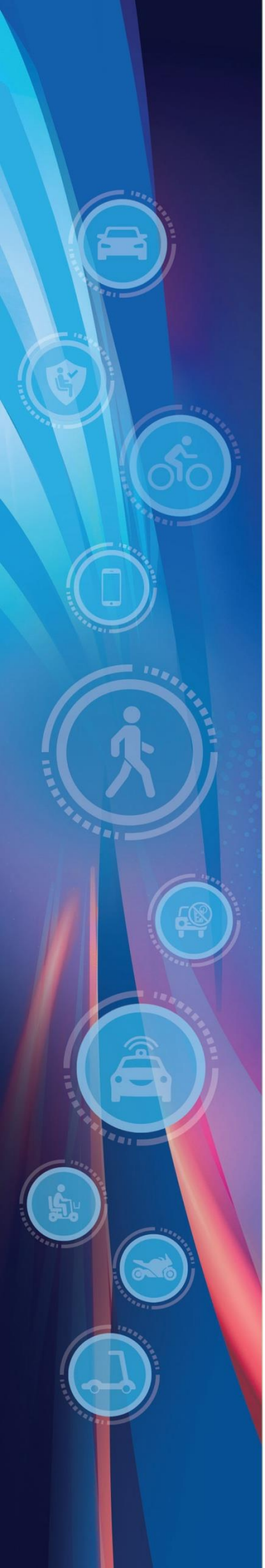

Centre for Accident Research & Road Safety - Queensland

Ipswich Connected Vehicle Pilot:

Summary of the Simulator Study Findings

iMOVE Project: 1-002, Cooperative Intelligent Transport Systems (C-ITS) Pilot – Field Operational Test (FOT) and Evaluation

24 March 2022

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BRIEF OVERVIEW OF THE IPSWICH CONNECTED VEHICLE PILOT – SIMULATOR STUDIES

The Ipswich Connected Vehicle Pilot (ICVP), an on-road Field Operational Test (FOT) of Cooperative Intelligent Transport System (C-ITS) technology, also incorporated test of vehicle-to-vehicle (V2V) warning messages conducted via advanced driving simulator studies. Findings across two simulator studies suggested that participants reduced their speed when presented with a warning in an emergency, and were generally positive towards the C-ITS technology.

Through the ICVP, the Department of Transport and Main Roads (TMR) aimed to build public awareness of C-ITS technology, as well as validate the safety benefits of the use cases, so that TMR can develop appropriate plans to encourage uptake of C-ITS. TMR also, strategically, grew organisational readiness for future widespread deployment in Queensland with this pilot.

C-ITS technology allows vehicles to 'talk' with other vehicles, roadside infrastructure, and transport management systems in real-time. This provides road users with information or visual warnings, on a dedicated display (see Figure 1), relevant to their current situation.

Figure 1: The Emergency Electronic Brake Light V2V warning as depicted on the HMI in the ICVP simulator studies.

To understand the impacts, and gather public perspective of the technology, the ICVP FOT ran between September 2020 and September 2021, involving 355 public participants in Ipswich driving their own vehicles retrofitted with C-ITS technology for a period of nine months.

Data were collected and transmitted directly through the Vehicle Intelligent Transport System Station (V-ITS-S) installed in participant's vehicles, to estimate the likely impacts on driving behaviour and crashes[1].

The vehicle-to-vehicle (V2V) warnings could not be incorporated into the ICVP FOT given they were unlikely to generate sufficient valid events on-road to meet the requirements for a safety evaluation. A valid V2V event would only occur if two participants were travelling within a close distance range. However, understanding the safety benefits of V2V functions was also essential to determining the impacts, and gather public perspective of the technology. Thus, two V2V functions, Emergency Electronic Brake Light (EEBL) and Slow stopped vehicle (SSV), were evaluated through studies within QUT's Advanced Driving Simulator (ADS). The simulator studies enabled the V2V warnings (or use cases), to be tested in a controlled environment and, in doing so, ensured that the required statistical validity and robustness was achieved.

[1] The results of the C-ITS impact on crashes will be reported in the *ICVP Safety Evaluation Report* in early 2022.

TYPES OF SAFETY INFORMATION AND WARNINGS

ICVP simulator study participants experienced safety information or warnings based on five different use cases. Brief descriptions of the warnings as well as representation of how such warnings appeared on the HMI are provided in Table 1.

Table 1: Vehicle-to-vehicle safety use cases.

Safety information		Purpose	Display icon[#]	Audio alert
EEBL	Emergency Electronic Brake Light	Alerts drivers there is a risk of a rear-end collision with a vehicle braking hard ahead.		Yes – (yellow: single soft "boop"; red: three quick "beeps")
SSV	Slow/stopped vehicle	Alerts drivers there is a risk of a rear-end collision with a slow/stopped vehicle ahead.		Yes – (yellow: single soft "boop"; red: three quick "beeps")
IVS	In-vehicle speed	Provides drivers with information about the current speed limit.		No
BOQ	Back of queue	Alerts drivers there is a risk they are travelling at an unsafe speed for an upcoming traffic queue.		Yes – (single soft "boop")
RWW	Road works warning	Alerts drivers there is a risk they are travelling at an unsafe speed for upcoming road works, giving them time to slow down or change lanes. It also alerts drivers if they exceed the speed limit within the road works.		Yes – (yellow: single soft "boop"; red: three quick "beeps")

[#] Yellow warnings informed drivers to prepare for a possible emergency situation. Red warnings informed the driver of an emergency situation requiring an immediate reaction.

Safety information was shown only when relevant to the driver (except for in-vehicle speed [IVS], which was always shown). For example, drivers were shown emergency electronic brake light (EEBL) warnings only if they were approaching a vehicle braking hard ahead. Only the V2V use cases of interest (i.e., EEBL and SSV) were tested in the simulated environment. Although, while driving, participants also experienced Road works warnings (RWWs) as well as a Back of queue (BoQ) warning at the entrance of the mortorway; no specific driving action was required regarding RWWs and BoQ warnings.

The main aims of the ICVP simulator studies were to:

(i) Determine participants' objective driving behaviour when presented with a warning message in these two types of critical situations relating to V2V communications; and

(ii) Understand participants' experiences using the connected vehicle technology (C-ITS).

For more information about the ICVP FOT and the subjective evaluation study findings see Pascale, M., Rodwell, D., Ho, B., Elrose, F., & Lewis, I. (2022). *Ipswich Connected Vehicle Pilot: Summary of the Subjective Evaluation Study Findings (MV32)*. Report prepared for the Queensland Department of Transport and Main Roads. Centre for Accident Research and Road Safety – Queensland, QUT, Brisbane, Australia.

STUDY METHODOLOGY

From the outset, it is noted that the design and methods of the ICVP simulator studies (and subsequent statistical analysis approach) were intended to replicate as much as was possible, the design and methods (and analysis) of the ICVP FOT. Thus, similar to the ICVP FOT including objective driving data as well as self-report user perception and experience data, the ICVP simulator studies featured both objective driving data (from the simulator) and subjective data (from a self-report questionnaire).

PARTICIPATION CRITERIA

To participate in the ICVP simulator studies, individuals were required to meet the participant criteria as shown in Table 2.

Table 2: Participant criteria

Participant criteria
☑ Hold a valid Queensland Provisional 2 or Open Driver Licence (or an Interstate or International equivalent)
☑ Are in sufficient good health to see the HMI device screen and hear the alerts (i.e., you are able to see what is on a standard mobile phone screen at arm's length)
☑ Are able to speak, read, and understand English
☑ Drive a minimum of 3 hours per week
☑ Are contable via mobile and/or email

BRIEF JUSTIFICATION OF PARTICIPATION CRITERIA

As previously noted, the ICVP simulator studies were to align as closely as possible with the design and methods of the ICVP FOT. While fewer participation criteria were specified for the simulator studies than the ICVP FOT, the criteria listed in Table 2 aligned with those from the FOT. The requirement to drive a minimum of 3 hours per week was specificied in the ICVP FOT to ensure sufficient data for analysis was collected. Although the ICVP FOT extended upon this criteria in terms of requiring participants to drive three hours per week within the designated pilot area (i.e., in and around Ipswich, Queensland), the simulator studies did not specify the location of participants' driving. In addition, although there were vehicle-related criteria for ICVP FOT participants, as driving simulator studies, ICVP simulator participants did not need to meet vehicle-related criteria.

ICVP FOT participants or those who underwent training in relation to the ICVP but who did not continue on with participation in the FOT for whatever reason were unable to participate in the ICVP simulator studies. This was set as an exclusionary criterion given that individuals who had undergone training from the FOT were already aware of various use cases and the intent was to hold constant the training information that was provided about the use cases to the ICVP simulator study participants.

For their participation, participants were offered a $50 shopping e-voucher or, if they were undergraduate psychology students at QUT, could choose to receive partial course credit. Participants who were unable to complete the testing session for whatever reason (e.g., who were unable to continue due to experiencing simulator sickness), received a $10 shopping e-voucher to thank them for their time.

ICVP SIMULATOR STUDIES – EEBL AND SSV: STUDY METHODS AND DESIGN

In the driving simulator, participants were exposed to the V2V functions (i.e., EEBL and SSV) in two separate studies; namely, Simluator Study – EEBL and Simulator Study - SSV. The study design for both simulator studies included objective driving data as well as self-report questionnaire data similar to the methodological approach implemented in the ICVP FOT. However, given that the simulator studies involved a one-off testing session with no follow-up or longitudinal data collection (i.e., the ICVP FOT extended over 9 months), the self-report questionnaire was administered to participants only once but at three time points in the simulator testing session; namely, pre-drive and pre-training (i.e., training regarding the use cases), pre-drive and post-training, and then post-drive and post-training. Figure 2 shows the procedure of the simulator studies from participant arrival and consent procedures through to completion of their testing session with the post-driving questionnaire and debrief. The testing session, as shown in Figure 2, was approximately 90 minutes' duration for each participant.

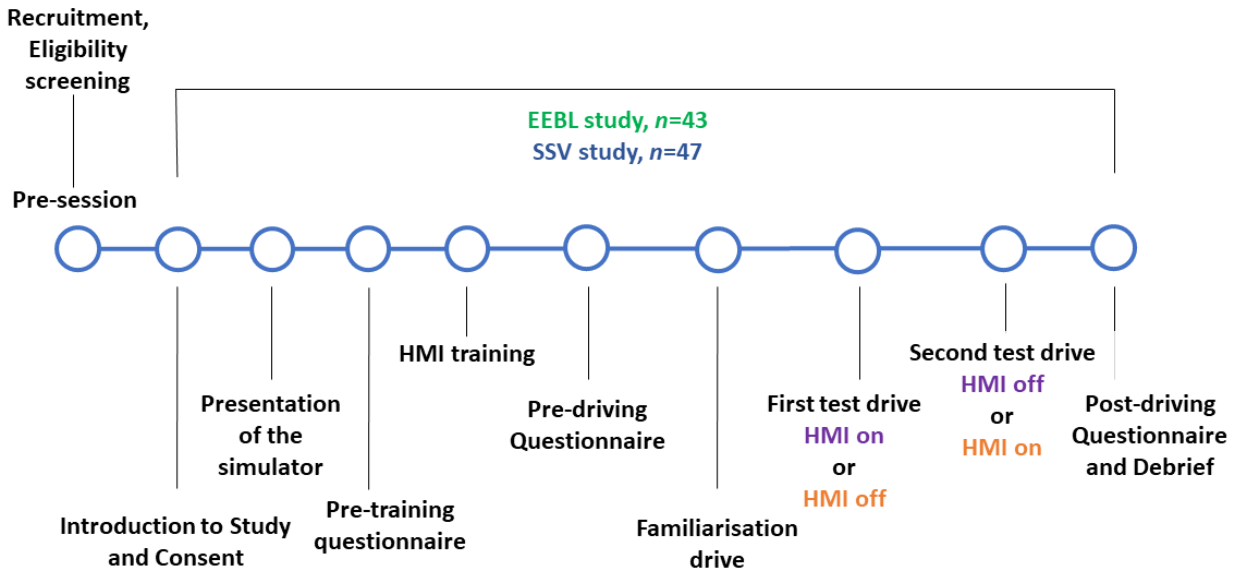

Figure 2. The design and methods used within the ICVP driving simulator studies.

ICVP SIMULATOR STUDIES PARTICIPANT SAMPLES

Simulator study 1 – EEBL. A total of 43 participants completed the driving simulation and the self-report questionnaire for the EEBL study. Most of the sample (see Figure 3) consisted of young to middle-aged drivers (mean age of 32.9 years, SD = 13.2 years) with diverse educations (majority had completed a university degree), diverse employment, some experience with advanced driving features in vehicles, such as navigation, blind-spot detection, speed warnings, and lane assist.

Simulator study 2 – SSV. A total of 47 participants completed the driving simulation and the self-report questionnaire for the SSV study. Most of the sample (see Figure 3) consisted of younger drivers compared to the EEBL study and the FOT (mean age of 25.7 years, SD = 10.7 years) with diverse educations (majority had completed a high school degree), diverse employment, some experience with advanced driving features in vehicles, such as navigation, blind-spot detection, speed warnings, and lane assist.

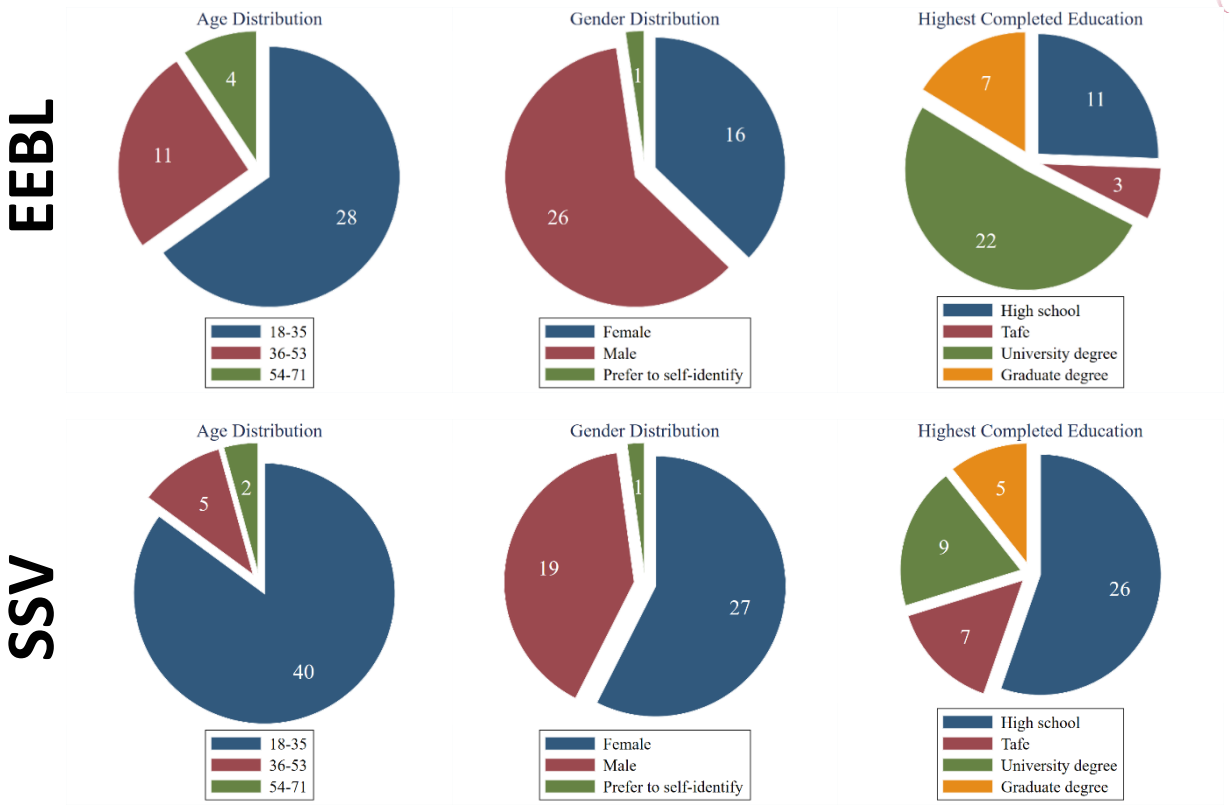

Figure 3. Snapshot of the demographics of the final sample of participants (first row: EEBL study; second row: SSV study).

ICVP SIMULATOR STUDY – EEBL FINDINGS

The key findings of the ICVP simulator study – EEBL were as follows:

(i) Regarding (simulated) driving behaviour, participants statistically significantly reduced their speed when they received the warning about the emergency braking event occurring in front of the vehicle. Their speed was 3.0 kph lower on arterial roads and 5.1 kph lower on motorways after the warning was displayed on the HMI.

(ii) Regarding user experience and participant perceptions as measured by the self-report questionnaire, overall participants reported favourably about all aspects of the C-ITS they experienced in the simulator. There were, however, some slight negative trends in ratings following their experience of the warnings when driving in the simulator. These negative trends were detected in relation to measures of perceived warning usefulness and warning timing, particularly for red (high-level) warnings and RWW. Table 3 provides the descriptive statistics (Means and (Standard Deviations)) based on participants' self-reported questionnaire responses relating to user perceptions of the C-ITS technology both pre- and post- simulator drive. Lines in bold show the largest differences, as reported by participants, between their pre- versus post-drive ratings.

(iii) Participants' perceptions of the C-ITS warnings corroborate the data provided by the ICVP FOT participants regarding a null or very slight negative trend in intention ratings and the usefulness of warnings after experiencing warnings on the HMI.

ICVP SIMULATOR STUDY – SSV FINDINGS

The key findings of the ICVP simulator study – SSV were as follows:

(i) Regarding (simulated) driving behaviour, participants statistically significantly reduced their speed when they received the warning about the slow or stopped vehicle ahead of the vehicle. Their speed was 2.4 kph lower on arterial roads and 4.0 kph lower on motorways after the warning was displayed.

(ii) Regarding user experience and participant peceptions as measured by the self-report questionnaire, participants reported favourably about almost all aspects of the C-ITS they experienced in the simulator, the only exclusions being in relation to ratings of warning inaccuracy and warning timing, as shown in Table 3.

(iii) For this use case, participants' perceptions of the C-ITS warnings corroborated the data provided by ICVP FOT participants in some instances but differed in others. Namely, a slight negative trend in ratings of intention, and the usefulness of warnings after experiencing warnings on the HMI, alongside positive ratings related to distraction and attention capture.

Table 3. Descriptive statistics (Means and (Standard Deviations)) from participants' self-reported questionnaire responses relating to user perceptions of the C-ITS technology both pre- and post- simulator drive.

	EEBL				SSV		
Construct	**Pre-drive**	**Post-drive**	**% Dif**		**Pre-drive**	**Post-drive**	**% Dif**
Bad/Good	81 (15)	81 (15)	-0.7		80 (17)	80 (15)	1.2
Useless/Useful	87 (12)	82 (14)	-6.2		84 (15)	81 (17)	-4.5
Undesirable/Desirable	77 (24)	72 (26)	-6.6		75 (24)	72 (25)	-4.0
Ineffective/Effective	82 (12)	82 (13)	-0.3		79 (18)	77 (17)	-1.7
Extremely Annoying/Not at all Annoying	68 (19)	74 (19)	8.7		63 (17)	67 (23)	7.4
Irritating/Likeable	70 (17)	75 (18)	6.1		69 (17)	70 (22)	1.9
Worthless/Assisting	83 (16)	79 (18)	-4.7		75 (25)	78 (20)	4.3
Improve driving performance	74 (22)	73 (22)	-1.6		**67 (24)**	**74 (17)**	**9.3**
Increase safety	80 (19)	81 (17)	0.7		73 (20)	78 (17)	6.4
Useful for driving	77 (19)	76 (22)	-0.1		73 (22)	76 (18)	3.7
Recommend to family,friends	69 (24)	71 (25)	2.9		68 (20)	73 (19)	6.7
Compatible with driving	**65 (24)**	**71 (24)**	**9.3**		**63 (24)**	**70 (20)**	**10.9**
Fits well with driving	68 (23)	71 (25)	5.0		65 (22)	70 (23)	7.7
Intend to purchase	72 (26)	69 (26)	-3.3		64 (27)	68 (24)	6.1
Intend to use (if installed in vehicle)	79 (22)	80 (21)	2.0		75 (18)	78 (19)	4.6
Driving safety (Not safe/Very safe)	77 (12)	75 (16)	2.3		79 (11)	75 (15)	-5.0
Slow down sooner	79 (14)	80 (16)	1.2		78 (16)	73 (21)	-6.3
Capture my attention	86 (13)	83 (18)	-3.3		79 (20)	84 (14)	6.3
Increase my awareness	87 (13)	84 (13)	-3.5		82 (14)	80 (18)	-1.5
Not distract me	69 (23)	72 (26)	5.2		**61 (25)**	**72 (25)**	**18.0**
Warnings clear and easily understood	81 (17)	82 (17)	2.0		84 (15)	87 (13)	3.4
Warnings contains enough info	80 (16)	83 (18)	3.4		80 (17)	83 (15)	3.4
Warnings inaccurate	68 (23)	69 (22)	1.0		**74 (21)**	**66 (26)**	**-10.7**
Warnings understood after rapid glance	**74 (23)**	**82 (20)**	**9.7**		**74 (19)**	**86 (15)**	**16.6**
Yellow warnings (Not useful/Very useful)	75 (12)	71 (19)	-4.8		75 (18)	77 (19)	2.5
Yellow warnings (Too early/Too Late)	50 (7)	49 (15)	-1.4		53 (11)	54 (14)	2.8
Red warnings (Not useful/Very useful)	**84 (16)**	**77 (21)**	**-9.3**		**82 (16)**	**70 (25)**	**-14.5**
Red warnings (Too early/Too Late)	60 (15)	55 (19)	-8.3		60 (17)	60 (14)	-1.3
EEBL (Not useful/Very useful)	80 (19)	79 (19)	-0.4		**80 (18)**	**72 (24)**	**-9.0**
BOQ (Not useful/Very useful)	**77 (20)**	**69 (27)**	**-10.0**		69 (24)	70 (23)	1.1
RWW (Not useful/Very useful)	**65 (24)**	**54 (31)**	**-16.9**		**68 (23)**	**58 (31)**	**-14.8**
SSV (Not useful/Very useful)	79 (17)	76 (19)	-4.9		78 (17)	77 (20)	-1.2
IVS (Not useful/Very useful)	87 (15)	92 (12)	5.6		87 (18)	87 (20)	0.3

Notes: Each contsruct was rated from 0 (e.g. 'Bad') to 100 (e.g. 'Good') or from Disagree (0) to Agree (100). Lines depicted in bold text show the largest differences reported between pre- versus post-drive ratings. EEBL = Electronic Emergency Brake Light. SSV = Slow/stopped vehicle.

SUMMARY OF FINDINGS FROM THE ICVP SIMULATOR STUDIES

Overall, the findings from the ICVP simulator studies complement the picture provided by the ICVP FOT participants. Similar to the ICVP FOT, the simulator studies offered insights into the C-ITS technology not only through assessment of user experience via a self-report questionnaire (see Table 3) but, also safety performance via behaviour assessed within the driving simulator. However, unlike the FOT, the simulator studies provided insight into warnings relating to communication between vehicles or V2V use cases; namely, Electronic emergency brake light (EEBL) and Slow/stopped vehicle (SSV).

Overall, findings across the two simulator studies suggested that participants reduced their speed when presented with a warning in an emergency, and were generally positive towards the C-ITS technology. The key findings emerging from the ICVP simulator studies for both the EEBL and SSV warnings were as follows:

(i) Safety performance measures indicated that acceleration and deceleration behaviours were not as smooth as when the HMI was off, suggesting that participants reacted to the warning at a moment when they had not yet identified the risk when driving without the assistance of the HMI.

(ii) It was not possible to evaluate the effects of the HMI on the likelihood of near-collisions as none occurred in the simulator.

(iii) Participant ratings of the usefulness of warnings that were experienced falsely was lower after the simulated drive possibly due to the warnings perceived as having limited relevance in the driving task ('false alarms'), and therefore not requiring a behavioural response from the participant.

(iv) When considered all together, and similar to the ICVP FOT, the self-report findings support positive attitudes towards C-ITS, however, the current implementation may not have met participants' expectations, as indicated by small but consistent decreases in many of the measures.

CONCLUDING REMARKS

At the time it was being conducted, the ICVP FOT represented Australia's largest on-road trial of C-ITS. The ICVP simulator studies of Emergency electronic brake light (EEBL) and Slow/stopped vehicle (SSV) warnings represented an important complement to the overall ICVP in enabling testing of use cases relating to communication between vehicles.

In conclusion, the findings suggest that ICVP simulator study participants had increased awareness of their surroundings and slowed down earlier with the C-ITS warning (than when it was absent) when approaching an emergency situation such as an emergency braking or a slow stopped vehicle. Despite participants not always perceiving that the system contributed to behaviour change or increased safety, their driving behaviour suggests that the C-ITS warning would benefit safety in relation to the two V2V use cases investigated. The findings of the ICVP simulator studies corroborate findings from the ICVP FOT in that, when considered overall, the findings support participants' positive attitudes towards C-ITS; however, the current implementation may not have met participants' expectations, as indicated by small but consistent decreases in many of the self-report measures.