

FIELD TEST OF A COOPERATIVE INTERSECTION COLLISION AVOIDANCE SYSTEM FOR VIOLATIONS (CICAS-V)

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ABSTRACT

The design objective of the Cooperative Intersection Collision Avoidance System for Violation (CICAS-V) project is to create a system that presents a timely and salient in-vehicle warning to those drivers who are predicted, by means of an algorithm, to violate a stop-sign or signal-controlled intersection. An on-road test was conducted to evaluate the CICAS-V using naïve participants to demonstrate that all systems are mature for a Field Operational Test (FOT). Data were evaluated from 72 naïve drivers representing both genders and three age groups who were placed into CICAS-V equipped vehicles to navigate a 2-hour prescribed route through equipped intersections in Virginia. During the prescribed route, drivers crossed 10 stop-controlled and 3 signal-controlled intersections equipped with CICAS-V making a variety of turn maneuvers through each for a total of 52 intersection crossings. The rate at which drivers received correct, false, and missed warnings was evaluated. Results indicate that the algorithms for both stop-controlled and signalized intersections were effective and that the prototype CICAS-V is mature for large-scale tests with naïve drivers. Participants in the study who received warnings rated the CICAS-V very favorably and felt that the system would be beneficial. Recommendations were made for continuing with an FOT. Furthermore, the methods for conducting the study were determined to be suitable for an FOT. This study marked the first field test of the CICAS-V with naïve drivers. Project participants included offices of the United States Department of Transportation, Daimler, Ford, General Motors, Honda, Toyota, and the Virginia Tech Transportation Institute.

INTRODUCTION

Intersection crashes account for thousands of injuries and fatalities in the United States every year (National Highway Traffic Safety Administration, 2006). Drivers running stop-controlled and red-phased signalized intersections cost over \$7.9 billion in economic loss each year (Najm et al., 2007). The objective of a Cooperative Intersection Collision

Avoidance System for Violations (CICAS-V) is to assist drivers in avoiding intersection crashes. The basic design objective of the CICAS-V is to create a system that presents a timely and salient in-vehicle warning to those drivers who are predicted, by means of an algorithm, to violate a stop light or a stop sign. The warning is intended to elicit a behavior from the driver that will motivate him or her to respond appropriately to avoid a violation; by doing this, the driver will also avoid a potential intersection crash should cross traffic be present.

The CICAS-V project consisted of 14 tasks to complete design, development, and testing of the CICAS-V (Maile et al., in print-c). This paper describes the process and results of an on-road study to test the system. Naïve drivers were placed into CICAS-V equipped vehicles to navigate a 2-hour prescribed route through designated intersections. The following sections report the method for this task.

METHOD

The experiment consisted of a Pseudo-Naturalistic Study (a pre-determined route on open roadways without an experimenter in the vehicle) investigating the CICAS-V in live traffic. The methods and equipment used are described in the subsequent sections.

Drivers

Drivers were recruited through the newspaper, posted flyers, word of mouth, and the Virginia Tech Transportation Institute (VTTI) database of people who had expressed an interest in participating in studies. On initial contact (usually over the phone), individuals were screened to ensure their eligibility for the study. Eligibility criteria included restrictions barring participation by individuals with: 1) health conditions or medication intake that may interfere with their ability to operate a motor vehicle, or 2) more than two moving violations or any at-fault accidents within the previous three years. The

criteria also included the requirement that drivers had to possess a valid driver's license.

CICAS-V Equipment and Data Acquisition System (DAS)

The following sections describe the hardware and software used. This includes the CICAS-V designed and developed, and the experimental equipment constructed, to directly support the study.

CICAS-V Description – The system engineering, system design, and prototype build of the CICAS-V were conducted by the Collision Avoidance Metrics Partnership Vehicle Safety Communications 2 Consortium (CAMP VSC2), which included the representatives of Ford, General Motors, Daimler, Honda, and Toyota (Maile et al., in print-c). The CICAS-V contains several components working together to predict a stop-sign or red-phased signal violation, and present a warning to the driver when appropriate. To provide context, an overview of the CICAS-V is included.

The CICAS-V is comprised of onboard equipment (OBE) and roadside equipment (RSE). As part of the OBE, the Wireless Safety Unit (WSU) developed by DENSO is the central processing component of the CICAS-V network. It is responsible for collecting data from the vehicle and sensors from which it computes an algorithm to predict when a violation may occur and, based on that prediction, issues a warning to the driver through the Driver-Vehicle Interface (DVI). The WSU receives data from the vehicle Controller Area Network (CAN), the global positioning system (GPS), and Dedicated Short Range Communications (DSRC) messages. These data are pre-processed and then evaluated in parallel with the warning algorithm. If the algorithm predicts a violation, the WSU activates the DVI.

The WSU controls the three DVI modalities – auditory, visual, and haptic. The DVI has three states: 1) an inactive state when the vehicle is not approaching an equipped intersection; 2) a visual-only indication when approaching an equipped intersection; and 3) a full warning mode that encompasses a “single stage” activation of the visual, auditory, and haptic alerts.

The auditory warning consisted of a female voice stating “Stop Light” or “Stop Sign”, presented at 72.6 dBA out of the front speakers, measured at the location of the driver's head.

The visual warning is displayed by a dash-mounted icon (Figure 1) positioned at the vehicle centerline

near the cowl of the windshield. As implemented in the vehicle, the visual icon was 11.6 mm (0.46 inches) high and 11.6 mm (0.46 inches) wide. It was illuminated as either steady, continuous blue (advisory), or flashing red (warning).



Figure 1. The visual display is located on the dash of the experimental vehicle.

The haptic brake pulse command was sent to the Original Equipment Manufacturer (OEM) brake controller. When the warning was activated, a single 600-millisecond (ms) brake pulse was presented in conjunction with the visual icon and an auditory warning. The brake pulse was triggered immediately before the onset of the visual and auditory warnings, so that deceleration would reach ~ 0.10 g at approximately the same time as the visual and auditory warning onset. Peak deceleration from the haptic pulse was ~ 0.3 g.

To appropriately activate the DVI, the WSU required vehicle kinematic data from which the threat assessment was performed. The OEM vehicle network provided data such as brake status and velocity to a Netway box. The Netway box, exclusively programmed by each of the OEMs, was used to translate OEM-specific controller area network (CAN) messages to a standardized CAN format compatible with the WSU.

A GPS system provided longitude/latitude positioning data to the WSU. This allowed the WSU to place the vehicle on a digital representation of the intersection called the Geometric Intersection Description (GID). GIDs were obtained from one of the three RSEs located at the signalized intersections. The RSEs provided GIDs for both stop-controlled and signalized intersections. Each GID was retained on the WSU unless a newer version was provided by the RSE.

In addition to the GIDs, the RSEs also sent differential GPS corrections (allowing the vehicle to accurately place itself on the GID) and signal phase and timing (SPaT) information. The messages were sent by a second WSU within the RSE. The SPaT message was supplied to the RSE by custom firmware installed on the traffic signal controllers, while a GPS base station provided the differential corrections.

Vehicle DAS - The vehicle DAS was used to record digital video and kinematic data from multiple sources, and was composed of hardware, software, and data storage components (Stone et al., in print). The DAS collected variables representing the information necessary to reconstruct a vehicle's intersection approach and the drivers' interaction with the CICAS-V. A short overview of the DAS is provided in this section.

The vehicle DAS hardware consisted of a main unit, a video system, front and rear radar, and a GPS unit. The main unit contained an Embedded Platform for Industrial Computing (EPIC) single-board computer, hard drive, CAN communication, battery backup system, and several VTTI-developed sensor modules. Four unobtrusive cameras installed in the passenger compartment captured the scene in and around the vehicle.

The DAS was attached directly to the OBE CAN which provided all of the CICAS-V variables. The DAS recorded the CICAS-V variables for use in system validation and driver performance analyses. Variables pertinent to the study included the velocity, distance to the stop bar, DVI status, signal phase and signal timing. Additional variables were also collected by the DAS from a network of sensors installed on the vehicle. Front and rear radar units provided the range and velocity of lead and following vehicles. A Crossbow™ inertial measurement unit provided three-axis acceleration and angular rate information.

Data were stored on a 120GB removable hard drive within the main unit. It was accessed and downloaded to a laptop over an Ethernet interface. The download interface included a system health-check component that ensured data integrity was maintained between drivers. This allowed quick transfer of data and indication of whether the participant received a warning without shutting down the system.

Custom-built Navigation System - In order to ensure that drivers could easily and reliably navigate the prescribed route, VTTI built a custom navigation

system. The custom navigation system consisted of a laptop computer and a low cost Wide Area Augmentation System (WAAS)-enabled GPS antenna. The system played auditory instructions over a speaker in the front of the vehicle based on the current position of the subject along the route. The custom software solution allowed the researchers to record the instructions to play and to guarantee the timing of the instructions so as not to distract the driver while approaching an equipped intersection.

Pseudo-Naturalistic Study Protocol

Upon arriving at the Institute, participants were met by the greeter and asked to read an informed consent form. The form provided specific information about the study, including the procedures, risks involved, and measures for confidentiality. After agreeing to the study and signing the informed consent, a health screening questionnaire was administered to ensure that participants did not have any conditions that would impair their ability to safely operate the test vehicle. A Snellen vision test was conducted to ensure the participants' visual abilities were within Virginia legal limits of corrected to 20/40 or better. A color vision test was conducted using the Ishihara Test for Color Blindness, and a contrast sensitivity test was performed. The color vision test and the contrast sensitivity tests were recorded for possible future analyses but were not used for screening purposes. If it was found that participants were not in good health, or if vision results fell outside the acceptable limits, they would be excused from the study and paid for their participation time. Eligible participants were issued a short pre-drive questionnaire focusing on their driving experiences and habits.

The pseudo-naturalistic field test was conducted on a predetermined route in Blacksburg and Christiansburg, Virginia. The route was crafted to pass through many stop-controlled and signalized intersections while performing a variety of maneuvers (i.e., straight, left, and right turns). The route was approximately 36 miles long, and contained 13 intersections that were integrated into the CICAS-V. Three signalized and 10 stop-controlled intersections were chosen for evaluation.

The route led drivers through each equipped intersection multiple times and was designed with three goals in mind. First, to ensure the driving participants' comfort and minimize driving fatigue, the route had to be less than 2 hours in duration. Second, the route had to maximize the number of intersection crossings while retaining a feasible

number of intersections (time constraints did not allow for a large number of intersections to be integrated into the CICAS-V). Finally, a variety of turn maneuvers were desirable in order to fully test the CICAS-V. For example, correct operation of the CICAS-V at signalized intersections often depends upon lane position information; therefore, various turn maneuvers at signalized intersections would indicate if the system was correctly mapping the lane to its signal indication. Also, a driver's intersection

approach often has different trajectory characteristics if the driver is turning left, right, or straight through the intersection; accommodating these approach variations directly relates to algorithm evaluation. The turn maneuver summary table for the 13 intersections can be seen in Table 1. There were a total of 20 signal-controlled intersection crossings and 32 stop-controlled intersection crossings along the route.

Table 1.
Summary of Turn Maneuvers for Pseudo-Naturalistic Study Experimental Method

3 Signalized Intersections				10 Stop-Controlled Intersections			Total
Permissive Left	Protected Left	Straight	Right	Left	Straight	Right	
2	5	11	2	12	6	14	52

After undergoing the initial paperwork process, participants were led outside where the experimenter introduced them to the test vehicle. Participants were given a brief tutorial on basic vehicle functions, including ignition procedures, seat movement, and the HVAC (heating, ventilation, and air conditioning) system. During the static pre-drive vehicle orientation, the different safety systems available in the experimental vehicle were briefly reviewed. The systems reviewed with the participants were the forward collision warning, backing aid, and the CICAS-V such that drivers were led to believe that various safety systems were being evaluated. The goal was to make the driver aware of the CICAS-V but not to emphasize it over the other available vehicle safety technologies.

During the route, participants received turn-by-turn directions from the custom-built GPS-based navigation system. The navigation system was audio-based and not an integrated vehicle system; therefore, in order to alleviate additional distractions, participants were instructed not to use the radio or CD player for the duration of the test drive. Emergency procedures were reviewed, including the location and proper use of a cellular telephone provided by VTTI. Participants were encouraged to call the experimenter at VTTI, from a stopped location, using a number taped to the phone if they encountered any problems (e.g., getting lost, failure of the navigation system, or mechanical problems with the vehicle). Once participants felt comfortable with the vehicle, they began the Pseudo-Naturalistic Study without any experimenter in the vehicle.

When participants returned, a laptop running specialized software was attached to the trunk-mounted DAS. While the experimenter downloaded the data, the interface indicated the number of warnings that were issued and the number of intersections that were crossed. This interface was used to determine which of the questionnaires was administered, based on whether a warning was issued. In addition, the number of equipped intersection crossings was used to determine the extent to which the driver experienced the entire test route. Since an experimenter was not present in the vehicle, it was foreseeable that some drivers might not follow the prescribed route or would not correctly understand the navigation instructions. Therefore, to motivate drivers to stay on route, a bonus was provided for drivers who crossed more than 40 equipped intersections.

At the same time, the greeter met the participants and led them indoors to a private office. Drivers then completed one of two post-drive questionnaires depending on whether they did or did not receive a warning. The questionnaires assessed what aspects of the CICAS-V system the drivers noticed and what they thought of the system.

Upon completion of the post-drive questionnaire, participants were paid, thanked for their time, and dismissed. The route took approximately 2 hours to complete, and with pre- and post-drive procedures, total participation time was 2 hours 45 minutes.

An important note for the Pseudo-Naturalistic Study protocol is that not every participant in the study experienced the same warning algorithms. As stated

previously, one of the goals of the study was to iteratively refine the warning algorithm. In other words, researchers conducted initial data reviews to determine the success of the warning algorithms, and make changes based on the driving outcomes. This aspect of the study, including the breakdown of subjects receiving each algorithm, is discussed in detail in the Results and Discussion section.

Validation and Analysis Techniques

Recall that the primary purpose of the study was to determine how well the CICAS-V operated in order to determine if the system was mature enough for an FOT. To determine the validity of a violation warning, several variables in addition to the video were viewed by the data reduction staff. These were:

- **DVI Status:** The DVI was disabled because the vehicle was not within range of an intersection, or it was within range of an intersection and providing the blue “intersection ahead” icon, or it was within range of an intersection and providing a violation warning.
- **Current Approach Phase:** Red, Yellow, or Green
- **Brake Status:** The driver was either pressing the brake or not pressing the brake.
- **Distance to Stop Bar (m):** Distance from the front of the vehicle to the stop bar. This was used together with “vehicle speed” to determine if the algorithm was warning correctly.
- **Improved Distance to Stop Bar (m):** Distance to stop bar with missing points filled in using GPS. The raw Distance to Stop Bar provided by the WSU would drop out whenever the vehicle was not placed on the GID. The Enhanced Distance to Stop Bar continued to provide data during those drop outs.
- **Intersection ID:** The identification number that was assigned to each CICAS-V intersection and incorporated into the GID.
- **Longitudinal Acceleration (g):** Used to determine whether or not the brake pulse activated appropriately.
- **On GID:** A binary indication of whether the vehicle is map-matched to the GID. It was used to determine when the vehicle was not map-matched within the warning region.
- **Present Lane:** As labeled and identified in the GID. Associated with the signal phase and video to ensure that the system was identifying the correct lane position and warning accordingly.
- **SPaT Counter:** A counter that increments when the OBE is receiving messages from the RSE. It was used to determine when SPaT messages were not received within the warning region.

- **Vehicle Speed (m/s):** Used with “distance to stop bar” to determine if the algorithm was warning correctly.

The primary goal of data reduction was to validate CICAS-V warnings that were automatically identified in the parametric data. Data reductionists determined if the CICAS-V warning was appropriate by reviewing the video. For the signalized intersections, data reductionists examined the intersection signal phase and timing relative to the vehicle proximity to the stop bar. If the signal phase was red and the vehicle was over the stop bar, the warning was deemed appropriate. For the stop-controlled intersections, data reductionists verified that the warning was provided at a stop-controlled intersection and prior to the vehicle crossing the stop bar.

The Data Analysis and Reduction Tool (DART) was used to validate events. DART is a software package developed at VTTI that provides a user interface for the viewing and reducing of digital data. It contains user-configurable video and graphical interfaces, and allows users to simultaneously view synchronized video and graphical data streams frame by frame.

RESULTS AND DISCUSSION

Ninety-three drivers participated in the Pseudo-Naturalistic Study. System failures (that will be discussed later in the paper) caused data to be retained for 87 drivers; these data were utilized to complete the analyses for the Pseudo-Naturalistic Study, as summarized in Table 2.

Table 2.
Distribution of Drivers by Age and Gender who had Data Analyzed in the Pseudo-Naturalistic Study Analyses

Age Group	Gender		Total
	Male	Female	
18-30	17	15	32
35-50	10	14	24
55+	15	16	31
Total	41	45	87

Recall that one of the goals of the study was to iteratively refine the warning algorithm. In other words, researchers conducted initial data reviews to determine the success of the warning algorithms and make changes based on the driving outcomes. Because drivers approach stop-controlled

intersections differently than they approach signalized intersections, two algorithms were used. The algorithms, the process for evaluation, and the criteria for determining success are discussed in the following sections.

Stop-Controlled Algorithm 1 Results - The initial stop-controlled intersection warning algorithm incorporated into the CICAS-V was derived directly from the results of a previous CICAS-V study, Neale et al. (in print). Over 160 algorithms were analyzed during the course of that effort. The performance of each potential algorithm was based on its effectiveness in predicting a pending violation while minimizing false detections based on naturalistic intersection approach data. In addition, other measures, such as the location at which a violation warning would be provided, likelihood of annoyance, algorithm complexity, and data requirements, were also considered.

Fifteen drivers experienced Stop-Controlled Algorithm 1, resulting in a total of 493 stop-controlled intersection crossings with 50 CICAS-V warnings being initiated. (Note that there were 32 stop-controlled intersection crossings on the route. When multiplied by the 15 drivers experiencing Stop-Controlled Algorithm 1, one would expect a total of 480 crossings. However, a few drivers made wrong turns along the route and actually crossed the intersections more often than was planned.) Table 3 illustrates the distribution of drivers, by age and gender, which experienced Stop-Controlled Algorithm 1.

Table 3.
Distribution of Drivers by Age and Gender who Experienced Stop-Controlled Algorithm 1*

Age Group	Gender		Total
	Male	Female	
18-30	2	1	3
35-50	1	4	5
55+	4	3	7
Total	7	8	15

*Note: These drivers are a portion of the total number of drivers who participated in the Pseudo-Naturalistic Study.

Since the data were downloaded after each drive, the number of warnings was immediately displayed on the vehicle DAS, which provided quick general feedback about alert frequency. When the driver received at least one warning, researchers reviewed the parametric and video data in detail to determine

the prevalent conditions of each warning. A review of the warnings indicated that the subset of drivers who experienced alerts received them at five stop-controlled intersections. After reviewing the intersections' geometry, it was noted that the alerts were occurring on intersection approaches that had a 3.8 to 7% uphill grade.

Stop-Controlled Algorithm 1 considered brake status when determining whether drivers should receive a violation alert. That is, if a driver was pressing the brake, it was assumed the driver was attentive to the intersection and the alert was suppressed. On uphill grades, drivers tended to press the brake later in their approach, using gravity to slow the vehicle. Since the algorithms were developed on flat intersection approaches, the later braking caused the warning to activate more often than was expected.

A review of the video and questionnaire data (discussed later) indicated that, although the drivers always came to a safe stop, they tended to become either annoyed or, possibly, entertained by repeated warnings. Based on these results, the decision was made to change the warning algorithm for stop-controlled intersections to one that did not rely on brake status to determine when a warning should be initiated. After reviewing the possible algorithms discussed in Neale et al. (in print), a new algorithm (Stop-Controlled Algorithm 2) was selected and integrated into the OBE.

The post-drive questionnaire was completed by the 13 drivers who received the total 49 valid warnings at stop-controlled intersections. Data show that drivers found the alerts useful, effective at communicating a possible violation, and attention getting. There were also several potential negative trends in responses. More drivers responded that, when receiving a violation warning, they tended to brake without checking for following traffic. Also, drivers tended to find the alert annoying when it was deemed unnecessary. This response is not surprising, and, in part, motivated the change to Stop-Controlled Algorithm 2. Three drivers admitted to intentionally trying to activate the warning system and three drivers said they would have turned the system off if they could. It is interesting to note that both aspects of the visual DVI, the blue "intersection ahead" icon and red flashing visual alert, were viewed less favorably than the speech alert and brake pulse warning. Several drivers noted, in the open-ended comment section, that they did not notice the visual icons. Suggested potential improvement to the visual DVI included a more conspicuous visual display that was a little larger and placed closer to the driver.

Stop-Controlled Algorithm 2 Results - Subtask 3.2 predicted that Stop-Controlled Algorithm 2 would correctly warn 60% of the violators and incorrectly warn less than 5% of the compliant drivers. A total of 72 drivers completed the Pseudo-Naturalistic Study protocol using the revised warning algorithm (Table 4). This resulted in a total of 2,125 valid intersection crossings at stop-controlled intersections with a total of three warnings issued. (Again, recall that there were 32 stop-controlled intersection crossings. When multiplied by the 72 drivers, one would expect a total of 2,304 crossings. However, as will be discussed in the Evaluation of the Study Systems section, data were sometimes lost due to system deficiencies.)

Table 4.
Distribution of Drivers by Age and Gender who Experienced Stop-Controlled Algorithm 2*

Age Group	Gender		Total
	Male	Female	
18-30	15	14	29
35-50	9	10	19
55+	11	13	24
Total	35	37	72

*Note: These drivers are a portion of the total number of drivers who participated in the Pseudo-Naturalistic Study.

All three warnings occurred at the same intersection while making the same straight-crossing maneuver. The intersection is in the middle of a straight road with a stop sign that is partially occluded at longer distances. The violation warnings were provided to three different drivers: a younger male, a middle-aged male, and an older male. In all three cases, they did not show indications of intending to stop prior to the warning, yet stopped before entering the intersection box after the warning was issued. The drivers' peak decelerations ranged from 0.46 g to 0.6 g and the average decelerations ranged from 0.33 g to 0.41 g.

The post-drive questionnaire results from drivers who experienced Stop-Controlled Algorithm 1 can be compared to those provided by the three drivers who each experienced a single violation warning while driving with Stop-Controlled Algorithm 2. These three drivers were issued a warning at the same occluded intersection. The subjective responses from these three drivers were more favorable than those provided by drivers who experienced Stop-Controlled Algorithm 1. This is an expected outcome, since one

would expect that drivers who experienced the CICAS-V in the manner it was intended to operate (rare warnings issued only when needed by the driver) would find the system more agreeable. Overall, drivers were satisfied with the system and recognized that they were in danger of violating the stop sign when they received the warning.

Signalized Intersection Algorithm Results

The signal-controlled intersection warning algorithm incorporated into the CICAS-V was also developed during the previous CICAS-V effort report in Neale et al. (in print). The Signalized Intersection Algorithm was predicted to correctly warn 83% of the violators and incorrectly warn less than 5% of the compliant drivers. As will be discussed, the warning was deemed successful throughout data collection and was not changed. Therefore, the CICAS-V utilized the same signalized warning timing for all drivers who participated in the Pseudo-Naturalistic Study. A total of 87 drivers completed the pseudo-naturalistic protocol, as summarized in Table 5. This resulted in a total of 1,455 valid intersection crossings at signalized intersections.

Recall that there were 20 signal-controlled intersection crossings that occurred through the three instrumented signalized intersections. When multiplied by the 87 drivers, one would expect a total of 1,740 crossings. However, as will be discussed in the Evaluation of the Study Systems section, data were sometimes lost due to system deficiencies.

Table 5.
Distribution of Drivers by Age and Gender who Experienced Signalized-Warning Algorithm during the Pseudo-Naturalistic Study*

Age Group	Gender		Total
	Male	Female	
18-30	17	15	32
35-50	10	14	24
55+	15	16	31
Total	41	45	87

*Note that these are all drivers who participated in the Pseudo-Naturalistic Study since the algorithm did not change.

A total of seven violation warnings occurred at signalized intersections: one valid warning, two invalid warnings due to an emergency vehicle signal preemption, and four invalid warnings due to an incorrect GID for the intersection.

For the valid warning, a middle-aged male approached a signalized intersection to make a straight-crossing maneuver. He was in the right-most straight through-lane following a vehicle with about 1-second headway. The signal became visible in the video at 53m (173 ft) and is in the yellow state. The driver does not show any indication of intending to brake until after the pre-warning process (a 500 ms process to initialize the warning) had started. Three-hundred ms later, the driver begins to brake. The pre-warning process finished and a warning is issued 200 ms after the braking began. The driver brakes safely to a stop before crossing the stop bar. Although it cannot be determined with certainty, the driver's braking prior to the warning likely indicates intent to stop. The driver did not show any visible expression in response to the warning. If the driver had not stopped, it appears a violation would have occurred, based on the location of the lead vehicle, which crosses over the stop bar as the signal turned red.

Two similar invalid warnings occurred when an emergency vehicle preempted the traffic signal. In both cases, the drivers were approaching a signalized intersection within a few minutes of the emergency vehicle. When the emergency vehicle approached the intersection, the traffic controller switched to a priority mode, which guarantees a green phase for the emergency vehicle. Unfortunately, the specialized firmware installed in the traffic controllers did not update the RSE with the correct SPaT messages when the signal was in the priority mode. As a result, the CICAS-V interpreted the signal phase as red when, in actuality, the preemption had caused the signal to turn green. This resulted in CICAS-V warnings issued on a green phase. One of the drivers handled the false warning in a calm manner without making any abrupt driving maneuvers. The second driver appeared startled and initially slowed the vehicle in response to the alert. The driver then made a quick assessment of the situation and chose to proceed through the intersection. Notably, a following vehicle did have to slow in response to the test vehicle. The signal priority addressable system issue is discussed further in the Evaluation of the Study Systems section.

Finally, four invalid warnings occurred due to an incorrect GID for one of the signalized intersections. The faulty GID incorrectly labeled the left-most through lane as the left turn lane, and associated the through lane with the dedicated left-turn signal head. The problem occurred when the drivers were making a straight-crossing maneuver in the left-most through lane, which had a green-phased light; the adjacent

left-turn lane had a red-phased light. The CICAS-V would note the red-phase for the left-turn lane, and warn the driver who was actually in the through lane with a green-phase.

The problem of the incorrect GID was identified by the research team the first time that a false alert was issued. However, since the driver responded calmly to the false alert and proceeded through the intersection appropriately, the incorrect GID was left in place. This allowed the team to learn more about how drivers respond when receiving a false alert during a green phase. The second and third time this occurred, those drivers also responded in a calm manner, assessed the situation quickly, and proceeded through the intersection. The final driver, however, was very startled by the warning on a green phase, and responded with abrupt braking that, under some conditions, had the potential to result in a rear-end collision with the following vehicle. Of particular importance, a following vehicle both applied the brakes and steered around the test vehicle in order to avoid a collision. Following this event, the correct GID was loaded onto the RSE. This issue is discussed further in the Evaluation of the Study Systems section.

The post-drive questionnaire was completed by the six drivers who experienced an invalid signalized violation warning while driving. One of these six drivers also received one valid signalized intersection violation warning. Overall, drivers thought the system was effective and did not rate the system as distracting or annoying. This is likely due to the fact that, even though the alerts were invalid, the alert frequency was considerably lower than with Stop-Controlled Algorithm 1. Also consistent with responses by drivers who received valid alerts, the red flashing visual alert and the "intersection ahead" icon were viewed less favorably than the speech and brake alerts.

Questionnaire Results from Drivers Who Did Not Experience a Violation Warning - Recall that drivers who completed the study without receiving a violation warning also completed a questionnaire. For these drivers, the only exposure to the CICAS-V would have been the opportunity to notice the blue "intersection ahead" icon at equipped intersections. Therefore, this questionnaire contained few questions, most of which asked the driver to rate their experiences with the "intersection ahead" display. The results are interesting in that there is a trend indicating that the drivers did not find the blue "intersection ahead" icon annoying or distracting; however, these drivers also felt that the visual-only

DVI was ineffective in communicating the intended information and not easily detected. Drivers often did not complete the questionnaire, presumably because they did not notice the blue icon. These results are consistent with the other questionnaire results that indicate that drivers often did not notice the blue “intersection ahead” display. Interestingly, many drivers took the time to provide feedback in the final open question on the questionnaire. Overall, drivers expressed a desire to have the display be more conspicuous.

Evaluation of the Study Systems

One goal of the study was to evaluate the CICAS-V and DAS hardware and software performance on live roads in order to demonstrate FOT readiness. However, it should be noted that the CICAS-V software tested during the field test was not the final software release. Version 1.11 of the software was implementable for this field test at the time of testing; however, the final release was Version 1.15. There were several improvements to the software during the releases after 1.11 that would have likely improved the results presented in this section. In particular, as will be discussed shortly, improvements made in the intersection selection method and the wireless protocol updates may have improved the system performance, as shown by tests performed in other CICAS-V tasks (Maile et al., in print-b, in print-a).

Another important note is that the DAS was not equipped with an independent set of sensors to verify these data. As a result, these analyses are somewhat limited in that they assume that the data provided by the WSUs are accurate.

The CICAS-V hardware and software were evaluated using two metrics; the system log and the DVI status variable. The system log was maintained by the experimenters. It consisted of a list of hardware and software issues that were encountered during the study. Most of the problems identified from the system log were addressed with upgrades to the CICAS-V application software or were not problems with the CICAS-V system itself. The predominant log entry indicated a Netway box failure. When the Netway failed, the WSU did not receive vehicle network information (e.g., speed). Without this information, the system was unable to perform the CICAS-V functions. Portions of several drives, and in some cases, entire drivers were lost due to this malfunction. Approximately 5% of data were lost due to this deficiency.

The DVI status variable was used to identify how often the CICAS-V was fully capable of providing a

warning. Using the blue “intersection ahead” icon as the indicator of the range of the vehicle, it was identified that the CICAS-V was enabled 96% of the time at either stop-controlled or signalized intersections. When the system was disabled, over half of the periods were longer than 1 second. From these results, it appears that most of these periods have the potential to result in a late warning if the driver happens to violate while the system is disabled, and the impact on the CICAS-V effectiveness may be substantial, potentially negating the CICAS-V safety benefit.

The hardware and software of the vehicle DAS were evaluated. The vehicle DAS hardware and software showed less than a 1% data loss.

RECOMMENDATIONS AND STUDY LIMITATIONS

This study was a pilot test to perform the first on-road naïve-driver system-level test of the CICAS-V. The following sections describe the implications that may be drawn.

The CICAS-V System is FOT Ready

The on-road data collection indicated that the CICAS-V functions reliably and as intended for the purpose of conducting an FOT. The issues that were noted with the system during data collection have already been largely resolved with CICAS-V application software upgrades. The problems that are outstanding at the time of writing this paper are not problems with the CICAS-V itself, but relate to just this initial implementation. First, the invalid warnings that occurred when an emergency vehicle preempted the signal, which caused the RSE to report incorrect phase information, are being addressed by the signal controller company. The occasional failure of the Netway box during data collection is not an issue of the CICAS-V per se; however, it is an issue that would need further attention in order to minimize data loss during an FOT. Approximately 5% of data were lost due to this deficiency. For the FOT, it is likely that the WSU software would be specialized for each vehicle platform, making the Netway box unnecessary.

CICAS-V Algorithms are FOT Ready

The study successfully tested two algorithms for stop-controlled intersections and one algorithm for signalized intersections. Although Stop-Controlled Algorithm 1 was not deemed successful, its successor, Stop-Controlled Algorithm 2, successfully warned three different drivers of an occluded

intersection. Signalized Intersection Algorithm 1 provided a valid and timely warning to a driver approaching a light through a phase change.

The Vehicle DAS is FOT Ready

The Vehicle DAS performed well during the study. Although there was a hard drive malfunction during the course of the study, very little data were lost (2 hours out of 191 hours total) due to Vehicle DAS equipment failures. It is recommended that variables that were not useful for the pilot be eliminated from collection to save storage space and simplify the resulting database.

Pilot Study Protocols are FOT Ready

The protocols, pre-drive questionnaires, and post-drive questionnaires worked well for the pilot study and can be implemented during an FOT.

The CICAS-V Appears to Provide a Benefit to the Driver

Every driver who was provided with a valid violation warning throughout data collection came to a stop before the intersection box. The valid violation warnings provided from the best performing algorithms, Stop-Controlled Algorithm 2 and the Signalized Intersection Algorithm, are of particular interest since the scenarios mimic those for which the CICAS-V was designed. Those scenarios are an occluded stop-controlled intersection that drivers had trouble detecting, and a signalized intersection with lead traffic going into a phase change. Of course, the results from this study alone cannot provide an accurate cost/benefit trade off, but the results from this study indicate a potential benefit of the system.

Drivers like the CICAS-V

Subjective data on post-test questionnaires indicate that drivers generally like the CICAS-V. A common critique of the system was the conspicuity of the visual display. Nonetheless, this is a minor critique considering that: 1) the visual display was not designed into the original dash configuration and was added; 2) drivers had little time with the vehicle (2 to 3 hours) to become accustomed to the display; 3) the speech and brake pulse modalities are very effective; and 4) for the purposes of conducting an FOT, the visual display can be viewed as a secondary indicator to the speech and brake pulse warning modes and could be modified to improve conspicuity.

Limitations of the Study

One shortcoming of the research is that data collection concluded without benefit of testing the final version of the CICAS-V application. As stated, the study was conducted using Version 1.11 of the software. By the time data collection had ended and the experimenters had given feedback to the CICAS-V developers, Version 1.15 had been developed, reflecting four software upgrades and several incorporated system refinements. Therefore, it is recommended that a small study be conducted prior to an FOT to test the upgraded software.

Also, this study was conducted in the small metropolitan region of Blacksburg, Virginia. In this area, the GPS coverage was adequate for testing the system, the state Department of Transportation was very supportive, and the proximity to data collectors was ideal. Alternative locations are likely to provide different and, likely, additional challenges relative to those that were met by the research staff. As such, the trade-offs of alternative locations would need to be carefully considered prior to selecting the final FOT site.

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