

# Understanding Driver Perceptions of a Vehicle to Vehicle (V2V) Communication System Using a Test Track Demonstration

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## ABSTRACT

Vehicle-to-vehicle (V2V) communication systems can enable a number of wireless-based vehicle features that can improve traffic safety, driver convenience, and roadway efficiency and facilitate many types of in-vehicle services. These systems have an extended communication range that can provide drivers with information about the position and movements of nearby V2V-equipped vehicles. Using this technology, these vehicles are able to communicate roadway events that are beyond the driver's view and provide advisory information that will aid drivers in avoiding collisions or congestion ahead. Given a typical communication range of 300 meters, drivers can potentially receive information well in advance of their arrival to a particular location. The timing and nature of presenting V2V information to the driver will vary depending on the nature and criticality of the scenario. The purpose of this study was to gather data on driver perceptions and opinions with respect to a V2V communication system. The 125 participants tested on the Virginia Smart Road experienced a V2V system capable of demonstrating various V2V applications. These applications included alerting the test participants to the following events ahead of the vehicle: vehicle braking hard, slow moving vehicle, vehicle with hazard warning lights activated, post-crash notification, electronic stability control (ESC) activation, and a potential intersection crash situation. The results indicated that the V2V applications demonstrated were well-received by test participants and were believed to provide safety benefits. These results, coupled with the relative affordability of V2V compared to other autonomous sensing systems, suggest that

the V2V system may with anticipated future levels of deployment provide a promising approach to improve traffic safety and increase the penetration of safety systems across the vehicle fleet.

## INTRODUCTION

Vehicle to Vehicle (V2V) wireless communication utilizes wireless technology to send information between vehicles that are similarly equipped. The vehicles can communicate and exchange information within a specific radius (e.g., ¼ mile) using global positioning system (GPS) capability and technology similar to Wi-Fi. For example, if a V2V-equipped vehicle brakes suddenly, this event can be relayed back to a following vehicle similarly equipped with V2V hardware which can trigger an alert (e.g., a flashing display and a beeping warning) to the following driver. More generally, V2V vehicles can exchange a wide range of safety, as well as non-safety, related information. The timing and nature of presenting information to the driver will vary depending on the nature and criticality of the scenario.

The purpose of this study was to gather data and information on driver perceptions and opinions with respect to potential near-term V2V applications. The prototype V2V system used a Driver Vehicle Interface (DVI) to communicate information associated with these applications to the driver.



**Figure 1. V2V Vehicles and DVI display mounted above the center stack**

## METHOD

### APPARATUS

The study used a combination of test vehicles that included two 2004 and two 2007 General Motors Cadillac CTS's equipped with prototype V2V technology, as well as two General Motors Cadillac sedans that were not equipped with V2V technology. The latter vehicles were driven by experimenters, and of the four V2V-equipped vehicles, two were driven by test participants and two were driven by experimenters.

A total of three vehicles constituted one experimental vehicle platoon (or research entity). For each platoon, a non-equipped V2V vehicle drove between the two equipped V2V vehicles. The lead (V2V-equipped) vehicle within a platoon, referred to as the “scenario vehicle”, was driven by an experimenter responsible for setting up each scenario. The second vehicle within a platoon, referred to as the “confederate vehicle”, was a non-equipped V2V vehicle driven by an experimenter. The last (V2V-equipped) vehicle within a platoon, referred to as the “participant vehicle”, was driven by a test participant and included an additional one or two passenger test participants. These “passenger” participants rode in the backseat, with a clear view of the DVI display area, while the experimenter in the participant vehicle rode as a front seat passenger.

Figure 1 shows the V2V vehicles and position of the top-of-dashboard DVI. When a V2V event was encountered an icon was displayed on the left side of the DVI display simultaneously with an auditory alert (i.e., a series of five warning beeps). A total of four icons were used which were based on previous icon comprehension/rating research conducted by General Motors. These icons were chosen based on the V2V applications examined under this effort. Only one icon and corresponding auditory alert was issued for each of the six scenarios included in the study. It should be noted that one of the icons was employed for three different scenario types.

The V2V auditory and visual alerts in the participant vehicle were activated by the V2V system in four of the scenarios and manually triggered by the experimenter (via a “Wizard of Oz” approach) in two of the scenarios for experimental convenience purposes. In the latter case, at a key point during the scenario, the experimenter in the lead V2 V-equipped vehicle would press a button that “artificially” triggered the V2V alert in the following participant vehicle.

The vehicles were instrumented to obtain both audio and video recordings. Audio recordings were made using a microphone located near the driver's steering wheel. Video recordings were gathered using four cameras mounted within the cabin of the vehicle. These cameras provided the

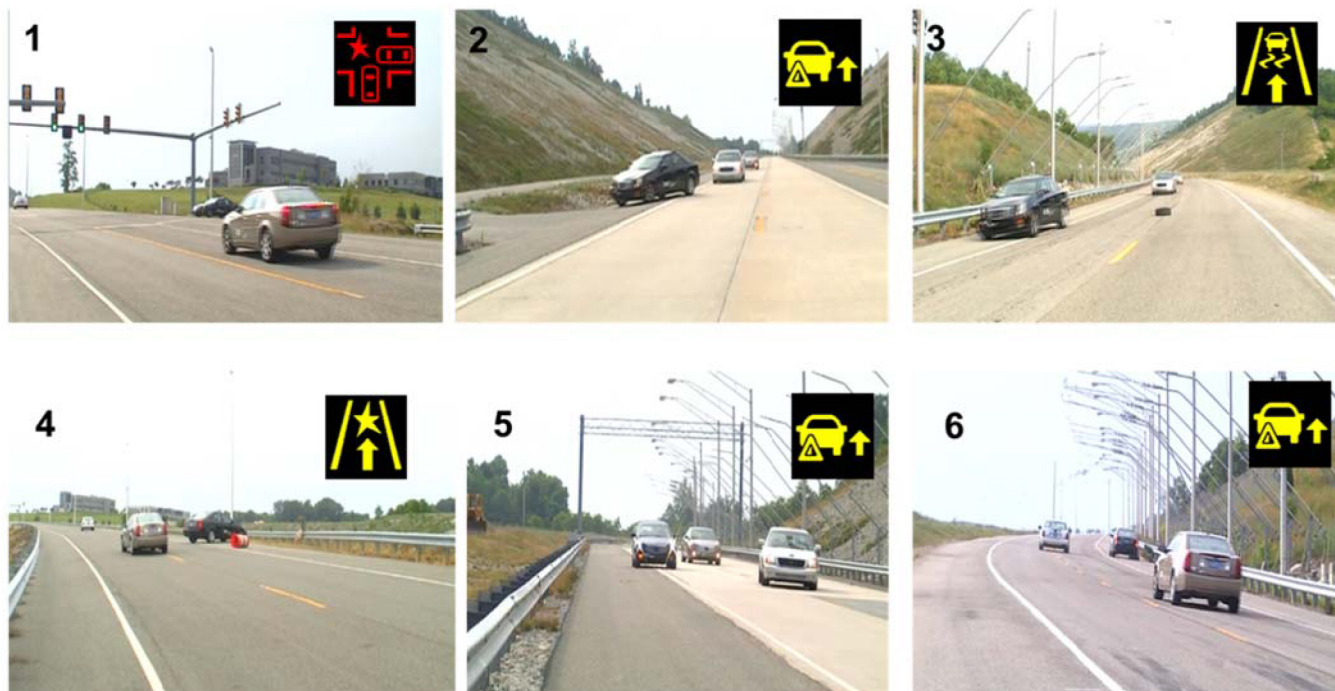


**Figure 2. V2V scenarios and corresponding icons that included: (1) a potential intersection crash situation, (2) vehicle braking hard, (3) ESC activation, (4) post-crash notification, (5) slow moving vehicle, and (6) vehicle with hazard warning lights activated.**

following views: driver face, forward roadway, over-the-shoulder steering wheel and the V2V display.

## Scenarios

A total of six V2V scenarios were examined which were linked to the corresponding icon presentations shown in [Figure 2](#). These scenarios illustrated to the participants how V2V technology could alert them to various types of events in their direction of travel, as well as the V2V alerting approach associated with each event type. Each of these scenarios corresponds to a potential V2V application (or feature). The scenarios included:

1. A potential intersection collision situation where the scenario vehicle was positioned in the crossing path at an intersection. Based on predefined timing, the scenario vehicle would accelerate as if it was going to run across the intersection and run the red light, but then stop short of entering the intersection. The alert was presented when the participant vehicle was approximately 4 seconds from the intersection.
2. A hard braking scenario where the lead platoon vehicle initiated a “last second” right turn and rapidly decelerated. When the deceleration exceeded 0.3 g's, the hard braking ahead alert in the participant vehicle was activated.
3. The Electronic Stability Control (ESC) alert scenario involved a tire tread being placed in the roadway well in advance of the vehicle platoon. The ESC alert was activated

in the participant vehicle when the scenario vehicle driver swerved aggressively to avoid the tire.

4. For the Post Crash Notification (PCN) scenario, the scenario vehicle accelerated well ahead of the other vehicles to the predetermined PCN location, and staged what appeared to be a minor collision situation with a roadside work zone barrel. An alert was issued to the V2V platoon vehicle up to ¼ mile before the mock accident site.
5. The slow moving vehicle scenario involved the scenario vehicle straddling the shoulder line with the right turn signal activated. The slow moving vehicle alert was received by the participant vehicle when the vehicle was within a ¼ mile radius of the scenario vehicle.
6. In the vehicle hazard light activated scenario, the scenario vehicle accelerated well ahead of the other vehicles to a location and pulled off to the shoulder of the roadway. Once positioned out of the participants' view (around a curve), the scenario vehicle driver placed a tire tread near the rear right tire of the vehicle (as if they were changing a tire) and activated the hazard warning lights.

## The Virginia Smart Road

The Virginia Smart Road is a unique, state-of-the-art, full-scale, 2.2 mile closed test-bed research facility managed by the Virginia Tech Transportation Institute (VTTI) and owned and maintained by Virginia Department of Transportation (VDOT). The scenario event locations and the platoon stopping points along the test roadway are shown in [Figure 3](#).

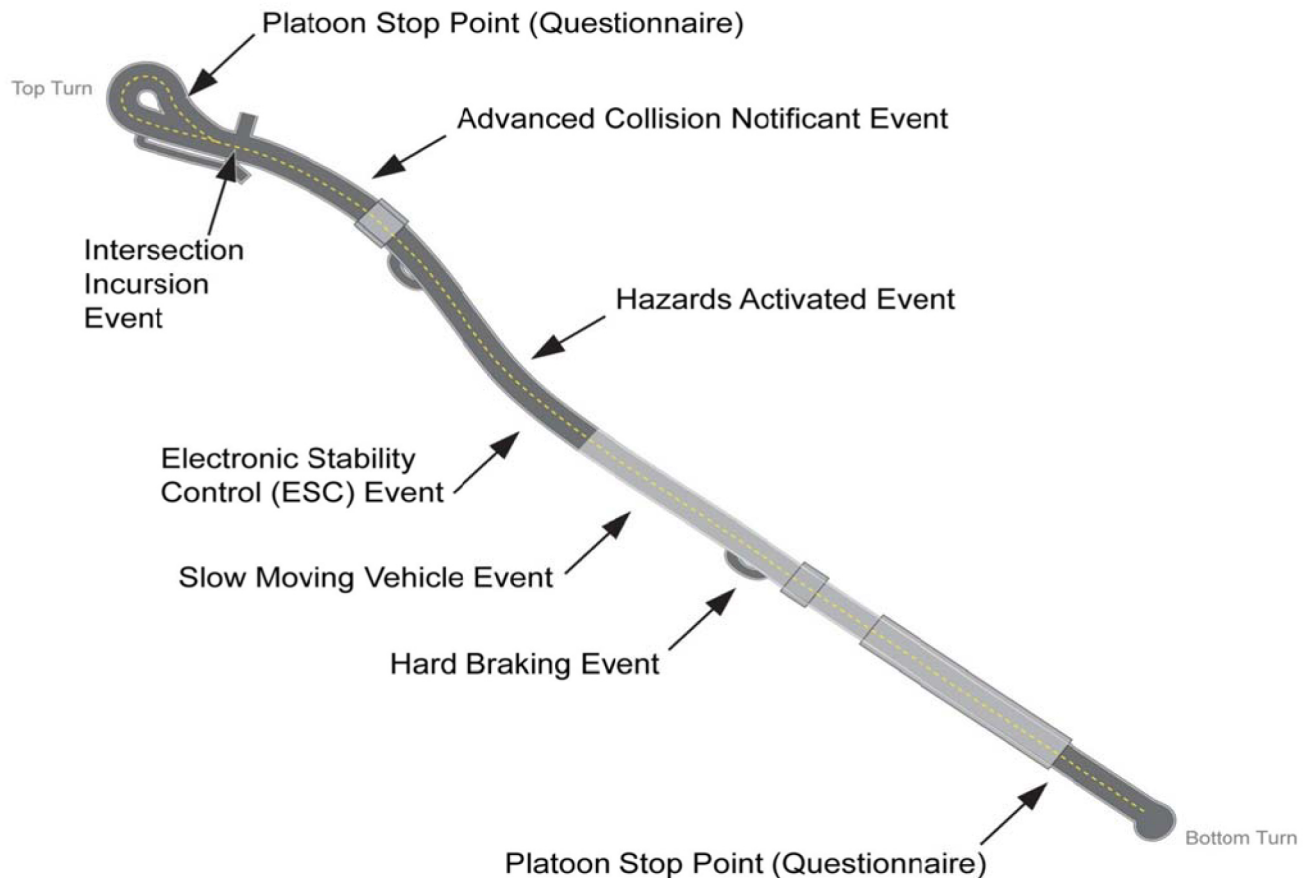


**Figure 3. Virginia Smart Road Test Track and Scenario Locations.** (\*Note: ESC, hazards activated, and slow moving vehicle events were randomized between the three locations marked by these events in the figure.)

These locations were chosen to enhance the realism of the various V2V scenarios. The intersection incursion, PCN, and hard braking ahead scenarios always occurred at the same pre-defined location. The remaining three scenarios (ESC, slow moving vehicle ahead, vehicle ahead with hazard warning lights activated) occurred in either an uphill or downhill direction on a relatively straight section at the midpoint of the test track. Figure 3 shows the locations of the scenario events. The ESC, slow moving vehicle, and hazard warning events were randomized between the three locations indicated by these events in the figure.

The stop points at each end of the roadway allowed the lead scenario vehicle to rejoin their respective vehicle platoon and clear the roadway for the next vehicle platoon to proceed. In addition, these stop points allowed the test participants to fill out a post-experience questionnaire about the scenario and their impression about the corresponding alert (DVI) approach that they had just experienced. The platoon vehicles were positioned such that one vehicle platoon could not view the scenarios the other vehicle platoon experienced.

## PARTICIPANTS

Of the 125 participants, 63 were male and 62 were female. The average age of the entire sample was 51 years old. The age distribution of these participants is provided in Table 1.

**Table 1. Age Groups Sample Sizes**

| Age Groups | Sample Size |
|------------|-------------|
| 18-29      | 20          |
| 30-39      | 16          |
| 40-49      | 13          |
| 50-59      | 29          |
| 60-69      | 33          |
| 70+        | 14          |
| Total      | 125         |

Participants were paid \$20 per hour and were free to withdraw from the study at any time (none elected to withdraw). The typical test session, which included pre-drive paperwork, test drives, and post-drive questionnaires, lasted about three and a half hours.

## STUDY DESIGN

The focus of this study was to obtain subjective feedback via questionnaires from the driver and passenger test participants riding in the participant vehicle. The questionnaires administered included a background (screening) questionnaire, a pre-drive questionnaire, a series of post-scenario questionnaires administered following each individual V2V scenario, and a post-drive questionnaire. Two-thirds of the participants were tested under daylight conditions (n=82), with remaining participants tested under nighttime conditions (n=43).

## PROCEDURE

Upon arrival, participants were asked to sign an informed consent statement. After consenting to participate, a simple visual and auditory test was administered. Following successful visual and auditory screening, each participant completed a pre-drive questionnaire. The test participants were then randomly chosen to ride in one of the two V2V-equipped participant vehicles. Test participants were provided a brief overview of V2V technology prior to the feature demonstration drives, but were not provided information in advance on the specific nature of the V2V features prior to experiencing them during the demonstration. This latter experimental strategy was employed to determine the extent to which the alert approach provided an intuitive explanation of the scenario, and to loosely approximate what drivers might experience when first exposed to the various V2V technology features examined in this effort.

Participants within each participant vehicle decided among themselves who would drive the participant vehicle for the entire test. If more than one participant wanted to drive, the driver was chosen by a coin flip. After escorting the participants to the participant vehicles and verifying that the rear seat test participant passengers were comfortable, the in-vehicle experimenter introduced the vehicle to the participant driver. These drivers were shown how to adjust the mirrors, activate the windshield wipers, and adjust the driver's seat. The in-vehicle experimenter then reviewed the protocol for the driving portion of the study. In addition to outlining the speed limit (45 MPH) and explaining the practice lap portion of the study, the in-vehicle experimenter reviewed the V2V system, pointed out the V2V display, and confirmed the participant could see the V2V display.

Participants were then informed that they would experience a series of scenarios while riding in the test vehicle, and were instructed to maintain view of the V2V display during the V2V feature demonstration drives. Passenger participants were instructed to evaluate the scenario as if they were driving the vehicle. Participants were asked to refrain from discussing any comments or thoughts they had with others in the vehicle during their entire set of feature demonstration drives. In addition, participants were told that they would

have the opportunity to openly share their views about their experiences with other participants and researcher after completing the entire test drive in a focus group session.

When the drivers and vehicles were ready to continue, each participant vehicle joined their respective vehicle platoon that included the confederate vehicle and the scenario vehicle. When each of the two vehicle platoons was ready to begin they drove to the Virginia Smart Road. On the test road, participants first experienced a practice lap to get familiar with the vehicle and the roadway. After this lap, participants experienced a different scenario during each "run" (or length) of the test road in a randomized order. All participants completed six runs and experienced each of the six V2V feature demonstration scenarios once. The test runs were choreographed such that the two vehicle platoon paths never crossed, and that both platoons experienced different orders of the six scenarios in order to minimize order bias.

After each V2V scenario, the participant vehicle drove to a pre-determined location (or platoon stop point) located at the top or bottom of the test track (see [Figure 3](#)). With the vehicle parked, participants were asked to individually complete a one-page written questionnaire concerning the V2V display/feature they had just experienced. It is important to note that participants were not provided any advance information on the V2V demonstration scenario prior to experiencing the scenario. The in-vehicle questionnaire administered following each scenario contained a picture of the corresponding icon (shown on the V2V display) they had experienced during the scenario. The questionnaire asked participants to rate the timing of the alert, interpret the message/icon in their own words for each scenario, and rate the icon clarity, usefulness of the alert, perceived safety and willingness to have V2V on their next vehicle.

When each participant had completed the questionnaire for a given scenario, the in-vehicle experimenter gathered the questionnaires in order to prevent participants from looking back to their previous questionnaire responses.

After completion of the in-vehicle questionnaire for a given scenario, the in-vehicle experimenter confirmed that the road was clear for the next scenario and signaled the driver of the scenario vehicle to begin the next run. When all six scenarios had been completed, the platoon then exited the test road and returned to the research building. Participants then completed a post-drive questionnaire on the V2V system.

## RESULTS

The result section discusses the participants' impressions of the V2V system. In cases where questions employed Likert scales (described below), Chi-Square statistics were conducted to examine the effects of gender (males versus females) and time of day (daytime versus nighttime). These

**Table 2. Percentage breakdown of responses to the post scenario questions for the intersection collision danger event.**

| Question                                                               | Gender       |              | Daytime/Nighttime |               |
|------------------------------------------------------------------------|--------------|--------------|-------------------|---------------|
|                                                                        | Male         | Female       | Day               | Night         |
| In my opinion, the message appeared: - At the right time (Too Late)    | 69%<br>(31%) | 52%<br>(45%) | 70%*<br>(27%)     | 40%*<br>(60%) |
| The icon clearly communicates the intended message? – Agree (Disagree) | 71%<br>(15%) | 80%<br>(12%) | 74%<br>(10%)      | 78%<br>(20%)  |
| The feature provides useful information? - Agree (Disagree)            | 84%<br>(12%) | 89% (8%)     | 89%<br>(8%)       | 82%<br>(16%)  |
| The feature would increase my driving safety? - Agree (Disagree)       | 79%<br>(13%) | 86%<br>(10%) | 85%<br>(8%)       | 76%<br>(16%)  |
| I want this feature on my next vehicle? Agree (Disagree)               | 75%<br>(17%) | 83%<br>(10%) | 82%<br>(10%)      | 75%<br>(21%)  |

(\* Significant difference between groups  $p < 0.05$ )

paired comparisons were made by collapsing the agree/disagree categories and removing the neutral category. Unless indicated, no significant differences were found between group pairs ( $p < 0.05$  criterion was used as the statistical significance criterion).

For each of the V2V scenarios, participants were asked to provide feedback on a variety of elements. First, participants were asked to describe in their own words what the DVI icon was communicating during the scenario and rate the appropriateness of the alert timing (“too early”, “at the right time”, or “too late”). The participant interpretations were categorized based on commonalities. Participants were then asked to rate four statements on a 5-point Likert scale (where: 1= Strongly Disagree, 2 = Disagree, 3 = Neutral, 4= Agree and 5= Strongly Agree). These statements addressed the extent to which the alert communicated the intended message (i.e., message interpretability), the alert was useful, the alert would increase their driving safety, and the alert was desirable in their next vehicle.

## INTERSECTION COLLISION DANGER

As shown in Table 2, 60% of the participants (ranging between 40% - 70% across groups) rated the timing of the intersection collision danger alert as occurring at the right time. A significant difference was found between daytime and nighttime groups,  $\chi^2(1, N=119) = 11.58, p < 0.01$ , with the nighttime group rating the alert as occurring “too late” in 60% of the cases compared to 27% under daytime conditions. This finding may be due to the added difficulty to observe this scenario under nighttime conditions. The remaining questions addressing icon usefulness, applicability to driver safety, and feature purchase interest received relatively high positive responses.

### Message Interpretation with Intersection Collision Danger Scenario

Table 3 outlines the response categories derived when participants were asked to provide an open-ended

interpretation of the DVI (i.e., visual alert icon) after experiencing this feature demonstration scenario. Consistent with the message interpretability ratings discussed above for this alert (i.e., “Icon communicates message?”), participants interpreted the message as intended. This suggests the driver would pay attention to the crossing vehicle and exhibit caution.

**Table 3. Intersection Collision Danger Message Categorization**

| Message Categories                                             | Percent Response |
|----------------------------------------------------------------|------------------|
| Car coming through intersection/intersection hazard            | 35%              |
| Car rapidly approaching/Car approaching from right             | 27%              |
| Possible collision/Collision course/Crash likely               | 18%              |
| Other: Car failing to stop/cross traffic/car pulling out, etc. | 18%              |

## HARD BRAKING AHEAD

As shown in Table 4, 60% of the participants (ranging between 52% - 60% across groups) rated the timing of the hard braking ahead alert as occurring at the right time, with 40% suggesting the alert timing was “too late”. This latter bias, similar to the Time of Day effect observed in the intersection incursion scenario, may be related once again to the perceived urgency of this scenario and the participant's desire for additional time to respond to this scenario. The reader should be reminded that the alert in this scenario was issued as soon as the (lead) scenario vehicle exceeded 0.3 g's. Therefore, from an alert timing perspective, there was no opportunity to issue the alert any sooner (given this 0.3 g braking criterion) than what drivers experienced in the current study. Furthermore, it should be noted that lowering the threshold for triggering this alert (which would have made the alert come on sooner) could be problematic from a nuisance alert (or false alarm) perspective. The icon