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# Connected Vehicle Training Framework and Lessons Learned to Improve Safety of Highway Patrol Troopers

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**Abstract**
The Wyoming Highway Patrol (WHP) investigates more than 7,000 vehicle crashes yearly, often as first-hand responders. They often drive at high speeds through difficult road/weather conditions and under enormous secondary workloads, leading to an increased risk of crash. Connected vehicle (CV) technology can communicate timely road and traveler information messages (TIMs) to troopers, which could significantly reduce the frequency, severity, or both, of these crashes. The majority of the troopers, however, might not be familiar with driving a CV. This paper developed a "first responder-specific" training program on safe interaction with the technology and an in-depth assessment of how these new technologies are perceived by the troopers. The training program contains an E-training module and a hands-on driving simulator training module. The E-training presents concept of various CV warnings and notifications, including forward collision warning (FCW), spot weather warnings, work zone warnings, and other TIMs. Two scenarios were developed to familiarize troopers to simulated driving, two single-alert scenarios to help mastering the two most important warnings (FCW and variable speed limit), and two multiple-alert scenarios to train the troopers to drive in a comprehensive connected environment. A quiz section in the E-training module and comprehensive pre- and post-training questionnaire surveys were performed to evaluate the effectiveness of the developed CV training program. According to the trainees from the WHP, the driving simulator provided impressively realistic real-life-like scenarios for the troopers to practice the CV warnings they learned during the E-training.

Incidents related to transportation and motor vehicle crashes are the leading cause of fatal occupational crashes, according to a national census (*1*). Many studies have been conducted to help reduce the frequency, severity, or both, of motor vehicle crashes. However, little to no study has been done to protect law enforcement officers (LEOs) who spend a great deal of time behind the wheel to protect and assist the general public. The complex environment inside the cab, requirement to drive under inclement road and weather conditions, driving at high speeds, and driving under enormous mental workload often result in law enforcement vehicle crashes (*2, 3*). Connected vehicle (CV) technology is expected to enhance traffic safety and operations by providing drivers with timely information of incoming hazardous conditions, and will eventually bring about other environmental and economic benefits. Communicating such information would increase drivers' expectancy of encountered danger, which positively affects their driving behavior and reactions. However, the benefits of this emerging technology cannot be realized without proper understanding of its capabilities and limitations.

Accurate data on the fatalities and injuries of LEOs resulting from roadway crashes is very hard to find. The Bureau of Labor Statistics estimates the number of police and sheriff patrol officers to be 661,330 as of May 2018 (*4*). The National Highway Traffic Safety and Administration in 2018 reported that, from 1980 to 2015, there were a total of 943 crashes involving 948 law enforcement vehicles that resulted in the death of 998 occupants (*3*). According to FBI's Law Enforcement Officers Killed and Assaulted (LEOKA) database, 26

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officers were killed in motor vehicle crashes in 2016, 35 in 2017, and 34 in 2018 in the U.S. (*5–7*).

Driving on the Interstate-80 (I-80) corridor in Wyoming can often be hazardous, with crash rates reaching up to 3 crashes per million vehicle miles traveled on some of the segments. The winter crash rate is found to be 3–5 times higher than the summer crash rate (*8*). Several studies showed that severe weather conditions are among the main factors increasing crash severity and frequency (*9–11*). These conditions not only affect public and commercial vehicles but also law enforcement vehicles, whose drivers often operate under heavy visual, mental, and cognitive workloads. Nearly 210 highway patrol troopers of Wyoming Highway Patrol (WHP) drive more than 5 million miles a year, patrolling along the 6,800-mi state highway system and attending around 7,000 crashes yearly (*12*).

To improve safety and mobility on the I-80 corridor, the U.S. Department of Transportation (U.S. DOT) has funded the Wyoming Department of Transportation (WYDOT) to deploy a Connected Vehicle Pilot Program. This CV pilot is expected to test, implement, and transfer the advanced CV technology from the research realm into operation. The pilot consists of installing 75 roadside units (RSUs) along the 402-mi corridor which will receive and broadcast safety-related messages via dedicated short-range communication (DSRC). The DSRC will leverage wireless vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. A total of 400 vehicles will be equipped with the CV technology initially, including 75 WHP vehicles (*13*).

Highway patrol troopers are often trained rigorously before they can work on the road. Almost all agencies provide an Emergency Vehicle Operation Course which trains the troopers in all aspects of emergency driving. Although the troopers are highly skilled drivers, the majority of the troopers might not be familiar with driving a CV (90% participants had not driven a CV as reported in the pre-survey). With this motivation, this paper develops a training program specific to highway patrol to provide an in-depth understanding of the CV applications, safe interaction with the CV technology, and its use in emergency situations (*14*).

## Literature Review

According to the LEOKA database, in 2018 alone, 51 LEOs suffered fatal crashes in the line of duty, out of which 34 were killed as a result of motor vehicle crashes. Of these 34 officers, nine were responding to emergencies, eight were patrolling, and four were engaged in high-speed vehicle pursuits (*7*). LEOs have several devices installed in their cab which demand a great deal of visual, mental, and cognitive load, leading to distracted driving (*15*). From 2010 to 2014, 1,021 crashes of emergency vehicles in Texas were attributed to officer distraction and inattention. Emergency vehicle crash reports in Minnesota from 2006 to 2010 show that 14% of crashes involved driver distraction. Of these crashes, 12% were because of distractions caused by in-vehicle technologies, and the use of the mobile data terminal (MDT) resulted in 7% of these crashes (*15*).

Noh led an extensive research effort analyzing the Fatality Analysis Reporting System (FARS) data for law enforcement vehicle crashes from 1980 to 2008 (*16*). The first harmful event data from 1980 to 2008 showed that "Collision with motor vehicle in-transport" accounted for 53% of crashes involving LEO fatalities in a passenger vehicle, the manner of collision being angled (55.4%), head-on crashes (27%), rear-end crashes (13%), and side-swipe crashes (5%) (*17*). Similarly, Wolfe et al. studied the characteristics of officer-involved vehicle collision in California (*18*). Some 35,840 vehicle collisions involving LEOs from 2000 to 2009 were studied. An average of 3,600 officer-involved collisions occurred each year in California. The results showed that rear-end collision were the most common and involved 30.4% of all the crashes studied (*18*). A similar study about LEO vehicle crashes in Florida examined 31,438 crashes that involved 33,639 law enforcement vehicles. Rear-end collision was found to be the most common, representing 16.2% of these law enforcement crashes (*19*).

The manner of these crashes shows that warning systems that alert drivers of impending hazardous situations might have helped in avoiding these crashes. Although the installation of conventional crash-avoidance systems such as cameras and sensors has certainly helped in reducing the number of crashes in police vehicles, they are still not significant enough (*20, 21*). The CV technology adds more to the currently available crash-avoidance systems. With DSRC system, which the CV technology uses, safety-related messages can be transmitted over a range of about 300 m. A true 360-degree coverage can be achieved, and this technology has the ability to connect vehicles around corners and is not restricted by line-of-sight limitations, unlike the cameras and sensors (*20*).

Real-time information can provide advanced warnings to drivers. Timely alerting of drivers can prevent hundreds of thousands of rear-end, work zone, and inclement weather-related crashes (*22–24*). Moreover, in a place like Wyoming, where the weather can be brutal with snow and ice conditions, reduced visibility, blowing snow, and high winds, CV technology can be very useful with its traveler information messages (TIMs) and basic safety messages (*25–27*).

Several studies have shown the significant benefits of CV technology in enhancing the traffic safety of drivers

(*28–34*). A study showed that traffic safety could be increased by providing the appropriate driving speed using CV technology (*35*). Providing the appropriate driving speed for the encountered conditions would lower the speed variation. Another study showed that work zone notifications would decrease the speed variation among drivers (*26*). In addition, the study showed that the forward collision warning (FCW) was useful in avoiding a rear-end crash.

The *Human Factors Design Guidelines for Driver–Vehicle Interfaces* suggests that any training on a driver support system should train the drivers to read and interpret the warning signs, provide instructions on appropriate response, and inform about any limitations in the system (*36*). The guideline also suggests that the effectiveness of training can be increased using a part-task approach or variable priority approach, in which different components of the system are focused on at different times (*37*). Payre et al. assessed the impact of an elaborated training on manual control recovery in an automated car. The results showed that training decreased response time, decreased the number of interactions with pedals, increased trust in automated driving, and also improved human–automation performance (*38*).

The *Law Enforcement Driver Training Reference Guide* suggests several instructional methodologies for training the drivers on different aspects of law enforcement driving. The methodology includes class lectures, slides, relevant videos, case studies, facts and statistics, and so forth. For hands-on training on emergency driving tasks, driving simulators are suggested as they provide realistic examples for training purpose (*39*). Many police driving agencies require officers to take a classroom course and a hands-on driving course. The classroom course is designed to give them knowledge and ideas about different aspects of law enforcement driving, whereas the hands-on driving is focused to implement the knowledge in the field (*40, 41*).

In summary, it was found that LEOs, because of the unique characteristics of their driving tasks, have been facing significantly higher crash risks in comparison with regular drivers, particularly when driving under adverse weather events. Previous research demonstrated that the emerging CV technology has the potential to enhance the traffic safety of drivers by providing them with real-time traffic and roadway basic safety messages; nevertheless, to date there is no such study that has focused on introducing CV technology to highway troopers. Also, there lacks a synthesis training program, such as the commonly used computer-based training, driving simulator training methodologies, or both, to deliver the CV technology to highway troopers. Because of the high workload of highway patrol drivers, and with consideration of the challenging mountainous freeway geometry and adverse weather events in Wyoming during winter, it is necessary to develop an effective training program to enhance highway patrol drivers' understanding of the emerging CV technology and make best use of it to reduce the risk of crashes.

## Training Methodology

Although the developed E-training and hands-on driving simulator training modules cannot fully replace training on actual law enforcement vehicles, they are regarded and have been approved by U.S. DOT FHWA, WYDOT, and the WHP as a safe and cost-effective method (*42–44*). Based on the state-of-the-practice review of post-license driver training, this research developed a CV training program that contains two major components: a computer-based E-learning module and a hands-on driving simulator training module. The E-training module aims at providing participants with an overview of the WYDOT CV Pilot development programs, the concept of the CV applications to be deployed, and videos or animations that show participants the appropriate responses to a received CV warning. Then, the hands-on driving simulator training module will provide participants with a simulated environment in which they can practice the CV warnings that they have learned during the E-training module.

The five-stage iterative training design model suggested by the U.S. DOT was used as shown in Figure 1. The framework of the entire training module is shown in Figure 2.

### *Ride-Along with the Wyoming Highway Patrol*

To understand and take a closer look at the complex driving environment and driving behavior of troopers, ride-alongs were performed with troopers of the WHP. Two shifts of ride-alongs were conducted by two researchers. Each ride-along lasted almost 3 h. Although previous studies have shown that the presence of a ride-along affects the normal driving of police officers (*45*), these ride-alongs were extremely helpful to get information about the driving behavior, driving requirements, and risks involved, which helped the development of a realistic framework of the training program. Before the ride-along, the researchers signed release and waiver of claims forms that contained detailed information about the anticipated risk that might result from the ride-along.

Before starting the ride-along, the officers provided information about the different devices equipped inside the patrol car. Once the ride-along started, the trooper scanned through hundreds of events that were displayed on his MDT screen. During the 3-h period of the first

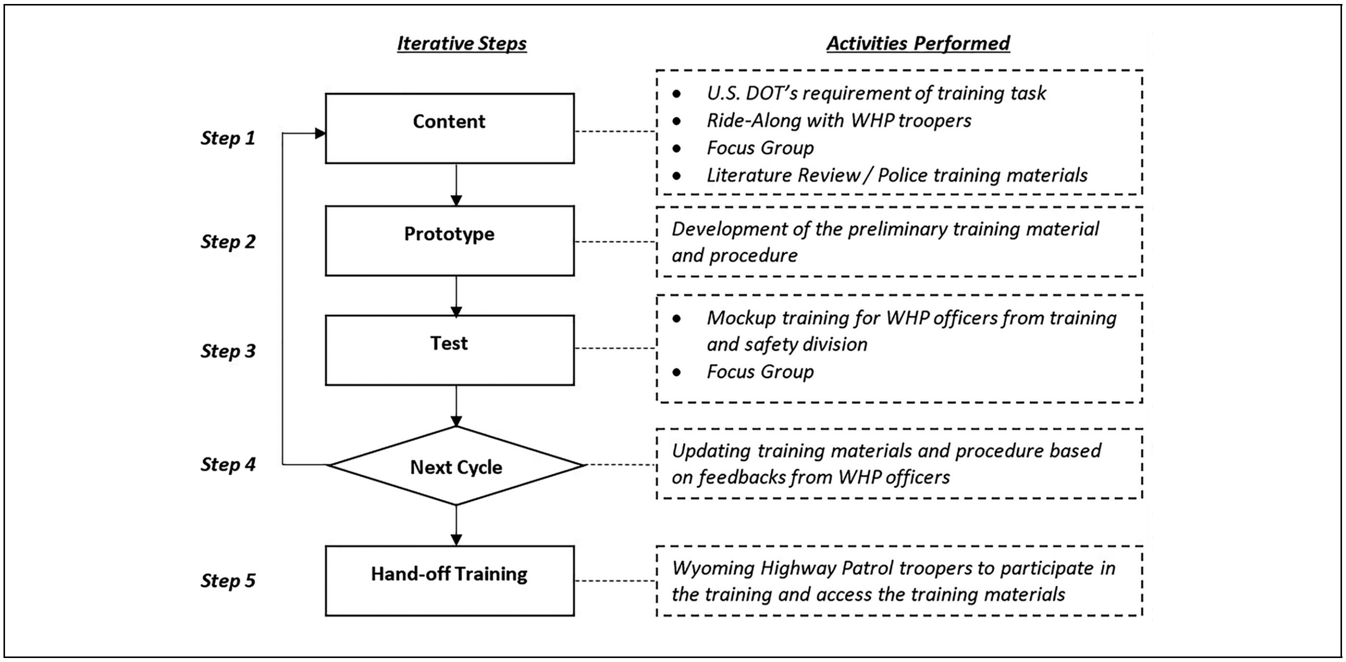



**Figure 1.** Simple 5-stage iterative training design model, adapted from Raddaoui et al. (27).
*Note*: WHP = Wyoming Highway Patrol.

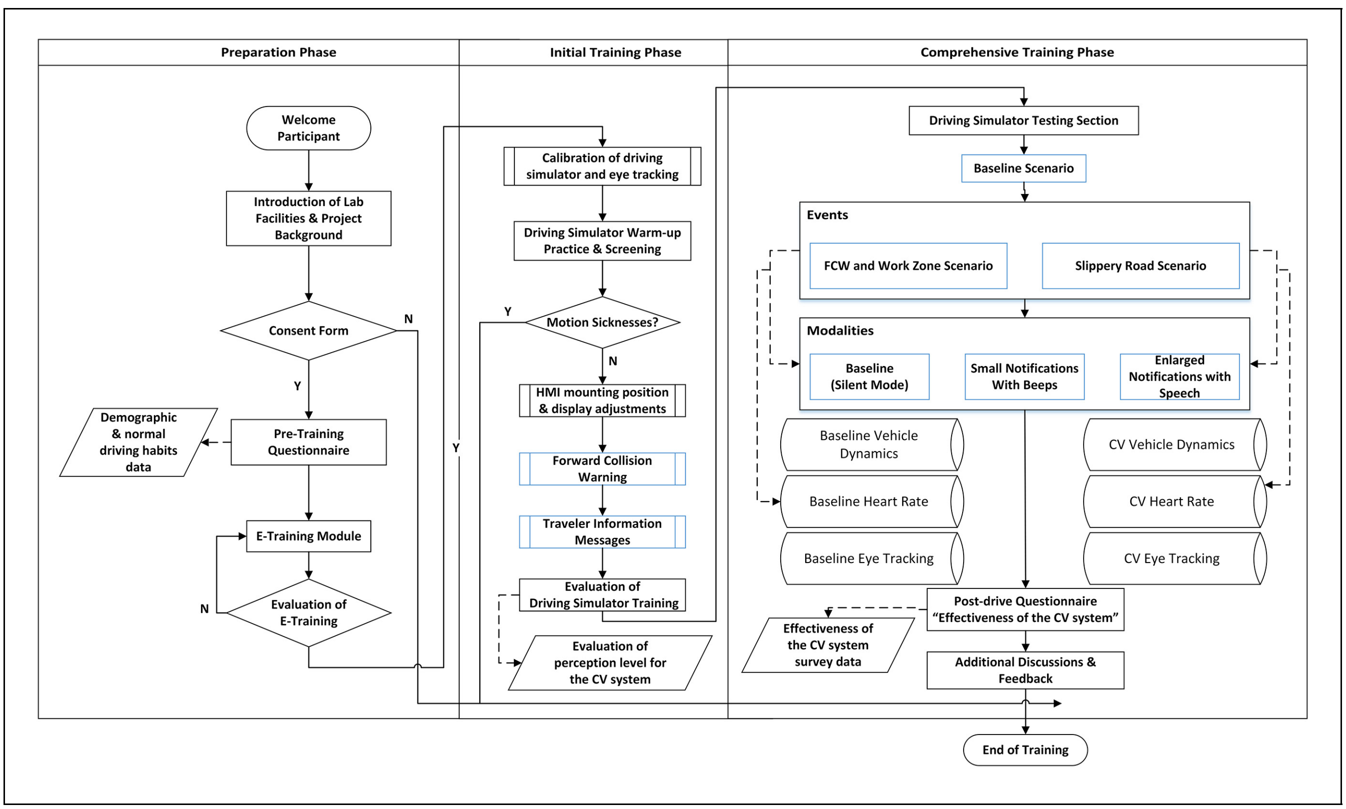



**Figure 2.** Flow chart of the developed Wyoming CV training framework for highway patrol.
*Note*: CV = connected vehicle; HMI = human–machine interface; FCW = forward collision warning.

ride-along, the trooper attended three events: two pull-overs and one crash. In both pull-overs, the officer drove at speeds much higher than posted speed to stop the violating vehicle. In one of the pull-overs, the speed of the patrol car reached over 130 mph. In the crash event, the trooper was assigned to two incidents at the same

**Table 1.** Summary of Activities Performed During an 18-Min (1080 s) Ride-Along Event

| Activities | Time (s) | % of Total time |
|---|---|---|
| MDT glance | 25 | 2.25 |
| Radio: listening | 40 | 3.60 |
| Radio: talking | 22 | 1.98 |
| MDT interaction (button press) | 2 | 0.18 |
| Cell phone interaction | 10 | 0.90 |
| Cell phone hands-free talk | 33 | 2.97 |
| Interacting with siren box | 335 | 30.18 |
| One-hand driving (including all activities that require a hand) | 630 | 56.76 |

*Note*: MDT = mobile data terminal.

time and had to make several calls via both radio and cell phone to figure out which incident the dispatch required him to respond to. He had to drive more than 38 mi to reach the incident scene, a journey that was completed in 18 min. For the majority of the time, the speed of the patrol car was well over 120 mph; he was even speeding through work zones. Similarly, in the second ride-along, the trooper attended two events: a traffic-stop and possible suicide attempt scene. As this was an emergency case, he was also speeding throughout the route to reach the incident scene on time.

Table 1 summarizes all the activities the trooper performed in the 18-min ride to the crash scene in the first ride-along. The most distractive and frequently performed events were observed to be radio/cell phone conversations, interaction with siren box, and glancing at the MDT. Even at such high speed, the trooper was observed to be driving one-handed most of the time (56.76%). Interaction with the siren box was observed to be one of the secondary tasks performed by the trooper while responding to a dispatched incident. Once information about an incident is received, the trooper turns the lights on. Siren sound was not triggered until a distant vehicle blocking the trooper's lane was observed. In addition, participants had their hands on the siren box for an extended duration of time to be able to manually alter the tone of the siren to alert drivers to clear the lane.

## *Mockup Training and Focus Group Review*

Before the comprehensive driving simulator experiment, WHP officers from the Safety Education and Training divisions were invited to test the entire experimental setup. Some important feedback was obtained during the focus group review. Some feedback obtained from the focus group review was:

- As the police cab is already crowded with a lot of in-vehicle devices, a small 5.5-in. screen shall be used as the human–machine interface (HMI) and it shall be mounted on the center console just beside the dashboard. The WYDOT CV Pilot Program is utilizing a 10-in. tablet for other vehicle types.
- The scenarios shall be made more difficult with higher visual/cognitive workloads. The scenarios shall include realistic events such as crashes or high-speed pursuits.
- All scenarios shall be designed to accommodate high-speed driving.
- The car cab shall be made more realistic and shall include the most frequently used in-vehicle devices such as MDT, radio, and siren, and so forth. Tasks related to these devices shall be included in the scenarios.
- The E-training module shall include a section to train troopers on the use of CV technology while in emergency situations.

After the focus group review, the scenarios were modified, and the issues were accounted for in the design of scenarios.

## *E-Training Module*

The E-training module included information about, followed by questions about, the introduction of CV technology and the Wyoming CV Pilot, different components of the CV system, the suite of the CV applications and notifications, and appropriate behaviors of drivers in response to notifications and warnings. This E-training module was an extension to the previously developed CV training program for truck drivers (*28*), but was modified to best suit the highway patrol troopers.

## *Overview*

The E-training module started with an official video of the Wyoming CV Pilot. This video introduced the Wyoming CV Pilot and provided information about the principle and technology involved, and described the importance of CV technology on I-80 corridor in Wyoming. It gave some statistics about adverse road/weather conditions and crashes occurring on this corridor. Moreover, this video summarized all the CV notifications and warnings that the troopers might receive while driving under different circumstances (*46*).

Different sections of E-training module are described under the headings below.

### Human–Machine Interface

HMI is a key component of the WYDOT CV technology. All messages to be delivered to drivers are provided via an HMI. The E-training module provided an introduction of the HMI and described the available customizations. The layout of the CV app was presented with all possible warnings/notifications. The troopers were urged to keep their eyes on road at all times and not to interact with the HMI while driving. They were also informed that the CV app only provides timely notifications and warnings about upcoming hazards and road/weather conditions, and does not take control of the vehicle or affect the driving in any way.

### Vehicles Equipped with CV System in Wyoming CV Pilot

In this section, information about different vehicles equipped with CV technology was presented. The drivers need to understand that the CV system will only be available to selected users, and will work only within the 402 mi I-80 corridor in Wyoming. This training module emphasized that all WHP vehicles will not be equipped with CV technology and the notifications will be received only if the other vehicle is connected as well.

### Description of CV Warnings/Notifications

In this section, the layout of the CV application was described, as shown in Figure 3. The training aimed to educate troopers about priority levels of different warnings if multiple warnings are presented at once. Based on urgency, the warnings were classified as: 1) FCW; 2) speed limits (variable speed limit [VSL] and advisory speed limit); 3) critical warnings (severe road/weather conditions, accident alerts, work zones); and 4) advisory warnings (weather alerts, TIMs). The messages on the left side of the HMI had higher importance.

CV warnings were classified into three groups: FCW, distress notification (DN), and TIMs. FCW alerts the driver of an impending collision while driving. FCW has two notification levels: Cautionary FCW (cautions drivers with a yellow warning sign if the time to collision less than 10 s) and Alert FCW (alerts drivers with a red warning sign and loud continuous beeps if the time to collision is less than 5 s). In addition, the researchers developed an animation of a distracted trooper who escapes a rear-end collision with the help of FCW. This animation showed how FCW works in real life.

DN allows drivers to transmit and receive emergency messages about a distress situation or crash to other approaching vehicles as well as Wyoming CV system via RSUs. The training emphasized that as the distress notifications can be sent only by vehicles equipped with CV

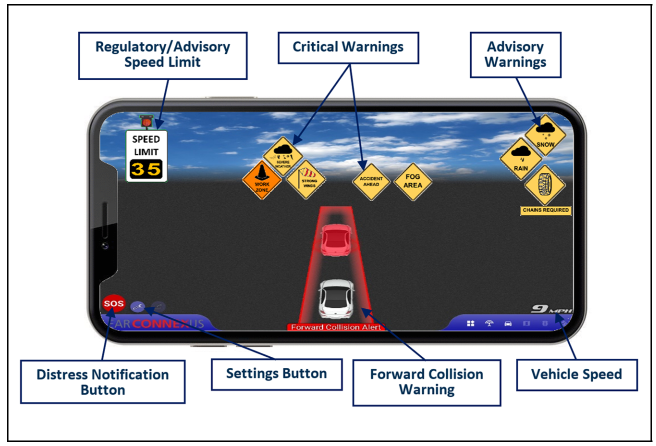



**Figure 3.** Layout of human–machine interface display.

system, the drivers need to be careful and look out for other distressed vehicles on the road.

TIMs are aimed to update drivers about any dangerous driving conditions that might be encountered and provide them with advisory notifications to eliminate these dangers. These messages appear with a beep sound or speech, depending on the modality chosen by the driver. The traveler messages include spot weather warnings (i.e., fog, severe weather, rain, snow, and strong wind), road surface conditions (i.e., icy, slick spots), work zone warnings (i.e., lane drops, speed limits, distance to work zone), speed limits (i.e., regulatory, advisory, and variable speed limits), and road closures and restrictions.

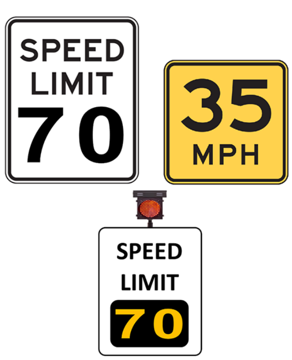
The E-training module was about 25–30 min long. Table 2 summarizes the details of each CV warnings developed for WHP troopers.

### Secondary Tasks and Distracted Driving

The nature of work often requires the troopers to perform secondary tasks. Although not advisable, they are often involved in performing tasks on the MDT, communicating with dispatch on their radio and cellphones, and driving one-handed. The troopers face additional stress from the noise of the siren, and pressure to arrest a suspect or reach a crash scene on time—often creating high cognitive workload and producing dangerous effects such as tunnel vision and adrenaline kick.

This E-training also included materials on the dangers of secondary tasks and distractions. MDT policies from different police agencies were reviewed and recommendations were made based on these policies (*47–49*). The training discouraged using any in-vehicle devices while the vehicle is in motion. However, if using the MDT becomes necessary, it was emphasized that the MDT should only be used for short transmissions and no

**Table 2.** Description of WYDOT Connected Vehicle Warnings and Appropriate Responses

| CV warning | Sign of warning | Messages delivered | Appropriate response |
|---|---|---|---|
| Forward collision warning (FCW) |  | Impending collision with a connected vehicle ahead in the same traffic lane and same travel direction.<br>Cautionary FCW(Yellow): $5\,s < TTC < 10\,s$<br>Alert FCW (Red): $TTC < 5\,s$ | Immediate braking to avoid rear ending the vehicle in front. |
| Distress notification |  | Distressed, stopped or slow-moving connected vehicle ahead. Pressing SOS button will send out a distress notification to other connected vehicles as well as Emergency Services and TMC. | Driver of distressed vehicle should press the SOS button and move the vehicle out of the travel lane if possible. Other CV drivers should drive with extreme care. |
| Adverse weather notifications |  | Warnings to notify drivers about spot weather conditions such as fog area, strong winds, rain, snow, and severe weather. | Keep the vehicle on right lane without overtaking any leading vehicle. Reduce speed and drive with extreme caution. Turn on the hazards lights if the visibility becomes low. |
| Road surface notifications |  | Notify drivers of the expected road surface conditions such as icy surface and slick spots. | Reduce speed and keep the vehicle on right lane without overtaking the leading vehicle. |
| Road closures and restrictions |  | Accident ahead: Any crash that has been detected and will be encountered ahead while driving.<br>Road closure: Road closure because of road damage or severe weather condition. | Accident ahead: Reduce speed and drive with extreme caution<br>Road closure: Rerouting or canceling the trip. |
| Work zones |  | Details about any upcoming work zones. Includes information about distance till the start of work zone, speed limits, lane drops, and end of work zone. | Prepare to slow down, change lanes if required, and watch out for any construction workers around. |
| Speed limits |  | Regulatory speed limits: Enforceable by law.<br>Variable speed limit (VSL): Enforceable by law.<br>Advisory speed limits: Non-regulatory but inform drivers of a safe driving speed. | Regulatory and VSLs should always be followed no matter what.<br>Advisory speed limits should be followed as far as possible. |

*Note*: CV = connected vehicle; TTC = Time-To-Collision; TMC = Traffic Management Center.

**Figure 4.** Troopers taking E-training and hands-on driving simulator training at University of Wyoming WyoSafeSim Lab.

glances off road should be greater than 2 s. The priority levels of different CV warnings were reiterated in this section. Troopers were instructed to follow urgent CV warnings such as FCW immediately, but to wait until it is safe to look at the HMI in the case of other CV warnings. To remove any distractions, the troopers were advised to take short intermittent glances rather than a long one if understanding the messages is difficult.

## *Hands-On Driving Simulator Training*

*Apparatus.* The driving simulator used was a high-fidelity open cockpit cab passenger car modeled after a Ford Fusion as shown in Figure 1. It was mounted on a D-Box motion-cueing system which provided two rotational and one translational degrees of freedom (roll, pitch, and heave). These motion cues created a close to realistic driving experience with kinematic changes in velocity and acceleration. Engine and road vibrations were provided with a vibration transducer mounted on the vehicle floor. The open source software allowed development of scenarios to replicate actual environments that the troopers face in their day-to-day work. In addition, a SimObserver system was fitted to capture high-definition videos of the entire experiment, and smart eye-tracking systems and heart rate sensors were set up to allow for further analysis of the performance of the drivers. A 5.5-in. HMI screen was mounted on the center console just beside the dashboard.

In addition, the most frequently used in-vehicle devices—MDT and radio scanner—were installed into the simulator (*15, 50*) (Figure 4). The MDT software was developed to mimic the software used by the WHP. The radio scanner was mounted on the center console. As the LEOs have their own lingo, jargons, and ten-codes, the transcript had to be developed by listening to several real-life conversations between a dispatcher and on-duty officers obtained from the WHP; the voice-over of dispatch recordings was performed by a professional radio presenter. The siren on/off system was embedded into one of the buttons on the steering wheel similar to a trooper's car.

## *Development of Driving Simulator Training*

The driving simulator training included three phases: preparation phase, initial training phase, and a comprehensive training phase (Figure 2).

*Preparation Phase.* Before the driving simulator training, the troopers were asked to review and sign a consent form which informed them about the research and risks involved in the research (motion sickness). Once they signed the consent form, they were asked to drive a non-CV warm-up scenario to be comfortable with the driving simulator vehicle kinematics. The warm-up session lasted for about 10 min; however, additional time was provided if needed. Anybody who felt motion sick while driving the simulator was allowed to quit the experiment.

*Initial Training Phase.* Two mini-scenarios with single CV application were developed for the initial training phase: the forward collision warning (FCW) scenario and the variable speed limit (VSL) scenario. The troopers frequently perform high-speed driving, lane changing/ overtaking, and tailgating, and perform multiple secondary tasks. Thus, speed limits and FCWs are among the most important warnings for troopers.

The driving simulator training on FCW was intended to provide hands-on driving experience to the troopers in a CV scenario with imminent collision. The trooper was asked to stay on the right lane throughout the training. On reaching normal driving speed a fog was gradually introduced, reducing the visibility to about 260 ft. A slow-moving truck was designed to appear from the fog in front of the simulator vehicle and make sudden unexpected stops. As the simulator vehicle came close to the truck, FCWs (cautionary and alert) were presented. To make sure that the warnings are triggered at exact times, a dynamic sensor was developed by combining time sensor, proximity sensor, and Time-To-Collision (TTC) sensor within the open source simulator software. The truck stopped several times during the scenario, thus providing enough chances for the driver to understand FCW.

The VSL scenario started with a snowy layout. The initial speed limit was 75 mph and as the participants drove down the corridor, beep sounds with changing speed limits were presented. Further downstream, visibility was reduced with thick fog conditions, and weather-related notifications were presented. This scenario aimed to train drivers to understand the use of CV VSLs under inclement weather conditions.

*Comprehensive Training Phase.* The testbed was developed to mimic the roadway, ambient traffic, environment, and weather conditions of I-80 corridor in Wyoming. After reviewing case studies of pursuits and crashes of the WHP (*51*) as well as the focus group review, it was decided that the scenarios must feature snowy and foggy weather, slippery road surfaces, and work zones.

First, the participants were asked to drive a baseline non-CV scenario, a four-lane freeway with clear road and weather conditions, to collect their driving behaviors. The layout of the work zone was developed in accordance with MUTCD and the Wyoming Traffic Control for Roadway Work Operations' guidelines (*52, 53*). Once the work zone ended, the speed limit went back to 75 mph and the crash scene appeared soon after that.

Next, the participants were trained on different CV applications using two comprehensive simulation scenarios. The first scenario trained participants to drive through a slippery road section under adverse weather condition and educated them to take advantage of different CV advisory speed limits. The second scenario, which was a work zone scenario with FCW in dense fog, trained participants to use the CV systems' work zone alerts and FCW alert to avoid a potential collision under adverse weather with low visibility. Each participant drove each of the scenarios four times to train on four different modalities: baseline with HMI deactivated (non-CV scenario), small sized CV notifications with beeps, enlarged CV notifications with speech, and enlarged CV notifications with beeps. To remove any learning effect, the scenarios were randomized. For each scenario, the roadway was a four-lane divided freeway segment with two lanes in each direction and with the base speed limit of 75 mph.

Figure 5*a* shows the layout of the slippery road scenario. For baseline, no CV warnings were played. The scenario started with snowy weather conditions. Within the first 600 m, the dispatch asked the participants to report the road and weather condition and their location. To replicate noises inside a police cab, random radio conversations between other trooper units obtained from the WHP were played. About 2,500 m from the start point, the dispatcher dispatched the participants to a crash scene at a certain milepost. This event popped-up on the MDT screen and the participants had to dispatch themselves to the event (clicking a button), change the status to "En-route" (clicking a button), and turn on the siren (clicking a button on steering wheel). At 11,125 m downstream of the start point, they approached another curve with ice patches and slippery road. In the middle of this curve, the participants were asked to solve a mathematical equation with a series of numbers and operators with a 2 s gap between each number. This mathematical equation task was included to simulate the intense cellular/radio conversations and high level of cognitive workload that highway patrol troopers perform during emergency situations (*54, 55*). The scenario ended when the participants reached the crash scene (14,210 m from start point). Once the baseline scenario was completed, they drove similar scenarios but with HMI activated. The CV warnings were provided based on respective modality (speech or beeps with small or enlarged icons). For every modality, the language of dispatch recording and the math equations were changed to remove any learning effect. The first CV warning provided participants with a CV advisory speed limit of 65 mph which played at 8,630 m front start point. At 9,820 m, the second CV warning warned participants to be aware of the ice patches ahead. Finally, at 10,695 m, just before the icy curve starts, an advisory speed limit of 55 mph alerted drivers to drive slow and carefully through the icy road.

The second scenario (training for work zone warnings and FCW applications) started with clear road and weather conditions with a far fog. Similar to the first scenario, the dispatch first asked participants to report road and weather conditions and location. About 5,600 m downstream of the start point, they were dispatched to a crash scene. The participants had to acknowledge the event on MDT, change the status to "En-route," and turn on the siren. Within the next 400 m, fog was gradually introduced. At 6,850 m from the start point, the participants were asked to provide answer to a mathematical equation. A work zone was placed at 8,075 m from start point. The work zone included an advance warning area (8,075–10,045 m), transition area (10,045–10,215 m), and activity area (starting from 10,215 m). As the participant

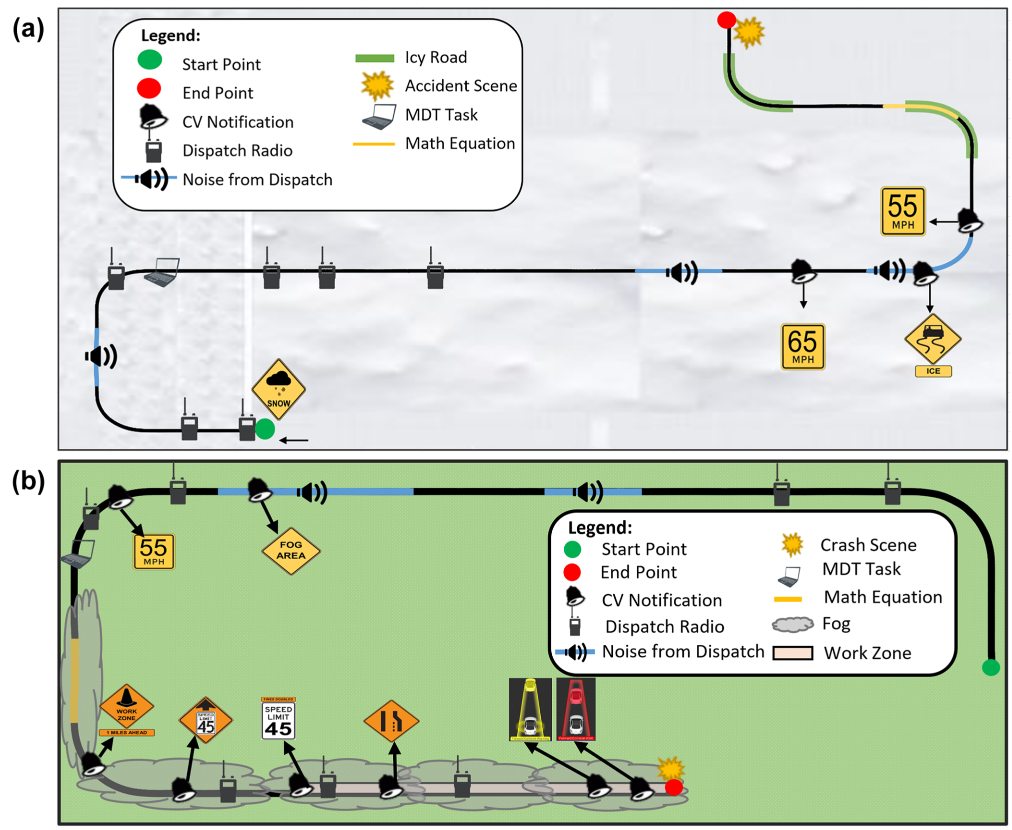



**Figure 5.** Depiction of the comprehensive driving simulator training scenarios: (*a*) slippery road with CV speed limits and (*b*) work zone with FCW in fog.
*Note*: CV = connected vehicle; MDT = mobile data terminal; FCW = forward collision warning.

drove through the work zone, a crash suddenly appeared from fog and the scenario ended. For other scenarios, CV warnings were presented based on their respective modality. The first CV warning was a "Fog Area Ahead" (5,220 m from start point) warning which alerted participants of the fog and low visibility ahead. At 6,040 m, before the fog starts, a 55 mph CV advisory speed limit was presented. One mile before the work zone started, a "Work Zone 1 mi ahead" CV warning was presented, which was followed by several work zone related CV warnings: "Speed Limit 45 mph Ahead," "Speed Limit 45 mph," and "Right Lane Closed." Once the participant came close to the vehicle pileup, advisory and imminent alert FCWs were displayed successively on the HMI alerting the drivers to brake quickly to avoid a forward collision.

### *Evaluation of the Training Program Participants*

All WHP troopers were invited to take this training program. The total number of police troopers that covers over 6,800 mi of state highways in Wyoming is 210. It was a daunting task to recruit and schedule highway troopers' hands-on training because of their busy schedule. The invited police troopers are assigned to different sections on I-80. Some troopers had to travel for more than 7 h (back and forth) to receive the training. In addition, several cancelations took place because of adverse weather conditions or occurrence of an incident that they had to respond to. However, the feedback from the hands-on training will be crucial for the development of a successful online training. At the time of writing, 10 WHP troopers have taken the training. The participating troopers were all males, with age ranging from 26 to 60 years. The troopers had been working for an average of 7.8 years for WHP (minimum 1 year and maximum 23 years). They reported their average annual mileage over the past 5 years to be over 30,000 mi. All the participating troopers said they performed secondary tasks of talking on radio, scanning road traffic condition, and using MDT while driving. All of them reported to be using I-80 corridor more than four times a week, with each trip being an average of 200 mi. All the participants reported that they had encountered reduction in visibility because of snow, blizzards, fog, smoke, or heavy rain while driving on the I-80 corridor. Two of the troopers reported that they had been involved in a crash on I-80 while on duty. One of the crashes was during inclement weather condition and resulted in personal injury.

### Evaluation of E-Training

The E-training module was developed in an "information-followed by-quiz" format. The quiz aimed to evaluate the understanding of the CV system and measure the effectiveness of the training program. The quiz contained a total of 25 single-choice questions covering all the topics of the E-training module. The participants had an average score of 85.2 (score range from 72 to 96). The summary of the quiz is shown in Table 3. Questions with low accuracy rates (less than 50%) were identified and were further explained to the troopers.

### Evaluation of Driving Simulator Training

To collect the troopers' opinion about the driving simulator training, a post-training questionnaire was developed. Different sections were focused on collecting opinions on different topics such as readability/display of CV notifications, usefulness, desirability and efficiency of CV applications, and others. The responses were collected based on a 7-point Likert scale (example: Not Useful at All to Extremely Useful). All the responses were later converted into a score of 1–7, where 1 means very low evaluation and 7 means very high evaluation.

On average, it was found that the troopers were positive about the developed training program. Nine out of 10 participants stated that the most effective training would be the combination of E-training and driving simulator training. They reported that in comparison with the E-training, the driving simulator training provided them with a more comprehensive knowledge about various CV applications (average score 5.7). On average, the troopers reported that the CV warnings displayed on the HMI were easy to understand (average score 6.2). Likewise, the troopers also evaluated specific CV notifications in relation to effectiveness, usefulness in the real world, and ease to understand. They voted an average of 5.3 for adverse weather notifications, 5.7 for FCW, 5.1 for road surface condition notifications, and 5.3 for work zone notifications.

Figure 6 shows the average speed profiles of all participants. The mean speed for the baseline (non-CV) scenario was higher and had higher fluctuations than the CV scenarios, as the participants did not know the safe speed limit. On average, the participants seemed to obey the CV warnings. However, as the troopers were speeding to attend the crash scene, they did not follow speed limits, as expected. Four participants slipped off the road in the slippery road non-CV scenario at Curve 4, whereas everyone made it safe to the crash scene in CV scenarios. In the work zone non-CV scenario, two participants met a crash and the rest of the participants braked very hard to avoid a collision, whereas everyone braked smoothly and safely when provided with FCW.

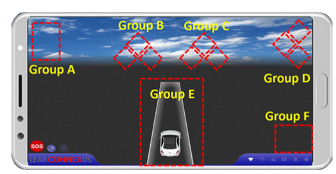
## Concluding Remarks and Lessons Learned

CV technology is rapidly developing and progressing from the research realm into real-life deployment. Thus, it is important for the end drivers to be trained on the technology before they start using it. As the driving conditions and driving behavior of the troopers is entirely different from normal drivers, it is essential to develop a training program specific to them. However, no training modules have yet been developed to train highway patrol troopers on the CV technology. The training program described in this paper is targeted at developing materials and methods to educate the highway patrol about the concept and applications of CV training, and also to train them using a hands-on driving simulator. In addition, the training program developed an assessment technique to not only evaluate how efficient the training is but also to help update the training materials in a more objective manner. The proposed training framework can be expanded to other emergency vehicles including fire trucks and ambulances. For instance, the E-training module is highly transferable to other response agencies, and the hands-on module also included customization of the CV applications as well as the size and modality for the HMI that can accommodate various users.

Throughout the development of this CV training program, the research team experienced unique challenges and learned valuable lessons that may be applicable to the development of other training programs for emergency responders. Some of the lessons learned are described below:

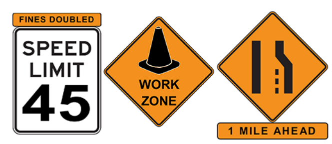
- The driving behavior and driving conditions of highway patrol troopers is very different from normal drivers. Thus, the training program needs to be designed and packaged specifically to the troopers.
- The troopers are highly skilled and confident about their driving skills. The scenarios had to be modified several times and the difficulty level had to be increased by several folds before they were deemed good enough for the troopers. Based on expert reviews by the WHP, it was decided that the scenarios should accommodate high-speed driving and include several secondary tasks.

**Table 3.** Summary of Connected Vehicle E-Learning Module Questions

| Q# | Description of question | Correct | Average score | Note |
|---|---|---|---|---|
| 1 | Which of the following communication technology is NOT used by connected vehicle system? | Send information to all the vehicles running on the freeway. | 100% | CV system sends and receives information to RSUs and other CVs only. |
| 2 | The FHWA/Wyoming DOT connected vehicle pilot project will be deployed on: | I-80 Corridor in Wyoming with a total of 402 mi. | 90% | |
| 3 | What is the purpose of connected vehicle technology in Wyoming Highway Patrol vehicles? | To increase safety and mobility by informing highway patrol about impending collision, weather conditions, and active work zones. | 90% | |
| 4 | Which of the following statements in relation to the connected vehicle system is correct? | Connected vehicle system aims to provide timely warnings and notifications about upcoming hazards and road conditions to drivers. | 100% | |
| 5 | Which of the following statements is NOT correct? | All the Wyoming Highway Patrol vehicles on I-80 will have the connected vehicle technology. | 80% | |
| 6 | How long will the warning be displayed on the screen? | The warning will be displayed on the screen until the event is over. | 100% | |
| 7 | The volume of notifications on your CV app should be adjusted before driving so that: | It is not masked by in-cab and siren noises; the beeps will not startle you while driving; you don't have to interact with the HMI while driving. | 60% | |
| 8 | How frequent should drivers look at the screen while driving? | Drivers can only look at screen when it is safe to do so. | 100% | |
| 9 | Click to select the following groups on the screen: | Answers were based on the CV warning locations illustrated in Figure. | 87.5% |   |
| 10 | Which of the following notifications has the highest priority when it appears on the screen simultaneously? Select its location in the display unit: (Figure same as above) | Forward collision warning | 95% | |
| 11 | Which of the following statements in relation to the forward collision warning (FCW) notification is NOT correct? | FCW notification will be displayed on the screen with a single beep sound to alert drivers of the forthcoming collision situation. | 80% | Continuous loud beeps will be played until the risk of having a crash is over. |
| 12 | When Forward Collision Warning appears on screen, what is the correct response that drivers should make? | Drivers need to brake immediately to avoid rear ending the leading vehicle. | 100% | |
| 13 | When you get a "Fog Area" notification, you should: | Keep the vehicle on the right lane without overtaking any leading vehicle; Reduce speed and drive with extreme caution; Turn on hazards lights. | 90% | |
| 14 | If you are driving on a highway in heavy rain, you must slow down your vehicle to avoid | Hydroplaning | 100% | |

*(continued)*

**Table 3.** (continued)

| Q# | Description of question | Correct | Average score | Note |
|---|---|---|---|---|
| 15 | When “Icy Road” notification appears on the screen, you should: | Reduce speed and keep the vehicle on the right lane without overtaking the leading vehicle. | 90% | |
| 16 | You are driving to attend a crash scene. On the way you hear beeps coming from the screen. What should be your reaction? | Drive with extreme caution as the road surface might have slippery spots and follow the recommended speed for your safety. | 87.5% |  |
| 17 | When “Road Closed” notification appears on the screen | Drivers should exit the road to a rest area or cancel the current trip. | 100% | |
| 18 | What should you do when the following notification appears on the screen? | Drivers should reduce speed and drive with extreme caution to avoid secondary crash. | 100% |  |
| 19 | When the following notifications appear on the screen, you should: | Be aware of the work zone warning and drive with extreme caution; change to (or keep driving on) the right lane when it is safe to do so; gradually reduce speed to 45 mph before entering the work zone. | 100% |  |
| 20 | What information should be placed under the work zone notification? | Distance till the work zone starts | 80% | |
| 21 | Which one of the following statements in relation to the advisory/regulatory variable speed limit notification is correct? | Advisory/regulatory variable speed limit notification aims to provide drivers advisory operating speed for the current road and weather conditions. | 70% | |
| 22 | While on a high-speed pursuit, the following notifications appear on the CV app. What should be your reaction to these notifications? | Reduce speed to match the advisory speed limit and drive with caution through the foggy area. | 44.4% |  |
| 23 | If it becomes necessary to perform a secondary task such as interacting with the MDT/ radio you should: | Not lose focus on primary driving task; Give high importance to CV warnings, especially FCW; Never take glances greater than 2 s off the road. | 89% | |
| 24 | If you hear loud continuous beeps while looking away from the road, what should you do first? | Quickly look ahead at the road and react appropriately. | 100% | |

(continued)

**Table 3.** (continued)

| Q# | Description of question | Correct | Average score | Note |
|---|---|---|---|---|
| 25 | What is the correct sequence of actions to be taken when the HMI beeps? Choose one from each of the pairs. | A. Look at the screen when it is safe to do so.<br>B. Scan through all the notifications on the screen.<br>C. Follow every mandatory as well as advisory warnings that are on the screen.<br>D. Take short intermittent glances rather than a long one if there are many warning messages. | 91.7% | |

*Note:* CV= Connected Vehicle; RSU=Roadside Unit; FHWA=Federal Highway Administration; DOT= Department of Transportation; MDT= Mobile Data Terminal; HMI= Human Machine Interface.

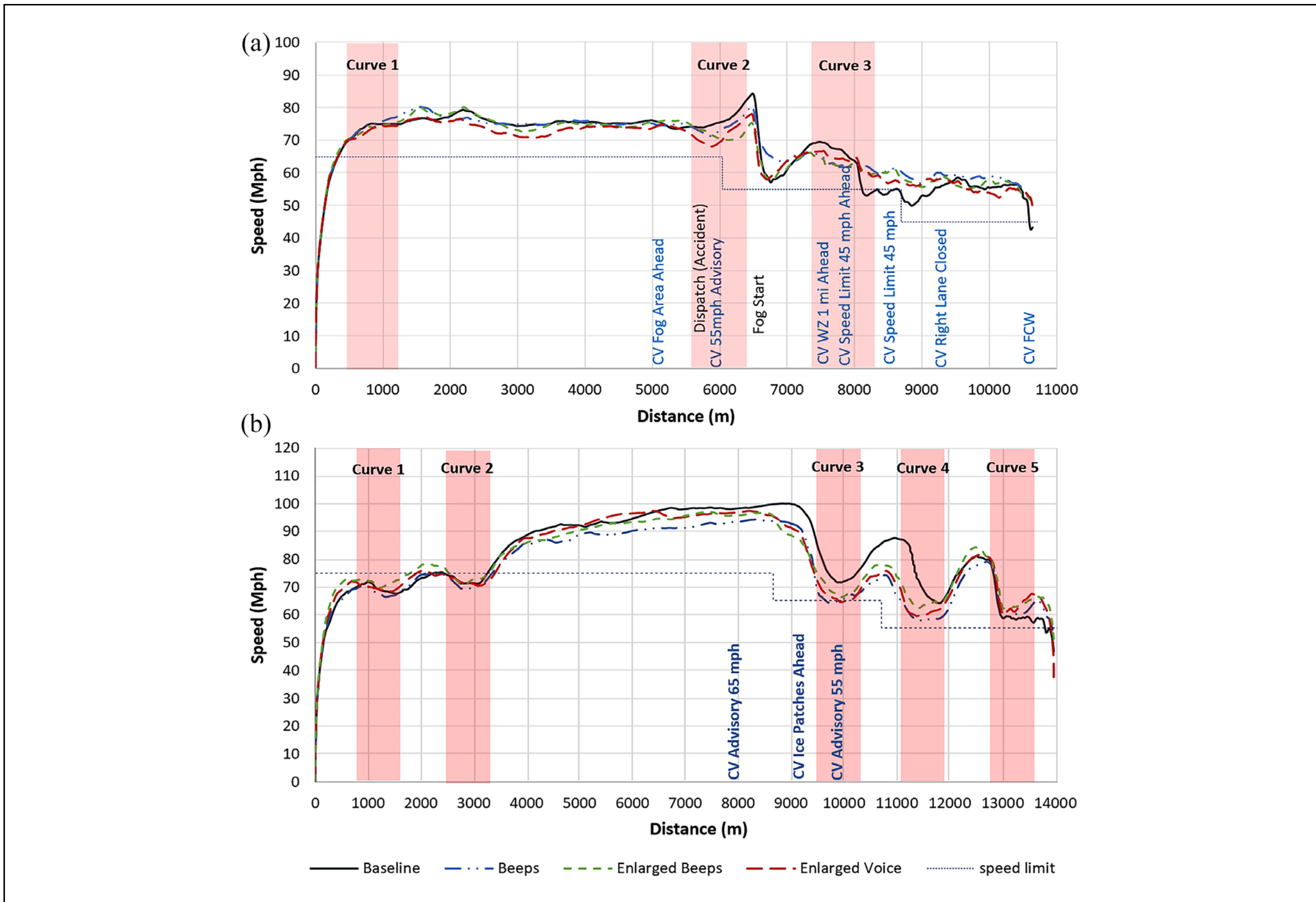



**Figure 6.** Speed profiles for (*a*) slippery road scenario and (*b*) work zone scenario.
*Note*: CV = connected vehicle; WZ = work zone; mobile data terminal; FCW = forward collision warning.

- The scenarios need to work perfectly without any glitches, as the troopers are highly demanding and their time is very valuable.
- As attending emergency events requires driving at high speeds, the troopers cannot be mandated to follow each and every regulatory and advisory

warning. Therefore, the contents of the training had to be prepared in such a way that the troopers understand the importance of these messages. The training instructs the troopers to quickly follow urgent warnings such as FCW and also to follow all other advisory warnings as far as possible, if not drive with extreme care when provided with these warnings.

- The training takes about 3 h to complete. Thus, it needs to be attractive and interactive to draw the participant's attention. Also, the training should use different training approaches such as a part-task approach or variable priority approach, in which different components of the system are focused on at different times. This approach was used to train the participants on important CV applications such as FCW and advisory speed limits.
- With the rapid development of vehicle and communication technologies, the training materials need to be kept updated to incorporate the evolving technologies and practices.

Future works will include developing an online training module for those troopers who may not be able to undertake hands-on training at the University of Wyoming WyoSafeSim lab. The link to the driving simulator training video is as follows: https://www.youtube.com/watch?v=JLaS-s1OvCI

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## Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: MA, SG, GY, BS; data collection: SG, BS; analysis and interpretation of results: BS, MA, SG; draft article preparation: BS, GY. All authors reviewed the results and approved the final version of the manuscript.

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