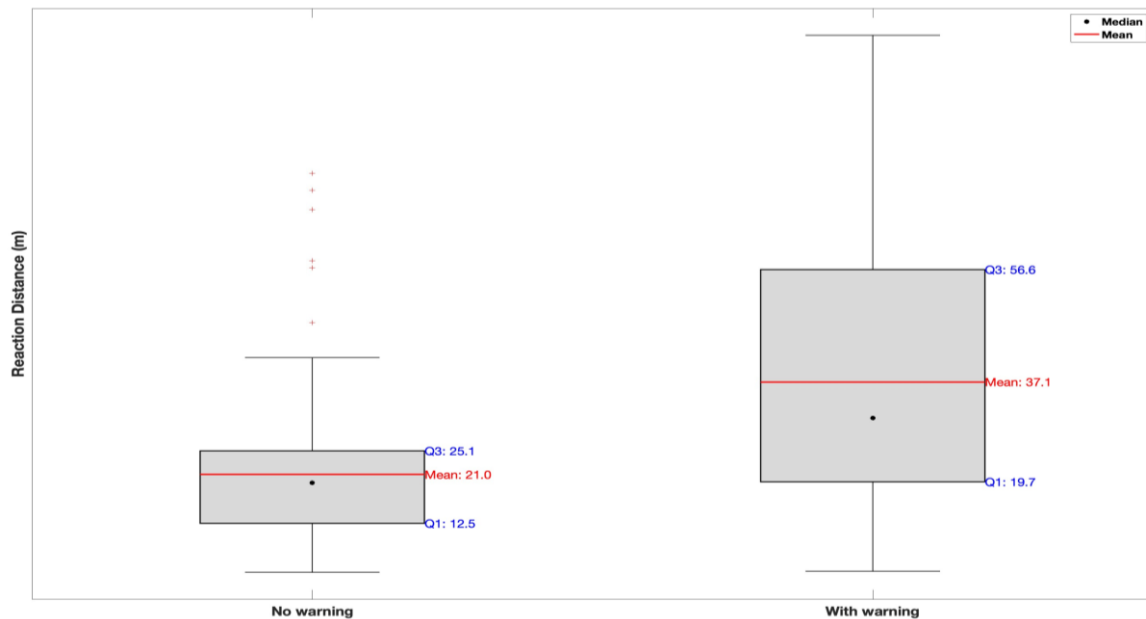
- Kolmogorov–Smirnov tests confirmed non-normal distributions in both groups.
- A Mann–Whitney U test showed a statistically significant difference ($p < 0.05$) between the warning and no-warning groups for reaction distance.

These findings are reflected in the reaction distance boxplot (Figure 42). Riders who received curve warnings exhibited a greater and more widely distributed reaction distance, with a median shift from ~19.5 meters (no warning) to over 30.8 meters (with warning).

While Curve Warnings were not avoidable and introduced a degree of learning adaptation, the results show clear benefits. Despite repeated exposure, warnings significantly enhanced reaction timing, distance, and collision avoidance potential.

Figure 42: Effect of C-ITS Dangerous Curve warning on Rider Reaction Distance: Simulator-Based Comparison

**Reaction Distance (m) With Warnings (on-Bike and Custom HMI) vs. No Warning (Baseline)
for Dangerous Curve Warning (Results from Simulator Trials N = 365)**



Overall, DCW warnings proved effective in:

- Extending rider decision space
- Enhancing safety even in familiar and repeated scenarios

These findings validate the role of infrastructure-triggered warnings in improving safety for riders navigating curves—especially when visibility or environmental conditions would otherwise limit natural reaction time.

3.6 Conclusion

The results from the simulator-based evaluation of **three C-ITS use cases—Forward Collision Warning (FCW), Intersection Movement Assist (IMA), and Dangerous Curve Warning (DCW)**—demonstrate that C-ITS warnings significantly enhance motorcycle rider safety across diverse road scenarios.

Across all use cases, riders who received warnings consistently showed:

- **Longer reaction distances**, providing increased time and space to respond (e.g., 8.64m of buffer in FCW, 21.58m in IMA, and 16.04 in DCW)
- **Greater time to collision**, reducing the likelihood of crash impact

Statistical analysis confirmed that these differences were **highly significant ($p < 0.05$)** for all use cases.

Whether the warnings were triggered by surrounding vehicles (V2V in FCW and IMA) or infrastructure (V2I in CSW), the results validate the potential of C-ITS technology to **improve rider awareness, reaction capability, and overall road safety**, especially when coupled with effective Human-Machine Interface (HMI) designs.

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Figure 43: A perfect example of public-private partnership. Representatives from Cohda wireless, Toyota, La Trobe, Tac, iMOVE and TMR



5. Pre-trial, during and post-trial survey questions

Researcher to provide rider UserID?

What is your gender?

1. Male
2. Female
3. Other

What is your age?

1. Under 18
2. 18-25
3. 26-35
4. 36-45
5. 46-55
6. 56 - 65
7. 66 - 75
8. 76-85
9. 85 - above

What type of motorcycle do you currently ride?

1. Cruiser
2. Touring/Riser
3. Naked/Sport
4. Adventure
5. Other _____

All up, how many years of active riding experience do you have?

1. 0 - 5 years
2. 6 - 10 years
3. 11 -15 years
4. 16 - 20 years
5. more than 20 years

Roughly how many hours do you ride per month (if it depends on the season, pick the closest for summertime)

1. 0
2. 5
3. 10
4. 15
5. 25
6. 50
7. 75
8. 100 or more

What safety precautions do you typically take when riding a motorcycle?

1. Wear a helmet
2. Wear protective clothing
3. Use hand signals when turning
4. Wear reflective clothing to increase visibility
5. Maintain a safe following distance
6. Rides sober
7. Maintain a safe buffer from other road users
8. Only ride in favorable weather conditions
9. Don't ride when tired

What type of rider would you say you are? (People can have various types, so please choose the one that best fits you most of the time.)

1. Commuter: I use my bike mostly to ride to work and back
2. Professional rider: Riding is a part of my job
3. Social rider: I enjoy sharing my riding experience with like-minded people. I ride with peers, as a part of a social group or with riders that have the same brand of motorcycle)
4. Thrill seeker: I enjoy testing myself and my bike, I enjoy off road sports or on road racing
5. Adventure rider: I like to explore new places and spaces, on and off the road
6. Motorcycle enthusiast: My life centres around my bike
7. Me-time riders: I enjoy getting away from it all

How would you describe your own riding style?

	Low risk	2	3	4	5	6	7	8	9	High risk
Risk profile	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

please enter userID?

Baseline

How would you rate the following road situations in terms of potential danger?

	1	2	3	4	5	6	7	8	9	10
Curve	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Change road surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Broken down vehicle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Intersection movement assist	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Blind spot/ lane change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why do you say so?

Do you feel that having warnings in these road situations will be useful?

--

Standard warning devices

How would you rate the following road situations in terms of potential danger?

	1	2	3	4	5	6	7	8	9	10
Curve	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Change road surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Broken down vehicle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Intersection movement assist	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Blind spot/ lane change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why do you say so?

--

How useful did you find the warnings delivered during each road traffic scenario?

	1	2	3	4	Neutral	6	7	8	9	10	Did not see the warning
Curve	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Change road surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Broken down vehicle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Intersection movement assist	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Blind spot/ lane change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why do you say so?

Custom warning devices

How would you rate the following road situations in terms of potential danger?

	1	2	3	4	5	6	7	8	9	10
Curve	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Change road surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Broken down vehicle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Intersection movement assist	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Blind spot/ lane change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why do you say so?

What is the custom warning device(s) chosen by the rider?

1. Helmet Audio
2. Helmet Visual
3. Wristband
4. Map-based warning
5. smart glassess
6. Dashboard

What is the custom warning device(s) preferred by the rider?

1. Helmet Audio
2. Helmet Visual
3. Wristband
4. Map-based warning
5. smart glassess
6. Dashboard

Any comments?

How useful did you find the warnings delivered during each road traffic scenario?

	1	2	3	4	5	6	7	8	9	10	Did not see the warnings
Curve	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Change road surface	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Broken down vehicle	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Intersection movement assist	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Blind spot/ lane change	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Comments/Suggestions:

Comparison Between Different Warning Devices: Riders will be asked to compare the usability and clarity of warnings across various warning devices used in the trial.

In your opinion, which device is best at communicating warnings?

compared to the standard warning device, how much better or worse is your custom device in communicating warnings?

	1	2	3	4	5	6	7	8	9	10
Custom compared to standard warning device										

Please enter UserID?

Usefulness: Feedback will focus on whether riders perceive the warnings as beneficial. Riders will reflect on whether the system helped them anticipate or avoid dangerous situations.

How useful did you find the warnings?

	1	2	3	4	5	6	7	8	9	10
Overall usefulness	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why do you say that?

Rider perspective on improving reaction time: riders will be asked for their perspective on how the warnings influenced their reaction times. This subjective data will provide insights into whether riders believe the warnings helped them to react more quickly and effectively in hazardous situations.

Did the warnings help you respond earlier to hazardous situations?

	1	2	3	4	5	6	7	8	9	10
Earlier responses due to warning	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

why do you say that?

Cognitive Impact: An essential part of the assessment will be to determine if the warnings overload the rider’s cognitive capacity or contribute to unnecessary stress. Riders will reflect on whether the warnings caused distraction, whether they disrupted the riding experience, or if they seamlessly integrated into their decision-making process.

Did the warnings feel manageable, or did they add to your mental load while riding? (from the preferred HMIs)

- 1. Manageable
- 2. Slightly distracting
- 3. Very distracting

Were there any moments where the warnings felt overwhelming or caused you to lose focus?

Did the warnings seamlessly integrate into your decision-making process?

	1	2	3	4	5	6	7	8	9	10
Integration with decision making	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why do you say so?

What changes would help the warnings fit more naturally into your riding experience?

Ease of Use: This will assess how easily riders can understand, process, and react to the C-ITS warnings. Riders will be asked how intuitive the system felt whether they required additional mental effort to interpret the warnings, and how quickly they could respond after receiving the warnings.

How long do you think it will take you to get used to it?

	1	2	3	4	5	6	7	8	9	10	I will never get used to it
Time to get used to it	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Comments/Suggestions:

What improvements would make the system easier to use and respond to while riding?

System Acceptability: Riders will rate how well they accept the C-ITS system as a useful tool in real-world

scenarios. The focus will be on the system's perceived value, whether they would be willing to use it regularly, and how much they trust its functionality.

How would you feel if your motorcycle came with C-ITS warning technology using...

	I like it	I accept it	I am neutral	I can tolerate it	I dislike it
C-ITS with standard LED warning device	☐	☐	☐	☐	☐
C-ITS with custom warning device	☐	☐	☐	☐	☐

How interested would you be in having this technology on a motorcycle you ride?

	Very uninterested	2	3	4	5	6	7	8	9	Very interested
Overall desirability	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Why do you say that?