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Studying the impacts of Vehicle-to-Infrastructure (V2I) technologies on drivers' behaviors and traffic safety

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13. Abstract

Connected vehicle technology offers encouraging opportunities to enhance traffic operation, improve roadways safety and reduce traffic emissions and fuel consumption. It has been indicated that if drivers comply with suggested recommendations, connected vehicle technology (e.g., Vehicle-to-Infrastructure (V2I) technologies) can present enormous advantages. However, whether drivers will accept advisories/recommendations and what factors will influence their likelihood of accepting the suggestions in a connected environment have not been explicitly studied. Drivers' preference, opinion and attitude towards these advisories are also not yet known. This study aimed mainly to examine the impact of V2I technologies on drivers' behavior and traffic safety as well as drivers' preferences, opinions and needs toward these V2I technologies. To achieve these objectives a driving simulator experiment and a national survey study were employed. The driving simulation experiment was conducted by recruiting 42 drivers with valid drivers' license. Drivers' reaction and response towards heavy rain warning through audio warning, in-vehicle screen warning and Dynamic message sign (DMS) were evaluated through four scenarios consist of one base scenario and three scenarios with aforementioned three warnings. Speed change after the warning, response speed after warning, adopted speed during the rain, maximum acceleration and deceleration were selected as performance measures. Descriptive statistics showed less variability of the speed and acceleration after receiving the warnings. Average compliance rate was around 54% across the three scenarios with heavy rain warnings and audio warning was found to be effective in significantly reducing the speed during heavy rain. Moreover, this warning was also proved safer with lowest deceleration during rain. However, more experienced drivers had higher speed and younger drivers had higher acceleration. Additionally, 1571 responses were collected by a questionnaire survey to investigate drivers' opinion, preference and needs towards V2I advisories on work zone warning, curve speed warning, emergency vehicle warning, train approaching warning and adverse weather warning. Analysis of the responses revealed that around 85% of the respondents think these V2I advisories will either be important or extremely important to increase their safety while driving.

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Studying the impacts of Vehicle-to-Infrastructure (V2I) technologies on drivers' behaviors and traffic safety

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Abstract

Connected vehicle technology offers encouraging opportunities to enhance traffic operation, improve roadways safety and reduce traffic emissions and fuel consumption. It has been indicated that if drivers comply with suggested recommendations, connected vehicle technology (e.g., Vehicle-to-Infrastructure (V2I) technologies) can present enormous advantages. However, whether drivers will accept advisories/recommendations and what factors will influence their likelihood of accepting the suggestions in a connected environment have not been explicitly studied. Drivers' preference, opinion and attitude towards these advisories are also not yet known. This study aimed mainly to examine the impact of V2I technologies on drivers' behavior and traffic safety as well as drivers' preferences, opinions and needs toward these V2I technologies. To achieve these objectives a driving simulator experiment and a national survey study were employed. The driving simulation experiment was conducted by recruiting 42 drivers with valid drivers' license. Drivers' reaction and response towards heavy rain warning through audio warning, in-vehicle screen warning and Dynamic message sign (DMS) were evaluated through four scenarios consist of one base scenario and three scenarios with aforementioned three warnings. Speed change after the warning, response speed after warning, adopted speed during the rain, maximum acceleration and deceleration were selected as performance measures. Descriptive statistics showed less variability of the speed and acceleration after receiving the warnings. Average compliance rate was around 54% across the three scenarios with heavy rain warnings and audio warning was found to be effective in significantly reducing the speed during heavy rain. Moreover, this warning was also proved safer with lowest deceleration during rain. However, more experienced drivers had higher speed and younger drivers had higher acceleration. Additionally, 1571 responses were collected by a questionnaire survey to investigate drivers' opinion, preference and needs towards V2I advisories on work zone warning, curve speed warning, emergency vehicle warning, train approaching warning and adverse weather warning. Analysis of the responses revealed that around 85% of the respondents think these V2I advisories will either be important or extremely important to increase their safety while driving.

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Implementation Statement

The results of this research will pave the road for better implementation of V2I in region 6 and elsewhere. Specifically, the findings of this research will enable transportation authorities in Louisiana (e.g., Louisiana Department of Transportation and Development) and elsewhere to tailor their transportation policies and plans as well as technological developments to better implement V2I communications and highway facilities.

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Introduction

Connected vehicle technology increases the awareness of drivers by providing real time traffic information on different road condition, traffic condition, weather condition etc. Thus, it can enhance traffic safety by reducing the crash frequency as well as increase the capacity of roadway network by smoothening the traffic flow [1]. Though it might take several years to fully realize the benefits of emerging Connected vehicle technology, Vehicle-to-infrastructure (V2I), the next generation of Intelligent Transportation Systems (ITS) [2] might be beneficial in the meantime by providing safety related messages to the drivers [3].

V2I technology can collect data on weather advisories, traffic light, traffic congestion and then these data are transmitted by the roadside devices to the drivers so that they can be aware of the upcoming situations and take actions accordingly. According to the Department of Transportation (DOT), there might be substantial deployment of V2I in coming few decades [4]. As part of this deployment, necessary arrangement for V2I will possibly occur in integration of previously installed ITS equipment [5]. Therefore, it is critical to study the potential benefits of V2I technologies on traffic safety and operation**.**

Potential benefits of several V2I technologies have been investigated in the literature. For example, V2I communication was used to examine the effect of connectivity on non-signalized intersection control through traffic simulation and found out that average fuel consumption, average vehicle delays and average queue length will be reduced by providing V2I advisories [6]. Providing the drivers with warning about upcoming red light helped them to avoid hard braking during red light phase [7]. Zhang et al. used congestion warning to increase safety and reduce travel delay [8]. Several other V2I warning advisories have also been recently investigated by scholars such as work zone warning, curve speed warning, rail crossing warning, adverse weather warning, curve speed warning etc.

However, drivers' preferences, needs and opinion regarding the advisory messages provided through V2I technology and whether they are going to respond appropriately to the V2I advisory messages is not yet clear. Therefore, this study aims to investigate the effect of V2I messages on drivers' behavior and traffic safety by two methods – questionnaire survey and driving simulation experiment.

Literature Review

Overview of V2I

V2I is wireless communication system between vehicles and the infrastructure. It generates connectivity which enables exchanging information from vehicle to the roadway infrastructure or vice versa [9]. The system uses Dedicated Short-Range Communications (DSRC) protocols to exchange operational, safety, mobility, and environment related data via roadside-installed hardware.

Though the primary objective of V2I system is to lessen the severity of crashes, it can also contribute to transportation mobility and other environmental benefits through traffic optimization and speed harmonization. V2I system warning can be relayed both by driver-infrastructure interface (DII) and a driver-vehicle interface (DVI). DII refers to information platform which are external for the vehicles and accessible to multiple roadway users. Examples of DIIs are changeable message sign (CMS), traffic control devices (TCDs), Dynamic Message Sign (DMS), dynamic signals, blank-out signs, triggered beacons accompanying static signs etc. On the other hand, DVIs are in-vehicle displays such as head-up displays, auditory displays etc. It is available only to the targeted drivers [10].

The eight V2I safety applications which were identified by FHWA are Red Light Violation Warning (RLVW), Stop Sign Violation Warning (SSVW), Stop Sign Gap Assist (SSGA), Curve Speed Warning (CSW), Reduced Speed Zone Warning (RSZW), Railroad Crossing Violation Warning (RCVW), Oversize Vehicle Warning (OVW), and Spot Weather Information Warning (SWIW) [11].

These safety applications can be categorized as intersection applications, speed applications, vulnerable road users' applications and others. More elaborate subdivisions under these four categories are as follows [9].

Intersection applications

- Red light violation
- Stop sign violation.
- Gap assistance at signalized intersections.
- Gap assistance at stop-controlled intersections.

Speed applications

- Curve speed warning.

- School zone speed warning.
- Work zone warning for reduced speed in work zones.
- Spot treatment/weather conditions.
- Speed zone warning.

Vulnerable road user applications

- Work zone alerts.
- Infrastructure pedestrian detection.
- Priority assignment for emergency vehicle preemption.
- At-grade rail crossing.
- Bridge clearance warning.

Other applications

- Secondary accident warning.
- Lane departure warning [9].

Previous studies focusing on these safety applications to investigate drivers' behavior and to determine the traffic safety and operations are discussed in the remaining part of this section.

V2I Warning at Different Traffic Condition

Intersection Warnings

Budan et al. analyzed the communication via V2I intersection to control non-signalized intersection under mixed driving behavior. The objective of this study was to examine the effect of connectivity on non-signalized intersection control. To analyze the mixed driving behavior and interaction between mixed vehicles, a comprehensive traffic simulation framework is built in PTV VISSIM where CAV driving behaviors were incorporated using C++ code. Then the proposed method for non-signalized control was compared to the traffic light control using simulation. National Instruments (NI) Laboratory Virtual Instrument Engineering Workbench (LabVIEW) platform was used to test the V2I communication. Windows Shared Memory was used to implement V2I communications. Four of the driving behaviors were tested for four different traffic flow condition. Performance measures selected were average delay, average speed, average length of queue, and average fuel consumption. Traffic light controlled intersection was compared to the non-signalized intersection and results showed that, average fuel consumption, average vehicle delays and average queue length were 42%, 96% and 93% less respectively under First-Come-First-Served (FCFS) based scheduling of the vehicle [6]. However, this study did not specify which advisories or warnings were provided through V2I communications and drivers' behaviors toward those messages.

To understand the drivers' behavioral change due to the advisory messages through V2I, a V2I architecture was introduced for signalized intersections. To achieve this objective, driver's behavior was analyzed and evaluated after providing an in-vehicle message. Two scenarios considered for this purpose were driving towards a green signal and driving towards a red signal. Speed change and acceleration changes were selected as performance indicators. Total of 30 runs (19 for scenario 1, driving towards green light and 11 for scenario 2, slowing down or stopping towards a red light in the intersection) were conducted without messages and 28 runs (18 for scenario 1 and 10 for scenario 2) with messages were produced in the test site area, a signalized intersection closed to the University of Alberta North campus, AB, Canada. Message delivered under scenario 1 was "keep current speed" and under scenario 2 was "signal will turn red". To analyze the behavior of the drivers, speed profiles were generated for both scenarios and two of the cases (with message and without message). Based on the Wilcoxon Signed Rank Test, difference in the speeds between with and without messages are significant for both of the scenarios (green and red light). The frequency of maximum speed which is typically used as a surrogate safety measure also reduced in presence of the message. Though the acceleration/deceleration profiles did not change significantly because of providing the message, the change was significant for the deceleration before 50 meters of the intersection. Overall, audible advisory message through V2I changed the drivers' behavior significantly. The limitation of this study is only single connected vehicle was tested with no leading vehicle [12].

Another study used V2I technology to warn the drivers about upcoming red light and speed if their speed is above 30 mph near the signalized intersection which can be named as Red-Light Violation Warning (RLVW) combinedly. This study had 93 participants for their driving simulator experiment and conducted pre and post-simulation survey. The participants first drove a base scenario without warning and then the similar network with the RLVW system consists of audible beeps. When the participants received RLVW, they started braking early compared to the hard braking in the base scenario. This is evident from the 3.81 seconds longer time to stop at the red light in the scenario with RLVW. To understand the impact of RLVW on braking behavior of the participants, the authors of this study developed a log-normal duration model. The model basically describes the speed reduction time of the participants due to the presence of the warning systems. However, RLVW had positive influence on speed reduction time. The video recording of the simulation experiment showed that some participants (40%) did not stop at the red light in the base scenario, but 55% of those stopped at the red light in the scenario with RLVW which also proves the benefits of such warning system [7].

Congestion Warning

To investigate the impact of queue alert system on traffic safety Zhang et al. used the variation of roadside alerts and auditory alerts in combination with normal, distracted, and drowsy drivers type as well as sunny and foggy weather types. They found in-vehicle auditory message to be more effective and worst performance in drowsy state [8]. Using the latitude and longitude of freight vehicles and intersections, queue warning application (Q-WARN) algorithm was developed and tested for 3 test bed locations in Wyoming. Performance measures from 10 simulation run in VISSIM was TTC, delays and vehicle spacing. Analysis of the results showed less speed variation, less delay and increased TTC in presence of queue warning system [13].

Railway Crossing Warning

Landry et al. investigated the necessity of rail warning through providing warning about the rail crossings. They found out that compliance scores of the participants in a driving simulation study was higher when they received both visual warning and auditory warning compared to providing with visual warning only [14]. Another study used combination of warnings and individual warnings as well to investigate the impact of type of auditory display. They provided warning on railway crossings through speech alerts, short synthetic tones, and combination of these two types. Using MANOVA to compare the performance, they found out that combination of the alert leads to better acceptance [15].

V2I Warning at Different Road Condition

Work Zone warning

Using the result from driving simulator experiment, work zone was simulated in the VISSIM to investigate the safety improvement due to work zone warning. Under different market penetration rate (MPR), performance measures considered for measuring safety were Modified Deceleration Rate to Avoid Crash (MDRAC), Time-To-Collision (TTC), Time-Integrated Time-to-collision (TIT), and Time Exposed Time-to-collision (TET). Results showed TTC and speed decreased with the increase of MPR [1].

To develop lane changing response time (LCRT) and Distance (LCRD) fuzzy models, Li et al. considered drivers' reaction towards lane changing signs and voice messages in work zone [16]. The trajectory data for that model were collected by a driving simulator experiment for which 40 participants were assigned based on census data base for Houston. One of the two scenarios considered was regular traffic signs and another one had advisory system. Results of this study showed that duration of the lane change was shortened because of the provided messages as the drivers were able to prepare earlier for the lane change maneuvers. They connected the lane changing response time (LCRT) and Distance (LCRD) with the socio demographic factors of the drivers and found out that age and education background have impact on lane change response distance.

Li et al. also examined the role of work zone warning in reducing crashes and emissions in work zones and. With 51 participants, this research tested a driving simulation experiment with three scenarios which are no warning, audio warning and combination of audio and image warning. Results of this experiment showed that speed was higher for the no warning scenario compared to other two scenarios. Performance measures considered were speed, delay, acceleration rate, lane changing positions, braking positions, workloads, and emission factors. Analysis of these measures shows that participants in the scenario of combined messages showed better performance than other two scenarios in terms of safety measures [17]. However, work zone warning (WZW) system test in a driving simulator with 20 truck drivers revealed that it leads to longer off-road eye glance and noticeable workload for the drivers [18].

Curve Speed Warning

An advanced system of using curve warning was proposed by providing speed suggestions throughout the curves. Drivers will receive multiple messages if they are speeding while driving on a horizontal curve. Using different illumination, wetness level and severity of curve, 30 participants were recruited to drive several curves in driving simulator experiment. Those curves were consisted of different roadway, geometric and traffic condition. Curve warnings were provided through three ways – curve sign only, one-time curve speed warning, guided warning throughout the entire course of curve. Performance measure was speed difference and mixed linear model was used to model the collected data, using individual drivers' behavior as random effect. Results shows that speed compliance increased for the males when they received guided message compared to when they received curve sign only and one-time curve speed warning. On the contrary, female drivers' speed compliance was improved with curve sign only compared to other two warning types [19].

Curve speed warning system (CSWS) was modified for firefighters and tested in a driving simulator with 24 firefighters. Results showed that number of severe braking as well as distance traveled over the safety speed limits on the curve were reduced in presence of CSWS. However, the travel time was not changed overall [20]. Ahmadi & Machiani considered reaction time of drivers on a curve to develop an adaptive curve speed warning (ACSW) system and then they compared the proposed system with original warning system. Results showed that speed of the drivers while approaching curve is related to the direction of curve and the advisory speed. Also, male drivers had higher speed than female drivers [21]. A field test was performed with 48 participants in Virginia to determine the effectiveness of curve warning devices. Authors of this study used three types of warning – no warning, audio and visual warning, and push back through throttle together with audio and visual warning. Analysis of the results showed that reaction time was quicker and speed approaching curve was more appropriate when provided with warning compared to no warning or base scenario. However, adding the push back did not make any significant difference in the reaction times as many drivers were not able to detect the throttle push back [22].

V2I Warning at Different Environmental Condition

To investigate the impact of fog warning through V2I system, a study was conducted based on the road data from Beijing using a fixed based driving simulator. The length of the simulated roadway was 5 km (approximately 3.1 miles) and 4-lane divided freeway. The objective was to understand the impact of warning about fog condition on drivers' behavior as well as traffic safety. The three weather conditions considered throughout the simulated length were clear zone (50% of the total length), transition zone (10% of the total length) and fog zone (remaining 40% of the total length). Thus, there were four total scenarios including base condition with no warning, scenario with On-Board Unit (OBU) warning, scenario with dynamic message sign and scenario with both DMS and OBU. Total participants were 35 and traffic flow were constant throughout all the scenarios. To determine the contributing factors behind the drivers' speed adjustment, linear mixed model was used in addition to the performance measures such as standard deviation of speed, standard deviation of headway, TIT (time integrated time-to collision), and TET (time exposed time-to-collision). Results showed that standard deviation of headway in clear condition headway was lower than that in fog condition. Results of TET and TIT reveals that longitudinal crash risk was higher in the no warning scenario whereas this risk was lower in the OBU only scenario. Speed adjustment indexes showed that warning about fog condition beforehand helped the drivers prepare for upcoming condition [23].

Li et al. also concluded that fog warning system helps drivers to control speed and decelerate earlier [24]. Ahmed et al. used work zone scenario in combination with fog and forward collision warning, snowy weather in combination with slippery road and road closure scenario due to accident happened in severe weather [25]. While compared to the base scenario, it was found that, speed was lower for the scenario with warning (CV scenarios). Zhao et al. also found reduced driving speed by simulating three foggy condition (no fog, light fog and heavy fog) in connected environment [26].

Under the Wyoming Department of Transportation (WYDOT) Connected Vehicle (CV) Pilot Program, a driving simulation study was performed with twenty truck drivers. The objective was to examine the drivers' behavior towards notification on work zone during poor visibility condition due to fog. Results of this study did not reveal any significant difference in speed reduction between baseline scenario and scenario with first notification about fog. On the contrary, there was a significant reduction of speed while fog warning was combined with advisory speed limit. The mean driver speeds among the base scenario and different work zone scenarios were not significantly different [27].

WYDOT CV pilot was also used to investigate the impact of TIM to improve traffic safety through three experiments - work zone with Forward Collision Warning in foggy weather, slippery road surface and Distress Notification due to snowy weather, and road closure due to accident in severe weather. Using two-sample t-test and Analysis of Variance (ANOVA) for the Standard Deviations of speeds, authors found that CV scenarios had lower speed compared to base scenario. The variation of speeds of the CV scenarios were also significantly lower than the baseline scenario, especially during adverse weather condition [28].

Besides improving the traffic safety, V2I can also play role in mitigating air pollution emissions. To examine this fact, a 1000 meters long industrial area including three intersections within 300 meters of each other was generated as track for driving simulator experiment. The three scenarios considered were – no sun glare and no V2I, sun glare and no V2I, and sun glare and V2I. The V2I messages were real time audio messages about the approaching signalized intersections and work zones. The distance from the intersection to receive the audio messages were selected based on perception-reaction distance, minimum sight distance, posted speed limit and play time of the audio messages. The distance from the traffic sign and risk warning for work zone were selected based on 2009 MUTCD and 2.5 seconds of reaction time. Total of 30 people participated in the experiment. Results showed that emission rates were significantly lower with V2I system due to smoother and safer driving offered by V2I audio instructions. Comparison of with V2I and without V2I assistance in the work zone driving also showed reduced emission [29].

Other V2I Warnings

V2I collision warning system was used for safety of motorcycle rider in Taiwan. A Motorcycle safety warning system (MSWS) was built for field study which was consist of on-board units (OBUs), roadside units (RSUs), and a warning device. Warning devices were set to give warnings via triangle signs, LED lights and LED text messages which were supposed to be activated if the riders exceed the speed limit. Motorcycles in two university areas (33.6% and 98% of total motorcycles) were equipped with OBUs and testing was continued for 14 consecutive days in fourteen study sites. Rider of the motorcycles passed through the designated sites as usual, and they were informed about the installation of warning devices. The scenarios were with MSWS and without MSWS. Performance measures used were average detection speed, high-speed motorcycle ratio (number of high-speed motorcycles tracks divided by total recorded tracks) and acceleration noise. Based on Kaiser-Meyer-Olkin (KMO) test and Bartlett's Sphericity test, three of these parameters were combined using principal component analysis and a composite index (CI) was established. To cluster the CI values, K-means was applied on the CI values and then road safety level (RSL) was classified. The analysis indicated seven of the fourteen sites had decreased CI values which represent higher RSL. Authors also showed activation of MSWS helped to reduce high-speed motorcycle ratio by an average of 5.6% [30].

Farah et al. investigated the impact of cooperative infrastructure-to-vehicle systems on drivers' behavior as well as traffic safety by recruiting 35 drivers for a field test [31] and providing different V2I messages on different road, traffic and environmental condition. In addition to the Roadside Units (RSUs) and on-board units (OBU), the system included a service center, Traffic Control Centre (TCC), and Traffic Information Centre (TIC). During the field test, there was 30 seconds of lags to send any messages to drivers from TCC. The messages were delivered to the vehicles through OBU as icons and text messages. The participants also filled up pre and post questionnaire survey, each taking 15 minutes. Total duration of the test was approximately 120 mins. Data collected were speed, distances (longitudinal and lateral), acceleration, eye movements and heart rate. Performance measures considered for evaluating the impacts of the system are lane changing frequency, speed, acceleration noise and following gaps. T-test analysis of the average speed and traffic occupancy data showed that traffic condition was similar with the system on and off. Similarly, there was no significant difference in the acceleration noise and lane changing frequency of the driver due to the presence of the system. However, speed profiles of the driver showed lower speed on average with the system. One interesting finding of this study was that some drivers reduced the speed in the presence of the system, though they expressed poor acceptance. Also, vehicle following gaps increased when there was the system which indicates a positive impact on safety in combination with lower speed. The limitation of this study was that the messages through the OBU was not audio message which restricted the authors to identify the exact time the drivers responded to the suggestion from V2I communications.

Another warning system namely, Road Hazard Warning (RHW) System through V2I was studied using microscopic traffic simulation to investigate the impact of V2I traffic efficiency and safety. The road hazard in this study is defined as abrupt stopping of a vehicle which will result in serious crashes with its following vehicles. When an incident happens, the information will be integrated to infrastructure through Traffic Control Server (TCS) using Cooperative Awareness Messages (CAMs) among the vehicles enabled with Cooperative Intelligent Transportation Systems (C-ITS). Then, TCS will distribute the message to the surrounding vehicles. Performance measures used are Time to collision (TTC), Time Integrated Time-to-collision (TIT) and Deceleration Rate to Avoid Collision (DRAC). Total of 17 simulation run were conducted for different C-ITS penetration rates and results showed that number of crashes decreased significantly if penetration rate of C-ITS enabled vehicles increases [32].

Jiang et al. proposed a Connected Vehicle (CV) Vehicle-to-Infrastructure (V2I) based Dynamic Merge Assistance (DMA) system to improve the safety and efficiency during merging. They assumed 100% penetration of CVs and VISSIM traffic simulation was used to evaluate the proposed method. Location selected for the simulation was a weaving section with an on-ramp and an off-ramp as well as with congested bottleneck during morning peak. Travel time of mainline and on-ramp, and the time to collision (TTC) during lane change were considered as performance measures for evaluating the method. The results showed significant increase in traffic efficiency due to the DMA system. The average and minimum TTC also increased which indicates safety improvement. The study mentioned about the need of including mixed vehicular environment and human factors in further research [33].

To evaluate the acceptance and driver behavior towards I2V communication of European project COOPERS (Co-operative Systems for Intelligent Road Safety), 51 participants were recruited for a simulator test. Scenarios considered for this study were accident warning along with an ambulance coming from behind, accident and wrong-way warning together, congestion warning and weather condition warning. To compare the driver behavior with and without the system, speeding and headway are used as performance measures. On the other hand, a questionnaire was considered for evaluating the acceptance of the system. With the fog warning as a part of the weather warning, drivers were tending to decrease their speed before entering the fog zone. The lower speed in the fog zone with the system-on compared to the system-off helped to decrease the braking distance, indicates a positive impact on traffic safety. Giving congestion warning too soon in this study helped to find out that drivers' speed was very low compared to driving without the warning. Regarding the acceptance and attitude of drivers towards the system, the survey results revealed that they received assistance in a difficult driving condition. By measuring the acceptance using questions (7-point Likert scale), it is found out that drivers were calm with the system on, and their stress level was reduced during critical situations. Also, participants' experience was outperformed by using the system while driving and they found the system easy to use. They also expressed their opinion about buying the system once it is available commercially [34].

Yu et al. determined drivers' behavior, acceptance as well as the contributing factors behind these by giving energy related and safety related warnings in a test track. Driver characteristics, vehicle kinematics, self-reported data and display status were used to find out the factors responsible for behavioral change of the drivers. Design of the experiment for this study was conducted in a controlled field environment. Three types of messages conveyed through tablet are current speed, change of signal from green to red and suggested speed. Each participant drove a particular path 15 times which are consist of 1 practice drive, 7 drives with the system device activated and 7 drives without the device. Data collected includes speed, use of brake pedal, throttle position, acceptance through questionnaire (5-point Likert scale). This study used 7 different scenarios with 7 types of messages. Using SAS, mixed model analysis was performed where dependent variable is the compliance to the suggestion and independent variables are demographic factors, presence of suggestion, scenarios, driving experience etc. Results of this analysis showed that compliance rate across all these 7 scenarios was 72% whereas similar behavior in the baseline scenario was observed for 54% of the drivers. Also, the compliance rate was higher for younger drivers compared to the middle-aged drivers [35].

Contributing Factors behind Warning Message Acceptance

Factors considered in the previous studies to link up with the driving behavior in connected environment are age, educational background, driving experience, gender and display type used to provide information to the drivers. For example, female drivers responded to a congestion warning message by lowering their speed remarkably more than the male drivers [31]. Other studies showed that young and highly educated drivers had lower response time to V2I communication received to change lane in work zones [16], interaction of drivers with curve speed warning are related to age and gender [21] etc. Lower duration in lane changing was also observed in connected environment when the drivers are experienced [36]. A study also showed the benefits of V2I technologies for older drivers that they decelerated smoothly and in lower rate on average in presence of V2I system [37].

There might be a change in drivers' behavior if they get information from two different sources, Driver-Infrastructure Interface (DII) and Driver-Vehicle Interface (DVI) simultaneously. This fact is examined by a scenario where drivers encountered repeated Left Turn Across Path (LTAP) at a signalized intersection. The objective was to observe if drivers choose gap-assist information form the source which gives conservative timing at the time of clear view on oncoming traffic and how this decision change at the time of obscured view. A driving simulator (MiniSIM-based) connected with a tablet computer (for DVI) was used to run experiment and the DII was displayed using the screen. Total of 49 people participated in the experiment which includes 17 youngers (18-25 years), 17 middle-aged (26-64 years) and 15 older drivers (65+ years). With clear view of oncoming traffic, drivers did not use the gap-assist system much which could make the driving task simpler but was not necessary as they were able to get all the information by observing the gaps in the oncoming traffic. When the view was vague due to a truck, participants made decisions using help from either of the available system. However, older participants preferred the DII over the DVI. Also, having redundant information from both DII and DVI did not affect the performance of the drivers [3].

Richard et al. conducted another study by giving the information through DVI and DII, but this time not simultaneously. The result was similar to the previous study. Participants preferred the DII over DVI and their performance was inconsistence due to this incongruence [38].

Gaps in the Previous Studies

Several studies investigated the impact of fog warning through V2I on driving behavior and performance. Fog warning was used to investiagate drivers's speed change and braking distance difference with the system on or off, Drivers' headway and time to collison was determined using both OBU warning and DMS warning on foggy weather. Wu et al. used a lead vehicle in front of the subject vehicle and then introduced a scenario where lead vehicle stopped in emergency in a foggy weather condition. Then, they issued a rear end crash warning to see the impact of warning system through both auditory and head-up display [39].

Though studies were conducted to examine the impact of fog warning, effect and necessity of heavy rain warning have not yet been clearly investigated. Also, drivers' acceptance towards different V2I messages, their attitude about existing features from navigation app (such as traffic collision message, queue warning etc.), their opinion on V2I messages at different traffic, road and environmental condition, their preference about receiving V2I messages and controlling the reception of those messages are yet to be discovered.

Objective

The primary objectives of this project are the following.

1. To examine how drivers will interact with different visual and audio advisories provided through V2I regarding real-time traffic, roads, and environment conditions.

2. To identify and quantify the factors that will impact drivers' likelihood of accepting advisories received through V2I.

3. To evaluate the impacts of V2I on improving traffic operation and safety at different traffic and environmental conditions.

To achieve these objectives, two different methods were applied- 1) a driving simulation experiment was designed and conducted among a sample of Louisiana drivers; 2) Conducting a survey on drivers' preference, needs, opinion and attitude toward V2I advisories.

Scope

The scope of this project is to examine drivers' reaction and behavior in different types of heavy rain warning and investigate drivers' attitude, opinion and preferences towards different traffic, road, and environmental conditions.

Methodology

Questionnaire survey study

In this task, an online national survey was designed and developed after undertaking a review of literature. As a pilot survey study, a small sample of drivers then were asked to collaborate on the survey design and comment on the initial format and questions to ensure clarity and completeness. The objective of this survey was to investigate drivers' needs, preferences, and challenges towards accepting V2I messages at different road, traffic, and environmental conditions. The survey questions covered the following aspects.

- Demographic characteristics (e.g., age, gender, driving experience, income, involvement in accident etc.)
- Drivers' attitude toward usefulness of V2I advisories/suggestions received about real-time traffic, roads, and environment conditions.
- Self-reported preferences, challenges and needs towards acceptance of advisories/suggestions received through V2I
- Factors that influence drivers' likelihood to accept V2I advisories

The survey development and implementation followed a design thinking, iterative, human-centered, and collaborative approach. To ensure collecting a well-representative national sample in this study, the online survey was administrated by Qualtrics company which maintains online panels of the general population and provide a suite of services to enable data collection through surveys. Qualtrics constantly work toward maintaining a database of survey panelists that are representative of the population of interest. In our case, the population of interest was American people of 18 years and older with valid drivers' license. Data collection process was started through a soft launch to verify any inconsistency in the responses. Based on the evaluation from the soft launch, final data collection was then started, and total of 1571 responses were collected.

Driving Simulation Experiment

To investigate drivers' reaction and acceptance to different V2I warning messages, a driving simulation experiment was designed and conducted among a sample of drivers. The experiment for the driving simulation was designed using LSU driving simulator. The current LSU Driving Simulator is a full-sized passenger car (Ford Fusion) combined with a series of cameras, projectors, and screens to provide a high-fidelity virtual environment that offers a high degree of driving realism. It provides one degree of freedom motion simulation to make a driver experience similar driving efforts as in an instrumented vehicle. Its open architecture software tools allow for data collection during simulation experiments, and creation of new networks and virtually an infinite number of simulation scenarios.

A sample of drivers from Louisiana from different age groups were invited to participate in the driving simulator experiment. Every participant was scheduled for a specific a time slot. To meet the requirements of the Institutional Review Board (IRB) and obtain their approval to conduct experiments on human subjects, the research assistant/experimenter of this project explained the experiment to participants in brief upon arrival. Then, participants were asked to sign the consent form after reading details on the objectives of this research, their role in the experiment, how to participate, how the collected driving behaviors data will be kept anonymous etc., followed by filling up some background questionnaire.

The participants were then led to the simulation car and then the experimenter explained how to start driving after adjusting seat, mirrors etc. The experimenter asked the participants to push a red button located near the gear shift if they do not want to continue driving the experiment due to feeling uncomfortable/motion sickness. Then, they were given around one minute to make sure that they are comfortable with the seat adjustment and air conditioning. Before starting the main experiment, each participant then drove a warmup scenario for 4 minutes to get used with the driving simulator such as making right and left turns, braking, lane changing, merging, taking exit etc.

Scenarios

Finally, each participant was asked to drive the four scenarios designed with heavy rain. The purpose was to determine drivers' reaction and acceptance towards different visual and audio V2I warning about heavy rain. To achieve that objective, following four scenarios were developed in a simulated roadway network.

1. Heavy rain without warning
2. Heavy rain with in-vehicle audio warning
3. Heavy rain with in-vehicle screen warning
4. Heavy rain with DMS

The experiment was conducted in two parts, where participants drove first two scenarios in the first part and last two scenarios in the second part. Participants were asked if they were doing alright in between the two parts as well as at the end. The length of the simulated roadway network was 8 miles which was consist of on-ramp, off-ramp and straight 2-lane divided highway. Total time of the whole experiment was approximately 20 minutes.

Analysis Method

Descriptive statistics and boxplots were used for initial analysis of driving simulation data and questionnaire survey data. To investigate drivers' behavior in different warning scenarios as well as determining the contributing factors that impact these behaviors, several driving simulator variables were collected.

As all individual participants drove all the four scenarios, all the samples are exposed to each warning types. Therefore, the measurement of the dependent variables (response speed, adopted speed, maximum acceleration and maximum deceleration) is repeated, and thus repeated measures ANOVA was used to analyze the results. Within subject factor of this method is warning types, whereas between subject factor groups are age, gender, education, driving experience, and accident involvement in last three years. Table 1 shows the criteria used for grouping the between subject factors. All the analysis were done at 95% significance level.

Table 1: Grouping criteria of the between subject factors

Variables	Criteria
Gender	Female
	Male
Age	16-24
	25 and above
Driving experience	More than 5 years
	5 and less than 5 years
Education	Bachelors and above
	Below bachelors
Prior Accident Involvement	Yes
	No

Discussion of Results

Survey Data Analysis

This section discusses survey's participants' attitude toward current in-vehicle features, their preference towards receiving V2I messages, and their opinion about warning messages on different traffic, road, and environmental conditions.

Demographic

Among the 1571 respondents, 49.3% was male and 50.3% was female. Table 2 shows the percentages of gender and age group which are well representative of the US population. According to the Table, 11.6% of respondents were aged 18-24, 25-54 were 26.4%, 40-54 were 24.4%, 55-64 were 16.7% and 65+ were 20.8%.

Table 2: Proportion of respondents by age and gender

Age	Male	Female	Others	Proportion of Respondents	Proportion of Age in US population
18-24	32	149	2	11.6%	12.02%
25-39	182	229	4	26.4%	26.39%
40-54	189	195	0	24.4%	24.30%
55-64	132	131	0	16.7%	16.62%
65+	240	86	0	20.8%	20.67%
Proportion of Respondents	49.30%	50.30%	0.40%	100%	
Proportion of Gender in US population	49.20%	50.80%			

The survey is also well representative based on the state share of the population. Table 3 enlisted the percentage of the survey respondents throughout the different state as well as expected percentage according to the percentage of American population in different states.

Table 3: Proportion of respondents by State

Respondent Percentage by State					
State	**Percentage**	**Expected Percentage**	**State**	**Percentage**	**Expected Percentage**
Alabama	1.50%	1.50%	Montana	0.30%	0.33%
Alaska	0.20%	0.22%	Nebraska	0.60%	0.57%
Arizona	2.20%	2.19%	Nevada	0.80%	0.92%
Arkansas	0.90%	0.91%	New Hampshire	0.40%	0.43%
California	12.10%	12.00%	New Jersey	2.70%	2.74%
Colorado	1.70%	1.75%	New Mexico	0.60%	0.64%
Connecticut	1.70%	1.12%	New York	6.10%	6.10%
Delaware	0.30%	0.30%	North Carolina	3.20%	3.19%
District of Columbia	0.30%	0.23%	North Dakota	0.30%	0.23%
Florida	6.70%	6.71%	Ohio	3.60%	3.59%
Georgia	3.10%	3.16%	Oklahoma	1.10%	1.18%
Hawaii	0.40%	0.44%	Oregon	1.30%	1.31%
Idaho	0.50%	0.52%	Pennsylvania	4.00%	4.01%
Illinois	3.90%	3.89%	Rhode Island	0.30%	0.34%
Indiana	2.00%	2.02%	South Carolina	1.60%	1.57%
Iowa	1.00%	0.96%	South Dakota	0.30%	0.26%
Kansas	0.90%	0.87%	Tennessee	2.10%	2.08%
Kentucky	1.30%	1.36%	Texas	8.50%	8.39%
Louisiana	1.40%	1.41%	Utah	0.90%	0.88%
Maine	0.40%	0.43%	Vermont	0.20%	0.20%
Maryland	1.70%	1.85%	Virginia	2.60%	2.62%
Massachusetts	2.20%	2.18%	Washington	2.20%	2.31%
Michigan	3.10%	3.08%	West Virginia	0.60%	0.57%
Minnesota	1.70%	1.70%	Wisconsin	1.80%	1.79%
Mississippi	0.90%	0.90%	Wyoming	0.20%	0.18%
Missouri	1.90%	1.87%	Total	100%	100%

Table 4 details various demographics that the 1571 respondents were asked questions on. Almost half of respondents live in suburban areas (47.8%), while a quarter of them live in rural areas (25.0%). Most do a mix between city and highway driving (58.1%), and few drive only on highways and interstates (13.6%). Over 60% of the respondents spend less than an hour in their daily commute, while only 16.8% spend 2 or more hours on it. In terms of education, around 40% of the respondents have only a high school diploma, next highest being bachelor's degree (24.7%), followed by associate degree (15.8%), master's degree (around 9%) and rest of the 10% being doctorate, no certification, and other categories. When these participants were asked about their employment, almost half of them (49.1%) claimed as employed, 26.6% are retired, and 14.6% are unemployed. Nearly 65% respondents make an annual salary of $20,000-89,999, with the remainder falling below or above that range. The vast majority (86.4%) have over five years of driving experience and nearly 60% own only one vehicle.

Table 4: Survey respondents' demographics by age and gender

Variable	Category	Frequency by gender			Frequency by age group					Total
		Male	Female	Others	18-24	25-39	40-54	55-64	65+	
Residential Area	Urban	219	207	2	48	156	116	51	57	428
	Suburban	385	363	3	90	180	165	133	183	751
	Rural	171	220	1	45	79	103	79	86	392
Total	-	775	790	6	183	415	384	263	326	**1571**
Driving Type	Highway/interstate driving	93	120	0	41	74	41	38	19	213
	City driving	222	222	1	41	135	105	69	95	445
	Mixed city/highway driving	460	448	5	101	206	238	156	212	913
Total	-	775	790	6	183	415	384	263	326	**1571**
Time Spent in Daily Commute	Less than 1 hour	491	509	4	76	188	229	215	296	1004
	1 Hour	154	148	1	56	116	76	35	20	303
	2 Hours	90	93	1	33	80	55	10	6	184
	3 Hours	24	22	0	8	20	16	1	1	46
	4 or more hours	16	18	0	10	11	8	2	3	34
Total	-	775	790	6	183	415	384	263	326	**1571**
Level of Education	No certification	19	27	0	7	16	12	7	4	46
	High school diploma	279	316	3	90	156	142	104	106	598
	College diploma	34	50	1	21	26	18	11	9	85
	Associate degree	108	139	1	26	63	66	40	53	248
	Bachelor's degree	215	172	1	30	104	100	68	86	388
	Master's degree	81	64	0	6	34	31	24	50	145
	Doctorate degree	28	5	0	0	13	6	3	11	33
	Other	11	17	0	3	3	9	6	7	28
Total	-	775	790	6	183	415	384	263	326	**1571**
Employment Status	Unemployed	75	153	1	37	78	68	42	4	229
	Employed	388	381	2	98	292	243	102	36	771
	Retired	274	143	1	0	2	33	99	284	418
	Student	11	52	1	41	19	2	2	0	64
	Other	27	61	1	7	24	38	18	2	89
Total	-	775	790	6	183	415	384	263	326	**1571**
Total Household Income	Less than $20,000	97	165	4	57	72	60	49	28	266
	$20,000 to $49,999	269	293	1	67	152	128	97	119	563
	$50,000-$89,999	237	218	1	39	121	117	68	111	456
	Greater than $90,000	172	114	0	20	70	79	49	68	286
Total	-	775	790	6	183	415	384	263	326	**1571**
Driving Experience	Less than 2 years	12	34	0	25	17	3	1	0	46
	2-5 years	51	115	2	100	61	6	1	0	168
	More than 5 years	712	641	4	58	337	375	261	326	1357
Total	-	775	790	6	183	415	384	263	326	**1571**
Number of Vehicles Owned	0	33	37	1	14	13	20	13	11	71
	1	443	483	2	136	264	206	147	175	928
	2	234	207	3	30	111	116	71	116	444
	3 or more	65	63	0	3	27	42	32	24	128
Total	-	775	790	6	183	415	384	263	326	**1571**

Participants' Attitude towards Current Features

In this section of the survey, participants were surveyed on their attitudes toward features that are currently present in navigation apps that many drivers use every day. Respondents were also asked about their opinions on the importance of various features that are found in recent vehicles.

Opinions about Current Features in Navigation Apps

Table 5 indicates that the majority of respondents find the messages currently present in various navigation apps to be useful, with traffic collision ahead messages being the most favored (63.4%), followed by lane closure ahead and construction zone ahead messages (57.0% and 49.7%, respectively). For each feature, the responses indicate that drivers find the respective feature to be either useful or very useful by a vast margin. The lowest combined percentage for the useful and very useful responses is 76.7% (speed trap ahead) while the largest is 89.1% (traffic collision ahead). Also, percentage of drivers who were unfamiliar or do not use navigation app are higher than those who found the features not useful or not at all useful. For example, nearly 4.5% respondents mentioned about not useful or not useful at all for "speed trap ahead", whereas this percentage is over 7% for the respondents who are not familiar or do not use this feature.

Table 5: Opinions on usefulness of features currently present in navigation apps

Features	Very useful	Useful	Neutral	Not useful	Not useful at all	I am not familiar / do not use navigation app
There is a slowdown ahead	43.6%	39.3%	8.8%	1.9%	0.8%	5.7%
Speed trap ahead	45.4%	31.3%	12.0%	2.7%	1.5%	7.1%
Traffic collision ahead	63.4%	25.7%	4.2%	1.3%	0.4%	5.0%
Stopped vehicle ahead	42.5%	37.2%	11.4%	2.4%	0.6%	6.0%
Construction zone ahead	49.7%	36.6%	7.4%	1.2%	0.4%	4.6%
Lane closure ahead	57.0%	31.3%	5.7%	0.8%	0.5%	4.7%

Opinions about Current In-Vehicle Features

According to the Table, 4 out of 6 features were mostly regarded as extremely important or important (with automatic high beams and adaptive cruise control being mostly regarded as important or neutral). For blind spot assistance, forward collision warning, lane departure warning, and reverse collision warnings, around 80-90% of the respondents mentioned as either extremely important or important (Table 6). Combined percentage of extremely important and important for these four features are 85.3%, 83.8%, 77.4%, and 88.9%, respectively. On the other hand, automatic high beams and adaptive cruise control have highest combined percentage for important and neutral options (65.6% and 69.0%, respectively). Also, these two features compared to other four features had a larger proportion of respondents who viewed them as not important and not important at all. More than 10% respondents claimed these two features as either not important or not important at all, whereas this percentages are below 4.5% for other four features.

Table 6: Opinions on importance of safety and assistive features presently available in many vehicles

Features	Extremely important	Important	Neutral	Not important	Not important at all
Blind spot assistance	46.0%	39.3%	12.1%	2.2%	0.3%
Forward collision warning	45.7%	38.1%	13.6%	2.1%	0.4%
Lane departure warning	33.9%	43.5%	18.3%	3.2%	1.1%
Collision warning during reverse maneuvers	52.0%	36.9%	9.2%	1.5%	0.4%
Automatic high beam	19.9%	32.8%	32.8%	11.3%	3.3%
Adaptive cruise control	19.0%	34.5%	34.5%	9.3%	2.7%

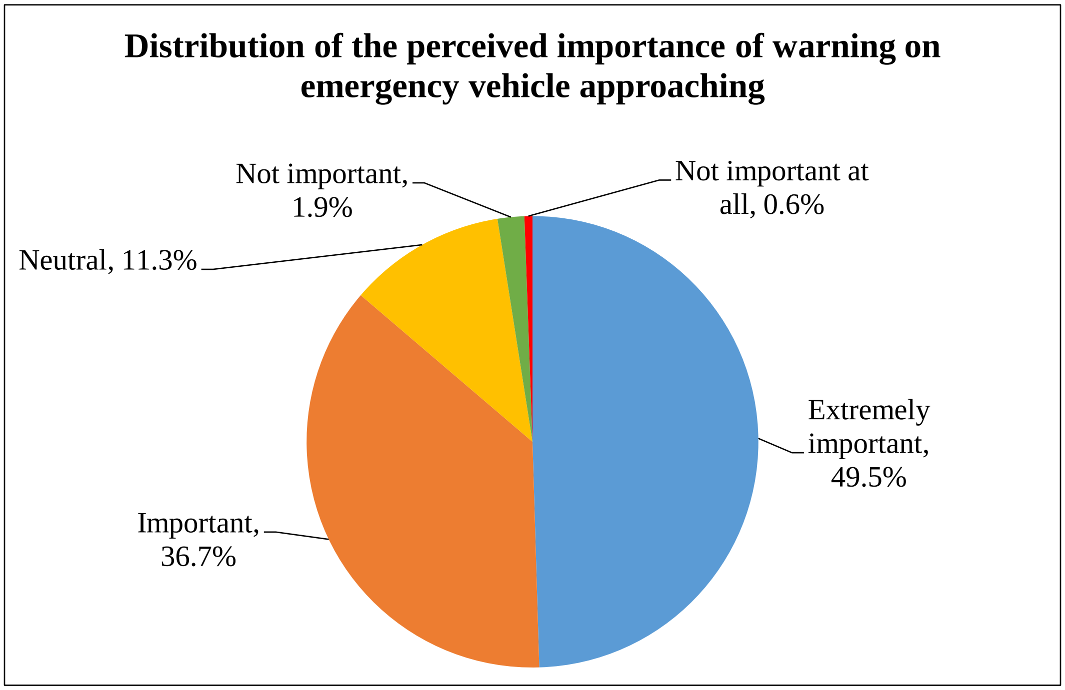
V2I Warning at Different Traffic Condition

In this section of the survey, participants were asked how important they think V2I messages would be regarding different traffic scenarios or conditions while driving a vehicle. At this end, respondents were asked about their opinion on the importance of receiving warning message about “emergency vehicle approaching “and “train approaching”.

Emergency Vehicle Warning

Survey respondents were asked about their perceived importance on receiving "emergency vehicle approaching" warning. Almost half of the respondents viewed this warning message as extremely important (49.5%). This was followed by the viewpoint of the messages being important (36.7%) and neutral (11.3%). The remaining 2.5% of responses was comprised of 1.9% not important and 0.6% not important at all. In total, 86.2% of respondents viewed emergency vehicle V2I messages as either important or extremely important (Figure 1).

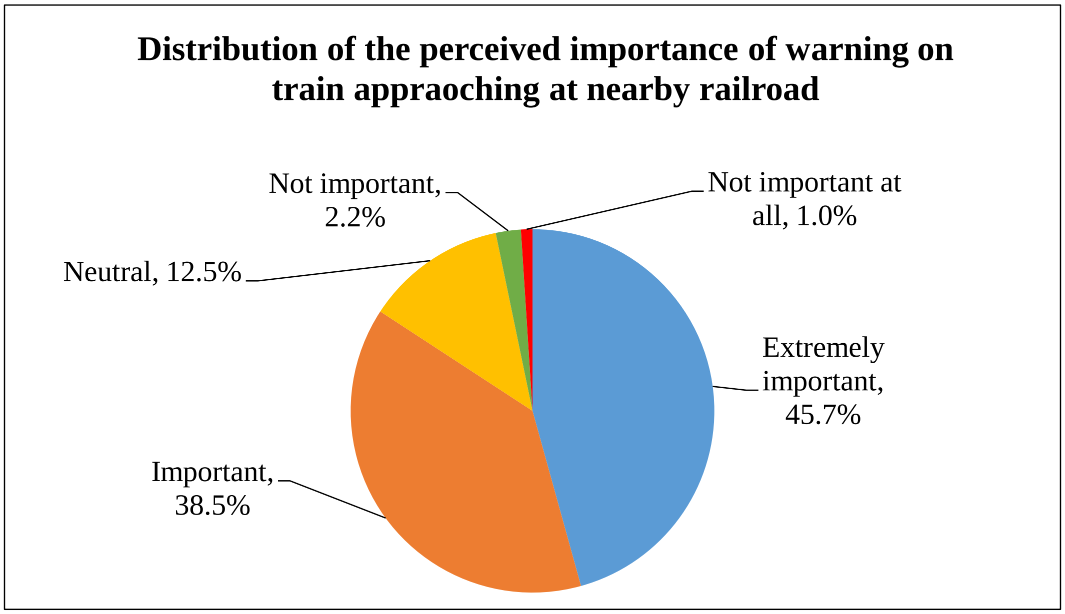
Figure 1: Perception toward importance of "emergency vehicle approaching" warning



Train Approaching Warning

This part of the survey asked the respondents about their opinion on the importance of receiving “train approaching at rail crossing ahead" warning. Figure 2 demonstrates that the respondents’ attitudes toward this V2I message follow almost similar trend as V2I message on emergency vehicle. Around 45% viewed this message to be extremely important, and 38.5% viewed it as important which comprised 84.2% of total respondents, again showing that the majority of respondents view these messages as either important or extremely important. The neutral category totaled 12.5%, with not important and not important at all being 2.2% and 1.0%, respectively.

Figure 2: Perception toward importance of "train approaching at rail crossing ahead" warning



V2I Warning at Different Road Conditions

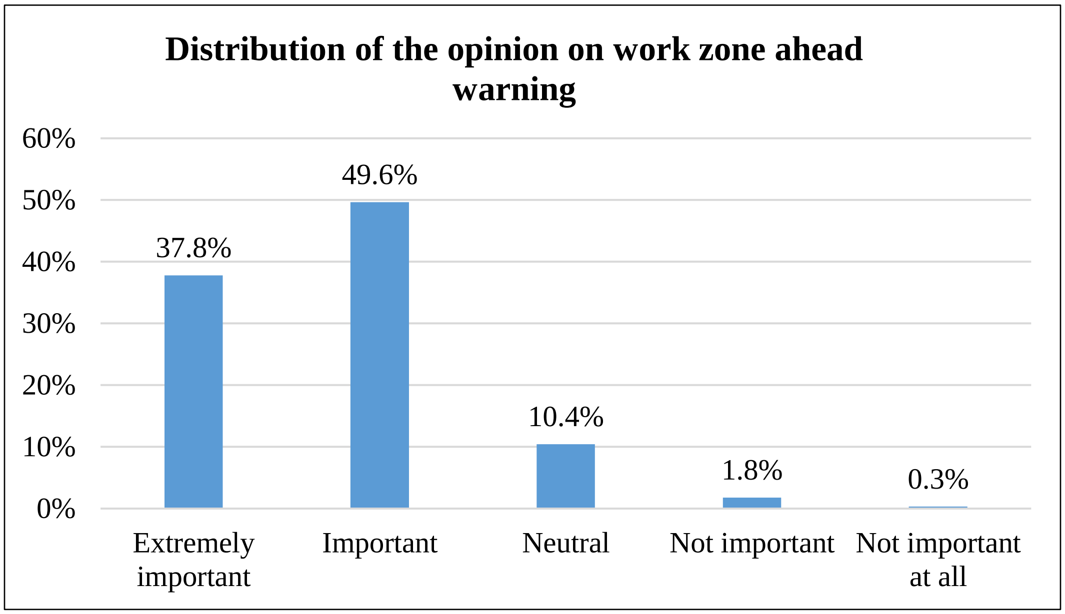
For this section of the survey, respondents were asked their opinions on the importance of the reception of various V2I messages, but with respect to physical road conditions. In this part, they were asked about their opinion on importance of "work zone warning" and "curve speed warning" messages.

As before, the majority of respondents viewed the V2I advisory messages as important. For work zone warnings, 87.4% of respondents felt the V2I messages were extremely important or important; for curve speed warnings, 87.1% responded for the same two options.

Work Zone Warning

To explore the drivers' opinion on receiving work zone warning, respondents were asked how important they think receiving a message "Work zone ahead, reduce your speed and be ready to merge/change lane" would be to enhance safety in work zone. For this warning around half of the respondents think V2I message about work zone will be important (Figure 3), followed by extremely important (37.8%) and neutral (around 10%). Total percentage of respondents for important and extremely important is 87.4%. Overall, there is a trend of the response proportion dropping with decreasing importance except important having more percentage than extremely important. Very few of the respondents reported this V2I message as not important and not important at all (total of 2.1%).

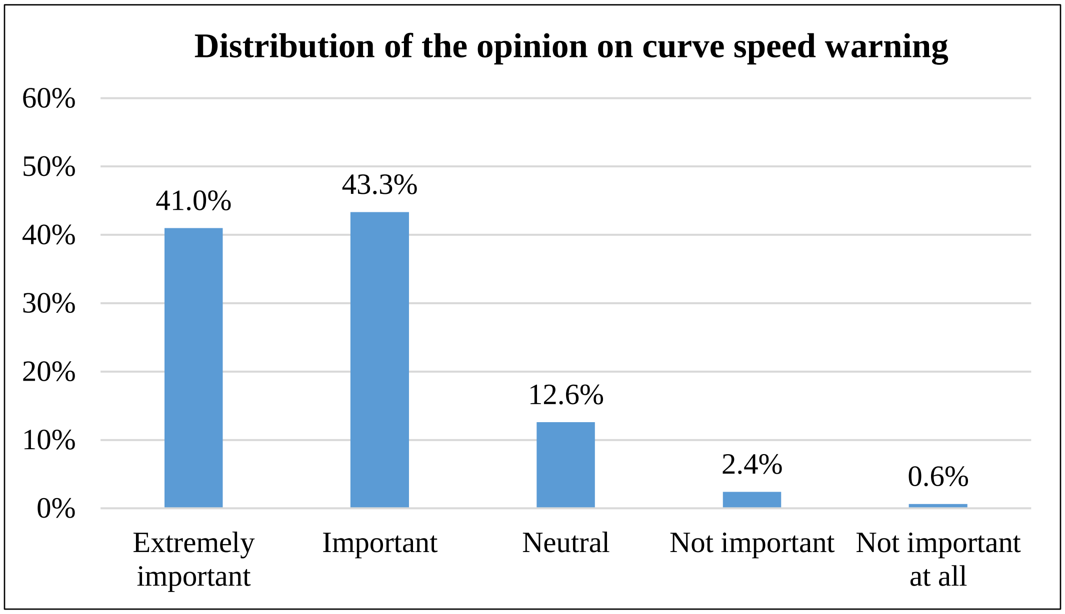
Figure 3: Opinion on the importance of "Work zone ahead, reduce your speed and be ready to merge/change lane" warning



Curve Speed Warning

While the respondents were asked about the importance of "Sharpe curve ahead, reduce your speed" message, vast majority of respondents felt that this warning is important, with the total percentage being 84.3% (41.0% extremely important and 43.3% important). Neutral comprised of 12.6% of responses, while not important and not important at all comprised of 2.4% and 0.6%, respectively (Figure 4).

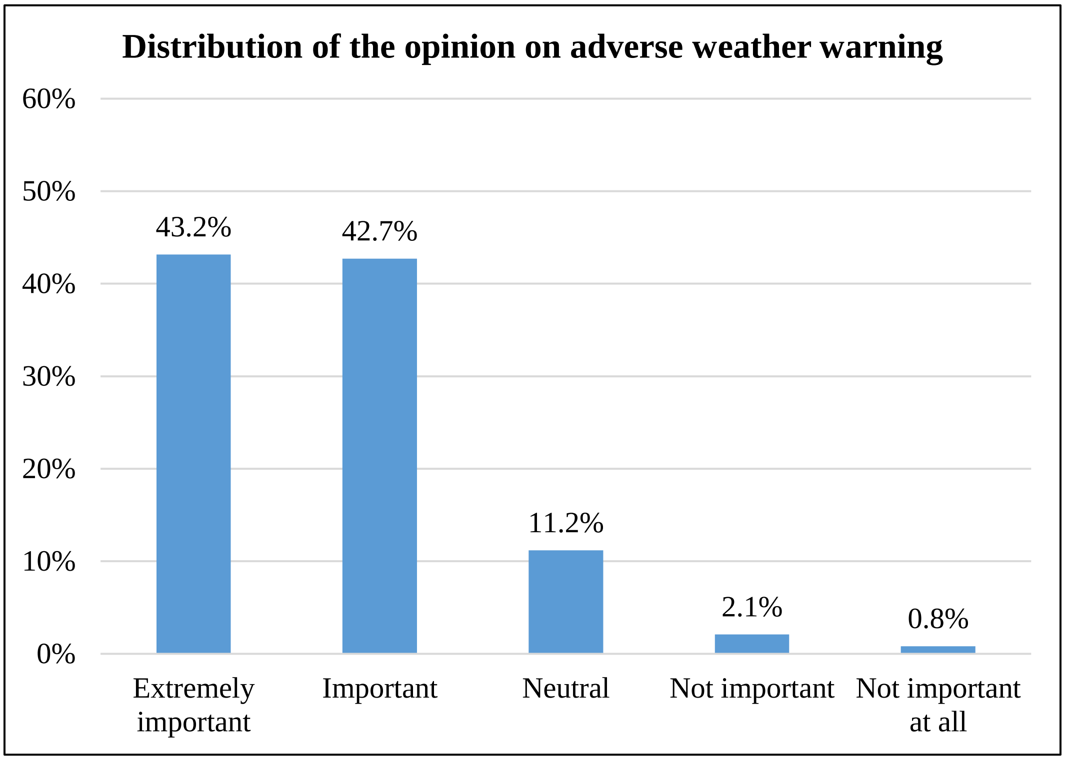
Figure 4: Opinion on the importance of "Sharpe curve ahead, reduce your speed" warning



V2I Warning during Adverse Weather Condition

The objective of this section is to discuss the opinions of respondents regarding receiving V2I messages about adverse weather condition. Unlike other V2I messages on traffic and road conditions discussed above, adverse weather condition warning is also favored by most of the respondents (Figure 5). Around 85% of the respondents claimed this warning as extremely important (43.2%) and important (42.7%). A little over 10% of responses indicate that the participants' opinion is neutral to this message, while only 2.9% do not find this useful (2.1% reported this warning as not important and 0.8% as not important at all).

Figure 5: Opinion on the importance of "Heavy rain/fog ahead, reduce your speed" warning



Peoples' Preference on Receiving V2I Warning

Participants were then asked about their preferences on receiving the V2I messages such as the methods of receiving V2I messages and how would they like to control the reception of those warning messages.

Preference toward method of V2I reception

This part of the survey asked if the drivers want their V2I warnings through in-vehicle display, in-vehicle auditory, DMS or combination of these three methods. Table 7 shows that out of 1571 respondents surveyed, around 63% preferred singular reception method (989 out of 1571); in-vehicle auditory seems the most popular of the three, with 29.9% of responses preferring it, followed by in-vehicle display (21.7%) and DMS (11.3%). From the remaining 37% who preferred more than one reception method, the combination of all the three methods received highest preference (14.7%). The second highest preference was found to be the combination of in-vehicle auditory and in-vehicle display (13.3% of respondents). Preference for the combination of DMS with in-vehicle auditory and in-vehicle display were not preferred much (5% and 4% respectively).

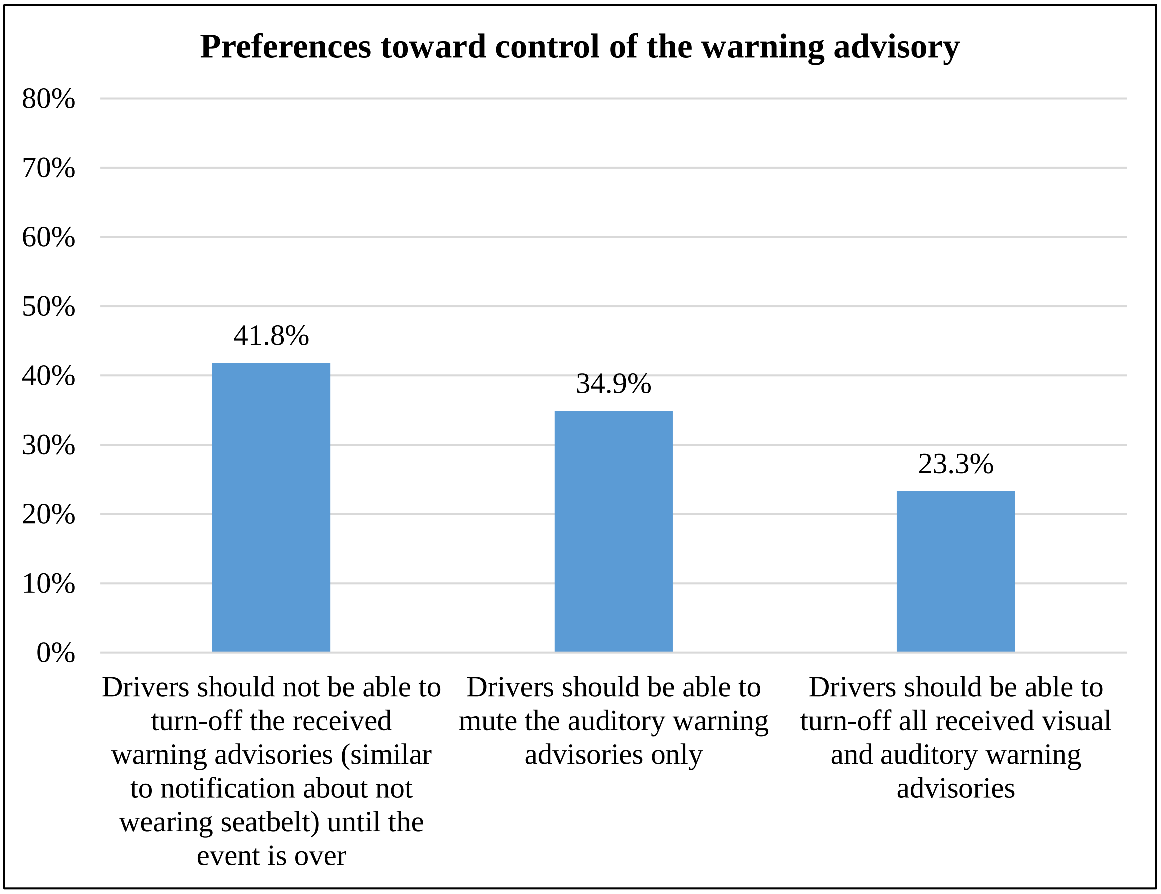
Table 7: Preferences toward the methods of the reception of V2I warning advisories

Receiving method	Frequency	Percentage
In-vehicle display	341	21.7%
In-vehicle auditory	470	29.9%
Dynamic message signs	178	11.3%
Total	**989**	**62.9%**
Combined preferences		
In-vehicle display and auditory	209	13.3%
In-vehicle display, and dynamic message signs	63	4.0%
In-vehicle auditory and dynamic message signs	79	5.0%
All options	231	14.7%
Total	**582**	**37.0%**

Preference toward Control of V2I Messages

Different drivers might have different opinions about controlling the received in-vehicle V2I warnings. Thus, survey respondents were asked about their preferred controlling method. Figure 6 provides distribution of peoples' preferences on controlling the received V2I messages through in-vehicle visual and auditory advisory system. Nearly 42% of the respondents believe that drivers should not be able to turn off the auditory and visual V2I messages off in their vehicles. Around 35% responded that drivers should be able to mute the auditory messages, but not turn them off entirely; 23.3% responses favored the ability to turn the messages off completely.

Figure 6: Preference toward drivers' freedom to alter or disable V2I advisory messages



Driving Simulation Data Analysis

To determine the effect of different types of V2I warnings on drivers' behavior and traffic safety, a driving simulation experiment was designed. Four scenarios were simulated in 8 miles roadway network. The objective of this section is to analyze the result of the driving simulation experiment through drivers' travel speed and acceleration/deceleration at different section of the simulated roadway.

Participants and Demographic

A total of 42 people (22 male, 19 female and 1 others) participated in the experiment. Among them, 34 drivers were able to complete the experiments and 8 drivers had to withdraw after driving for a while due to simulation's motion sickness. However, due to some unrealistic driving behavior, data for two drivers were not considered for analysis in this section. Therefore, total number of participants' responses considered in the analysis is 32 (20 male and 12 female). Among them, around 60% was in the 18-24 years age group and remaining 40% consists of drivers from age group 25-39, 40-54 and 55-64. More than 60% of these drivers had more than 5 years of driving experience, around 30% had 2-5 years of driving experience and only 6% of the drivers were with less than 5 years of driving experience. Nearly 60% of the participants have bachelor's degree, around 18% and 12% had high school diploma and college degree, while rest of 10% participants had master's and doctorate degree. In terms of involvement in an accident, approximately 70% of the participants reported that they were involved in accidents in the last 3 years. Table 8 summarizes the demographic characteristics of all the 32 drivers included in this study.

Dependent Variables

Drivers' speed and acceleration/deceleration in different zone of the heavy rain scenarios were collected to study the impact of audio and visual warning. Following are the dependent variables considered for examining the safety and drivers' behavior through speed and acceleration/deceleration.

Initial Speed

This is the speed of the participants just before they received the audio and visual warnings. This variable is collected to use as reference speed while driver's acceptance of the V2I warnings is examined.

Table 8: Driving simulation participants' demographic

Variables	Categories	Frequency
Gender	Female	12
	Male	20
	Total	**32**
Age	18-24	20
	25-39	7
	40-54	4
	55-64	1
	Total	**32**
Driving experience	Less than 2 years	2
	2-5 years	10
	More than 5 years	20
	Total	**32**
Education	High School Diploma	6
	College Diploma	4
	Bachelor's degree	19
	Master's degree	2
	Doctorate degree	1
	Total	**32**
Accident Involvement	Yes	22
	No	10
	Total	**32**

Response Speed

The travel speed of the participants which is recorded after providing the warnings and before the beginning of the rain. The objective of this variable is to examine the difference of travel speed throughout the four scenarios after giving warnings on upcoming heavy rain.

Adopted Speed

Speed adopted by the participants once heavy rain starts. There is a transition period of 10s from light rain to heavy rain. This speed is recorded after heavy rain started. This variable is selected to determine whether speed after the rain starts varying due to different warning types in the four scenarios.

Maximum acceleration

Maximum acceleration of the participants after the warnings were provided. This is to determine if the warnings help drivers accelerate safely. This is the highest acceleration value of the participants in the area between giving the warning and starting of the rain.

Maximum deceleration

This is the maximum deceleration of the participants during heavy rain. If the provided warnings are helpful to reduce the speed beforehand, likelihood of sudden deceleration will be less during the heavy rain, thus deceleration should be smaller.

Speed and acceleration/deceleration value for the no warning scenario were recorded at the same location as other warnings.

Response Speed Analysis

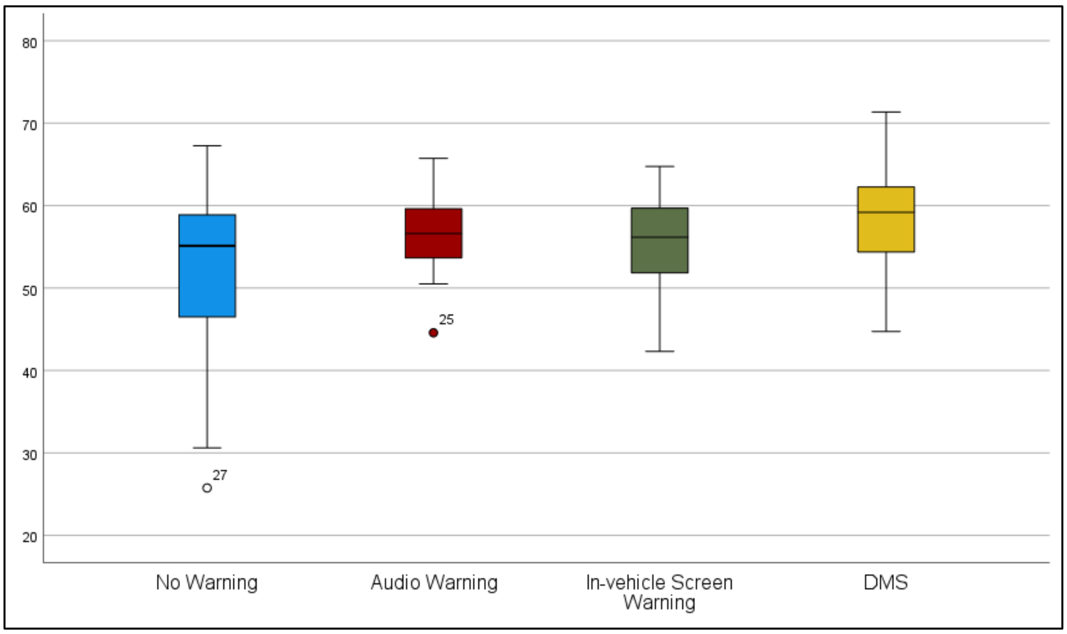
The mean values of the response speed values are 52.49 mph, 56.76 mph, 55.47 mph, and 58.31 mph for no warning, audio warning, in-vehicle screen warning and DMS, respectively. According to Table 9, no warning has highest standard deviation of response speed and audio warning has lowest standard deviation. Maximum and minimum values in the table suggest that some people were driving at higher or lower than the speed limit 60 mph. Figure 7 shows the boxplots for response speeds throughout the four scenarios which suggests that median speeds were almost similar in all the scenarios, DMS scenario being little higher. No warning scenario has highest variability in response speeds of all the four scenarios. This demonstrates how speed variability is minimized in the scenarios with warnings compared to the no warning scenario. Among the three scenarios with warnings, audio warning has less variability in response speed. There are two outlier values in no warning and audio warning scenario.

To further analyze if these differences are significant, repeated measures ANOVA with one within subject factor (warning type) and 5 between-subject factors (age, gender, experience, education, and accident involvement) were conducted.

Table 9: Summary of response speed for the four scenarios

	Mean	STD	Minimum	Maximum
No warning	52.49	10.05	25.76	67.27
Audio warning	56.76	4.73	44.58	65.73
In-vehicle screen warning	55.47	5.57	42.32	64.76
DMS	58.31	6.35	44.74	71.36

Figure 7: Response speed in four scenarios



Assumption Check for Repeated Measures ANOVA

To meet the assumption of repeated measures ANOVA method, it is necessary to check for possible outliers, normality of the residuals and sphericity or homogeneity check for variances of differences between all concerned groups.

The Q-Q plots in Figure 8 show that residuals are approximately normally distributed, no significant outliers are visible. Another important requirement that must be met before conducting repeated-measures ANOVA is the sphericity assumption. Mauchly's Test of Sphericity was applied for this purpose. Null hypothesis of this test is that variance of difference between the response speeds of the four scenarios are homogeneous. As the p-value in Figure 9 is 0.204 which is greater than 0.05, we fail to reject the null hypothesis at 95% significance level. Therefore, the variances of differences are homogeneous.

Figure 8: Q-Q plots for response speed in four scenarios

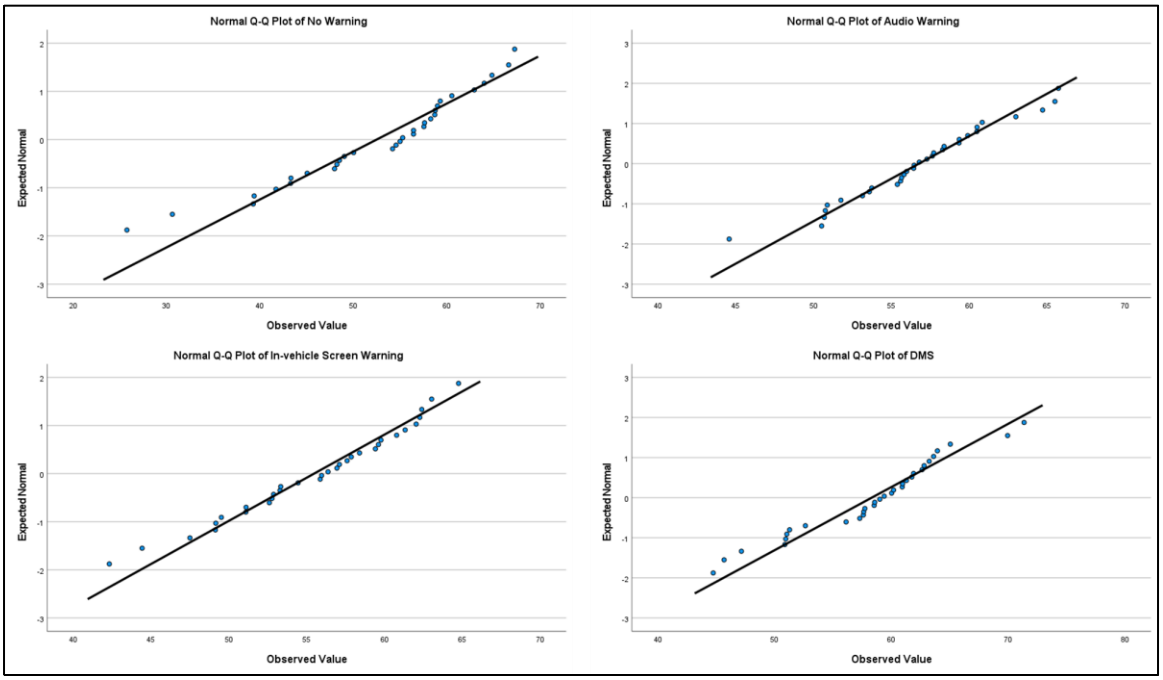


Figure 9: Mauchly's test for response speed

Mauchly's Test of Sphericity[a]

Measure: Adopted_speed

					Epsilon[b]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
warning	.649	7.240	5	.204	.766	1.000	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Results of ANOVA

As the sphericity assumption is met, repeated measures ANOVA with sphericity assumed was used to determine whether there is a significant difference in the response speed among the four scenarios. According to Table 10, p-value of within subject factor (warning types) is $0.046 < 0.05$, which indicates that response speeds are significantly different across the four scenarios. To further investigate pairwise difference between the warning types, post hoc test was conducted (Table 11) using the Bonferroni correction which did not reveal any significant difference between the scenarios. That might be because very large p-value of the ANOVA test. Any significant interaction effect between warning and driver's demographic characteristics was not also found for response speed.

Table 10: ANOVA results for response speed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
warning	345.067	3	115.022	2.854	**0.046**	0.137
warning * Gender	40.519	3	13.506	0.335	0.8	0.018
warning * Age	79.38	3	26.46	0.657	0.582	0.035
warning * Experience	41.589	3	13.863	0.344	0.794	0.019
warning * Education	59.959	3	19.986	0.496	0.687	0.027
warning * Accident	144.296	3	48.099	1.194	0.321	0.062

Table 11: Post hoc tests for response speed

(I) warning	(J) warning	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	-4.135	2.09	0.38	-10.327	2.056
	3	-3.293	2.087	0.791	-9.476	2.889
	4	-5.733	2.2	0.107	-12.252	0.786
2	1	4.135	2.09	0.38	-2.056	10.327
	3	0.842	1.3	1	-3.009	4.693
	4	-1.598	1.433	1	-5.845	2.649
3	1	3.293	2.087	0.791	-2.889	9.476
	2	-0.842	1.3	1	-4.693	3.009
	4	-2.44	1.519	0.754	-6.94	2.061
4	1	5.733	2.2	0.107	-0.786	12.252
	2	1.598	1.433	1	-2.649	5.845
	3	2.44	1.519	0.754	-2.061	6.94

To determine if there is any effect of drivers' demographic characteristics on the response speed, age, gender, education, driving experience and accident involvement in last 3 years were added as between subject factor in the repeated measure ANOVA. Results from thr tests of between-subject factors in Table 12 suggests that only driving experience have significant impact $(p - value = 0.016 < 0.05)$ on the response speed. Results from descriptive statistics of estimated marginal mean of the response speed showed that participants with 5 years and less than 5 years of driving experience had average response speed of 53.86 mph, whereas participants with more than 5 years of experience had larger response speed (56.32 mph).

Table 12: Analysis results for association of drivers' demographics and V2I warnings

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	232849.929	1	232849.929	3806	0	0.995
Gender	225.382	1	225.382	3.684	0.071	0.17
Age	143.776	1	143.776	2.35	0.143	0.115
Experience	434.153	1	434.153	7.096	**0.016**	0.283
Education	131.597	1	131.597	2.151	0.16	0.107
Accident	8.232	1	8.232	0.135	0.718	0.007

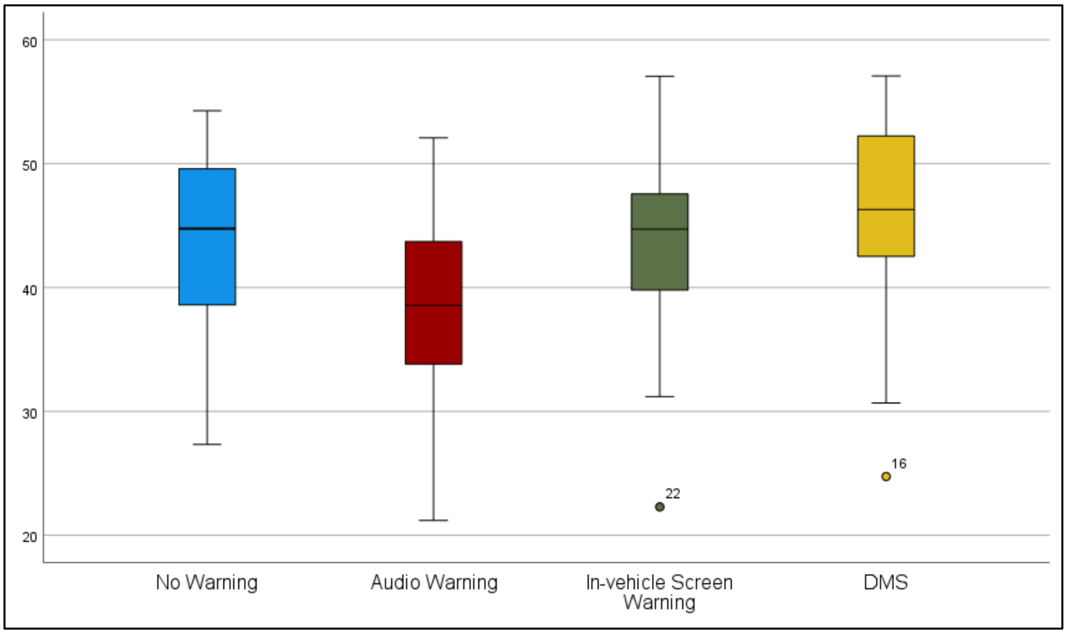
Adopted Speed Analysis

Table 13 shows that mean adopted speeds during the heavy rain in the no warning, audio warning, in-vehicle screen warning and DMS were 43.59 mph, 38.62 mph, 43.18 mph and 46.25 mph, respectively. The maximum and minimum values of this variable are listed in Table 13. Standard deviation of the adopted speed during heavy rain are higher in all the scenarios which is also visible in the dispersed boxplots in Figure 10. Overall, in-vehicle screen warning has less variation in adopted speed. Median adopted speed is lower for audio warning, followed by no warning and in-vehicle screen warning. Heavy rain scenario with DMS has the highest median adopted speed value. In-vehicle screen warning and DMS have mild outliers.

Table 13: Summary of adopted speed for the four scenarios

	Mean	STD	Minimum	Maximum
No warning	43.59	6.94	27.34	54.28
Audio warning	38.62	7.43	21.20	52.09
In-vehicle screen warning	43.18	7.02	22.29	57.06
DMS	46.25	7.61	24.74	57.08

Figure 10: Adopted speed in four scenarios



Assumption Check for Repeated Measures ANOVA

According to Figure 11, as p-value is 0.037< 0.05 for Mauchly's Test of Sphericity, the sphericity assumption is violated. Therefore, to determine the statistically significant difference among the adopted speed of the four scenarios, repeated measures ANOVA with Greenhouse-Geisser correction was used. Figure 12 proves that residuals of the adopted speed for all the scenarios are normally distributed, and no significant outliers are visible.

Figure 11: Mauchly's test for adopted speed

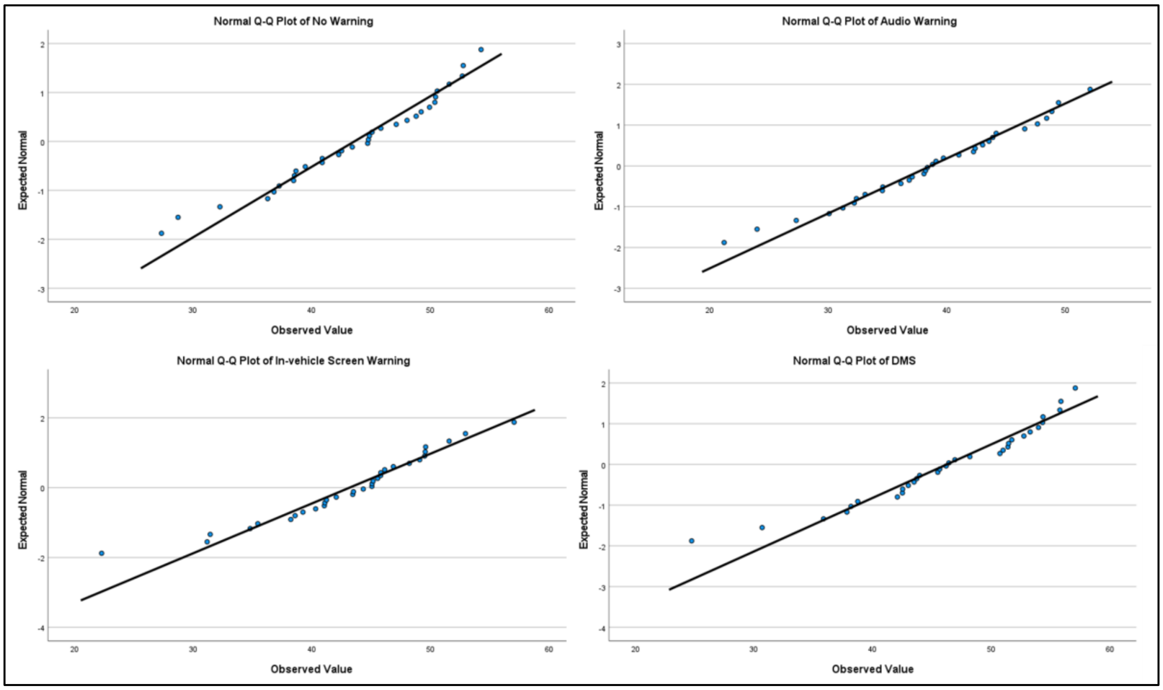
Mauchly's Test of Sphericity[a]

Measure: Adopted_speed

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
warning	.492	11.858	5	.037	.756	1.000	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Figure 12: Q-Q plots for adopted speed in four scenarios



Results of ANOVA

Results of the ANOVA in Table 14 indicates that adopted speed differs significantly ($p - value = 0.001$) across the four scenarios. As it is not clear that which scenarios have significant difference between them, post hoc test with Bonferroni correction was used for further investigation (Table 15). The objective of the post hoc test here is to examine if the scenarios with warning has significantly different adopted speed value compared to that in no warning scenario.

Table 14: ANOVA results for adopted speed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
warning	601.478	2	265.234	7.186	**0.001**	0.285
warning * Gender	13.205	2	5.823	0.158	0.879	0.009
warning * Age	140.46	2	61.939	1.678	0.196	0.085
warning * Experience	53.092	2	23.412	0.634	0.555	0.034
warning * Education	109.291	2	48.194	1.306	0.284	0.068
warning * Accident	102.772	2	45.319	1.228	0.307	0.064

Result of the post hoc tests in Table 15 shows that adopted speed in audio warning is significantly different (($p - value\ =\ 0.007$) than no warning scenario. Mean difference between these two scenarios is 5.736, which is very small (0.136 and -3.235) for other two scenarios (in-vehicle screen and DMS). That is why, scenarios with in-vehicle screen warning and DMS are not significantly different than no warning scenario with respect to adopted speed during heavy rain. On the contrast, these two scenarios (in-vehicle screen and DMS) are significantly different than audio warning. Their p-values are highlighted in Table 15.

In terms of interaction effect, there was no significant interaction effect (Table 14) between warning and other between-subject factors (demographic characteristics). Unlike response speed, only driving experience has significant impact ($p = 0.038 < 0.05$) on adopted speed (Table 16) and drivers with more than 5 years of experience had higher adopted speed (43.16 mph) than their counterparts (41.83 mph).

Table 15: Post hoc tests for adopted speed

(I) warning	(J) warning	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	5.736*	1.496	**0.007**	1.303	10.169
	3	0.139	1.585	1	-4.556	4.833
	4	-3.235	1.201	0.089	-6.794	0.325
2	1	-5.736*	1.496	0.007	-10.169	-1.303
	3	-5.597*	1.363	**0.004**	-9.635	-1.559
	4	-8.970*	1.902	**0.001**	-14.606	-3.335
3	1	-0.139	1.585	1	-4.833	4.556
	2	5.597*	1.363	0.004	1.559	9.635
	4	-3.373	1.383	0.152	-7.47	0.723
4	1	3.235	1.201	0.089	-0.325	6.794
	2	8.970*	1.902	0.001	3.335	14.606
	3	3.373	1.383	0.152	-0.723	7.47

Table 16: Analysis results for association of drivers' demographics and V2I warnings

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	134411.802	1	134411.802	1267.589	0	0.986
Gender	216.802	1	216.802	2.045	0.17	0.102
Age	219.063	1	219.063	2.066	0.168	0.103
Experience	532.684	1	532.684	5.024	**0.038**	0.218
Education	0.028	1	0.028	0	0.987	0
Accident	410.476	1	410.476	3.871	0.065	0.177

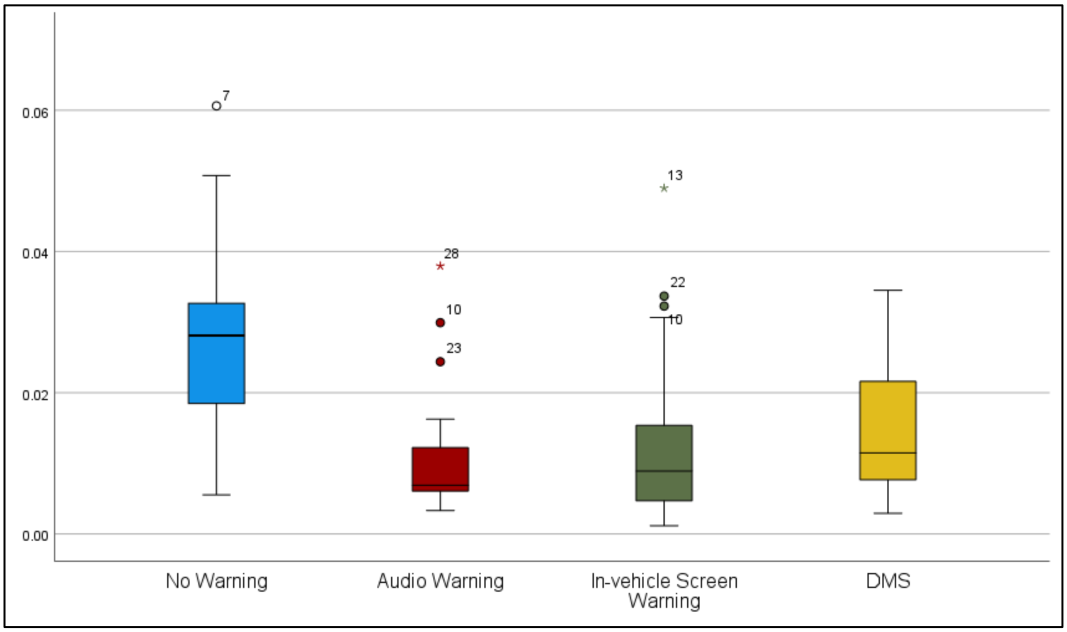
Maximum Acceleration Analysis

The average values of maximum acceleration found from descriptive statistics of this variable are 0.027 fts^{-2}, 0.010 fts^{-2}, 0.013 fts^{-2}, and 0.015 fts^{-2} for no warning, audio warning, in-vehicle screen warning and DMS, respectively (Table 17). Out of 32 sample data, 3 observations (0.71 fts^{-2}, 0.16 fts^{-2}, 0.08 fts^{-2}) were deleted from the analysis of acceleration for being very different from the rest of the data. Figure 13 shows the boxplots for maximum acceleration for all the four scenarios. The median value of the maximum accelerations is smallest in audio warning, followed by in-vehicle screen warning and DMS. On the other hand, no warning scenario has the highest acceleration value. This implies that after the warnings were provided, participants did not accelerate much. There are some outlier values in all the scenarios except DMS. Accelerations in the no warning scenarios are more dispersed than other three scenario with warnings, which indicated less variability of acceleration after receiving the warning. However, audio warning has the least variability among all three scenarios with warning.

Table 17: Summary of maximum acceleration for the four scenarios

	Mean	STD	Minimum	Maximum
No warning	0.027	0.015	0.006	0.061
Audio warning	0.010	0.008	0.003	0.038
In-vehicle screen warning	0.013	0.012	0.001	0.049
DMS	0.015	0.010	0.003	0.035

Figure 13: Maximum acceleration in four scenarios



As can be seen from Figure 13, acceleration is higher in no warning scenario than other 3 scenarios with warning. To further explore these differences, repeated measure ANOVA was used.

Assumption Check for Repeated Measures ANOVA

The Q-Q plots in Figure 14 show that most of the residuals are approximately normally distributed except for two outliers in the maximum acceleration of audio warning and in-vehicle screen warning scenario. Mauchly's Test of Sphericity (Figure 15) gives p-value = 0.237 (Figure) which is greater than 0.05. Thus, we fail to reject the null hypothesis that the variance of difference in maximum acceleration between the warning types are homogeneous.

Figure 14: Q-Q plots for maximum acceleration in four scenarios

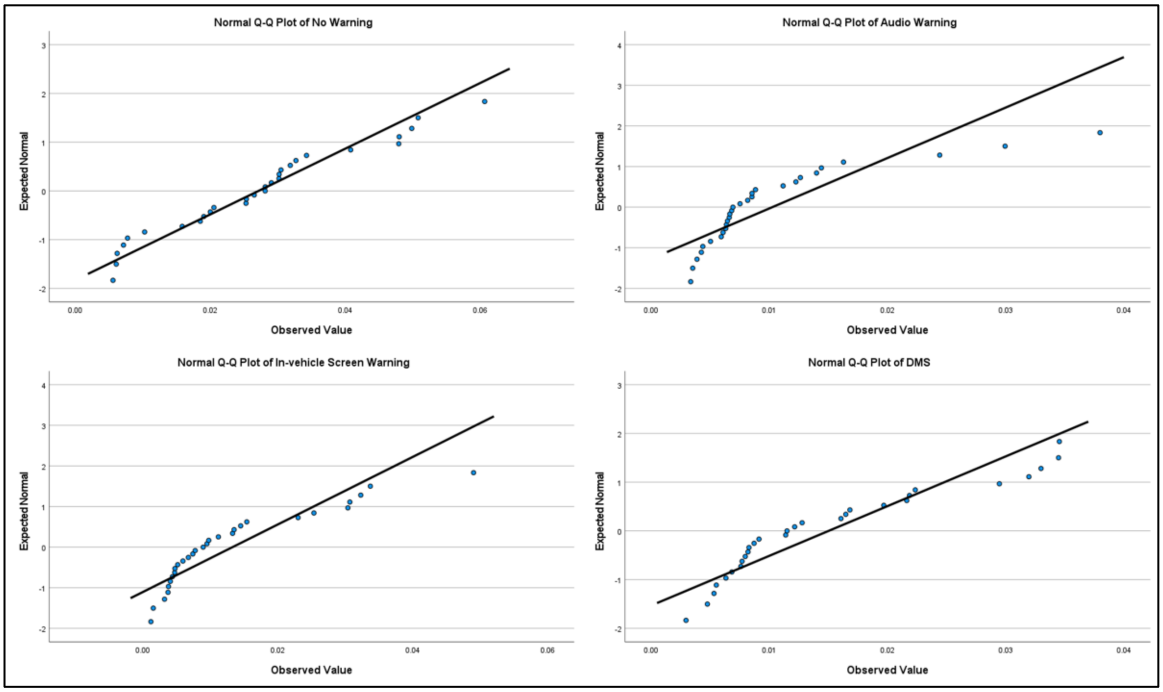


Figure 15: Mauchly's test for maximum acceleration

Mauchly's Test of Sphericity[a]

Measure: Maximum_Acceleration

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Warning	.630	6.799	5	.237	.791	1.000	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Results of ANOVA

As the sphericity assumption is met, the repeated measures ANOVA with sphericity assumed was used to determine the significant difference in maximum acceleration across the four scenarios. As p-value of within subject factor (warning types) is <0.001 in Table 18, it indicates that there is a significant difference in the maximum acceleration of the four scenarios. Results of post hoc tests (Table 19) using Bonferroni correction revealed significant difference of all three warnings with no warning scenario. Mean difference values indicate that maximum acceleration values were lower in all the scenarios with warning compared to that in no warning scenario.

Table 18: ANOVA results for maximum acceleration

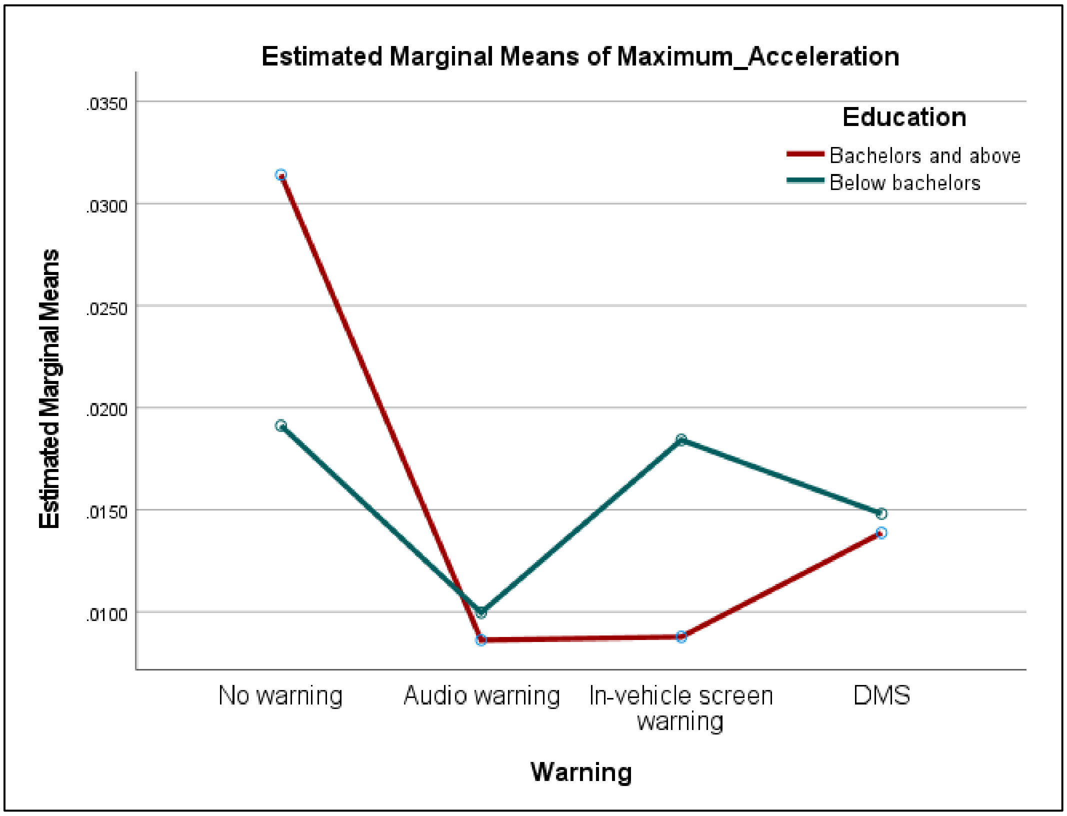
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
warning	0.003	3	0.001	8.212	**<.001**	0.339
warning * Gender	0.001	3	0	2.799	0.05	0.149
warning * Age	2.66E-05	3	8.87E-06	0.08	0.971	0.005
warning * Experience	0	3	8.90E-05	0.798	0.501	0.048
warning * Education	0.002	3	0.001	5.496	**0.003**	0.256
warning * Accident	0	3	6.49E-05	0.582	0.63	0.035

Table 19: Post hoc tests for maximum acceleration

(I) warning	(J) warning	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	0.019*	0.002	**<.001**	0.012	0.025
	3	0.016*	0.004	**0.005**	0.004	0.028
	4	0.013*	0.003	**0.005**	0.004	0.023
2	1	-0.019*	0.002	<.001	-0.025	-0.012
	3	-0.003	0.003	1	-0.012	0.006
	4	-0.005	0.003	0.44	-0.013	0.003
3	1	-0.016*	0.004	0.005	-0.028	-0.004
	2	0.003	0.003	1	-0.006	0.012
	4	-0.002	0.003	1	-0.012	0.007
4	1	-0.013*	0.003	0.005	-0.023	-0.004
	2	0.005	0.003	0.44	-0.003	0.013
	3	0.002	0.003	1	-0.007	0.012

There is also significant interaction between warning and education (p-value = 0.003). according to Table 18. Figure 16 suggests that education group 1 (Bachelors and above) has higher acceleration value than group 2 (Below bachelors) for no warning scenario which is opposite for audio warning scenario. Though acceleration reduced in audio warning scenario for both of the education group, group 2 now has little higher value. Whereas group 1 has same acceleration in In-vehicle screen warning, it is increased from 0.010 fts^{-2} to 0.018 fts^{-2} (by 80%) for group 2 drivers.

Figure 16: Profile plot for interactions between warning and education



In terms of between-subject factors, Table 20 indicates significant effect of age on maximum acceleration. Descriptive statistics reveal that participants of age 25 and above has little lower acceleration (0.015 fts^{-2}) than participants of age 18-24 (0.016 fts^{-2}).

Table 20: Analysis results for association of drivers' demographics and V2I warnings

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	0.019	1	0.019	181.49	<.001	0.919
Gender	5.20E-05	1	5.20E-05	0.505	0.488	0.031
Age	0	1	0	4.651	**0.047**	0.225
Experience	0	1	0	3.331	0.087	0.172
Education	0	1	0	1.174	0.295	0.068
Accident	1.94E-05	1	1.94E-05	0.188	0.67	0.012

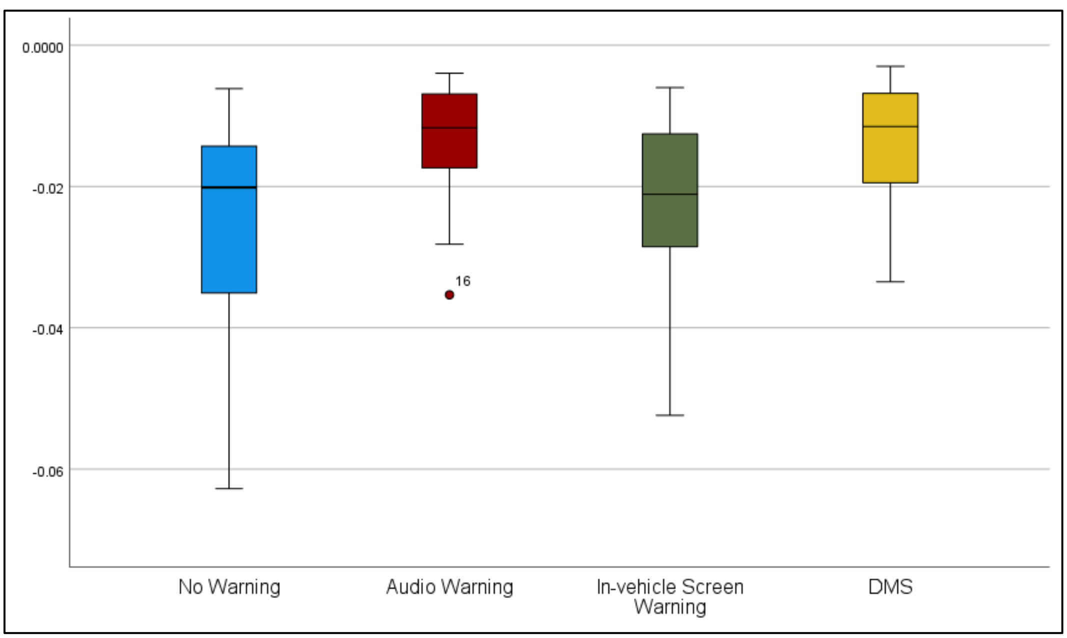
Maximum Deceleration Analysis

Table 21 shows the mean maximum deceleration values with standard deviation, minimum and maximum value throughout the four scenarios. Four observations were deleted for analyzing the maximum deceleration as those are very different from the remaining data. No warning has the highest maximum deceleration (-0.024 fts^{-2}) and audio warning has the lowest mean deceleration value (-0.013 fts^{-2}). This indicates audio warning as safer compared to other warning types. From the boxplots of this variable, it is visible that maximum deceleration has larger variability in all the scenarios except the scenario where audio warning was provided. This scenario also has lowest standard deviation among all of the scenarios (0.008). Overall, it can be suggested that drivers' deceleration behavior during heavy rain are safer if provided with audio warning compared to other two warnings. However, this warning type have one outlier.

Table 21: Summary of maximum deceleration for the four scenarios

	Mean	STD	Minimum	Maximum
No warning	-0.024	0.013	-0.063	-0.006
Audio warning	-0.013	0.008	-0.035	-0.004
In-vehicle screen warning	-0.022	0.012	-0.052	-0.006
DMS	-0.014	0.009	-0.033	-0.003

Figure 17: Maximum deceleration in four scenarios



Assumption Check for Repeated Measures ANOVA

For maximum deceleration, the Q-Q plots in Figure 18 indicates the normal distribution of the residuals and no significant outlier is visible. However, sphericity assumption is not met according to the p-value (0.020) of Mauchly's Test in Figure 19.

Figure 18: Q-Q plots for maximum deceleration in four scenarios

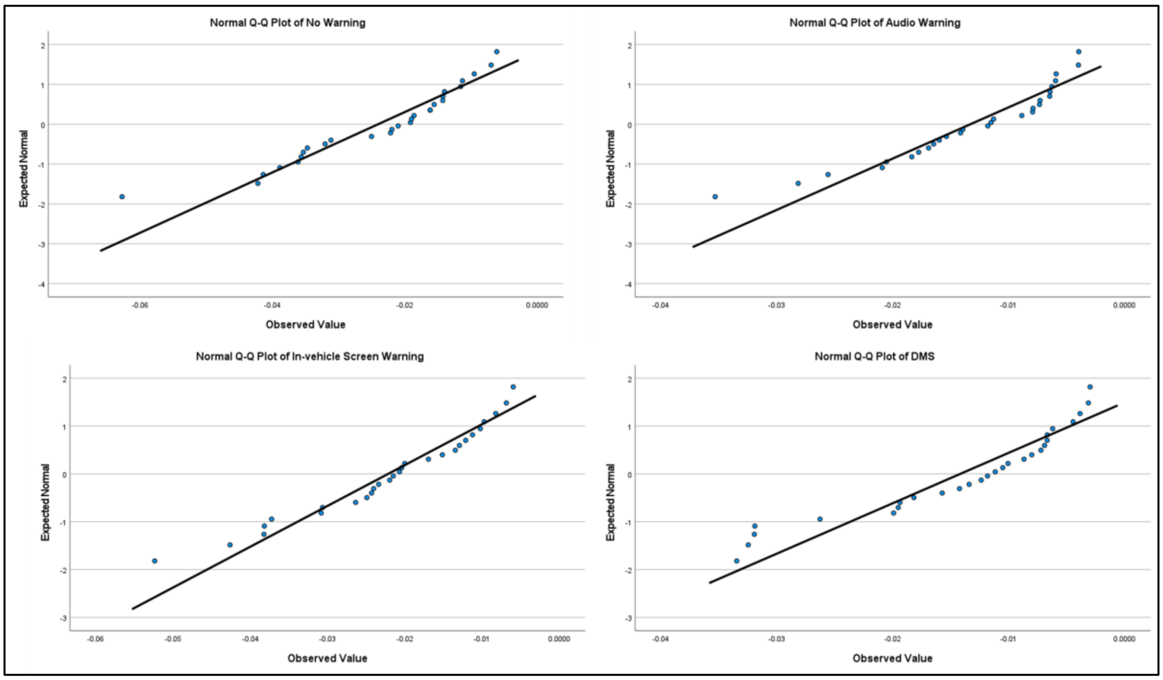


Figure 19: Mauchly's test for maximum deceleration

Mauchly's Test of Sphericity[a]

Measure: Maximum_Deceleration

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Warning	.377	13.374	5	.020	.629	1.000	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Results of ANOVA

As sphericity assumption was violated, to determine the statistically significant difference among the maximum deceleration of the four scenarios, repeated measures ANOVA with Greenhouse-Geisser correction was used. As seen in Table 22, at least one pair of scenarios have significantly different maximum deceleration ($p = 0.037 < 0.05$) which is further tested using post hoc test with Bonferroni correction. Results of the post hoc test in Table 23 indicates only audio warning has statically significant difference with no warning scenario in term maximum deceleration values.

According to Table 24 and Table 22, no significant between-subject (demographic characteristics of the drivers) main effect as well as no interaction between demographic and warning types were observed for maximum deceleration value during heavy rain.

Table 22: ANOVA results for maximum deceleration

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
warning	0.001	1.887	0.001	3.801	**0.037**	0.202
warning * Gender	0.001	1.887	0	2.02	0.153	0.119
warning * Age	0	1.887	0	1.747	0.194	0.104
warning * Experience	2.16E-05	1.887	1.14E-05	0.077	0.917	0.005
warning * Education	0.001	1.887	0	2.714	0.086	0.153
warning * Accident	2.97E-05	1.887	1.57E-05	0.106	0.89	0.007

Table 23: Post hoc tests for maximum deceleration

(I) warning	(J) warning	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1	2	-0.011*	0.002	**<.001**	-0.017	-0.005
	3	-0.003	0.004	1	-0.015	0.008
	4	-0.01	0.003	0.068	-0.02	0.001
2	1	0.011*	0.002	<.001	0.005	0.017
	3	0.008	0.003	0.14	-0.002	0.017
	4	0.001	0.002	1	-0.006	0.008
3	1	0.003	0.004	1	-0.008	0.015
	2	-0.008	0.003	0.14	-0.017	0.002
	4	-0.006	0.002	0.098	-0.014	0.001
4	1	0.01	0.003	0.068	-0.001	0.02
	2	-0.001	0.002	1	-0.008	0.006
	3	0.006	0.002	0.098	-0.001	0.014

Table 24: Analysis results for association of drivers' demographics and V2I warnings

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	.017	1	.017	77.073	<.001	.837
Gender	2.562E-5	1	2.562E-5	.119	.735	.008
Age	.000	1	.000	1.140	.303	.071
Experience	3.318E-5	1	3.318E-5	.154	.700	.010
Education	7.077E-5	1	7.077E-5	.329	.575	.021
Accident	5.699E-5	1	5.699E-5	.265	.614	.017

Compliance to the Warnings

Table 25 shows the mean initial speed and mean response speed for the heavy rain scenarios provided with warnings. From the difference it can be suggested that drivers reduced their speed after they received the audio warning and in-vehicle screen warning. However, negative value of difference for DMS suggests that drivers speed was not reduced after receiving this warning. To further analyze of the difference of these two variables, paired sample t-tests were conducted for every scenario. The p-values are enlisted in Table 25. Results show that only audio warning led to statistically significant difference between initial speed and response speed. Therefore, it can be suggested that drivers' compliance was higher in case of audio warning than other two warnings. Preference and efficiency of audio warnings (beeps/speech) over other visual warnings were also observed in the previous studies ([40]; [41]; [14]).

Table 25: Comparison of initial speed and response speed for four scenarios

Warning types	Initial speed	Response speed	Mean difference	P-value
Audio warning	61.1	56.8	4.2	<0.001
In-vehicle screen warning	56.2	55.5	0.6	0.199
DMS	56.4	58.4	-2.0	0.143

As can be seen from Table 25, audio warning and in-vehicle screen warning is helping to reduce travel speed beforehand of starting heavy rain. Thus, these warnings can be helpful in achieving speed harmonization to reduce the congestion or risk of crashes during heavy rain. Usually, traffic condition and weather condition are used to determine the recommendation of speed for speed harmonization application [42]. The speed recommendation then helps to gradually lower the speed before approaching traffic incidents, congestion or any other condition that might affect traffic flow [43]. However, speed harmonization, if achieved through heavy rain warning will facilitate in smoothing traffic operation by avoiding congestion and crash.

Table 26 enlists the number of participants who responded to the heavy rain warning by reducing their initial speed after receiving the warnings. For audio warning, 26 out of 32 participants responded to the warning by reducing their speed which led to 81.3% response rate. More than 50% of the participants responded to the in-vehicle screen warning and only one quarter of them responded to DMS warning for heavy rain. On average 54.2% compliance rate was observed across these three scenarios with heavy rain warning, whereas this percentage is only 31% for the same situation with no heavy rain warning. It indicates that participants' behaviors were changed due to the reaction to the V2I warnings. This result is consistent with the findings in a study where compliance rate was evaluated for response to V2I warning on intersection maneuvers [35].

Table 26: Response rate for the warnings

	Audio warning	In-vehicle screen warning	DMS	No warning
Responded	26	18	8	10
Ignored	6	14	24	22
Response rate	81.3%	56.3%	25%	31.3%

Conclusions

As we are proceeding towards the advancement of connected vehicle technology, it is necessary to understand how different technologies associated to connected vehicles (e.g., V2I) will be accepted to drivers. The objectives of this study are to investigate acceptance/attitude towards the advisories provided through V2I, examine the contributing factors behind the acceptance and evaluate the effect of V2I on traffic safety and operation.

To achieve these objectives, two main methods were applied in this study. First, a driving simulator experiment was designed and conducted to examine driver's reaction towards V2I warning on upcoming heavy rain. Four scenarios with three types of warning and one base scenario without any warning were simulated for this purpose. Second, a questionnaire survey was designed to understand drivers' preferences, opinion and need towards different visual and audio advisories. Participants of this survey were asked about their opinion on existing in-vehicle feature, navigation app features, their perceived importance regarding some V2I advisories, and their preferred method of receiving those warnings. Following are the findings from these two methods.

1. Survey respondents mostly appreciate various warning messages currently found in navigation applications, indicating that they prefer to have the warnings when possible. Only around 7% mentioned about not being familiar with certain features of navigation apps. Regarding the current in-vehicle features in recent vehicles, traffic collision ahead and lane closure ahead messages are favored heavily. Except the automatic high beam and adaptive cruise control, opinion about the importance of all other current in-vehicle features were mostly viewed as important or extremely important.

2. While investigating the participants' opinion toward V2I messages on different traffic condition (e.g., emergency vehicle warning), road condition (e.g., work zone warning) and environmental conditions, vast majority of participants (around 85%) claimed that V2I messages would be important or extremely important. The respondents had varying opinions on how to receive the messages. With most preferring in-vehicle auditory or visual messaging, DMS did not get much attention. Similarly, opinions on muting or outright disable were varied. Most felt they should not be able to be silenced (as with seatbelt warnings), while some felt that muting or outright disable should be allowed.

3. In terms of response rate, around 81% of the participants followed the audio warning and reduced their speed, followed by 56.3% and 25% for in-vehicle screen warning and DMS, respectively. Analysis of initial speed and response speed data from driving simulation experiment revealed that drivers complied to the audio warning and in-vehicle screen warning on heavy rain by reducing their speed. This speed reduction in advance of approaching the heavy rain is beneficial to alleviate the risk of crashes and reducing the congestion during the period of rain, thus increase the traffic efficiency and improve the traffic safety.

4. Results from Repeated measures ANOVA determined that warning had significant impact on response speed (speed after warning) and adopted speed (during remain) especially the adopted speed in audio warning scenario was significantly lower than no warning scenario. Both maximum acceleration and maximum deceleration during rain were affected by the warning. All the three scenarios with warning had lower acceleration than no warning scenarios for maximum acceleration, whereas only audio warning had significantly lower deceleration than no waning scenario.

5. Only driving experience was found to be associated with the speed variables of driving simulation experiment. Drivers with more than 5 years of experience had higher response speed as well as adopted speed compared to their counterparts. Drivers' age was associated with the maximum acceleration with younger driving having higher acceleration.

6. No significant effect of gender was found on either speed or acceleration/deceleration, which is consistent with previous studies on V2I warnings on intersection maneuvers [35] and V2I warnings on lane changing maneuvers in work zone [16].

7. However, there is an interaction effect of warning and drivers' education on maximum acceleration. Drivers with bachelors and higher degree was found to maintain almost similar acceleration both in audio and in-vehicle screen warning. On the contrasts, their counterparts' acceleration was increased by 80% in in-vehicle screen warning.

Overall, the result of this study concludes that most of the survey respondents perceive the V2I messages as important to improve their safety during driving at different traffic, road and environmental condition. In terms of acceptance of V2I message, audio warning and in-vehicle screen warning provides better compliance by reducing speed.

Though all the three warnings were helpful in reducing acceleration after the warning, only audio warning had significantly lowest speed during heavy rain. Driving experience, education and age were found to be contributing factors behind drivers' behaviors towards V2I warnings provided in this study.

The highest compliance rate to audio warning on heavy rain informs the transportation authorities that necessary arrangements can be taken to enhance safety by providing audio warning during heavy rain. Moreover, results of questionnaire survey provide insights about drivers' attitude towards importance of different V2I warnings as well as their preferences on receiving those warnings. Transportation authorities can use these results as a guide when prioritizing V2I warnings to be integrated with existing intelligent transportation systems as well as can better plan for implementing the method of providing these warnings. The results of this study can benefit all key stakeholders in strategic adoption and implementation of V2I technologies and in making informed decisions for the development of policies, guidelines, and procedures.

Recommendations

Audio warning were found to be more effective in facilitating the safety by reducing speed and acceleration. However, in-vehicle screen warning was also found to have little impact in terms of compliance. Therefore, it is recommended to collect more sample to verify these impacts of audio warning and in-vehicle screen warning in future studies. Another potential future work could be testing the combined effect of audio warning and in-vehicle screen warning.

Acronyms, Abbreviations, and Symbols

Term	**Description**
DMS	Dynamic Message Signs
V2I	Vehicle to Infrastructure
FHWA	Federal Highway Administration
ft.	foot (feet)
ITS	Intelligent Transportation Systems
DOT	Department of Transportation
LTRC	Louisiana Transportation Research Center
OBU	On-Board Unit
mph	Mile/hour
fts^{-2}	Feet per second squared

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