

# Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V)

Subtask 3.1: Mining of the 100-Car  
Naturalistic Driving Database to  
Determine Factors Related to  
Intersection Violations and Near  
Violations

(Appendix A-1)

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## List of Acronyms

ANSI	American National Standards Institute
ATIS	Advanced Traveler Information System
C2C	Center to Center
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network. Wired network system common in newer model vehicles.
CICAS	Cooperative Intersection Collision Avoidance System
CICAS-V	Cooperative Intersection Collision Avoidance System for Violations
ConOps	Concept of Operations
DFD	Data Flow Diagrams
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
ESS	Environmental Sensor Stations
ETMCC	External Traffic Management Center Communication
FHWA	Federal Highway Administration
FOT	Field Operational Test
GID	Geometric Intersection Description
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Human-Machine Interface
ID	Identification or Identifier
IEEE	Institute of Electrical and Electronics Engineers
IGN	Ignition
ISO	International Standards Organization
ITS	Intelligent Transportation Systems
LRMS	Location Referencing Message Specification
MS/ETMCC	Message Sets for External Traffic Management Center Communications
NDGPS	Nationwide Differential Global Positioning System

NHTSA	National Highway Traffic Safety Administration
NMEA	National Marine Electronics Association, Inc.
NTCIP	National Transportation Communications for ITS Protocol
OBE	On-board Equipment
OEM	Original Equipment Manufacturer
POC	Proof of Concept
RSE	Roadside Equipment
RTCM	Radio Technical Commission for Maritime Services
SAE	SAE International, an organization formerly known as Society for Automotive Engineers
SPaT	Signal Phase and Timing
SWC	Single Wire CAN
TCIP	Transit Communications Interface Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TIA	Telecommunications Industry Association
TMDD	Traffic Management Data Dictionary
USDOT	United States Department of Transportation
UTC	Coordinated Universal Time
UUID	Universal Unique Identifier
VAN	Vehicle Area Network
VII	Vehicle Infrastructure Integration
VSC2	Vehicle Safety Communications 2
WAAS	Wide Area Augmentation System
WAV/MP3	Audio file formats
WAVE	Wireless Access in Vehicular Environments
WSA	WAVE Service Announcement

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## Executive Summary

This report presents the Final Phase I Summary Report for the Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Project. The report covers the period from project inception on May 1, 2006 through September 30, 2008.

The CICAS-V Project's objective was to develop a cooperative intersection collision avoidance system to assist drivers in avoiding crashes in the intersection by warning the driver of an impending violation of a traffic signal or a stop sign. The Vehicle Safety Communications 2 Consortium (VSC2) conducted the project under Federal Highway Administration (FHWA) Cooperative Agreement No. DTFH61-01-X-00014, Work Order W-05-001. Members of VSC2 are Ford Motor Company, General Motors Corporation, Honda R & D Americas, Inc., Mercedes-Benz Research and Development North America, Inc., and Toyota Motor Engineering & Manufacturing North America, Inc. Funding for this project was provided from the Joint Program Office of the United States Department of Transportation (USDOT). The project was also supported by Virginia Tech Transportation Institute (VTTI), who played a major role in the human factors research to define and evaluate the CICAS-V warning system.

The project was divided into two phases. Phase I featured the development and testing of a prototype of a CICAS-V system that is now ready for testing with naïve users. Phase II will feature a full-scale Field Operational Test (FOT) of the system. However, at the end of Phase I, the USDOT decided not to immediately continue with the FOT in Phase II even though the system was shown to be FOT-ready

Phase I of the project consists of 14 tasks. These tasks, collectively, addressed four major elements of the research needed to develop an FOT-ready system by the end of Phase I. The elements were:

- Human factors research to identify a driver-vehicle interface (DVI) for the CICAS-V system and the operational parameters for the driver warning algorithm
- Systems engineering activities to design the CICAS-V system
- System development and validation tasks to build and test a prototype FOT system. This includes both software and hardware components for the intersection and the vehicle.
- Project management and coordination with outside organizations

The project fully achieved the Phase I goals and objectives that were defined in the beginning of the project. The main accomplishments of this phase were:

- Development of a reference implementation of a CICAS-V system that can be used for a large-scale Field Operational Test (FOT) with naïve drivers
- Successful testing of the system with 87 naïve drivers in a pseudo-naturalistic setting

- Development of a highly effective warning algorithm and driver-vehicle interface (DVI) which warns the driver when a potential violation is detected while minimizing false alerts
- Definition of objective test procedures, all of which the system passed
- The developed system is simple, requiring only a DSRC radio, a GPS system and processing capabilities in the vehicle
- Robust implementation of the infrastructure part of the system with virtually maintenance-free operation
- Development of a local positioning correction system that enables lane-level positioning accuracy within the mapped area of an intersection

### **Systems Engineering**

The project defined a systems engineering process that was then used to develop an operational concept, architecture, requirements and specifications, all of which comprised the system design. The systems engineering effort is documented in a set of reports that include:

- Concept of Operations (Maile et al., “Concept of Operations,” In Print)
- High-Level Requirements (Maile et al., “High Level Requirements,” In Print)
- System Architecture Description (Maile et al., “System Architecture Description,” In Print)
- System Requirements Specifications (Maile et al., “System Requirements Specifications,” In Print)
- System Design Specifications – Infrastructure (Maile et al., “System Design Specifications – Infrastructure,” In Print)
- System Performance Specifications – Vehicle (Maile et al., “System Performance Specifications – Vehicle,” In Print)

During the system engineering activities, a Concept of Operations workshop, a Preliminary Design Review and a Critical Design Review were held to communicate the design of the CICAS-V to a wider audience and to solicit feedback from the stakeholders. The received feedback was included in the next version of the documents and a final update was made at the end of Phase I that included the lessons learned during the design and testing phase of the project.

### **System Prototyping**

In Task 8, Prototype Build and Testing, the individual technology elements that enable the CICAS-V were developed. This included the development of the concept and format of a small local map, called a Geometric Intersection Description (GID), that could be sent from the intersection to the vehicle to enable map/lane matching, the development of message sets to transmit the necessary information from the intersection to the vehicle, the development of local positioning corrections, map matching algorithm and initial

warning algorithm logic. On the intersection side, the software components to receive the signal phase and timing information from the traffic signal controller and to send it to the vehicle together with the GID and the positioning corrections were developed. To test the technologies, intersections in California and Michigan were equipped with the prototype CICAS-V. The work also led to an initial set of specifications for the development of the final CICAS-V in Task 10 (Integration of Subsystems, Building of Prototype Vehicles and Outfitting of Intersections).

### **Driver-Vehicle-Interface (DVI) Development**

The DVI conveys the warning to the driver and it is an important aspect of the overall CICAS-V. The development of the DVI consisted of several Task 3, Human Factors Research, subtasks as described in the following paragraphs.

#### **Subtask 3.1 - Mining the VTTI 100-Car Naturalistic Driving Study Database**

In this task, the VTTI 100-Car database was examined to determine the conditions under which drivers commit violations of stop signs and traffic signals. The results of this task, reported in Sudweeks et al., (In Print), gave information about the design of the CICAS-V warning. The main implications for the design of CICAS-V were:

- Visual DVI placement in the forward field of view
- A visual DVI should be supplemented with another modality
- Speed thresholds in the warning algorithm were needed to minimize false alerts

#### **Subtask 3.2 - Warning Algorithm Development**

During the task (Doerzaph et al., In Print), radars and cameras were installed at three signalized intersections and four stop-controlled intersections in the Blacksburg, VA area to collect vehicle approach information. The information collected included the range, range-rate, acceleration, signal phase and timing, weather as well as video to validate the radar data and identify additional measures such as vehicle type, vehicle maneuvers, etc. The data was used to develop CICAS-V alert timing algorithms based on regression of collected data samples and on laws of physics. The developed algorithms were then used in pseudo real-time simulations with raw vehicle data to determine the performance of each algorithm. The analysis of the data showed that the warning timings for the approach to a stop controlled intersection and a signalized intersection differed enough to make the use of two algorithms necessary. All of the algorithms had a minimum speed threshold to reduce the number of nuisance warning for rolling stops.

The task also determined violation rates for intersections. At the stop-controlled intersections, the approximate violation rate was 607 violations per 100,000 vehicles. At signalized intersections, the approximate overall violation rate was 126 violations per 100,000 vehicles approaching during the time where the signal was red or yellow. The violation rates for the signalized intersections varied from 47 per 100,000 vehicles at Peppers Ferry and Franklin to 423 per 100,000 vehicles at Independence and Franklin in Blacksburg, VA.

### **Subtask 3.3 - Test of alternative DVI on the VTTI Smart Road**

In this task, several combinations of DVI were tested with naïve drivers using a distracted driving surprise trial methodology on the VTTI Smart Road. Participants were asked to perform a number of HVAC and radio tasks throughout their drive. The last task was presented right before the light was changed to surprise participants (“surprise trial”). The DVI with the highest effectiveness to get people to a stop before entering the intersection crash zone was a visual icon that was flashing red when warning, a brake pulse of 600 ms duration and 0.1 g intensity, and a speech-based warning that, depending on the type of intersection that the car approached, said “Stop Light” or “Stop Sign.” The compliance rate for this DVI combination was 96%. Additional tests included PBA in an effort to determine if assisted braking could reduce the time to intersection needed for alerts. The test indicated no benefit from PBA so it was not implemented. (Perez et al., In Print).

### **System Development**

The goal of the Phase I system development activities was to develop a CICAS-V prototype system that would be tested in the Pilot FOT, Subtask 3.4, and the Objective Tests - Task 11 to determine the prototypes readiness to support a full FOT. The system development consisted of selecting the hardware for the intersection and the vehicle installation and the software development on the hardware and the testing of the system. The hardware that was chosen was the DENSO Wireless Safety Unit (WSU). DENSO was also responsible for the software development of the vehicle part of the CICAS-V application. The intersection Road-Side Equipment (RSE) also used the DENSO WSU but the software for the RSE was written by the CICAS-V technical team. The technical team also defined system test procedures to test the various releases that were supplied by DENSO and to provide DENSO with the necessary feedback for the system improvements. The release v1.11 was used for the Pilot FOT and the results and issues found in this test were used to further improve the system. The final release, v1.15, was used for the objective tests and is the final release for Phase I of the project (Maile et al., In Print).

VTTI developed Data Acquisition Systems (DAS) that were used in the Pilot FOT and the objective tests to collect data about the performance of the CICAS-V system. The vehicle DAS consisted of a set of video cameras that would take video images of the driver’s face, the interior of the car, the forward view and the rearward view as well as 24 GHz radars located behind the front and rear bumper of the vehicle. The DAS also collected and stored all the information that came from the vehicle Controller Area Network (CAN) bus, the status variables of the CICAS-V as well as the messages that the vehicle received from the intersection. The intersection DAS collected video and radar data from the video cameras and radars installed at the intersections during Subtask 3.2 as well as the messages that the RSE sent out (Stone et al., In Print). The vehicle and intersection data acquisition systems developed in Phase I will serve as the templates for the data acquisition systems used in the full FOT in Phase II.

## **System Tests**

There were two major system tests in Phase I – the objective tests in Task 11 and the Pilot FOT in Task 3.4. The goal of the Pilot FOT was to stress test the system with naïve drivers and receive feedback about the effectiveness and user acceptance of the warning algorithm. The Pilot FOT included naïve drivers driving a scripted fixed route on public roads with three signalized and 10 stop sign-controlled intersections equipped with the CICAS-V system. Overall, 87 drivers tested the system successfully and generated 4,526 intersection crossings. The test was complemented by post test subject surveys and by Smart Road tests with a subset of the 87 drivers. Overall, the system performed well. The observations suggested generally a positive acceptance of the DVI.

The warning algorithm for stop-controlled intersections was refined during the Pilot FOT due to a large number of nuisance warnings that were generated at stop signs that were located on the crest of a steep hill. The adjusted algorithm performed very well in that it provided valid warnings and minimized false alerts, which eliminated this problem. Three valid alerts were issued with the second algorithm at stop-controlled intersections. One valid alert was issued at a signalized intersection. The Smart Road tests with the Pilot FOT subjects confirmed the results of Subtask 3.3: Test Alternative DVIs on the Smart Road, surprise trial studies and the effectiveness of the DVI (Neale et al., In Print). The analysis of the post test subject surveys showed that users liked the system and that the favorable rating was higher for the second warning algorithm than the first, as could be expected. The overall outcome of the Pilot FOT was that the system (CICAS-V as well as vehicle and intersection DAS) performed well and was ready for the next phase.

The goal of the objective tests was to determine the FOT readiness of the system that included the improvements after the Pilot FOT and to test whether the system performed according to the specifications defined in the systems engineering process. For those objective tests, test procedures and a test plan were developed in Task 7: Development of Test Plans and Objective Test Procedures, (Maile et al., In Print) and the tests were conducted in Task 11: Objective Testing on the Smart Road at VTTI. The test procedures were grouped into three categories:

- Warning tests, where the objective was to get a warning at the expected distance from the intersection
- Nuisance tests, where the objective was to not get a warning
- Engineering tests to determine performance limits of the system

The warning tests and the nuisance tests had pass/fail criteria associated with them while the engineering test did not. The engineering tests did not have pass/fail criteria since the test was designed to determine the operation of the system under conditions outside the performance specifications.

The test procedures replicated typical scenarios that could be encountered while approaching an intersection and queried whether the system responses were correct. The procedures included approaches at multiple speeds (25, 35 and 55 mph), lane change maneuvers during the approach, driving at the edge of the lane, multiple intersections within communication range and dynamic signal change scenarios from green to yellow to red, and red to green.

The tests were conducted with a test driver who was not affiliated with the project, an observer who recorded the test conditions and results along with a government witness. The system passed all the tests, and out of 120 valid intersection approaches, only one approach failed due to the brake pulse not coming on, even though the other warning modalities did. The overall outcome of the tests was that the CICAS-V system is FOT-ready and performs according to the specifications or better.

### **FOT Planning**

Before a widespread deployment of CICAS-V in the vehicle fleet and intersections, several questions need to be answered, namely:

- Safety Benefit of CICAS-V
- User Acceptance
- Unintended Consequences

Those questions can only realistically be answered in a large field trial with naïve drivers. Together with the USDOT, a Field Operational Test (FOT) that could address those questions was specified in Task 13: Preparation for Field Operational Test and additional FOT planning was subsequently conducted to prepare for the full FOT in Phase II of the project. The size of the FOT was specified at 204 drivers, 53 vehicles, 24 signalized intersections, and 50+, stop-controlled intersections. The duration of the FOT data collection period is one year. The FOT planning work also included the definition of a process to select the site of the FOT and criteria for the selection of intersections at the FOT site. The overall cost of the FOT lies between \$12 million and \$16 million, depending on the site location, types of vehicles used and whether intersections DASs are required.

### **Summary**

- The project developed a Cooperative Intersection Collision Avoidance System for preventing crashes in the intersection that have their origination in violation of traffic signals and stop signs (CICAS-V)
- The system was tested with naïve drivers in a Pilot FOT and performed well. Issues found with the system during the Pilot FOT were resolved in later releases of the software.
- Test subjects liked the system
- The system passed all the objective tests
- The CICAS-V system is ready for a full-sized FOT
- An FOT has been defined that can be used as a template for Phase II of the project

# 1 Introduction

This document presents the final Phase I Report for the Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Project. The period covered by the report is from May 1, 2006 through September 30, 2008. The report is meant to give an overview over the work and the results of the project. For more detail, the reader is referred to the final task reports.

## 1.1 Project Description

The CICAS-V Project was originally conceived as a four-year project to develop a cooperative intersection collision avoidance system to assist drivers in avoiding crashes in the intersection by warning the driver of an impending violation of a traffic signal or a stop sign. Cooperative means that the system involves both infrastructure and in-vehicle elements working together. The Vehicle Safety Communications 2 Consortium (VSC2) is executing the project under Federal Highway Administration (FHWA) Cooperative Agreement No. DTFH61-01-X-00014, Work Order W-05-001. Members of the VSC2 Consortium included Ford Motor Company, General Motors Corporation, Honda R & D Americas, Inc., Mercedes-Benz Research and Development North America, Inc. and Toyota Motor Engineering & Manufacturing North America, Inc. Funding for this project was provided from the Joint Program Office of the United States Department of Transportation (USDOT). The project was also supported by Virginia Tech University (Virginia Tech), who played a major role in the human factors research to define and evaluate the CICAS-V warning system. The work at Virginia Tech was conducted through its research group at the Virginia Tech Transportation Institute (VTTI).

The project was initiated in May 2006 and was supposed to be divided into two phases. In Phase I the project team was to develop and test a prototype of a CICAS-V system that will be ready for testing with naïve users. Phase I was scheduled to run through September, 2008. At the end of Phase I, the USDOT and VSC2 originally were jointly planning to determine if the system will be tested in a Field Operational Test (FOT) in Phase II of the project. If a “go” decision were made by the two organizations, Phase II would have been scheduled to run for two additional years. In July 2008, the USDOT decided to end the project after Phase I and not continue immediately with a Phase II, independent of the readiness of the system.

## 1.2 Purpose for Implementing the System

The purpose of implementing CICAS-V is to reduce crashes due to violation of traffic control devices (both traffic signals and stop signs).

When deployed, this system is intended to:

- Reduce fatalities at controlled intersections
- Reduce the number of injuries at controlled intersections
- Reduce the severity of injuries at controlled intersections
- Reduce property damage associated with collisions at controlled intersections

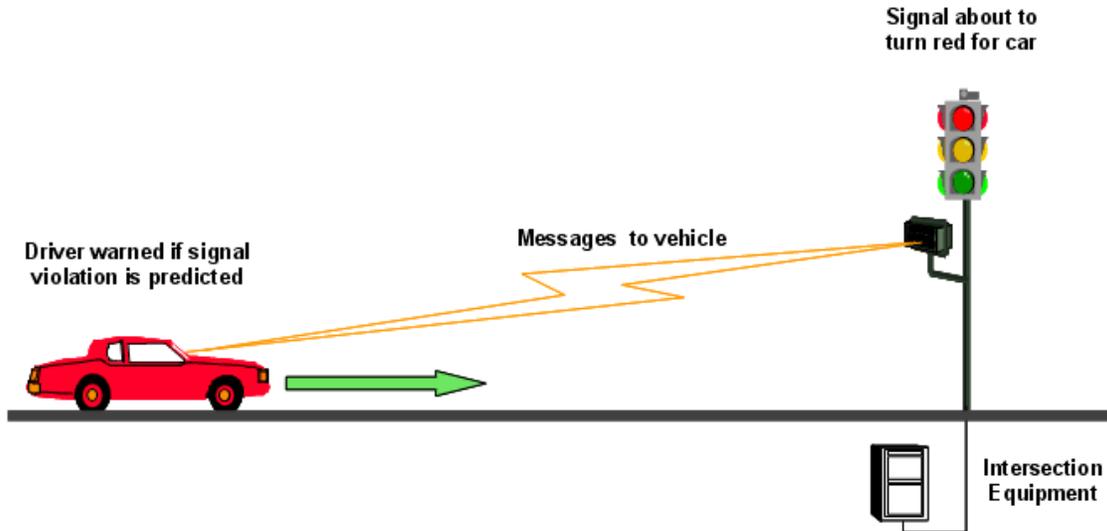
- Create an enabling environment that additional technologies can leverage to further extend safety benefits

Intersection crashes account for 27.3% of all police-reported crashes, or 1.72 million crashes annually in the U.S. About 44% occur at traffic signals and 56% at stop signs. In 2004, stop sign and traffic signal violations accounted for approximately 302,000 crashes, resulting in 163,000 functional years lost and \$7.9 billion of economic loss (Najm et al., 2007).

An initial analysis of relevant National Highway Traffic Safety Administration (NHTSA) crash databases shows that violation crashes have a variety of causal factors. The CICAS-V system is intended to address the causal factors that include driver distraction (a frequent factor [Campbell, Smith and Najm, 2004, p. 65]), obstructed/limited visibility due to weather or intersection geometry or other vehicles, the presence of a new control device not previously known to the driver, and driver judgment errors. Driver warnings, such as those planned for CICAS-V, may prevent many violation-related crashes by alerting the distracted driver, thus increasing the likelihood that the driver will stop the vehicle and avoid the crash.

### **1.3 Goals and Objectives**

CICAS-V is intended to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at intersections by warning the vehicle driver that a violation, at an intersection controlled by a stop sign or by traffic signal, is predicted to occur. The basic concept of CICAS-V is illustrated at a high level in Figure 1 for a signalized intersection. In the figure, a CICAS-V equipped vehicle approaching a CICAS-V equipped intersection receives messages about the intersection geometry, GPS differential corrections and status of the traffic signal. The driver is issued a warning if the equipment in the vehicle determines that, given current operating conditions, the driver is predicted to violate the signal in a manner which is likely to result in the vehicle entering the intersection. While the system may not prevent all crashes through such warnings, it is expected that, with an effective warning, the number of traffic control device violations will decrease and result in a decrease in the number and severity of crashes at controlled intersections.



**Figure 1: Basic Concept of the CICAS-V System at a Signalized Intersection**

Specific goals of CICAS-V include the establishment of:

- A warning system that will be effective at reducing the number of fatal crashes, the severity of injuries and property damage at CICAS-V intersections
- A warning system that is acceptable to users
- A vehicle-infrastructure cooperative system that helps vehicle drivers avoid crashes due to violations of a traffic signal or stop sign
- A system that is deployable throughout the United States

## 1.4 Project Summary

The project consisted of 14 tasks as shown in Table 1. The tasks are summarized in the material following the table.

**Table 1: Project Tasks**

Task No.	Task Name
1	Project Management
2	Coordinate with Standards Development Activities
3	Human Factors Research
4	Concepts of Operations and Systems Requirements
5	System Architecture and System Design
6	Development of Performance Specifications
7	Development of Test Plans and Objective Test Procedures

<b>Task No.</b>	<b>Task Name</b>
8	Prototype Building and Testing
9	System Development Plan
10	Integration of Subsystems, Building of Prototype Vehicles and Outfitting of Intersections
11	Vehicle and Intersection Objective Testing
12	FOT Data Acquisition Systems
13	Prepare for Field Operational Test
14	Human Use Approval

Task 1 provided the overall project oversight to ensure that the project achieved its technical objectives within the timeframe and resources allocated for the effort.

Task 2 provided the support activities needed to define and incorporate CICAS-V requirements into the standards established by standards-setting organizations such as the Society of Automotive Engineers (SAE), Institute of Electrical and Electronics Engineers, Inc. (IEEE) and Institute of Transportation Engineers (ITE). These activities were intended to facilitate the future deployment of the CICAS-V system by having needed standards in place when suppliers begin developing production equipment.

The driver-vehicle interface (DVI) and the alert timing warning algorithm that activate the CICAS-V warning in the vehicle were developed and evaluated in Task 3. In addition, data generated from this task were provided to the USDOT's independent evaluator to facilitate the independent evaluation of the prototype to determine the prototype's FOT readiness and identify enhancements that could be made to the design of an FOT to increase the FOT's ability to support the estimation of benefits. The task culminated in a Pilot FOT to evaluate the prototype DVI in a limited on-road test with naïve drivers prior to the onset of the project's Phase II activities. Task 3 consisted of four major subtasks that will be listed for clarity.

- In Subtask 3.1, the VTTI 100-Car Naturalistic Driving Database was mined to determine the factors associated with violations and near violations of signalized and stop-controlled intersections
- Subtask 3.2 focused on the collection of naturalistic intersection approach data for signalized and stop sign controlled intersections to optimize the warning timing
- In Subtask 3.3, three alternative DVIs were examined in a series of studies conducted on a closed-course test track in order to determine the preferred DVI for the CICAS-V system
- A pilot study with the prototype CICAS-V system was conducted in Subtask 3.4 using a small sample of drivers recruited from the population of

drivers at large to assess the overall readiness of the prototype for the larger FOT planned for Phase II of the project

The project undertook a rigorous systems engineering effort by following the methodology recommended by the Federal Highway Administration (FHWA). Together with a systems engineering contractor the following documents in the following sections were developed.

### **Concept of Operations**

In Task 4, the Concept of Operations (ConOps) for the CICAS-V system was prepared and a set of high-level system requirements was developed.

### **System Architecture**

Following the work in Task 4, Task 5 developed the system architecture and the detailed system requirements.

### **System Performance Requirements**

The system performance requirements were developed in Task 6. These were presented in two documents. The first document addressed the performance requirements for the vehicle portion of the system and the second document addressed the performance requirements for the infrastructure portion of the system.

### **Object Test Procedures**

Objective test procedures, which can be used to verify the correct functioning of the system before it is placed into a field test, were developed in Task 7. The actual verification testing of the CICAS-V system was conducted in Task 11 as described below.

In Task 8, a prototype system to test the various system elements was developed. Work in this task included development of both the vehicle and intersection system components.

Task 9 contained the activities associated with the development of the systems engineering process and the system engineering oversight that were used in Tasks 4 through 7, as stated above, to design the CICAS-V system and the verification procedures. It included the organization and conduct of a Concept of Operations workshop, a Preliminary Design Review and a Critical Design Review.

Task 10 featured the building of the final vehicle and intersection prototype that is ready for a field evaluation in an unattended setting with naïve users. The prototype was subsequently validated in Task 11 and evaluated in an on-road pilot test in Subtask 3.4.

Task 11 involved the verification of the CICAS-V system design using the objective test procedures developed in Task 7 and the prototype system built in Task 10. The test results will also serve as benchmarks that manufacturers could use to verify their system implementation.

Development of the vehicle and intersection data acquisition systems, which were used in the Pilot FOT and the Objective Tests to be used in a possible, future, full FOT to collect

data to assess system benefits, user acceptance and potential unintended consequences, was accomplished in Task 12.

Task 13 featured the development and evaluation of various testing strategies intended to obtain data about user acceptance, unintended consequences and safety benefit of the CICAS-V system.

In Task 14, approval to conduct any of the tests in this project involving human participants was obtained from an established institutional review board (IRB). This process was required of the project in order to safeguard the rights of naïve participants.

## **1.5 Organization of the Report**

Section 2 of the report presents a summary of the activities that occurred within each active task during the project from May 1, 2006 to September 2008. The task descriptions in this section are only meant as an overview. The reader interested in more detail regarding the tasks and findings will be referred to the individual final task reports. Section 3 contains the references for reports cited in the document.

# **2 Summary of Project Activities**

## **2.1 Task 1 – Project Management**

The objective of the Project Management task was to provide the administrative and technical oversight to keep the project on track from a schedule and budget perspective and to ensure that the project objectives are fulfilled. Included in the scope of activities in this task were:

- Leadership over all work within the CICAS-V Project
- Maintenance of a project plan
- Risk identification and management throughout the project
- Project progress reporting
- Coordination with other related programs such as the Vehicle Infrastructure Integration Consortium (VIIC), Vehicle Infrastructure Integration (VII) Program, the Cooperative Intersection Collision Avoidance System projects for Signalized Left Turn Assistance (CICAS-SLTA) and Stop Sign Assist (CICAS-SSA), and the various state or local departments of transportation supporting the project
- Changes in the Statements of Work (SOW) and project budget
- Tracking of costs, milestones and deliverables

To support these activities, a project plan was developed early in the project as was a risk management plan that outlined the risks associated with project execution and plans to mitigate the more significant of those. To facilitate project progress reporting, a quarterly report format was developed in conjunction with the USDOT. This report format was subsequently used to provide quarterly progress and financial reports to the USDOT. Quarterly progress briefings were also provided to USDOT during the project as were weekly updates delivered during teleconferences with VSC2 and USDOT managers.

Coordination activities with the VIIC and VII Programs were conducted throughout Phase I to support on-going exchange of status information among the three programs and to support planning of the VIIC's Proof-of-Concept (POC) tests planned for late 2007. Activities undertaken in these efforts included participation in the VII Program Management Reviews (PMRs) and participation in teleconferences and meetings with both the VIIC and VII Program to plan the POC testing. These latter meetings facilitated defining the tests that were conducted, identifying CICAS-V's role in the POC tests and formulating a timeline for CICAS-V POC preparations. A Concept of Operations document and a Requirements document, specifically directed toward the CICAS-V participation in the POC, were prepared and provided to the VII Program for their use in planning the POC tests.

The cooperation with the VII program included the delivery of On-Board and Roadside equipment to the CICAS-V program. During the course of the project, it was decided to use equipment separate from the VII to expedite the development of the CICAS-V system and to maintain the timeline, budget and objectives of the project while still maintaining compatibility with the VII. The decision was also made to not include a CICAS-V test in the POC testing but rather to use the VII POC to test the capabilities of the communications link.

## **2.2 Task 2 - Standards Development**

The objective of this task was to foster the inclusion of CICAS-V application requirements in the standards established by the various standards-setting organizations both within the United States and world-wide. Such standards will facilitate the future deployment of the CICAS-V system following successful completion of a field operational trial. Work in Task 2 focused on the three standards areas listed below:

- Communications
- Message formats for transmission of information from the infrastructure to the vehicles approaching equipped intersections
- A geometric intersection description (i.e., a specialized digital map of a CICAS-V equipped intersection)

The communications standards are currently under development within the Institute of Electrical and Electronics Engineers, Inc. (IEEE), where working groups are in the process of writing and evaluating the IEEE 802.11p and IEEE 1609.x family of standards. These standards describe the Dedicated Short Range Communication (DSRC) system, which is one of the enabling technologies of the CICAS-V system. DSRC allows vehicles to communicate with other vehicles and the infrastructure, wirelessly, using a 5.9 GHz-based radio. Standardizing this communication system is essential to the successful development and interoperability of any communication-based system, such as CICAS-V. The specific details of these standards are highly technical in nature and are, consequently, beyond the scope of this report. However to aid reader understanding, it is worth noting that the IEEE 802.11p standard addresses how messages are sent over the wireless channel, while the IEEE 1609.x family of standards defines an architecture and networking services referred to as Wireless Access in Vehicular Environments (WAVE).

These standards are interrelated, as IEEE 1609.x is a higher-layer standard which builds upon the IEEE 802.11p lower-layer standard.

The standards related to the message formats and the geometric intersection description (GID) are under development within the Society of Automotive Engineers (SAE) DSRC Data Dictionary and Message Set Technical Committee (J2735). Efforts within this group will initially define a Recommended Practice, and later a Standard Practice, covering data elements, data frames and message sets. Such efforts are needed to produce interoperable applications in the future. Currently, formats for the message that will transmit traffic signal status information (referred to as the signal phase and timing information) and the message that will contain the information about the GID are being considered by J2735.

In the Task 2 work performed throughout the project, CICAS-V Project team members participated in the working groups of IEEE 802.11p, IEEE 1609.x and SAE J2735 and worked to include the requirements needed by CICAS-V in the documents currently being drafted. In addition, the project team members assisted with answering questions, resolving technical issues and addressing comments received on the draft standards that have been developed to date. Several members of the project team are also voting members of the standards working groups and worked to affect passage of a standard through the voting processes defined by each of the respective standards organization.

As the project ended, a draft of the IEEE 802.11p standard was approved by a letter ballot. The IEEE 1609.x standards are nearly complete. All of the IEEE 1609.x standards have passed sponsor ballot for trial use. It is anticipated that the IEEE 1609.x trial use series will be revised during 2008 based on collected field experience, and then subsequently balloted as full IEEE standards. IEEE 1609.0 is also being prepared to address the overall communications architecture. Additionally, the SAE J2735 technical committee continues discussion of the message formats and the contents of the GID. It is expected that a second version of J2735 will be published in 2008. At the end of the project, the SAE J2735 committee has not published recommended practices for the CICAS-V message sets, including the GID definitions. The trend in the committee was to move away from the messaging framework that CICAS-V developed and use an XML representation for the messages even though the byte efficiency would be less. Discussions in this area are still ongoing.

## **2.3 Task 3 – Human Factors Research**

The human factors research in the project played a key role in helping to ensure that the CICAS-V system developed is effective from both a safety and customer acceptance perspective. The scope of this task included four subtasks, as shown below:

- Subtask 3.1 – Mine the 100-Car Database
- Subtask 3.2 – Collect Naturalistic (No Alert) Infrastructure-based Driving Data
- Subtask 3.3 – Test Alternative Driver-Vehicle Interfaces (DVI) on the Smart Road
- Subtask 3.4 – Conduct Pilot FOT Human Factors Assessments

Subtasks 3.1 through 3.3 aided in the design of the CICAS-V DVI through examination of experimental data to help define the type of warning the driver receives and the timing of the warnings during an approach to an intersection. Efforts in these subtasks were interrelated. The following material summarizes the accomplishments within Subtasks 3.1 through 3.4.

### **2.3.1 Subtask 3.1 – Mining of the 100-Car Naturalistic Driving Database**

Subtask 3.1 was conducted to classify driver behaviors and driving conditions associated with stop-controlled and signalized violations and to identify how observed driver behaviors and driving conditions could support the development of a CICAS-V. The driver behaviors and driving conditions observed in the 100-Car Naturalistic Driving Study (100-Car Study: Dingus et al., 2006) were reviewed and evaluated to determine the preliminary DVI approach. For detailed information regarding the research described in this section, please refer to Subtask 3.1: Mining of the 100-Car Naturalistic Driving Database to Determine Factors Related to Intersection Violations and Near Violations (Sudweeks et al., in print).

#### *2.3.1.1 Subtask 3.1 Method*

To determine the conditions under which drivers commit violations, their behaviors and driving conditions were classified for violations observed within the 100-Car Study database. A compelling feature of this database is that both driver and vehicle performance variables are concurrently available to evaluate several aspects of the intersection crossing. Data for 77 drivers who had driven at least 1,000 miles during the course of the 100-Car Study were examined for intersection violations. Video reductionists validated, classified, and provided detailed descriptions of intersection crossings. Since the original sample of the 100-Car Study drivers was intentionally skewed toward younger males, the composition of the 77 individuals selected for evaluation did not allow a sensitive evaluation of any age or gender effects.

#### *2.3.1.2 Subtask 3.1 Results*

The results for violations and near violations for stop-controlled and signalized intersection types are described separately. A brief comparison of the behaviors observed at these two intersection types follows this discussion.

#### *2.3.1.3 Stop-controlled Intersection Results*

Intersection crossings at 143 stop-controlled intersections were examined. These violations were defined as crossings in which the vehicle did not come to a complete stop at the stop bar and the estimated stop-bar speed exceeded 5 mph. Near violations were defined as either crossings in which the driver prevented a violation with hard braking (i.e. braking above 0.5 g), or as crossings in which a driver violated the stop-controlled intersection at a speed estimated to be less than 5 mph. A total of 772 stop-controlled intersection violations and 108 near violations were observed. A brief summary of these violations and near violations is followed by a discussion of the subject's interaction with the intersection. Driver behaviors and driving conditions observed during these violations are then discussed.

#### 2.3.1.3.1 Stop-Controlled Intersection Violation and Near Violations Summary

Five of the stop-controlled intersection near violations involved hard-deceleration events (i.e. 0.5 g or more), which are distinctly different from an intentional “rolling stop” through the intersection. Detailed descriptions of these five near violations were compiled. The remaining near violation incidents consisted primarily of slow-rolling stops and situations in which drivers followed a leading vehicle into the intersection without coming to a stop. These near violations were not subject to further analysis.

Thirty-nine percent of the stop-controlled intersection violations (defined to be above a 5 mph stop-bar speed) occurred at a stop-bar speed between 6 and 10 mph. The remaining 61 percent of the violations occurred at a stop-bar speed in excess of 10 mph. Approximately 50 percent, 27 percent, and 23 percent of the stop-controlled intersection violations were straight-crossings, left turns, and right turns, respectively.

##### 2.3.1.3.1.1 **Stop-Controlled Intersection and Driver Summary**

Four of the 77 drivers committed approximately 40 percent of all observed stop-controlled intersection violations. While it is possible that these individuals are representative of the most frequent violators, it is also possible that the method used to select stop-controlled intersections and the relatively small number of intersections evaluated served as sources of bias. A number of participants had moderate to low-crossing counts at stop-controlled intersections, which limited their opportunity to commit these violations. The low-crossing counts for many of the drivers were believed to be a function of the selection of stop-controlled intersections, which introduced the potential confound that a few individuals could significantly influence the pattern of results.

Forty percent of stop-controlled violations occurred at five intersections. Violations with high vehicle speed at the stop bar (in excess of 15 mph) were seen primarily at a limited number of intersections. In some cases, individual drivers accounted for most violations of a given type at a given intersection. For example, when violations with stop-bar speeds in excess of 15 mph were considered, 40 percent of the violations were observed at three intersections. Although several different subjects traveled through these three intersections at least once, the high stop-bar speed violations were dominated by a handful of drivers. For example, one subject accounted for 100 percent of the violations at a particular intersection, with stop-bar speeds in excess of 15 mph, and another subject accounted for 90 percent of the high stop-bar speed violations at a separate intersection. One possible explanation could be that drivers consistently travel a certain route (e.g., through the same intersections) on their daily commute and the intersection familiarity leads to more aggressive approach behavior and an increased number of violations.

##### 2.3.1.3.1.2 **Stop-Controlled Intersection Driver Behavior Summary**

Following conventions in Klauer et al. (2006), driving inattention was broadly defined as any point in time that a driver engaged in a secondary task, exhibited symptoms of impairment, or looked away from the forward roadway. These categories of inattention are operationally defined as follows:

*Secondary task distraction* – driver behavior that diverts the driver’s attention away from the driving task

*Impairment* – driving behaviors that indicate diminished physical and or mental capabilities

*Driving-related inattention to the forward roadway (DRI)* – driver behavior that is directly related to the driving task but diverts driver’s attention away from the forward field of view

In the context of examining drivers traversing an intersection, driving-related glances that diverted attention from the forward roadway were further classified. The glances were assessed to determine whether the behavior was perceived as inattention or as a sign of scanning the environment before making a vehicle maneuver (i.e., a lane change). The latter was considered as appropriate intersection approach driving behavior.

Video reductionists were asked to provide a subjective assessment of apparent driver intent during stop-controlled intersection violations by classifying whether they regarded the violation as an intentional act (i.e., willful) by the driver. Regardless of estimated stop-bar speed and turn intent, reductionists scored 100 percent of the violations as willful violations. This evaluation of the driver’s intention to violate in an intersection based solely on the available face video was limited by the inherent difficulty of judging the driver’s state of mind. For example, the same characteristics may be seen (e.g., driving-related glances, secondary tasks etc.) for drivers who are attempting to “beat the light” as for those who have miss-calculated the length of the amber phase.

Impairment was rarely observed. Driving-related glances without secondary task engagement were observed in 38 percent of the events, and no observable driver inattention was reported in 3 percent of the events. Secondary task engagement without driving-related glances was observed in 11 percent of stop-controlled intersection violations, while secondary task engagement combined with driving-related glances were observed in 45 percent of the events.

The most common secondary tasks observed during stop-controlled intersection violations, regardless of the presence or absence of driving-related inattention glances, were cell phone tasks, passenger-related distractions, and talking or singing without an obvious passenger present. The presence of a secondary task, in conjunction with driving-related glances, did not significantly change the eye-scanning patterns. Stop-controlled intersection violations in which only driving-related glances were observed exhibited similar eye-scanning patterns.

The level of observed distraction influenced the amount of time spent looking toward the forward roadway during the 5 seconds (s) prior to crossing the stop bar. The mean for those violations in which a secondary task was observed, was 4.2 s with a standard deviation of 1.2 s. For those violations in which a secondary task was observed in conjunction with driving-related glances, the mean was 3.4 s with a standard deviation of 1.4 s. For those stop-controlled intersection violations in which only driving-related glances were observed, the mean was 3.5 s with a standard deviation of 1.6 s.

Left-turn and right-turn, stop-controlled, intersection violations showed similar eye-scanning patterns. Left and right glances or left-only glances were observed in approximately 87 percent of left-turn and right-turn stop-controlled intersection violation events. Straight-crossing violations differed from left-turn and right-turn violations. Left

and right glances or left-only glances were observed in approximately 63 percent of straight-crossing violation events, with right-only glances being observed in 18 percent of straight-crossing violation events. No glances were reported in 14 percent of straight-crossing violation events.

Turn intent, without regard to level of observed distraction discussed previously, had a minor effect on the amount of time spent looking toward the forward roadway during the 5 s prior to crossing the stop bar. For left-turn, stop-controlled, intersection violations, the mean was 3.9 s with a standard deviation of 1.3 s. For right-turn violations, the mean was 3.5 s with a standard deviation of 1.5 s. For straight-crossing violations, the mean was 3.6 s with a standard deviation of 1.6 s.

In approximately 70 percent of stop-controlled intersection violations, crossing errors (e.g., right of way decision errors or failure to use turn signals) or maneuvers to avoid objects (e.g., other vehicles or pedestrians) were not observed based on the judgment of the video reductionists. In 11 percent of violations, drivers failed to use their turn signal. In almost 10 percent of violations, drivers made an improper turn at the intersection. These improper turns consisted primarily of situations in which the driver was judged to have turned too sharply or turned into an incorrect lane.

#### **2.3.1.3.1.3 Stop-Controlled Intersection Driving Conditions Summary**

Daylight conditions were observed in 65 percent of stop-controlled intersection violations. Darkness (lighted and unlighted) was observed 33 percent of the time and transition (dawn/dusk) lighting conditions were observed 2 percent of the time. Clear weather was observed in 88 percent of violations, with any form of precipitation recorded only 7 percent of the time and cloudy weather recorded 5 percent of the time. Dry roads were observed in 87 percent of violations, wet roads were observed 12 percent of the time, and snowy and icy conditions were observed in approximately 1 percent of violations. The observed results for time of day, weather, and surface conditions during stop-controlled intersection violations were similar to results reported in existing literature.

A lead vehicle was observed in fewer than 21 percent of stop-controlled intersection violations, and a following vehicle was observed in only 10 percent of the events. Potential visual obstructions of the stop sign were observed in 13 percent of violations. Five percent of these obstructions were due to a parked vehicle, 4 percent was due to vegetation, and 4 percent was attributed to particulate matter or sun glare.

#### **2.3.1.3.2 Signalized Intersection Results**

Crossings at a total of 163 signalized intersections were examined. The violations were defined as crossings in which the driver proceeded through the intersection when the observed signal phase at the stop bar was red. Near violations were defined as crossings in which the driver proceeded through the intersection when the observed signal phase at the stop bar was yellow and the last visible signal phase was red or crossings in which the driver prevented a violation by hard braking (i.e. braking above 0.5 g). A total of 1,215 signalized intersection violations and 394 near violations were observed. A brief summary of these violations, followed by a discussion of the subject's interaction with the intersection, will now be discussed.

#### **2.3.1.3.2.1 Signalized Intersection Violation and Near Violation Summary**

Violations during right turns were the vast majority of the observed signalized intersection violations (i.e., 96 percent of the 1,215 violations). However, these events are considered the least interesting in terms of risk exposure and possible benefits from an intersection collision avoidance system. Detailed video reduction revealed that a number of these right-turn violations occurred at low speeds and during situations in which the driver's lane had a designated signal (e.g., the protected left- and right-turn signal phase for cross traffic). As a result, right turns violations were excluded from further consideration.

There were only 12 left-turn signalized intersection violations observed. Such a small number of observations could not be meaningfully partitioned across the driver behavior and environmental factors under consideration. Instead, these violations were each reviewed in detail. In order to augment the low frequency of left-turn and straight-crossing violations, left-turn and straight-crossing signalized intersection near violations were included in the analyses. This approach was deemed reasonable as the primary difference between signalized intersection violations and moving near violations was the signal phase at the stop bar. These violations received further consideration: 33 straight-crossing violations, 280 straight-crossing near violations, and 65 left-turn near violations.

The estimated stop-bar speed for straight-crossing maneuvers varied considerably. Stop-bar speeds for straight-crossing signalized intersection violations ranged from 19 mph to 69 mph with an average speed of 40 mph and a corresponding standard deviation of 12 mph. Stop-bar speeds for straight-crossing near violations ranged from 7 mph to 68 mph with an average speed of 37 mph and a standard deviation of 10 mph. Left-turn, near-violation, stop-bar speeds ranged from 4 mph to 34 mph with an average speed of 21 mph and a standard deviation of 6 mph.

#### **2.3.1.3.2.2 Signalized Intersection and Driver Summary**

The number of signalized intersection crossings per driver varied considerably, ranging from 60 to 4,481 with an average of 1,306 crossings and a standard deviation of 963 crossings. A number of subjects had relatively few intersection crossings, which limited their opportunity to commit signalized intersection violations.

The low-crossing counts for many of the drivers can likely be directly attributed to the selection of the signalized intersections. These low counts also introduced the potential confound that a few individuals have significantly influenced the observed results. Indeed, 27 percent of observed straight-crossing and left-turn violations can be traced to just three of the drivers analyzed in this effort. It is possible that these individuals are representative of the worst signalized intersection violators. It is also possible that the method used to select intersections for consideration, along with the small number of intersections evaluated, biased the observed results. The distribution of left-turn and straight-crossing, signalized, intersection violations across the 163 intersections appeared to be somewhat uniform.

### 2.3.1.3.2.3 Signalized Intersection Driver Behavior Summary

As indicated above, inattention was broadly defined as any point in time that a driver engages in a secondary task, exhibits symptoms of impairment, or looks away from the forward roadway (Klauer et al., 2006).

For signalized intersection violations and near violations, secondary task engagement without driving-related glances was observed 33 percent of the time. Secondary task engagement with driving-related glances was observed 14 percent of the time. Driving-related glances without secondary task engagement were observed 14 percent of the time, and no form of driving inattention was observed in 38 percent of events. The most common secondary tasks when no driving-related glances were observed were cell phone tasks, passenger-related distractions, and talking or singing without an obvious passenger present. The most common secondary tasks when driving-related glances were observed were passenger-related distractions and talking or singing without an obvious passenger present.

The nature of the distraction influenced the time spent looking toward the forward roadway during the 5 s prior to crossing the stop bar. For those straight-crossing violations in which a secondary task was observed, the mean was 4.4 s with a standard deviation of 1.0 s. Straight-crossing violations, in which a secondary task was observed in conjunction with driving-related glances, had a mean of 4.1 s with a standard deviation of 1.5 s. The mean for straight-crossing signalized intersection violations with driving-related glances was 4.4 s with a standard deviation of 1.2 s.

The total forward glance time varied, based upon the type of signalized intersection violation. Straight-crossing violations had a mean of 4.6 s with a standard deviation of 0.6 s. For straight-crossing near violations, the mean was 4.4 s with a standard deviation of 1.1 s. For left-turn near violations, the mean was 4 s with a standard deviation of 1.5 s.

Scanning patterns for signalized violations and near violations consisted primarily of partial scanning (i.e., not glancing left and right). Glances to the left and right were observed in only 4 percent of the events. “Only left” or “only right” glances were observed in 27 percent of the events. The presence of a secondary task, in conjunction with driving-related glances, did not significantly change the eye-scanning patterns. Violations and near violations, in which only driving-related glances were observed, showed the same eye-scanning patterns.

Video reductionists’ subjective assessment of apparent driver intent scored all but 3 of the 377 signalized intersection violations and near violations as willful. As discussed above, distinguishing willful versus unintentional violations, based on 100-Car data, is inherently problematic. This is particularly true if the driver is looking forward (such as during conversations on a cell phone or with a passenger).

The evaluation of a driver’s willingness to violate a signalized intersection raised the possibility that drivers who were committing violations or near violations did not regard opposing traffic as a threat. This may have been an artifact of drivers who violated in relation to how long the light phase had been red. Based on the available video, it was not possible to tell how long into the red phase the drivers were violating. Previous research showed that most drivers violate within 1 or 2 s into the red phase (Zimmerman

and Bonneson, 2005). For the observed violations, perhaps drivers took willful, albeit inappropriate, advantage of the all-red phase.

Avoidance maneuvers and crossing errors were observed in signalized intersection violations less than 4 percent of the time. As with stop-controlled intersection violations, the improper turns observed consisted primarily of situations in which the participant was judged to have turned too sharply or turned into an incorrect lane. Lane changes within 5 s of crossing the intersection were observed for 6 percent of signalized intersection violations and near violations.

Drivers were observed in a left-turn-only lane during 90 percent of signalized intersection left-turn near violations. Eighty-five percent of straight-crossing violations and near violations were observed in a designated straight-only lane, with the remaining 15 percent observed in dual purpose lanes.

#### **2.3.1.3.2.4 Signalized Intersection Driving Conditions Summary**

Results for time of day, weather, and surface condition analyses for signalized intersection violations were similar to those found in existing literature. For signalized intersection violations and near violations, 78 percent occurred during daylight conditions, 11 percent occurred during transitional (dawn/dusk) lighting, and 11 percent occurred during dark conditions with street lights present. Clear conditions were observed during 83 percent of these violations, while snow, mist, and rain were observed approximately 9 percent of the time and cloudy conditions were observed 8 percent of the time. Dry surface conditions were observed in 88 percent of violations and near violations, and snowy or wet conditions were recorded for the remaining 12 percent.

A lead vehicle was observed in 53 percent of signalized intersection violations and near violations while a following vehicle was observed in approximately 32 percent of the cases. It should be noted that the prevalence of center mirror glances was high for straight-crossing near violations. This suggested that drivers may have taken into account the presence of a following vehicle when deciding whether or not to proceed into an intersection during the yellow-light phase.

No visual obstructions were noted in approximately 90 percent of signalized intersection events. When a visual obstruction was noted, 5 percent were recorded as sunlight glare and 4 percent were marked as particulate matter such as rain, snow, smoke or dust.

#### **2.3.1.3.3 Comparison of Signalized and Stop-controlled Intersection Results**

The following section briefly compares stop-controlled and signalized intersection violations and near violations as they relate to the observed driver behaviors and driving conditions.

Secondary task engagement, without driving-related glances around the vehicle, was observed in 11 percent of stop-controlled intersection violations as compared to 33 percent in signalized intersection violations and near violations. Similar to stop-controlled intersection violations, the secondary tasks most frequently observed during signalized intersection violations and near violations were cell phone use and passenger-related inattention.

In general, there were far fewer driving-related glances around the vehicle for signalized intersection violations and near violations than for stop-controlled intersection violations. When drivers committed a left-turn, signalized–intersection, near violation; straight-crossing signalized–intersection violation; or straight-crossing signalized–intersection, near violation, they were more likely to have been looking at the forward roadway than for stop-controlled intersection violations. They were less likely to have been scanning the driving environment than drivers who committed a stop-controlled intersection violation. There was, however, a notable exception: drivers, who approached a stop-controlled intersection while engaged in a secondary task, spent most of their time looking forward and did not make driving-related glances around their vehicles.

Fewer avoidance maneuvers and crossing errors were noted in signalized–intersection violations than at stop-controlled intersection violations. In both cases, crossing errors consisted primarily of situations in which the participant turned into the incorrect lane or was judged to have turned too sharply. Time of day, weather, and surface condition analysis results for both signalized and stop-controlled intersection violations were similar to those found in existing literature. In 61 percent of the signalized intersection events no following vehicle was observed, as compared to 82 percent of stop-controlled intersection events.

#### 2.3.1.3.4 Subtask 3.1 Implications for the Design of a CICAS-V Warning System

The objective of a CICAS-V is to assist drivers in avoiding crashes at intersections by warning the vehicle driver that a violation, at an intersection controlled by a stop sign or by traffic signal, is predicted to occur. The following are the implications for a CICAS-V warning, based upon the results of the Subtask 3.1 study.

1. A high location (i.e., head-up or high head-down) is recommended for the visual display.

*Supporting rationale:* This recommendation is based upon two values: 1) estimates of the amount of time drivers are looking forward during the 5 s prior to crossing the stop bar; and 2) the predominant type of (“looking ahead”) secondary tasks observed.

2. A visual warning DVI should be complimented by another warning mode.

*Supporting rationale:* This recommendation relies upon estimates of the scanning patterns and the amount of time drivers look forward during the 5 s prior to crossing the stop bar at a stop-controlled intersection. In addition, a multi-modality alert is useful for drivers that may not detect the visual warning.

3. A DVI that conveys a sense of urgency and the potential risk of a violation may be effective in addressing frequently-occurring willful violations.

*Supporting rationale:* The evaluation of driver intent to violate an intersection, based on the available face video, was limited in part by the difficulty in judging the driver’s state of mind when he or she was looking at the road ahead. Given this significant and important limitation, unintentional violations were rarely judged to have occurred by the video scorers. For signalized intersection events, a portion of the apparently willful violations may actually have been the result of

drivers underestimating the time remaining in the yellow light duration. This occurs when a driver, attempting to take advantage of the entire yellow light duration, performs a late-intersection crossing without intending to commit a violation. In such situations, a DVI may prove very effective at changing driver behavior.

4. Results from video reduction indicate that the presence of a following vehicle should not be a dominant concern when developing a CICAS-V warning algorithm

*Supporting rationale:* In 61 percent of the signalized intersection events no following vehicle was observed, as compared to 82 percent of stop-controlled intersection events. It should be noted that the prevalence of center-mirror glances was much higher for straight-crossing, signalized intersection, near violations than for the other signalized intersection violation and near violation maneuvers (i.e. left-turn near violation and straight violation). Of the 78 straight-crossing, signalized intersection, near violations, 39 involved center mirror glances. Perhaps this indicated that drivers took into account the presence of a following vehicle when deciding whether or not to proceed into an intersection during the yellow phase.

5. To minimize false alarm rates (and the associated customer annoyance) and to address the fact that “rolling stops” are common events, a CICAS-V warning algorithm will likely need a minimum speed threshold, below which a warning should not be presented to the driver

*Supporting rationale:* Sixty-one percent of stop-controlled intersection violations occurred with drivers traveling more than 10 mph at the stop bar.

6. A CICAS-V warning algorithm for signalized intersections may benefit from having information regarding the lane of travel

*Supporting rationale:* Most signalized intersection violations occurred in a lane marked solely for a particular maneuver (i.e., left turn lane only). There were also indications that some drivers made late lane changes and improper maneuvers that could lead to false or missed warnings.

7. Based on the results of Subtask 3.1, it was determined that infrastructure-based data collection at multiple intersections was needed to supplement the current findings

*Supporting rationale:* Additional naturalistic data collection provides more precise estimates of an appropriate speed threshold necessary to develop an effective warning algorithm. While the data analyzed in this study demonstrates a difference in the range of speed for left-turn and straight-crossing violators, it does not address differences in approach profiles that would aid in algorithm development. To develop a warning algorithm, detailed information regarding the signal phase and timing, paired with vehicle information (e.g., range to intersection), is necessary. An infrastructure-based intersection data collection system was utilized to address this need in Subtask 3.2 of the CICAS-V Project.

#### 2.3.1.3.5 Subtask 3.1 Study Limitations

There are limitations to the 100-Car Study data that should be considered when drawing inferences from these analyses, including the composition and nature of the study participants. The 100-Car Study had 42,000 hours of driving data collected from 109 primary participants and 132 secondary drivers. The identification of data files by vehicle, rather than by participant, necessitated focusing on a subset of 77 primary participants. This subset of drivers is known to be skewed toward younger male drivers. Thus, it should be noted that the large number of intersection crossings and violations reported here represent repeated observations on this subset of primary participants at a limited number of intersections in one metropolitan area.

In addition, intersection selection may have influenced the results of these analyses. Thus, care should be exercised in extending these results to intersections in large metropolitan areas to dissimilar geographic areas. Beyond that, the selected intersections did not have comparable crossing rates across all 77 subjects. Without a sufficient number of total crossings for each individual, it is not known if observed violation rates are stable for all individuals. In addition, the dominance of certain classes of violations by a few individuals may be more a function of observing those individuals traversing the same intersections repeatedly rather than an indication that their violation rate is significantly higher than those of other drivers.

Inferences for the classes of violations dominated by a few individuals should be made very carefully. A final consideration for selection deals with the types of intersections considered. To the extent possible, high-risk intersections were selected so that more violations could be observed. It is unknown if results from high-risk intersections readily transfer to other lower-risk intersections. Of course, as this evaluation only applies to stop-controlled and signalized intersections, these conditions are not known for other intersection types (e.g., yield-controlled).

Finally, the rarity of these violations imposes inherent constraints on possible analyses. Even with the tremendous amount of driving data collected during the 100-Car Study, the data quickly became too sparse to support definitive conclusions when events of interest are analyzed in increasing levels of detail.

Despite these limitations, this research provides an important naturalistic investigation of driver behavior and circumstances surrounding intersection violations. This information was useful in the development of the CICAS-V warning algorithms and driver interfaces. The data analyzed in this subtask was augmented with the results from the focused algorithm and DVI investigations in Subtasks 3.2 and 3.3.

### **2.3.2 Subtask 3.2: Naturalistic, Infrastructure-Based, Driving Data Collection and Intersection, Collision Avoidance, Algorithm Development**

To be effective, CICAS-V must present the warning to drivers who will benefit from it without inadvertently annoying compliant drivers. Using data obtained from the vehicle and intersection, a warning algorithm performs computations to predict whether the driver will comply with the intersection stop sign or stop light. The algorithm must correctly predict the driver's stopping decision at a distance that provides sufficient time

for that driver to stop before entering into crossing traffic. Subtask 3.2 was created with the aim of developing and evaluating warning algorithms for the CICAS-V prototype to meet this requirement. For further information concerning the research described in this section, please refer to Subtask 3.2: Naturalistic Infrastructure-Based Driving Data Collection and Intersection Collision Avoidance Algorithm Development (Doerzaph et al., in print).

#### *2.3.2.1 Subtask 3.2 Method*

Under this subtask, data collection efforts were undertaken at three signalized intersections and five stop-controlled intersections in the New River Valley area of southwest Virginia. Please refer to CICAS-V Subtask 3.2 Interim Report (Doerzaph, et. al, in print) for the list of the selected intersections. Data collection equipment was installed at these intersections and recorded a large array of vehicle data. Detailed information was obtained for every vehicle approaching the instrumented stop-controlled and signalized approaches.

Analysis of these data focused on the development of an algorithm that would predict driver stopping behavior at intersection approaches so that a warning would be provided to a violating driver without annoying compliant drivers. From the raw data collected, driver approach behavior was dissected and analyzed for trends. Assessment algorithms, designed to predict whether or not a driver will stop, were developed and then evaluated in a pseudo-real-time simulation using the raw intersection approach data.

The performance of each potential algorithm was based on the effectiveness of a potential algorithm to predict a pending violation while minimizing false detections (alarms). In addition, other measures, such as the location at which a violation warning was provided, likelihood of annoyance, algorithm complexity, and data requirements, were also considered. Two algorithms for stop-controlled intersections and two algorithms for signalized intersections were recommended for the system-level tests of Subtask 3.4.

To obtain data for developing and testing the algorithms, data collection efforts focused on six approaches at five stop-controlled intersections and each approach at three four-way signalized intersections. These sites were selected based upon intersection characteristics (e.g., representative posted speed limits), crash statistics, traffic volume, and recommendations by the Virginia Department of Transportation (VDOT). Selections were made to represent types of intersections that are expected to benefit from a CICAS-V system.

Custom, non-obtrusive DASs were installed at the selected intersections. The DASs consisted of three major subsystems: 1) sensing network, 2) processing stack, and 3) associated hardware enclosures and mounts. The sensing network consisted of a distributed subsystem of components that provided raw inputs to the processing stack at a rate of 20 Hz. The sensor suite consisted of the following:

1. Radar to provide parametric vehicle data
2. Video cameras to collect the visual scene
3. Weather stations (signalized intersections only)

4. Signal phase sniffer to provide the signal phase and timing at signalized intersections
5. Global Positioning System to provide synchronized global time

The processing stack pre-processed the sensor data and assembled the data set in real time while simultaneously archiving to binary data and compressed video files. The DAS was completely contained at the intersection sites and virtually invisible to drivers.

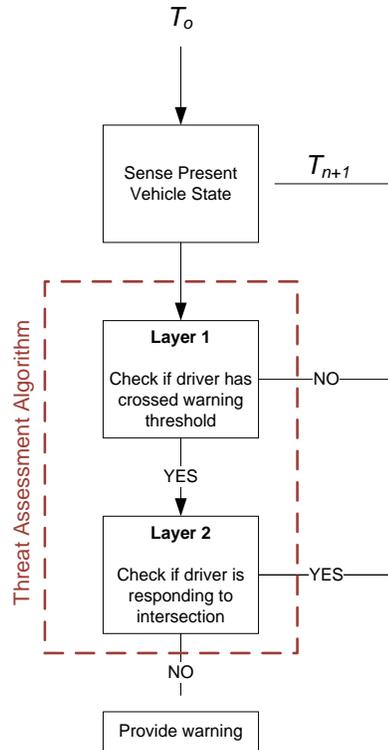
Data was transported at regular intervals to the Virginia Tech Transportation Institute (VTTI), where it was uploaded to secure servers for storage. Post-processing of the stop-controlled and signalized data consisted of a series of data filtering, extrapolation, and smoothing techniques to prepare the data set for analyses. These measures improved the quality of the raw data set and derived additional measurements that were used for the algorithm development and evaluation.

The first stage of data analysis included exploratory investigations of the stop-controlled and signalized data sets. When these investigations began, little was known about the trajectories of vehicles as they approached intersections. The results from Subtask 3.1 aided in identifying which drivers should receive a warning; however, there was no consensus on which metrics should be used in the threat assessment algorithm. The analyses included investigations of driver decisions at intersections regarding stopping, minimum stop-bar speed, brake onset, and overall vehicle trajectories. These exploratory analyses were performed with the goal of developing the CICAS-V algorithm.

After the exploratory analyses, a procedure was developed to test and evaluate the algorithm. Synthesis of the literature, engineering theory, and intersection-approach analysis generated data inputs for the algorithm development. The preliminary algorithms were tested in a pseudo-real-time simulation using the actual vehicle trajectory data collected for this study. This analysis generated a set of assessment algorithms that were carried forward into the CICAS-V development and testing during subsequent tasks in the CICAS-V Project.

Each algorithm was evaluated utilizing the theory of signal detection (Swets, J.A., 1996), which was extended to consider additional factors within the CICAS-V context. In addition to warning accuracy, the “extended” signal detection method also evaluated the algorithms in terms of the warning timing (i.e., required braking levels) and their anticipated level of nuisance. Analysis of the results determined possible regions for improvement based on the algorithm’s classification of vehicle trajectories. Improvements were made and the iterations of the simulation cycle were conducted until additional revisions ceased to yield significant algorithm performance improvements.

All of the algorithms tested follow the same basic framework (Figure 2). An approaching vehicle first enters the monitored region of the intersection at time  $T_0$ . Once the vehicle enters the region of interest, its kinematic state is measured every 50 milliseconds. During the research for Subtask 3.2, the measurements were obtained by the radar at the intersection. In the CICAS-V application, these measures were obtained from the vehicle’s onboard sensors.



**Figure 2: Top-level Algorithm Architecture**

Once the kinematic measures are evaluated, they are fed into the first layer of the algorithm. The first layer contains a computational component that evaluates whether or not the warning should be provided, based on the present kinematic state of the vehicle. This layer gathers together a variety of measures into a single metric, which is then compared to a prediction criterion. If the outcome of the comparison indicates driver compliance, the algorithm computations cease for that time frame. The evaluation process then starts over for the next time cycle. If the outcome of the comparison predicts a violation, the present vehicle kinematics are passed to the second layer of the algorithm.

The second layer of the algorithm was added to reduce the number of false alerts that were being produced by the first layer. The second layer evaluates the present state of the vehicle to predict whether the driver is attentive to the intersection. If the driver appears to be attentive (e.g., has started braking or is below a set speed), the warning is suppressed. If the driver is not attentive, the warning is set to active and the algorithm is terminated for the remainder of the intersection approach trajectory. If the warning is suppressed, the entire process begins again with the next time window and is repeated through the entire intersection approach trajectory unless a warning is presented.

### 2.3.2.2 Subtask 3.2 Results and Implications for the Design of a CICAS-V Warning System

Due to the technical aspect of this subtask, the results and implications sections have been combined.

Overall, more than 160 individual algorithms were tested with more than 7,000 unique parameter combinations. Some of the algorithms were based on the laws of physics and used standard kinematic equations, while other algorithms were based on regression techniques. The algorithm analysis process generated a series of graphical outputs. They represented the accuracy of the algorithm, the timing of the produced warnings, and the anticipated level of nuisance that may result from the associated false warnings. The reader is referred to the Subtask 3.2 Report (Doerzaph et al., in print) for details on the graphical analysis.

The most notable trends identified from the graphical outputs include the following:

1. The highest performing algorithms at stop-controlled intersections are not typically the highest performing algorithms for signalized intersections.
2. At stop-controlled intersections, the braking criterion for warning suppression (located in the second layer of the algorithm) tends to provide the best results if braking effort (i.e., braking at 0.1 g or higher) rather than brake status (i.e., brake pressed) is used. This trend was not observed at signalized intersections.
3. The low-speed cutoff in the second layer of the algorithm tends to provide the best results if it is set above 4.4 m/s (10 mph) at both stop-controlled and signalized intersections.
4. The results of the simulation show that algorithms discriminate better between compliant and violation approaches when higher violation thresholds are selected. The violation threshold represents the stop-bar speed used to classify compliant and violation intersection approaches. Thus, drivers who roll through a stop sign or a signalized intersection in the red phase at a speed below the violation threshold are not considered violators by the system.

Three heuristics were used to rank-order the algorithms in terms of differing performance criteria. There is an inherent trade-off between providing the most overall true positives (warning a driver who would have otherwise violated), appropriately timed warnings (warning early enough for the driver to react and stop the vehicle with reasonable levels of hard braking), and minimizing the number of false positives (warning a driver who would have otherwise been compliant). The preferred heuristic provided a compromise by simultaneously performing the following:

1. Allowing no more than either 5 percent or 1 percent false positives (both cases were examined)
2. Maximizing the overall number of total true positives
3. Maximizing the number of appropriately timed warnings (which allows sufficient braking distance)
4. Minimizing the number of false positives (alarms) likely to be perceived as nuisance

Presently, the driver's tolerance for false positives is not known. It is possible that some of the false positives will not be perceived as annoying. For instance, although a driver may have complied with the traffic control device, he or she may have braked late due to inattention or misjudgment and may have valued, or at least tolerated, a warning if it was

provided. By executing the heuristic while allowing either a 5 percent or a 1 percent false positive rate, two sets of algorithms were identified. The 5 percent algorithm results in more true positives than the 1 percent algorithms, and thus should be selected for initial evaluations. If drivers find the false positives annoying during the on-road testing, the 1 percent algorithms should provide viable alternative algorithms.

Assuming a projected 5 percent false positive rate, the final set of recommended algorithms are predicted to correctly warn 68 percent of the violating drivers at stop-controlled intersections and 82 percent of violating drivers at signalized intersections. On the other hand, assuming a projected 1 percent false positive rate, 56 percent and 68 percent of the violating drivers are predicted to be correctly warned at stop-controlled and signalized intersections, respectively. Additional algorithms were identified that improved the performance rates, particularly at stop-controlled intersections. However, these additional algorithms use a “braking effort” criterion (e.g. a direct measurement of the force/torque applied by driver) that could not be feasibly integrated into the current CICAS-V prototype.

### *2.3.2.3 Subtask 3.2 Study Limitations*

There are certain limitations that need to be considered when interpreting the results of this subtask. First, the geographic region was limited to southwest Virginia and urban corridor intersections. Drivers from different regions and across other roadway types may approach intersections differently. Furthermore, the data collection took place over two consecutive months during the spring season, and, thus, may not necessarily reflect seasonal differences in intersection driving behavior.

From a practical standpoint, placing the DAS at the intersection was necessary in order to obtain the volume of intersection approach data desired to construct a robust and valid CICAS-V algorithm. However, the lack of in-vehicle data results in a lack of information about the driver actions and intent that led up to the violation. Furthermore, measures such as brake status and acceleration had to be inferred. While care was taken to validate these measures, there may be some situations (e.g., foot resting on the brake without actively braking) that are unaccounted for in the analyses.

Finally, the radar sometimes provided sparse data rather than in-vehicle continuous data. This was especially true for the radar used for the stop-controlled intersection data collection. This required an enormous post-processing effort to improve the data so that continuous algorithms could be evaluated. During this effort, only vehicle tracks that contained sufficient fidelity were carried through to the analysis portion of the study. While there was no direct evidence to suggest that this systematic selection confounded the data, it remains possible that certain types of vehicles or vehicle approach characteristics may have been prone to degraded radar performance. Thus, certain types of vehicles or approach types may be unknowingly underrepresented in the data set.

### **2.3.3 Subtask 3.3: Test of Alternative DVI on the Smart Road**

The DVI is the means through which the warning information is presented to the potential violator. The importance of this particular subsystem is based on its function: prompting the driver to take the appropriate violation avoidance maneuver. For this reason, a series of Human Factors test-track studies were conducted for Subtask 3.3 of the

CICAS-V Project for the exploration of the DVI. These studies focused on two primary goals:

1. Determine the DVI, and associated warning algorithm, that would be integrated into the CICAS-V system for a pilot FOT, (Phase 1, Subtask 3.4, Neale et al., in print) and Objective Tests (Task 11, Maile et al., in print).
2. Provide the United States Department of Transportation Independent Evaluator (USDOT/IE) with data for use in the estimation of safety benefits.

For detailed information concerning the research described in this section, please refer to Subtask 3.3: Test of Alternative Driver-Vehicle Interfaces (DVI) on the Smart Road (Perez et al., in print).

#### *2.3.3.1 Subtask 3.3 Method*

Experimental scenarios were developed to attain a set of test conditions that simulated “representative” signal violation scenarios. Naive drivers were exposed to these scenarios while being aided by one of several DVI alternatives. In addition, a baseline condition was also examined in which drivers experienced the signal violation scenario without a CICAS-V alert. For a detailed description of the simulated violation scenarios, please refer to CICAS-V Subtask 3.3 Interim Report (Perez, et. al. (in print). This section describes the effort to determine the characteristics of the DVI associated with the warning given to a driver predicted to violate the traffic control device for the CICAS-V prototype. The assessment approach and candidate DVIs selected for these studies were based on previous research and consensus of stakeholders within the CICAS-V Project, and are summarized within Table 2.

**Table 2: Final List of Studies Completed as Part of CICAS-V Subtask 3.3.**

Study #	DVI*	Time to Intersection (TTI, s)	Protocol for testing
1	Crash Avoidance Metrics Partnership (CAMP) Tone	2.24	Occlusion
2	CAMP Tone	2.44	Occlusion
3	CAMP Tone	2.44	Naturalistic Distraction
4	Speech	2.44	Naturalistic Distraction
5	CAMP Tone and Brake Pulse	2.44	Naturalistic Distraction
6	Speech and Brake Pulse	2.44	Naturalistic Distraction
7	Beep Tone and Brake Pulse with Panic Brake Assist (PBA)	2.24	Naturalistic Distraction
8	Speech and Brake Pulse with PBA	2.24	Naturalistic Distraction
9	Speech and Brake Pulse with PBA	2.04	Naturalistic Distraction
10	Speech and Brake Pulse with PBA	1.84	Naturalistic Distraction
11	Baseline Condition (No warning)	2.44**	Naturalistic Distraction

\*All of these studies featured a visual display that performed both advisory and warning functions (only the advisory function of this display was used in Study 11).

\*\* The yellow light change occurred at 2.44 s

In an effort to determine the best method to evaluate the DVIs, two protocols were developed that employed different methods to distract drivers' attention from the forward roadway. One protocol used visual occlusion, in which the driver's sight was occluded for predetermined intervals using occlusion goggles, while the other protocol used a naturalistic distraction method, in which the drivers were asked to perform in-vehicle tasks (e.g., adjusting the radio). Both protocols for Subtask 3.3 were tailored to maximize the probability that drivers would not be attending to the forward roadway (and, consequently, the intersection signal) upon their first encounter with the CICAS-V violation warning. The naturalistic distraction protocol was determined to better serve the goals of this subtask and, therefore, was used in the majority of the studies.

Most of the experimental groups used contained 18 participants, counterbalanced for age and gender. However, when it was apparent that the DVI being tested would not yield desired intersection stopping behaviors (e.g., not stopping or stopping in the collision zone), some studies were terminated early in an effort to conserve experimental resources (e.g., subjects) for later experiments. Participants across three age groups were recruited for all experiments: younger drivers aged 20-30, middle-aged drivers aged 40-50, and older drivers aged 60-70. Altogether, data from 172 participants were used to support the recommendations for the design of the CICAS-V warning system.

Participants drove a 2006 Cadillac STS on the Smart Road for several loops before being exposed to a surprise signal violation trial. This surprise scenario created a situation in which the driver needed to make a split-second decision about the potential consequences of an intersection collision if cross-traffic was present versus a rear-end collision since following traffic was present. The experimental vehicle was instrumented with multiple DVI modalities. A "top of dashboard" visual icon (blue stop sign icon) was displayed

when the vehicle was approaching an equipped intersection. The warning DVI modalities included the following:

- a) a “top of dashboard” visual warning (in the form of a flashing red signal and stop sign icon)
- b) loudspeakers to produce an auditory warning (either the CAMP Tone in Kiefer et al. (1999), a ‘Stop Light’ speech warning, or a Beep Tone)
- c) modifications to the braking system to allow for the generation of a single brake pulse (or vehicle jerk) and Panic Brake Assist (PBA)

Unlike the vehicle jerk cue from the brake pulse warning, PBA would heighten the braking level once the participant initiated braking. Any subset of these warnings could be selected for concurrent presentation. In addition to these warning modalities, the experimental vehicle was also outfitted with data acquisition equipment that coordinated the presentation of distractions, triggered the DVIs, and provided automated control of the traffic signal. The data acquisition equipment also collected video and driver performance data, all of which supported the Subtask 3.3 analyses.

#### *2.3.3.2 Subtask 3.3 Results*

As previously stated, the primary goal of these experiments was to issue a recommendation for the DVI to be used for Subtask 3.4, a pilot test of the CICAS-V system, and to support the selection of the warning algorithm and alert timing. In support of this goal, Table 3 shows a summary of the compliance results obtained for each of the 11 studies that were completed. For the purposes of these studies, compliance occurred if the driver fully stopped the vehicle prior to entering the area of the intersection where cross-traffic may have been present (i.e., the collision zone).

**Table 3: Summary of Results for CICAS-V Subtask 3.3**

**Note: Studies in bold used the warning recommended based on the results presented in this report.**

Study	DVI*	TTI (s)	Protocol	Number of drivers who complied	Number of drivers who did not comply	Compliant drivers who activated PBA
1	CAMP Tone	2.24	Occlusion	9 (50%)	9 (50%)	N.A.
2	CAMP Tone	2.44	Occlusion	13 (72%)	5 (28%)	N.A.
3	CAMP Tone	2.44	Naturalistic Distraction	7 (39%)	11 (61%)	N.A.
4	Speech	2.44	Naturalistic Distraction	7 (39%)	11 (61%)	N.A.
5	CAMP Tone with Brake Pulse	2.44	Naturalistic Distraction	14 (78%)	4 (22%)	N.A.
<b>6</b>	<b>Speech with Brake Pulse</b>	<b>2.44</b>	<b>Naturalistic Distraction</b>	<b>17 (94%)</b>	<b>1 (6%)</b>	N.A.
7	Beep Tone with Brake Pulse and PBA	2.24	Naturalistic Distraction	5 (50%)	5 (50%)	0
<b>8</b>	<b>Speech with Brake Pulse and PBA</b>	<b>2.24</b>	<b>Naturalistic Distraction</b>	<b>16 (89%)</b>	<b>2 (11%)</b>	<b>1</b>
<b>9</b>	<b>Speech with Brake Pulse and PBA</b>	<b>2.04</b>	<b>Naturalistic Distraction</b>	<b>7 (78%)</b>	<b>2 (22%)</b>	<b>0</b>
<b>10</b>	<b>Speech with Brake Pulse and PBA</b>	<b>1.84</b>	<b>Naturalistic Distraction</b>	<b>3 (33%)</b>	<b>6 (67%)</b>	<b>1</b>
11	Baseline	N.A.	Naturalistic Distraction	1 (6%)	17 (94%)	N.A.

\*All of these studies featured a visual display that performed both advisory and warning functions (only the advisory function of this display was used in Study 11).

N.A. – Not applicable

The studies that used the Visual icon + Speech (‘Stop Light’) + Brake Pulse warning are shown in bold in Table 3. Driver behavior, performance, and compliance with the warnings suggest that this particular combination of DVIs has the highest probability of successfully alerting drivers amongst the warnings tested. PBA was used in conjunction with the three DVIs, however there was a low incidence of activation (two occurrences total for all drivers tested). Therefore, this warning combination of DVIs was recommended for use as the warning format for the CICAS-V Subtask 3.4 pilot test. This warning format, which contains elements from the visual, auditory, and haptic modalities, also performed relatively well when coupled with a range of alert timing approaches, providing positive implications for the Subtask 3.2 algorithm development.

### 2.3.3.3 Subtask 3.3 Implications for the Design of a CICAS-V Warning System

The results suggested a number of potential recommendations for the design and implementation of DVIs for intersection violation avoidance systems. These are:

1. The brake pulse, speech warning, and visual warning should all be included as part of the DVI warning approach for intersection violation avoidance systems.

*Supporting rationale:* The brake pulse warning appears to play the primary, dominant role in the observed effectiveness of this warning format. The speech warning appears to play a secondary role increasing the effectiveness of this warning format and provides relatively specific information in the context of the warning. Finally, although the particular visual warning examined appeared to have limited utility as a warning, a visual warning offers an opportunity to explain non-visual alerts (e.g., in the current study the same visual display was used to convey intersection ahead and intersection violation information to the driver). This may have particular importance in cases where drivers may not perceive non-visual alerts (e.g., the speech warning may not be heard due to hearing impairments, interior noises, or exterior noises). It should also be noted there was no observation of ‘visual capture’ effects with the visual warning employed.

2. Provide the above three modalities simultaneously as the CICAS-V violation warning.

*Supporting rationale:* Amongst the warning formats tested, a Visual Icon + Speech (‘Stop Light’) + Brake Pulse warning yielded the best traffic control device compliance results. Thus, this warning approach should be used as the benchmark to compare alternative DVI approaches. Furthermore, it should be considered for use as a DVI in the CICAS-V FOT prototype.

### 2.3.3.4 Subtask 3.3 Study Limitations

When combined with some of the warning modalities tested, PBA did not have any measurable effects on the outcome of the evaluations. No incompatibilities or issues were identified when PBA was active in combination with one or more other warnings tested in these studies. Instances of PBA activation in response to the different intersection violation warnings were rare under these experimental conditions. However, it should be stressed that the threat levels experienced by test participants in these test-track studies may not be representative of those experienced by drivers during real-world, intersection, crash-threat conditions (where there may be a higher incidence of PBA system activations). Furthermore, the results in no way support discounting PBA as ineffective in other driving situations where it may be activated.

The main goal of this series of studies was to inform the selection of a DVI for the CICAS-V system. In the process of accomplishing that goal, data were obtained that describe relative compliance levels and performance measures for these systems under a small sample of warning timings. While these compliance levels and performance measures (as a function of timing and warning) may inform the activation algorithm for CICAS-V, finalization of such algorithm should be based on data from real-world exposure to these systems, as identified in Subtask 3.2.

### **2.3.4 Subtask 3.4: Human Factors Pilot Test of the CICAS-V**

The recommendations from the previous three subtasks provided support in designing the CICAS-V system that was used for the Subtask 3.4 Pilot FOT. The goals of Subtask 3.4 were to:

1. Perform an on-road naive-driver system-level test
2. Iteratively refine the CICAS-V warning algorithm, as appropriate
3. Closely monitor data from the vehicle and intersection DASs during testing to ensure equipment readiness for a field operational test (FOT)
4. Conduct pseudo-naturalistic and test track evaluations of the driver-vehicle interface (DVI) motivated by previous CICAS-V research
5. Recommend refinement of the CICAS-V in preparation for the final FOT release

For detailed information regarding the research described in this section, please refer to Subtask 3.4: Human Factors Pilot Test of the CICAS-V (Neale et al., in print).

#### *2.3.4.1 Subtask 3.4 Method*

The following section describes the study participants, the equipment and data acquisition procedures, and methods for the two studies performed in this subtask.

##### 2.3.4.1.1 Study Participants

To meet the Subtask 3.4 goals, data were evaluated from 87 naive drivers who were placed into CICAS-V equipped vehicles. They navigated a two-hour prescribed route through equipped intersections without an experimenter in the vehicle. To ensure that sufficient data were obtained to understand drivers' impressions during appropriate warning conditions, 18 drivers completed a test-track study following their on-road study participation.

##### 2.3.4.1.2 CICAS-V Equipment and Data Acquisition

The drivers who participated in the study drove vehicles equipped with a CICAS-V and DAS. The CICAS-V contained several components working together to predict a stop-sign or red-phased signal violation, and provided the driver with a warning when appropriate. The CICAS-V included on-board equipment (OBE) and roadside equipment (RSE).

The Wireless Safety Unit (WSU), developed by DENSO, is the central processing component of the OBE. It collects data from the vehicle and sensors, and then computes an algorithm to predict when a violation may occur. Based on that prediction, the WSU issues a warning to the driver through the DVI, which then presents a violation warning to the driver using the three modalities recommended from the Subtask 3.3 Smart Road studies (auditory, visual, and haptic). The DVI has three states:

- a) an inactive state when the vehicle is not approaching an equipped intersection
- b) a visual-only indication when approaching an equipped intersection

- c) a full “single stage” warning mode that encompasses the simultaneous presentation of the visual, auditory, and haptic alerts

The auditory warning consisted of a female voice stating either “Stop Light” or “Stop Sign,” and was presented at 72.6 dBA via the front speakers as measured at the location of the driver’s head. The visual warning (Figure 3) displayed a traffic signal and stop-sign icon from a high “head down” display located on top, center of the dashboard near the windshield. Finally, the haptic brake pulse warning consisted of a single 600 millisecond brake pulse (or vehicle jerk) presented in conjunction with the visual icon and an auditory warning.



**Figure 3 The Visual Display is Located on the Dash of the Experimental Vehicle**

To activate the DVI, the WSU required the vehicle kinematic data from which the threat assessment was performed. The original equipment manufacturer (OEM) vehicle network provided data such as brake status and velocity to the 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 standard CAN format compatible with the WSU.

A Global Positioning System (GPS) 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. These RSEs provided GIDs for both stop-controlled and signalized intersections. Each GID was retained on the WSU, unless a newer version was available from the RSE.

In addition to the GIDs, the RSEs also sent differential GPS corrections that allowed the vehicle to accurately place itself on the GID and signal phase and timing (SPaT) information. 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.

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. The

DAS collected variables representing the information necessary to reconstruct a vehicle’s intersection approach and the driver’s interaction with the CICAS-V. A detailed discussion of the DAS is available in the Task 12 report (Stone et al., in print).

The infrastructure DAS was installed at one of the equipped signalized intersections used in order to determine the utility of having an infrastructure DAS in the planned FOT. For a detailed description of the infrastructure DAS, please refer to the Subtask 3.2 and Task 12 reports (Doerzaph et al., in print; Stone et al., in print).

#### 2.3.4.1.3 Pseudo-Naturalistic Study

The Pseudo-Naturalistic Study was conducted on a predetermined route in Blacksburg and Christiansburg, Virginia. The route was approximately 36 miles long and contained 13 intersections that were part of the CICAS-V. Three signalized intersections, previously instrumented for Subtask 3.2, and ten stop-controlled intersections were chosen for evaluation.

Participants drove the route without the accompaniment of an experimenter. 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 two hours in duration. Second, the route had to maximize the number of intersection crossings while retaining a practically 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 was desirable in order to fully test the CICAS-V. A summary of the turn maneuver for the 13 intersections employed in this effort is provided in Table 4.

**Table 4: 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

#### 2.3.4.1.4 Smart Road Study

A subset of the drivers from the Pseudo-Naturalistic Study also participated in the Smart Road test-track study. The primary purpose of this study was to ensure that a group of drivers would experience the CICAS-V warning. CICAS-V warnings are generally rare on the open roadway and the test-track study was essential to validate the full CICAS-V system against the Subtask 3.3 results. The protocol for the Smart Road Study was the same as that used for the Subtask 3.3 studies which distracted drivers during a signal phase change prior to the presentation of the CICAS-V warning. This surprise phase change was designed to represent a scenario in which the driver needed to make a split-second decision about the potential consequences of a rear-end collision (since following traffic was present) versus the consequences of an intersection collision if cross-traffic was present.

### 2.3.4.2 Subtask 3.4 Results

#### 2.3.4.2.1 Stop-Controlled Algorithm 1 Results

The initial stop-controlled intersection warning algorithm incorporated into the CICAS-V was derived directly from the results of Subtask 3.2. Fifteen drivers experienced Stop-Controlled Algorithm 1 (Table 5). Of those drivers, 14 received a total of 50 CICAS-V warnings over the course of their drives.

**Table 5: 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
<b>Total</b>	7	8	15

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

A review of the warnings indicated that all of the drivers who experienced alerts with Stop-Controlled Algorithm 1 received them at only a few of the total number of stop-controlled intersections examined. After reviewing the intersections' geometry, it was noted that the warnings were occurring on those approaches that had a 3.8 to 7 percent uphill grade. Stop-Controlled Algorithm 1 developed in Task 3.2 considered brake status when determining whether drivers should receive a violation alert. Hence, if a driver was pressing the brake, it was assumed the driver was attentive to the intersection and the alert was suppressed. However, on uphill grades, drivers in this study tended to press the brake later in their approach, thus, using gravity to slow the vehicle.

Consequently, since the algorithms were developed based on flat intersection approaches, braking during uphill intersection approaches caused the warning to activate more often than was expected. Hence, the decision was made to change the warning algorithm for stop-controlled intersections to one that did not rely on brake status. After reviewing the possible algorithms created in Subtask 3.2, a new stop-controlled algorithm (Stop-controlled Algorithm 2) was selected and integrated into the CICAS-V.

#### 2.3.4.2.2 Stop-Controlled Algorithm 2 Results

A total of 72 drivers completed the Pseudo-Naturalistic Study protocol equipped with Stop-Controlled Algorithm 2 (Table 6). The three violation warnings observed occurred at the same intersection while drivers were making a straight-crossing maneuver where the stop sign was partially occluded at longer distances. These three violation warnings were issued to a younger male, a middle-aged male, and an older male. In all three cases, the drivers did not show any indication of intending to stop prior to the warning and stopped prior to the intersection box after the warning was issued.

**Table 6: 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
<b>Total</b>	35	37	72

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

**2.3.4.2.3 Signalized Intersection Algorithm Results**

The signal-controlled intersection warning algorithm incorporated into the CICAS-V was also developed in Subtask 3.2. 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 Study protocol, as summarized in Table 7.

**Table 7: 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
<b>Total</b>	42	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. These included 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 driver approached the signalized intersection to make a straight-crossing maneuver. The driver braked safely to a stop before crossing the stop bar. If the driver had not stopped, it appears a violation would have occurred, based on the location of the lead vehicle, which crossed 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 couple 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 this 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 during the green phase.

Four invalid warnings occurred due to an incorrect GID for one of the signalized intersections. The faulty GID incorrectly labeled the left-most straight-crossing lane as the left turn lane and associated the straight-crossing lane with the dedicated left-turn signal head. The problem occurred when the drivers were making a straight-crossing maneuver in the left-most, straight-crossing lane, which had a green-phased light, while 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 straight-crossing lane with a green-phase. The problem of the incorrect GID was noted the first time that a false alert was issued. However, since the first driver responded calmly to the false alert and proceeded through the intersection, the incorrect GID was left in place in order 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, which, under some conditions, could have led to a rear-end crash with the following driver. After this event the GID was corrected and no additional false alerts were observed at this intersection.

**2.3.4.2.4 Smart Road Study Results**

As stated previously, a Smart Road test-track study was conducted using the same protocol used in Subtask 3.3 with 18 drivers. The distribution of the 18 drivers by age and gender is shown in Table 8.

**Table 8: Distribution of Drivers by Age and Gender with Date Analyzed for the Subtask 3.4 Smart Road Study**

Age Group	Gender		Total
	Male	Female	
18-30	3	3	6
35-50	2	4	6
55+	3	3	6
<b>Total</b>	8	10	18

A comparison was made between these results and those of the Subtask 3.3 Study 6 (S6). Subtask 3.3 S6 tested the same DVI, the flashing red visual display, an auditory speech warning, and a brake pulse, but with a CICAS-V emulator and preliminary warning algorithm. As such, one goal of the Subtask 3.4 Smart Road Study was to compare compliance rates to Subtask 3.3 S6 to validate the Subtask 3.3 results using the full CICAS-V.

Both the Subtask 3.4 and Subtask 3.3 S6 resulted in 17 of 18 drivers making a compliant stop prior to the collision zone (i.e., a 94 percent compliance rate). In each study, one driver was non-compliant when he/she failed to stop and continued through the

intersection. The distribution of compliant drivers by age and gender is presented in Table 9.

**Table 9: Comparing Demographics of Compliant Drivers for Subtask 3.2 SRS and Subtask 3.3 Study 6**

Subtask 3.4 SR Study	Male	Female	Total	Subtask 3.3 Study 6	Male	Female	Total
Young	3	3	6	Young	3	3	6
Middle	2	4	6	Middle	3	2	5
Old	2	3	5	Old	3	3	6
Total	7	10	17	Total	9	8	17

The alert timing and driver braking behavior data obtained in the two studies is compared in Table 10. The average warning onset Time to Intersection (TTI) in Subtask 3.4 is 2.57s, which is 0.13 s earlier than the preset TTI value in Subtask 3.3 S6. This translated to an average distance to stop bar of 132.17 ft for the Subtask 3.4 Smart Road warnings, compared to 123.2 ft for Subtask 3.3 S6 warnings.

**Table 10: Parametric Measures of Subtask 3.4 Smart Road Study and Subtask 3.3 S6**

Parameter	Subtask 3.4 Smart Road Study		Subtask 3.3 S6	
	Mean	SD	Mean	SD
Warning TTI	2.57 s	0.11 s	2.44 s	0.02s
Distance to Stop Bar	40.26 m/132.17 ft	3.29 m/10.48 ft	37.55 m/123.2 ft	1.80 m/5.93 ft
Peak Deceleration	0.58 g	0.08 g	0.60 g	0.07 g
Reaction Time	1.01 s	0.36 s	0.74 s	0.14 s

The difference in warning timing resulted in drivers exhibiting slightly lower peak deceleration in Subtask 3.4 (0.58 g) compared to Subtask 3.3 (0.60 g). The reaction time of the drivers in the Subtask 3.4 Smart Road Study was also longer than the reaction times (time to brake) in the Subtask 3.3 S6. This may be the result of drivers having more time to respond to the warning with the increased TTI and safely stop the vehicle. In any case, the Smart Road experiment demonstrated that the full CICAS-V system performed similar to the system tested in Subtask 3.3.

#### 2.3.4.2.5 Post-Drive Questionnaire Results

After participating in the driving portion of the study, drivers completed one of three post-drive questionnaires. The questionnaire completed depended on whether or not they received a violation warning while participating in the study and whether it occurred during the Pseudo-Naturalistic Study or only during the Smart Road Study.

As might be expected, general trends in the data show that drivers who experienced the CICAS-V with Stop-Controlled Algorithm 2 (3 drivers each received one warning) were more satisfied with the system than drivers who experienced Stop-Controlled Algorithm 1 (14 drivers received 50 warnings). That is, drivers who experienced the CICAS-V in the manner it was intended to operate (warnings issued when there is a high probability

the driver will violate a traffic control device) would find the system more agreeable than drivers who received warnings when they were not necessary. Overall, drivers were satisfied with the system and recognized that they were in danger of violating the stop sign when they received the warning.

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 did not report noticing the visual icon following the surprise intersection event, which suggests that a more conspicuous visual display should be considered.

#### 2.3.4.2.6 Evaluation of the Study Systems

One goal of Subtask 3.4 was to evaluate the CICAS-V and DAS hardware and software performance on live roads and, thereby, demonstrate FOT readiness. It should be noted that the CICAS-V software tested during Subtask 3.4 was not the final Phase I release. Version 1.11 of the software was implemented for Subtask 3.4 at the time of testing. However, at the writing of this report, the final Phase I is Version 1.15. There were several improvements to the software during the releases after 1.11 that would have likely improved the results. In addition, the analyses completed in this section relied on the data provided by the WSU. The DAS was not equipped with an independent set of sensors to verify that data. As a result, these analyses are somewhat limited in that they assume the data provided by the WSU is accurate.

On an average of 96 percent of the time, the CICAS-V appeared to be enabled at either stop-controlled or signalized intersections. The disabled period ranged from 0.1 s up to almost 5 s. Ninety-nine percent of the time over which the DVI was disabled at stop-controlled intersections was due to GID map-matching. Interestingly, at signalized intersections, almost none of the disabled periods were due to the GID map-matching. This is likely explained by the improved skyline and differential GPS available at these intersections. Most of the outages (99%) at signalized intersections were due to the SPaT messages not being received. There were no false alerts or missed warnings due to positioning or SPaT errors detected during data analysis.

It is important to note that instances in which the DVI is only disabled for brief periods (i.e., a few hundred milliseconds) will not have a large impact on system performance. In contrast, for time periods when the DVI is disabled for several seconds, the impact on the CICAS-V effectiveness is problematic. It was determined that half of the disabled periods at both signalized and stop-controlled intersections were longer than one second. Although there were fewer disabled periods at signalized intersections, they typically lasted longer than at stop-controlled intersections. From these results, it appears that some of these periods have the potential to result in a late warning if the system is momentarily disabled when driver happens to violate. In this instance, the warning would be activated when the system becomes enabled.

A system log that tracked hardware problems that occurred during data collection indicated minor failures that were addressed quickly. The only outstanding issue not being addressed at the time of this writing is the failure of the Netway box during data collection. The OEM vehicle network provided data such as brake status and velocity to

the Netway box. The box, exclusively programmed by each of the OEM, was used to translate OEM-specific CAN messages into a standard CAN format compatible with the WSU. When the box failed, data was not received by the DAS. Failure of the Netway is not an issue of the CICAS-V per se; however, approximately 5 percent of data was lost due to its failure. This issue should be addressed in order to minimize data loss during an FOT.

The vehicle DAS collected the specified measures throughout the Subtask 3.4 studies. There was one malfunction recorded on the DAS issues log that was maintained by experimenters throughout Subtask 3.4. A hard drive failure caused the video file to be lost for one driver in the Pseudo-Naturalistic Study. This equates to two hours of data lost out of 191 hours, or just over 1 percent data loss.

The intersection DAS collected the specified measures during the Subtask 3.4 Pseudo-Naturalistic Study. There was one malfunction that occurred during the data collection, as indicated by the issues log maintained by the Subtask 3.4 experimenters. The system overheated when the DAS was initially installed in a weather-tight, non-vented enclosure, which caused the video board to overheat. A redesign of the enclosure to include venting and a fan solved the problem.

#### *2.3.4.3 Subtask 3.4 Implications for a CICAS-V Warning System*

Subtask 3.4 was a pilot test to perform the first, on-road, naive-driver, system-level test of the CICAS-V. Drivers were placed into CICAS-V equipped vehicles to navigate a two-hour prescribed route through equipped intersections without an experimenter on-board the vehicle. To ensure that sufficient data were obtained to understand drivers' impressions of the warning and to validate earlier Smart Road test results, a subset of the drivers followed the on-road study with a test-track study. Based on the results presented, the following conclusions may be drawn.

1. The CICAS-V System is FOT Ready

*Supporting rationale:* The on-road and test-track portions of data collection, as well as evaluations provided in other reports (e.g., the Task 11 report (Maile et al., in print)), indicate that the CICAS-V system functions reliably and as intended for the purpose of conducting an FOT. The issues noted during data collection have already been addressed with CICAS-V application software upgrades. The problem that occurs when an emergency vehicle preempts the signal, which causes the RSE to report incorrect phase information, is being investigated by a signal controller company, whose solution has a very high probability of success. 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 should be addressed in order to minimize data loss during an FOT. Approximately 5 percent of data was lost due to the box's failure. One option would be to integrate the functionality of the Netway box into the WSU for the FOT.

2. CICAS-V Algorithms are FOT Ready

*Supporting rationale:* The study tested two algorithms for stop-controlled intersections and one algorithm for signalized intersections. Stop-Controlled Algorithm 2 successfully warned three different drivers of an occluded

intersection. The Signalized Intersection Algorithm provided a valid and timely warning to a driver approaching a light that was going through a phase change.

3. The Vehicle DAS is FOT Ready

*Supporting rationale:* The Vehicle DAS performed well during the on-road and test-track portions of the study. Although there was a hard drive failure during the course of the study, very little data was lost (2 hours out of 191 hours total) due to Vehicle DAS equipment failures.

4. The Infrastructure DAS is FOT Ready

*Supporting rationale:* The Infrastructure DAS also performed well during the study and is ready for an FOT. The bigger issue for an operational test in the field is to determine if the benefit of collecting infrastructure DAS data is worth the cost to collect, store, reduce, and analyze it. The benefit can be measured in terms of the probability that a violation warning would occur at an equipped intersection and that there would be information that could only be gleaned from an infrastructure DAS. In addition, the vehicle DAS may be capable of being upgraded to provide sufficient information (e.g., for the purpose of measuring and characterizing cross traffic).

5. Pilot Study Protocols are FOT Ready

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

6. The CICAS-V Appears to Provide a Benefit

*Supporting rationale:* The driver successfully stopped prior to entering the collision zone for every instance in which the driver was provided a valid violation warning. The valid violation warnings from the best performing algorithms, Stop-Controlled Algorithm 2 and the Signalized Intersection Algorithm, are of particular interest since these scenarios mimic those for which the CICAS-V was designed: 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.

7. Drivers like the CICAS-V

*Supporting rationale:* Subjective data on post-test questionnaires indicate that drivers generally like the CICAS-V. A common critique of the system was the conspicuousness of the visual display. Nonetheless, this is a minor critique, considering the following:

- a) the visual display was not designed into the original instrument panel configuration and was added later
- b) drivers had little time with the vehicle (two to three hours) to become accustomed to the display

- c) the speech and brake pulse modalities are very effective
- d) 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

#### *2.3.4.4 Subtask 3.4 Study Limitations*

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 Subtask 3.4 studies were 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, which reflected 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 DOT 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.

## **2.4 Task 4 – Concept of Operations and High-Level Requirements**

The systems engineering activities represented the second major thrust of the development effort. Activities in Tasks 4, 5, 6, and 9 defined the system concepts and requirements, the architecture, the performance specifications and the processes for reviewing, testing and revising the proposed CICAS-V design. Task 4 focused on the development of the Concept of Operations (ConOps) document and the definition of the High-Level Requirements, while Task 9 focused on defining the processes needed to review, test, and revise the system design. Task 5 featured the development of the System Architecture and the detailed System Requirements and Task 6 featured the preparation of Performance Specifications. Except for the Performance Specifications and System Requirements Specifications, all the documents were issued in 3 revisions: preliminary, interim and final. The preliminary revision formed the documentary basis for the Preliminary Design Review (PDR) in the case of the ConOps, System Architecture Description and High-Level Requirements; and for the Critical Design Review in the case of the System Requirements Specifications and the Performance Specifications. After the PDR, the mentioned documents were revised, incorporating the feedback from the stakeholders. This revision formed the interim version of those documents. After the end of the objective tests and the Pilot-FOT, the documents were revised a final time, incorporating the lessons learned. This revision formed the final version of the documents. Due to time constraints, no interim version for the System Requirements Specifications and the Performance Specifications were developed after the CDR. The stakeholder feedback and the lessons learned were included in the final version.

Task 4 developed the Concept of Operations (ConOps) on which the further CICAS-V System Engineering and System Development was based. The document followed the guidance given in a FHWA pooled fund study, Developing and Using a Concept of Operations in Transportation Management Systems (Smith, 2005), which is based on the American National Standards Institute (ANSI)/ American Institute of Aeronautics and Astronautics (AIAA) standard, Guide for the Preparation of Operational Concept Documents.

In the first year of project operations, a joint USDOT/VSC2 writing team was formed to cooperatively prepare the ConOps and to identify the revisions needed to the document based on the comments received during the various stakeholder reviews that were conducted. A ConOps is a document that describes the system's overall quantitative and qualitative characteristics to the user, buyer, developer and other organizational elements (e.g., training, facilities, staffing, and maintenance).

The preliminary version of the ConOps document was prepared by the joint writing team in October 2006. The document that resulted from these efforts contained the following general categories of information:

- System purpose
- Assumptions, constraints and system boundaries
- Operational description and operational needs
- System overview
- Operational and support environment
- Description of operational scenarios.

The preliminary version of the ConOps was then presented to CICAS-V stakeholders from the signal controller manufacturing industry at a meeting held in Austin, TX in November 2006. Comments received during the meeting and the later PDR were subsequently incorporated into the ConOps document along with others received during internal team reviews conducted project. The document was then upgraded to interim status and to final status at the end of the project (Maile et al., "Concept of Operations," In Print).

After the preliminary ConOps was completed, work on the High-Level Requirements document was initiated. The High-Level Requirements is a document that describes what the users expect the CICAS-V system to do for them, details the system's expected environment and the system's usage profile, and presents the system requirements (including the functional, physical, external, interface, etc. requirements) from a high-level perspective. The preliminary version of the High-Level Requirements was presented at the PDR in September 2007. The feedback from the stakeholders was incorporated for the interim version and a final version was developed at the end of the project (Maile et al., "High-Level Requirements," In Print).

## **2.5 Task 5 – System Architecture Description and System Requirements Specification**

The principal activities in Task 5 were associated with the preparation of two systems engineering documents: the System Architecture Description and the System Requirements Specification. The System Architecture Description defines how the CICAS-V system is organized and shows its decomposition into functional blocks that work together to satisfy the high-level requirements developed in Task 4. The functional blocks include both hardware and software components. The preliminary version of the System Architecture Description was presented at the PDR in September 2007. The feedback from the stakeholders was incorporated for the interim version and a final version was developed at the end of the project (Maile et al., System Architecture Description, In Print)

After the completion of the preceding documents, the preliminary System Requirements Specifications document was developed. The document identifies and describes the detailed requirements of CICAS-V roadside and vehicle based modules that define the specific behavior of a system, that is, they provide a description of what the system is intended to do. The document, together with the Performance Specifications formed the basis for the CDR. As mentioned before, the step of producing the interim version of the document was skipped and the final version was developed at the end of the project (Maile et al., System Requirements Specifications, In Print).

## **2.6 Task 6 – Performance Specifications**

Work in Task 6 developed the Performance Specifications for the system based on the ConOps developed in Task 4 and the System Requirements Specification prepared in Task 5. The performance specifications are presented in two documents. One document presents the specifications for the vehicle, while the second document presents the specifications for the infrastructure portion of the system. This document structure was chosen to provide compatibility with the design processes for the automotive and intersection equipment manufacturers, which have distinct differences between them.

The initial document was developed in the beginning of the project and revised after the development of the System Requirements Specifications. This revision formed the preliminary version of the documents and was used as a basis for the CDR. As with the System Requirements Specifications, the step of developing an interim version of the document was skipped and the final version of the documents was developed at the end of the project [Maile et al., “System Performance Specification-Vehicle,” (In Print); Maile et al., “System Design Specifications – Infrastructure,” (In Print)].

## **2.7 Task 7 – Objective Test Procedures**

The objective test procedures developed in Task 7 were essential for deciding whether the CICAS-V system was ready for a large-scale Field Operational Test. The Test Procedures also provide the methods and benchmarks to judge other CICAS-V implementations as to whether they fulfill the performance specifications. Finally, those test procedures include the typical scenarios that can be found when a CICAS-V equipped vehicle approaches an equipped signalized or stop controlled intersection. The

tests procedures that were developed are shown in Table 11. The tests are divided into three categories:

- Warning Tests - where the objective is to get the warning at the correct distance from the intersection. An example for this test is the variable speed approaches for signalized and stop sign controlled intersections.
- Nuisance Tests - where the objective is to not get a warning when no warning is warranted. An example for this test is the edge of lane approach where the vehicle is in the lane when the signal is green but is operated close to a lane boundary when the signal is red.
- Engineering Tests - where the objective is to test the limits of the system. An example is the SPaT Reflection and Reception Test, where a vehicle is driving closely behind a tractor-trailer combination, which blocks the reception of the DSRC messages from the intersection.

In addition to the test procedures the work in Task 7 also defined the Test Plan that was used to conduct the Objective Tests in Task 11 (Maile et al., Objective Test Procedures, In Print). A summary of the Task 11 activities is presented later in the report.

**Table 11: Test Scenarios Overview**

Name	Purpose	Kind
Signalized Various Speed Approaches Test	Test whether warning distance is as specified for signalized intersections and given vehicle speed	Objective Requirement Warning
Edge of Approach Testing for Warning	Test whether expected warning is given when vehicle is driven on edge of lane	Objective Requirement Warning
Late Lane Shift Test	Test whether expected warning is given when shifting from green lane into red lane after red lane's warning distance passed	Objective Requirement Warning
Multiple Intersections within 300m Radius	Test whether warning is appropriate for approaching intersection in presence of multiple nearby intersections	Objective Requirement Warning
Dynamic Signal to Red, In Time for Warning	Test whether expected warning is given on signal change from green to yellow when red occurs before vehicle passes stop bar.	Objective Requirement Warning
Stop Sign Various Approach Speeds Test	Test whether warning distance is as specified for stop sign intersections and given vehicle speed	Objective Requirement Warning
Edge of Approach Testing for Nuisance Warning	Test whether nuisance warnings are avoided when vehicle is driven on edge of lane	Objective Requirement Nuisance
Late Lane Shift Test	Test whether nuisance warning is avoided when shifting from red lane into green lane before red lane's warning distance passed	Objective Requirement Nuisance
Dynamic Signal Change to Yellow, Too Late to Warn	Test whether warning is avoided on signal change from green to yellow when red arrives after the stop bar	Objective Requirement Nuisance
Dynamic Signal to Green, No Warning Case	Test whether warning is avoided when signal change from red to green before the warning distance	Objective Requirement Nuisance
Multiple Intersections within 300m Radius	Test whether warning is appropriate for approaching intersection in presence of multiple nearby intersections	Objective Requirement Nuisance
SPaT Reflection and Reception	Tests the system performance/ system limits when line of sight between intersection and vehicle is obscured by other vehicles	Engineering Test

## **2.8 Task 8 – Prototype Build and Testing**

Work in Task 8 developed the technology basis for the CICAS-V prototype and tested the elements that make up the overall system. This work, described in the Task 8 Final Report (Maile et al., In Print), included:

- Vehicle selection and purchase
- Intersection selection, equipment installation and functional tests
- Intersection map development and verification
- Application design and testing

### **2.8.1 Vehicle Selection**

The vehicle selection was based on two principal vehicle requirements. First, a Brake Pulse and/or Panic Brake Assist feature might be necessary to implement as part of a Driver-Vehicle Interface. Consequently, test vehicles needed to have production brake systems that would support these features since retrofitting the vehicles would be prohibitively expensive and could raise potential safety issues. Second, the vehicle platforms needed to be stable for at least two years after the project start so that the test vehicles would be available for procurement when the FOT started. The vehicles chosen were:

- Mercedes-Benz ML350
- Volvo S80
- Cadillac STS
- Acura RL
- Toyota Prius

The vehicles were instrumented with the VSC1 WAVE Radio Modules produced by DENSO Corporation, OEM-V GPS receivers from NovAtel, Inc. and laptop computers on which the application modules ran.

### **2.8.2 Intersection Selection**

In a joint decision with the USDOT, three intersections each in California and Michigan and four intersections in Blacksburg, VA were selected for CICAS-V installation and testing. The intersections in California and Michigan were used for engineering development that included installation and testing of CICAS-V components and application software. The intersections in Virginia, also equipped with CICAS-V components, were used to support the Human Factors Research conducted in Task 3. The criteria for the intersection selection were that one intersection should be:

- A simple intersection (i.e., one without protected turn lanes at least in one direction)
- A complex intersection with protected left turn lanes
- A stop sign controlled intersection

In the early phase of the project, it was decided not to install Roadside Equipment (RSEs) at the stop controlled intersections but rather to send the intersection map (GID) for the stop controlled intersection from the RSEs at the signalized intersections.

The intersections selected in Michigan were:

- West 10 Mile and Orchard Lake Roads (simple)
- West 12 Mile and Farmington Roads (complex)
- West 10 Mile and Drake Roads (stop sign)

The intersections identified in California were:

- El Camino Real and 5th Ave in Redwood City/Atherton (simple/complex)
- Hillview and Hanover in Palo Alto (simple)
- Peter Coutts and Raimundo Way in Palo Alto (stop sign)

The intersections chosen for Virginia were in the Christiansburg/Blacksburg area and included:

- US 460 Business and Virginia Route 114 (complex)
- Depot and N. Franklin Sts. (simple/complex)
- N. Franklin St. and Independence Blvd. (simple/complex)

Intersections that are labeled as simple/complex are intersections that are simple in one approach and complex at another.

Several stop-controlled intersections in the Blacksburg, VA, area were selected for the Subtask 3.2 data collection and initially it was intended to use one of those intersections for the Pilot FOT. As described in Subtask 3.4, new stop sign intersections were subsequently selected in the Blacksburg/Christiansburg, VA area that were located more conveniently for the test route. The number of stop sign controlled intersections was also increased in Subtask 3.4 to maximize the number of intersection crossings for analysis.

Because of institutional issues, the Hillview and Hanover intersection in Palo Alto was replaced with El Camino Real and Oakwood/Dumbarton Ave in Redwood City, CA.

### **2.8.3 Intersection Instrumentation**

The intersection instrumentation included the first Multiband Configurable Networking Unit (MCNU) from TechnoCom Corporation that was compatible with the WAVE Radio Modules from DENSO (developed in the first VSC Project) as the roadside equipment (RSE). Also installed were a NovAtel OEM-4 receiver that functioned as the base station for the local GPS correction and miscellaneous hardware that was dependent on the local intersection. This receiver was later exchanged with the NovAtel OEM-5 receiver for cost reasons. The intersection instrumentation differed between California and Michigan, due to the different types of cabinets and cabinet locations.

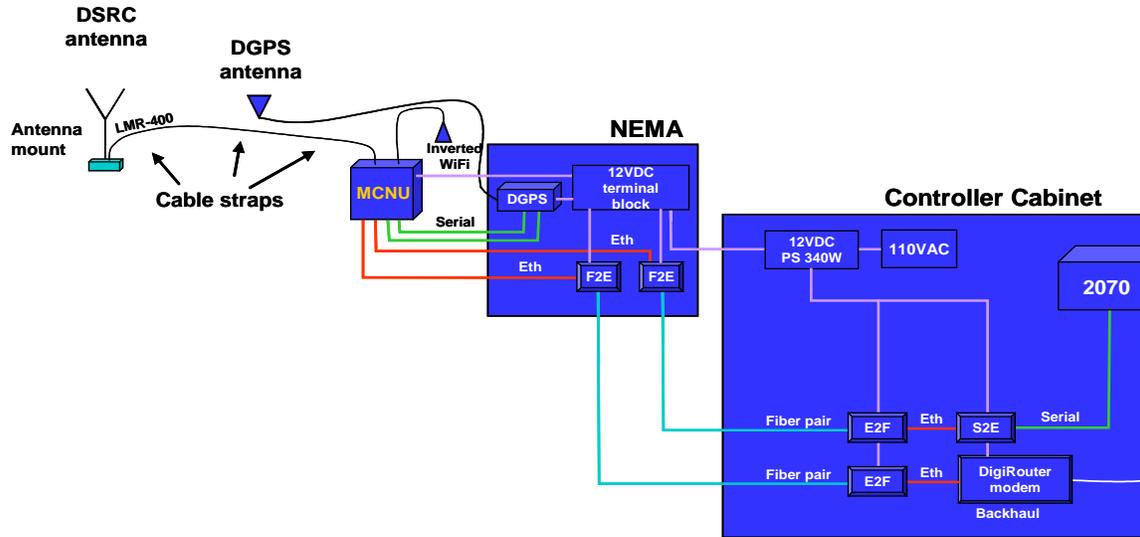
The intersection of El Camino Real and 5<sup>th</sup> Ave. in Redwood City/Atherton in California as shown in Figure 4 was the first CICAS-V instrumented intersection. This intersection

came online in February 2007 and has been working almost uninterruptedly since then. The intersection was instrumented in cooperation with UC Berkeley/PATH and Caltrans.



**Figure 4: Intersection at El Camino Real and 5th Avenue in Redwood City, CA**

The setup of this intersection was elaborate due to the constraints imposed by the environment, such as optimal antenna placement, controller cabinet location and the presence of high-voltage power lines that made the antenna placement challenging. The block diagram in Figure 5 shows the components and the connections for the intersections.



**Figure 5: Block Diagram of the Intersection Equipment and Connections**

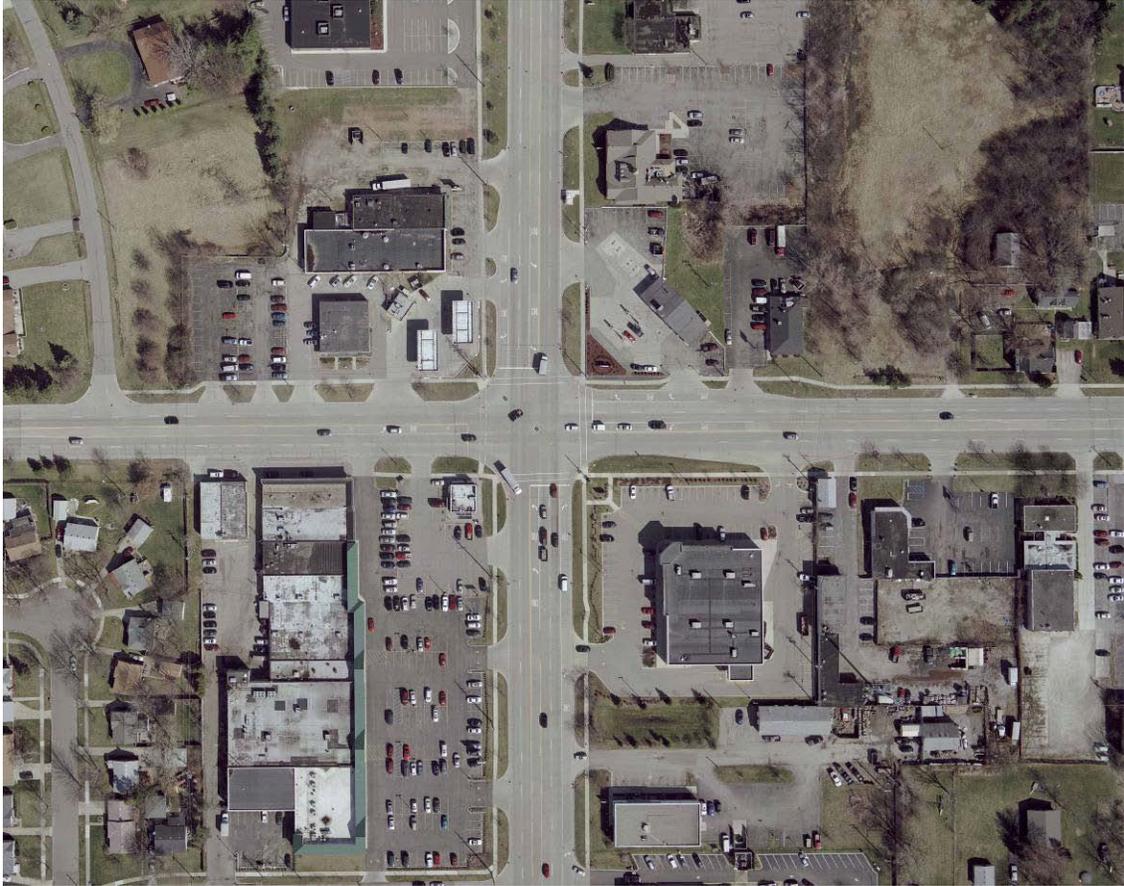
Figure 6 shows a picture of the installation of the equipment in the intersection. The MCNU can be seen on the top of the metal plate and the cabinet at the bottom holds the GPS receiver and the fiber optic to Ethernet converters.



**Figure 6: RSE Installation at the First California Intersection**

The intersection signal controller is an Econolite 2070 that can export signal phase and timing over a serial port. The protocol that is used to transmit the information is the AB3418a protocol, which is not optimal for CICAS-V purposes. The primary concern about the protocol is that the information that the controller exports for each signal indication is limited to whether or not the light is green. No information about the red phases is available. However, the length of the yellow phase is known for the intersection and, from this information, a state machine was constructed that accurately determined the phases for each of the signal indications for all the movements in the intersection. In addition, the protocol is a query-and-response type of protocol and has response latencies that are longer than desired for the CICAS-V application.

The first intersection in Michigan to come online was the intersection at West 10 Mile and Orchard Lake Roads (Figure 7).



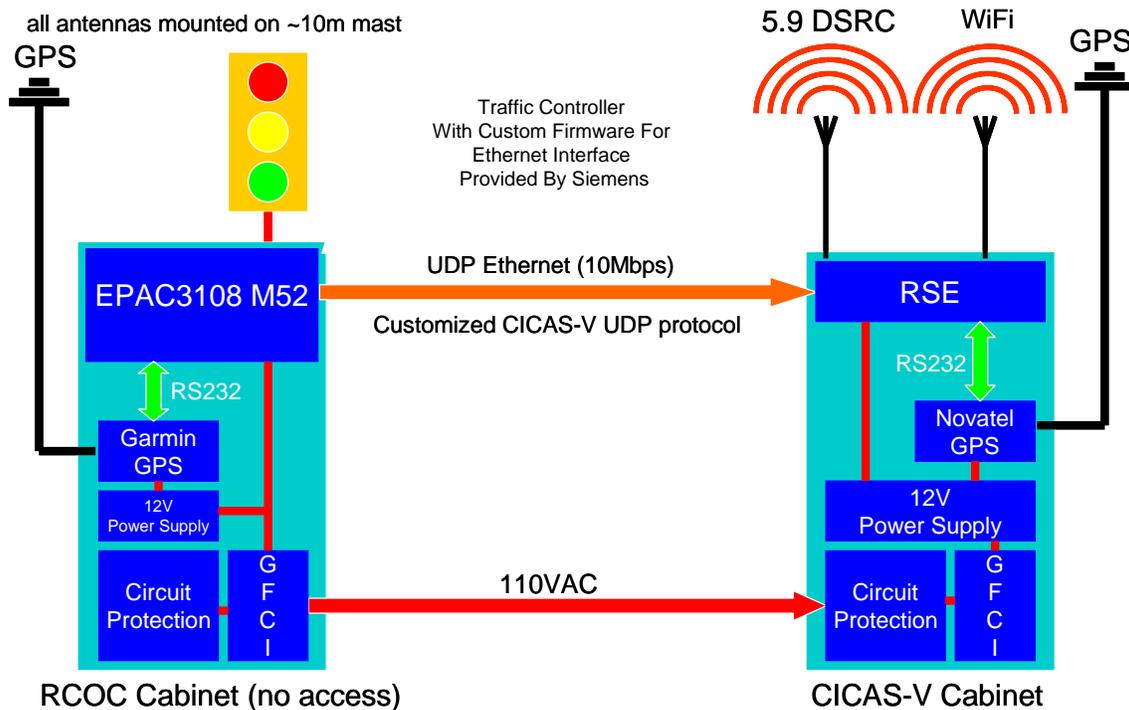
**Figure 7: Intersection at West 10 Mile and Orchard Lake Roads in Michigan**

The CICAS-V intersection installation for West 10 Mile and Orchard Lake Roads is shown in Figure 8.



**Figure 8: CICAS-V Intersection Equipment**

The installation in Michigan was more straightforward than the installation in California due to the signal controller being located in a cabinet on the mast itself with the possibility to install the antennas on the same mast as the intersection controller. The intersection was set up in cooperation with the Road Commission of Oakland County. The signal controller used in Michigan was the Siemens EPAC M52 with special software that exported the signal phase and timing whenever a signal phase changed via an Ethernet link to the RSE. The latency between the change in the controller and the message being sent out by the RSE was measured to be substantially less than 100 ms. Figure 9 shows a block diagram of the installation in the intersections in Michigan. It should be noted that the WiFi shown in Figure 9 was used to establish a link between the RSE and a laptop computer to permit changes to the RSE software during system development and testing. This feature would not likely be present in a deployment version of the CICAS-V since a connection to a backend network is assumed.



**Figure 9: Block Diagram of the Intersection Installation in Michigan**

### 2.8.4 Message Set Definition

The CICAS-V Project defined three message sets that communicate the necessary information from the intersection to the vehicle so that the vehicle can warn of an impending red-light violation:

- Geometric Intersection Description (GID)
- GPS correction (GPSC)
- Signal Phase and Timing (SPaT)

The above messages were designed to be sent as Wave Short Message (WSM) packets over DSRC, the standard way in which safety messages are broadcast. The project also developed a unifying framework for those messages that made them both compact and easily extensible.

A fourth message, the Wave Service Advertisement (WSA) was included at a later stage to be compatible with the VII program. This message identifies an intersection to the vehicle as CICAS-V equipped, informs the vehicle of the version number of the GID and the service channel where the GID can be received.

### 2.8.5 GID Definition and Intersection Mapping

The CICAS-V application requires that the vehicle determine which traffic signal applies to its path through the intersection. In the CICAS-V application, this is achieved by

giving the vehicle a lane-level accurate map of the intersection where necessary (called a GID) and associate the lanes with the correct signal. The vehicle, using its GPS and assisted by the GPSC message from the intersection, matches itself to the correct lane and determines the correct signal. Those lane-level accurate maps are sent from the intersection to the vehicle, also in a WAVE Short Message (WSM) packet. Since the size of the packet is limited to about 1.4K bytes of information, it was necessary to develop a map format that would allow the transmission of even complex intersections within this byte size. In addition to the precise lane geometry (accurate to 30 cm or better), the GID also contains for each lane the information which traffic signal applies to the lane.

The mapping data for the GIDs were obtained by aerial survey of the intersections and accurate GPS survey of selected points to ortho-rectify the image.

#### *2.8.5.1 GPS Correction*

The CICAS-V application requires accurate lane matching in the cases where protected left turn lanes and signals are present so that the vehicle can correctly determine the applicable traffic signal indication. This requires that the GPS positioning in the vehicle is aided by differential corrections. The intersection is generating the differential correction through a GPS base station at the intersection and sends the differential correction to the vehicle via the GPSC message in the RTCM 104 v3format.

#### *2.8.5.2 Signal Phase and Timing*

The CICAS-V system in the intersection generates the Signal Phase and Timing (SPaT) message from information received from the intersection controller. The SPaT message contains the information for all the signal indications in the intersection (more precisely, all the movements in the intersection). The information in the SPaT message contains at a minimum the current phase for all the movements and, if a movement is in the yellow phase, how much time is left in that phase.

### **2.8.6 Application Development**

The CICAS-V Project developed prototype applications to test the individual elements that together comprise the CICAS-V application. All the application components were tested successfully and shown to the USDOT during the quarterly briefings. The focus of Task 8 was the definition and testing of the individual modules that would comprise the CICAS-V system. The applications were not integrated into an overall CICAS-V prototype system in Task 8 since this was the objective of Task 10. The application development also led to the development of the specifications for the software development for the CICAS-V FOT prototype system in Task 10. The individual components that were developed are discussed below.

#### *2.8.6.1 Map Matching*

The project developed a map-matching algorithm that was based on the GID. The positioning augmented by the GPSC message was able to reliably match the vehicle to the correct lane.

#### *2.8.6.2 Warning Algorithm*

The project developed the basic warning algorithm logic that was used as a starting point for the FOT warning algorithm development.

#### *2.8.6.3 GPS Correction*

The project developed a GPSC methodology based on locally generated differential corrections that are sent to the vehicle via the GPSC message set. The positioning accuracy achieved with this correction was around 50 cm.

#### *2.8.6.4 Message Parsing*

The project developed the message generators in the intersection and the message parsing software on the vehicle side.

#### *2.8.6.5 System Software Specifications*

The project developed the system specifications for the Task 10 FOT system development. The specifications were reviewed by DENSO and resulted in the overall statement of work and system specifications for the system that DENSO implemented in Task 10. The application development effort in Task 10 will be discussed in Section 2.10.

## **2.9 Task 9 – System Development Plan**

The main focus of Task 9 was to define the systems engineering process that would govern the CICAS-V design activities and development work conducted during Phase I of the project. A second focus of the task was to provide the systems engineering oversight to ensure that activities adhered to the process and that the system's requirements were met by the design that emerges from the Phase I efforts.

The first activity undertaken in this task was to define the specific design documents needed for the project and the organization of each. To accomplish this, the technical team in conjunction with the USDOT identified an initial set of documents for inclusion into the development process along with the IEEE standard that would define the organization of each document. The set of documents was subsequently refined during additional discussions with the USDOT that took place in the second quarter of 2007. The list that resulted for the project is presented below. It includes:

- Concept of Operations (Task 4)
- High-Level Requirements (Task 4)
- System Architecture Description (Task 5)
- System Requirements Specification (Task 5)
- System Performance Specification – Vehicle (Task 6)
- System Design Specification – Infrastructure (Task 6)
- System Test Plan and Test Procedures (Task 7)

In addition, it was also decided that three public workshops would be held during Phase I to review elements of the system design with CICAS-V stakeholders and obtain feedback. The workshops included:

- Concept of Operations Workshop (Task 4)
- Preliminary Design Review (PDR, Task 9)
- Critical Design Review (CDR, Task 9)

The ConOps Technical Workshop was held in November 2006, as previously mentioned in the summary for Task 4.

The PDR was held on October 29-30, 2007 at the University of Virginia/Virginia Tech campus in Falls Church, Virginia. The objective of the PDR was to assess the suitability of the High-Level System Requirements (HRS) and the System Architecture Description (SAD) as bases for further development of the CICAS-V system. The objectives of this PDR were to:

- Ensure that the CICAS-V high-level requirements accurately and completely reflected the intent of the Concept of Operations, captured the functional capabilities, and described interface conditions and constraints
- Ensure that the CICAS-V system architecture adequately implemented the intent of the Concept of Operations and represents the essential system perspectives

The meeting included participants from the CAMP/VSC2, USDOT, state and local transportation agencies, traffic signal controller manufacturers, academia, and the standards community. The CAMP design team presented a review of the Concept of Operations (ConOps) as the basis for both the high-level requirements and the system architecture. The requirements and architecture were then presented and reviewed in a moderated discussion.

The comments received at the PDR were incorporated in the interim revisions of the respective documents.

Key discussions addressed topics such as:

- Interfaces between the CICAS-V, VII, and traffic signal controller systems
- Opportunities to be less prescriptive of technologies and implementations (for example, in specifying “location” services rather than “GPS”) within the requirements and architecture
- Deployment, maintenance, and administration of CICAS-V roadside equipment amongst other intersection equipment
- Continued and enhanced inclusion of state and local transportation agencies, the standards community, and traffic signal controller manufacturers in the development process

The Critical Design Review was held on June 10, 2008, via teleconference and Web Conferencing. The objectives of the CDR were to:

- Review the performance specifications for the CICAS-V system to ensure that the proposed specifications adequately address the System Requirements
- Provide feedback from CICAS-V stakeholders and facilitate finalization of the performance specifications prior to objective testing

The meeting included participants from the CAMP/VSC2, USDOT, state and local transportation agencies, traffic signal controller manufacturers, academia, and the standards community. The CAMP design team presented a review of the project status. The System Design Specifications-Infrastructure and System Performance Specifications-Vehicle were then presented and reviewed in a moderated discussion.

The results of the CDR were incorporated in the final revisions of the respective documents.

## **2.10 Task 10 – Integration of Subsystems, Building of Prototype Vehicles and Outfitting of Intersections**

The goal of Task 10 (Maile et al., In Print) was to upgrade the vehicles and intersections to the final FOT hardware and software. The task also included the installation of the vehicle DAS that was developed by VTTI. The FOT vehicle build included the final results from Subtask 3.2 (warning algorithm and timing parameters) and from Subtask 3.3 (effective DVI). All the components, including the DVI, were tested for functionality.

The task selected the on-board equipment (OBE) that was used as the computing platform for the Task 10 development, the Pilot FOT and the Objective Tests. The selected unit was the DENSO Wireless Safety Unit (WSU) on which DENSO, as the contractor for the development of the FOT system, developed the necessary software.

The vehicle build was initiated during the first year of the project. The test vehicles were sent to VTTI to be outfitted with the DAS. The DAS system is comprised of in-vehicle cameras to monitor the driver, the interior of the car and the forward direction as well as forward and rearward facing 24 GHz radars to detect vehicles surrounding the CICAS vehicle. The DAS also records vehicle operating parameters, vehicle position and the messages the vehicle receives from the intersection. More information on the development of the DAS is presented in the Task 12 summary below and the Task 12 final report (Stone et al., In Print).



**Figure 10: CICAS-V Components in the Vehicle**



**Figure 11: Forward View and Driver View Cameras**



**Figure 12: Front Radar Installation**

Figure 10 to Figure 12 show the installation of the in-vehicle components of the CICAS-V system, the cameras and radar.

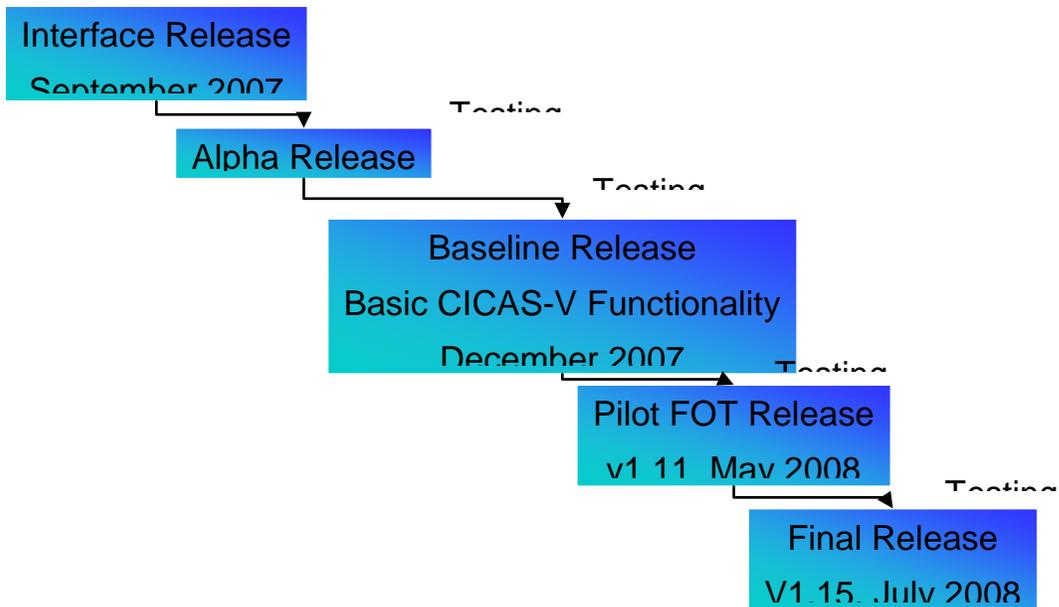
The hardware components of the CICAS-V system include the Wireless Safety Unit (WSU) from DENSO, the Netway box and a NovAtel OEM-V GPS system and the warning icon.

The WSU is the main computing component of CICAS-V and it includes a single board embedded computing device utilizing the Freescale MPC5200 PowerPC and extended automotive and IT peripherals and a DSRC radio. The unit has CAN, Serial and Ethernet interfaces that are used to connect to the various CICAS-V subsystems. The operating system used was Linux. The DSRC radio is compatible with the radio that the VII-C developed under the VII program and interoperability between the VII RSE, VII OBE and the DENSO OBE was established.

The Netway box is the interface to the vehicle CAN bus. It translates the OEM-specific CAN messages on the vehicle to a generic CAN message that the WSU uses in its warning algorithm computations. The CAN messages include vehicle speed, brake status, braking level, throttle position, etc. The use of the Netway box simplified the software development since DENSO only needed to develop one system that works on all the vehicles whereas the vehicle specific components (such as the CAN translation) could be developed by each OEM separately and installed on the Netway box. In later production-level systems, the Netway or similar CAN translating systems are not necessary since each OEM can include the CAN matrix directly into the computing unit of the CICAS-V system.

The GPS receiver is a Novatel OEMV L1 receiver. The receiver can use received DGPS corrections for accurate positioning. The same receiver was used in the intersection installation for the generation of the differential corrections and in the vehicle. The corrections that were sent from the intersection to the vehicle were in RTCM 104 v3 format and made it possible for the vehicle to use Real-Time Kinematics (RTK) to establish its position relative to the intersection with an accuracy of better than 0.5 m.

The vehicle component of the software development in Task 10 was accomplished in several stages where increased functionality was added and tested in a tight feedback loop with DENSO (Figure 13). The tests included system level tests (such as scenario testing at the intersection) and component tests at the subsystem level where individual components of the software were tested for correct functionality. The technical team developed the individual procedures and test plans to conduct the tests.



**Figure 13: Development Sequence**

The first release to include the warning functionality of the CICAS-V system was the Baseline Release in December 2007. The release 1.11 was judged to be sufficiently mature for the Pilot FOT and was used for the tests with naïve drivers. During the Pilot FOT a number of additional problems were found and corrected in subsequent releases. The final release, version 1.15, was used in the objective tests in Task 11. Figure 14 shows the CICAS-V OBE software architecture.

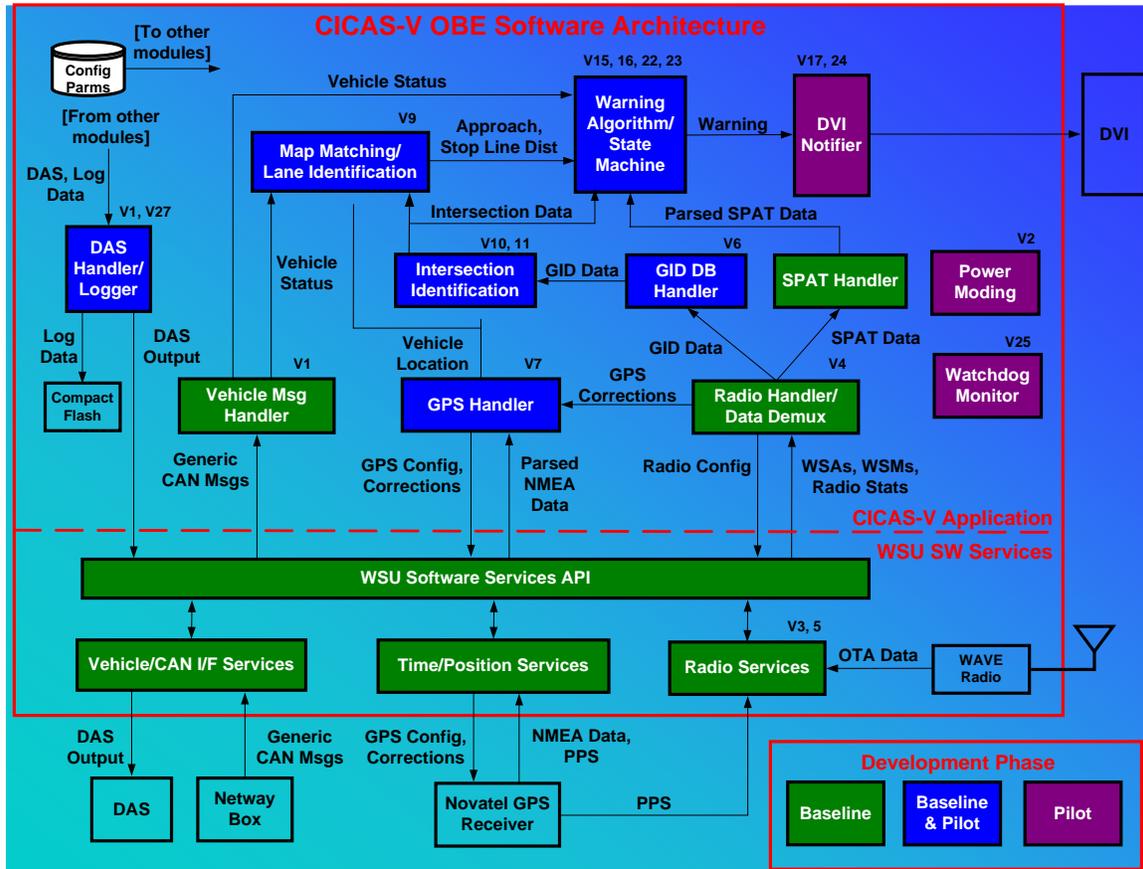


Figure 14: CICAS-V OBE Software Architecture

In addition to the tests that the CICAS-V technical team conducted, DENSO also performed their own system acceptance tests to certify the correct functionality of the system on the component level.

The intersection component of the CICAS-V used the DENSO WSU as the hardware for the Road-Side Equipment (RSE). The RSE was installed in cabinets on the mast with the signal heads at the intersection. The cabinets also included the GPS receiver and in the installation in Blacksburg, VA, the intersection Data Acquisition System (DAS). Figure 15 shows a picture of the intersection installation at Franklin and Peppers Ferry in Blacksburg.



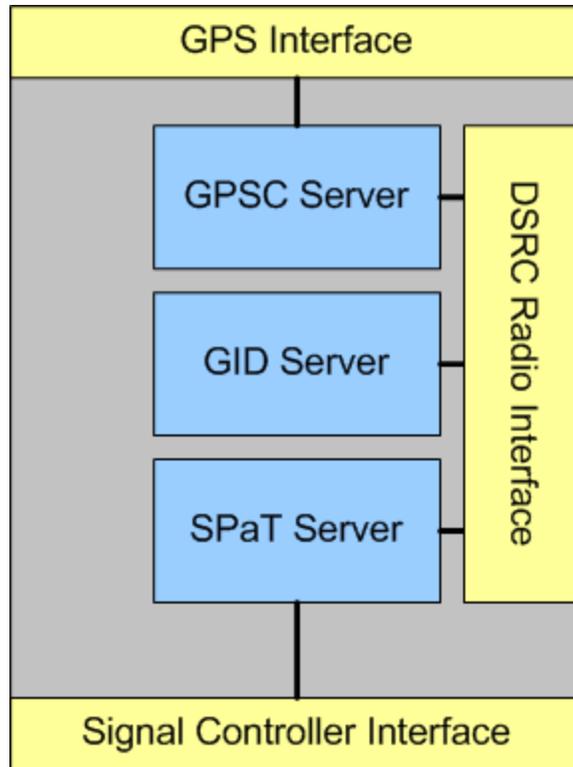
CICAS-V Cabinet with GPS, RSE and Data Acquisition System



DSRC, GPS Antennas

### Figure 15: CICAS-V Intersection Installation in Blacksburg, VA

The software components for the intersection part of the CICAS-V were developed by the CICAS-V technical team and the components differed for the installations in California and Michigan just as in Task 8 due to different signal controllers and signal controller software. The Task 10 installation ported the developed software in Task 8 to the new RSE and added functionality that took advantage of the improved hardware, such as channel switching. This enabled the transmission of GID and GPSC messages on a service channel that could be different for intersections within communication range of each other and would in a deployment scenario improve channel utilization. Figure 16 shows a block diagram of the software components of the RSE.



**Figure 16: RSE Software Components**

The SPaT server received the signal phase and timing information from the signal controller, formatted it in the correct message set, and sent it to the vehicle through the DSRC radio 10 times a second. The GID server sent the GID that was stored on the RSE to the vehicle once a second. It also sent Area GIDs that contained the GIDs for several stop signs in the area around the RSE at a rate of once a second. The GPSC server took the differential correction information from the GPS receiver in the intersection and sent it to the vehicle once a second.

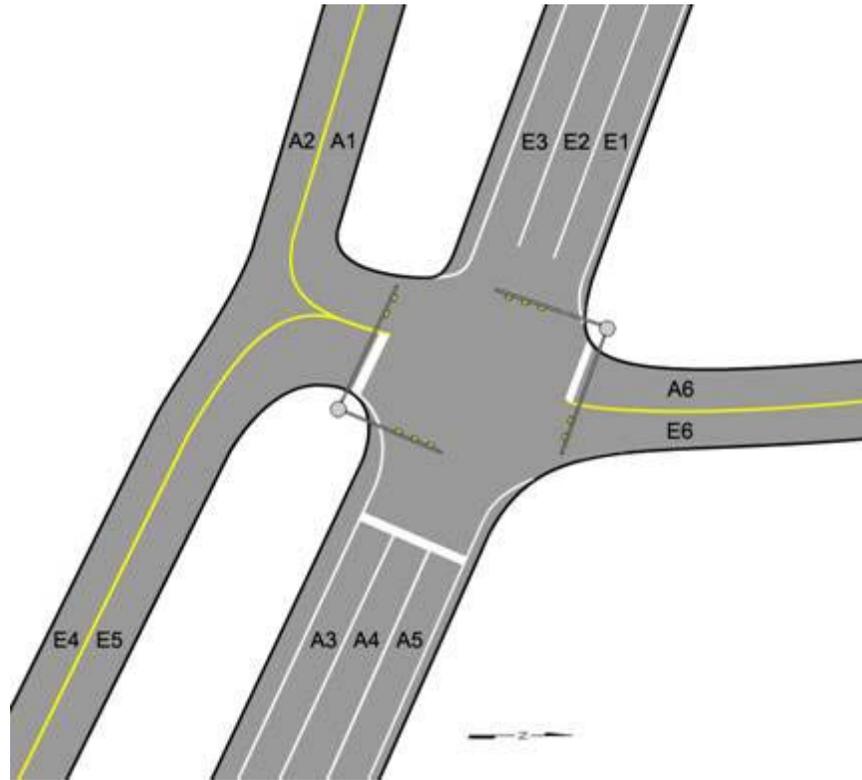
After the initial installation, the RSE worked virtually maintenance free with the exception of CICAS-V RSE application software upgrades that were necessary due to changes in the WSU native software services that were released periodically by DENSO.

## **2.11 Task 11: Objective Tests**

The purpose of the objective tests is to determine the FOT readiness of the CICAS-V and to test the performance of the system with regard to the performance specifications. The performed tests are listed in Task 7 and Table 11.

The objective tests were conducted on the Virginia Tech Transportation Institute Smart Road in Blacksburg, VA. The Smart Road includes a signalized intersection whose signal phases and timing could be accurately controlled. The intersection had four approach roads with several approach lanes of which one was used for the tests. The technical team created the GIDs for the intersection that were used in all the tests. Different intersection configurations were used in the tests.

Figure 17 shows the intersection with the numbering of the approach lanes



**Figure 17: Smart Road Intersection GID Approach Lane Numbering**

For the objective tests the lanes A3, A4 and A5 were used. The GID supported the use of the intersection as both a signalized and stop-controlled intersection.

The vehicles used for conducting the objective tests were the VTTI Cadillac STS vehicles that were also used in Task 3.4 for the Pilot FOT (Figure 18) and a Tractor-Trailer as the leading vehicle in the SPaT Reflection and Reception test.





**Figure 18: Cadillac STS and Tractor-Trailer Used for the Objective Tests**

The vehicles had some additional equipment installed:

- High precision DGPS using corrections from a base station at VTTI
- Camera to record the DVI warning icon state
- System to change the signal dynamically during testing

The conditions for the objective tests were:

- A procedure could contain multiple tests
- Each test had to have at least 8 valid runs (intersection approaches)
- A test was judged to have passed if 6 out of 8 runs passed based on the pass/fail criteria for the individual test (e.g., warning came within the expected range)
- A test run was judged successful if all the validity criteria were fulfilled (e.g., speed was within the allowed range, sufficient packets from the alternate intersection were received at the point where a warning was going to be issued, etc.)

During the objective tests, the same set of data was collected as in the Pilot FOT with the addition of the high precision GPS data and the video images of the icon state. The data was used to analyze the test results and to determine whether the system passed or failed any of the tests.

In addition to the data collection, the road was also set up to provide visual feedback to the experimenters. A set of cones was set up to demark the zone within which the warning would have to occur for the speed of the individual procedure. Figure 19 shows the cones for the warning zone.



**Figure 19: Cones with Flags Demarking the Warning Zone**

The test personnel included:

- A driver, not affiliated with the project
- An observer to protocol the test and observe the outcome
- A government witness from either NHTSA or Volpe
- Additional personnel to perform specific tasks in the vehicle such as changing the signal or determine the distance from a leading vehicle

The objective test procedures consisted of 15 individual tests with pass/fail criteria (120 valid runs) and one engineering test without pass/fail criteria (8 valid runs)

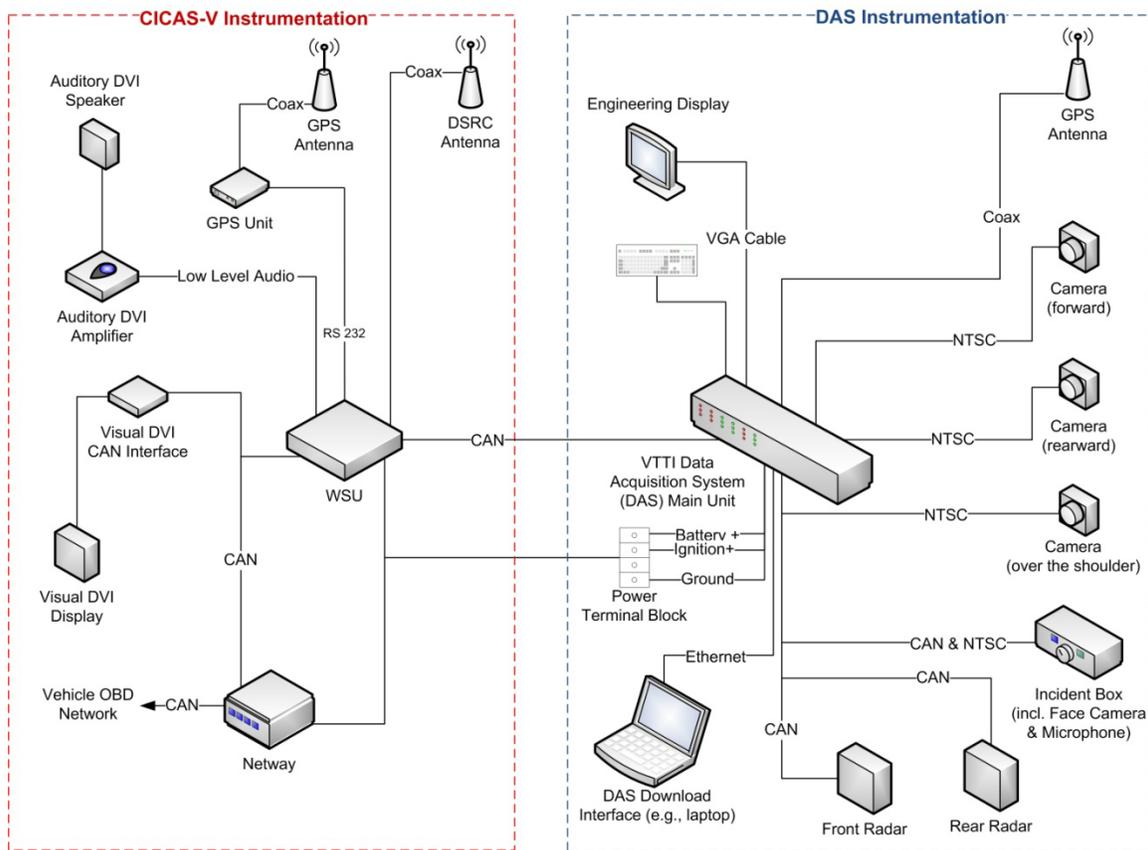
The CICAS-V system failed one run at the variable speed signalized intersection approach test (55 mph approach speed). In this run, the brake pulse not activate even though the other DVI modalities performed correctly.

The outcome of the objective tests (Maile et al., In Print) is that the CICAS-V is performing as well or better than originally specified and that the system is FOT ready.

## 2.12 Task 12: Vehicle and Intersection DAS

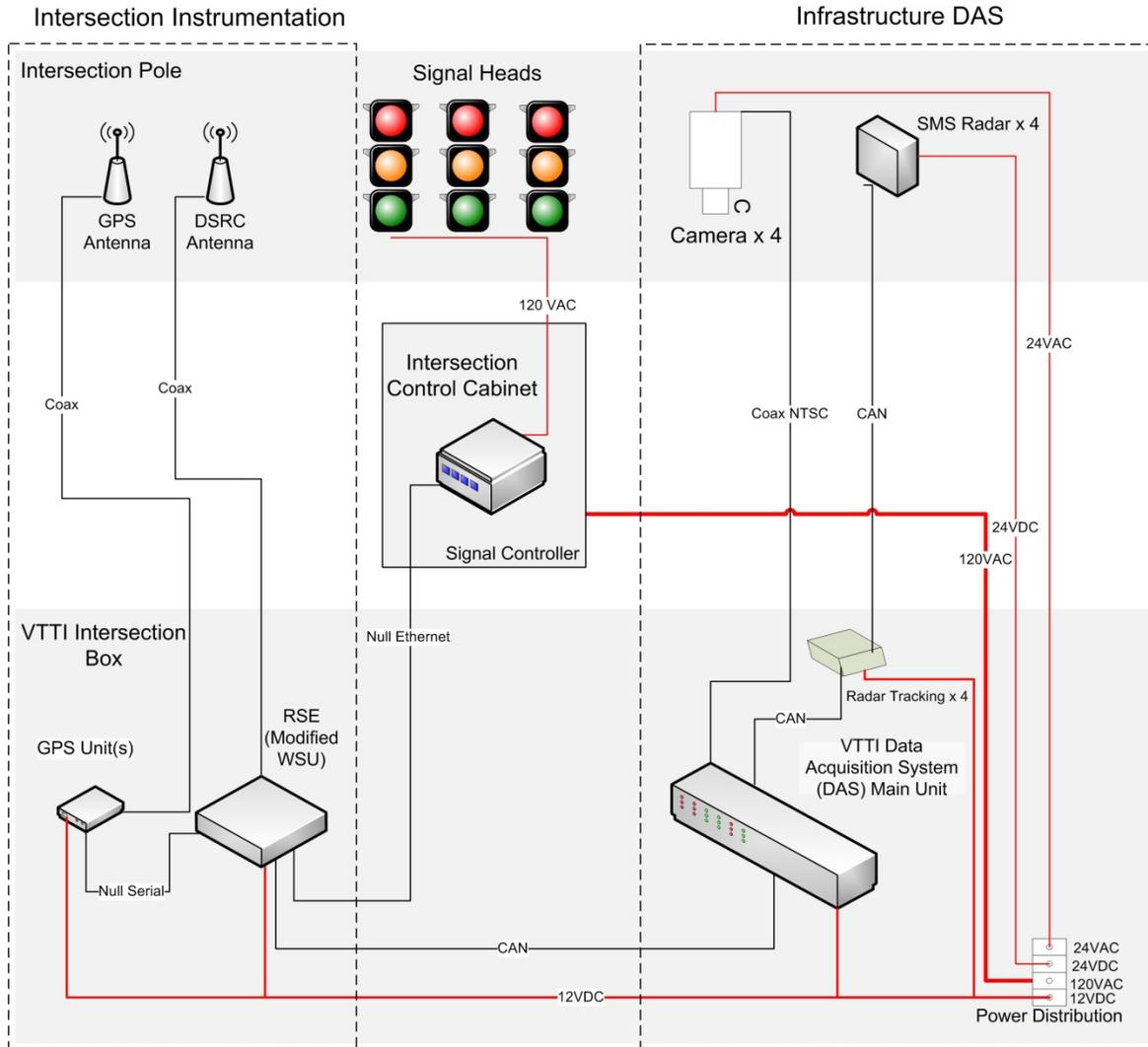
Task 12 of the project developed the data acquisition systems for the infrastructure and vehicle that will be used in the Phase II FOT. The two DASs were tested during the development of the CICAS-V system and in the Pilot FOT conducted in Subtask 3.4.

The vehicle DAS developed for the CICAS-V Project is based on the high-performance, adaptable data collection system developed by the Virginia Tech Transportation Institute (VTTI). It is ideal for collecting a wide range of variables in a manner that is unobtrusive to the driver and made possible by hardware, software, and data storage components. Each of the vehicle DAS components are depicted in Figure 20 with further elaboration provided in the Task 12 Final Report (Stone et al., In Print).



**Figure 20: Vehicle DAS System Schematic**

The infrastructure DAS is also based on the same VTTI DAS system. It is depicted in Figure 21 with further elaboration provided in the Task 12 Final Report.



**Figure 21: Infrastructure DAS System Schematic**

### 2.13 Task 13: FOT planning

Task 13 had the goal to plan a future Field Operational Test (FOT) and to define the basic parameters for such an FOT. The FOT is regarded as a necessary step before CICAS-V can be deployed in vehicles and in the infrastructure. In the FOT, a large number of naïve test subjects would drive the vehicles as their own personal cars for a period of time using the protocols developed in Subtask 3.4 and the data acquisition systems developed in Task 12. The data collected during the FOT would provide the data to address the following three basic questions (FOT questions):

- What are the safety benefits of the CICAS-V?
- What is the user acceptance of CICAS-V?
- Are there potential unintended consequences?

The FOT would also provide additional insight into the operational issues and costs associated with the installation and maintenance of a CICAS-V system at a larger number of intersections than were used during Phase I. Moreover, the FOT would also provide experience with the behavior of communication-based safety applications in a real-world environment.

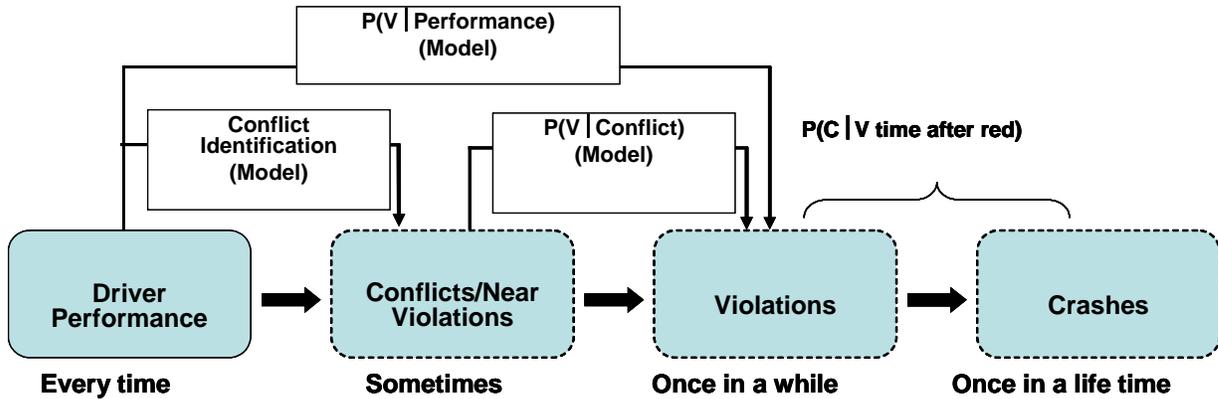
In addition to the full FOT, Phase II also contained an extended Pilot FOT that was also planned during Task 13. The function of the extended Pilot FOT is to test the protocols and assumptions of the full FOT and to assess whether the algorithm timing planned for the FOT is acceptable to the drivers.

Initially, this task had the goal to fully plan the FOT in Phase II of the CICAS-V Project, but this was changed during the course of the project to satisfy the following objectives:

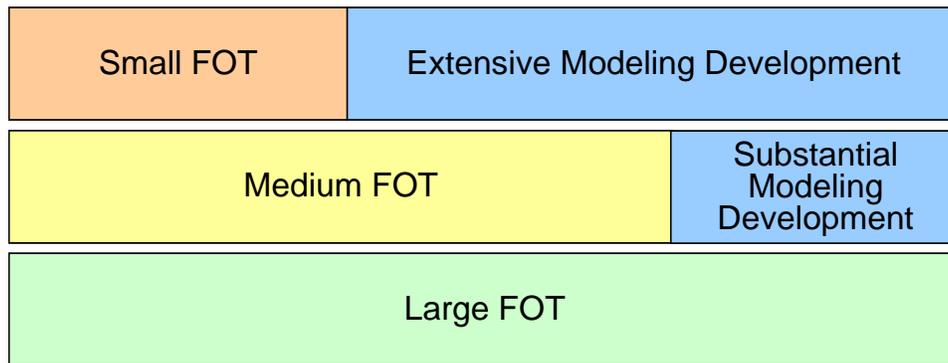
- Identification of the process for selecting an FOT location and the intersection sites at this location. This included:
  - Description of the necessary steps to identify a location
  - Development of criteria for the location selection and intersection selection
  - Development of guidelines for the test area layout and methods to increase exposure (number of intersection crossing per test subject)
- Development of the protocol for the Extended Pilot FOT and the full FOT

The determining factor for the size of the FOT is the number of genuine alerts that the system generates over the lifetime of the FOT. Without drivers experiencing alerts, no valid statements can be made about user acceptance and unintended consequences, and the determination of safety benefits from driver performance requires substantial modeling effort with the uncertainty about the validity of the results increasing with each modeling step.

Figure 22 shows the modeling steps necessary to get from indirect and more frequent surrogate measures of driver performance and conflicts/near-violations to violations. Direct violation observations or modeling to estimate violations must then go through a separate process using data collected outside of the FOT to determine the connection between violations and crashes given a violation severity or time after red. As shown in Figure 22, and reinforced in Figure 23, a small FOT requires extensive modeling, in this case two steps, to determine the connection between driver performance and crashes. Figure 23 also illustrates how direct measurement of violations in a large FOT requires no modeling. It is important, however, to note that a large FOT will still use driver performance and conflict/near violation surrogate measures to support direct violations measures, especially in the event of fewer violations than anticipated.



**Figure 22: Data Flow for Safety Benefits Estimation**



**Figure 23: Modeling Effort for Different FOT Sizes**

In order to keep the modeling effort and the uncertainties in the accuracy of the answers to the FOT questions low, a majority of the FOT drivers must experience CICAS-V alerts during their participation. The number of intersection crossings is a primary determinant of the number of alerts that will be triggered. This means that the number of intersection crossings per driver must be maximized so that alert opportunities are generated. Alerts would come from violations and near-violations at signalized and stop-controlled intersections.

To determine the necessary size of the FOT, three alternatives were identified by the USDOT, based on a statistical power analysis (Table 12). Designs of varying sizes were deemed necessary to provide testing options with different funding requirements. For each FOT alternative, the experimental design process estimated the number of drivers needed to study the effect of the CICAS-V system on a key driver performance measure (e.g., number of violations for the large FOT) based on initial assumptions about system effectiveness and driver exposure to events during the FOT. For example, the large FOT design was based on the ability to detect a 50 percent change in violations between baseline (without CICAS-V assistance) and treatment (with CICAS-V assistance) with a 95 percent confidence level and 80 percent statistical power. Similar assessments were

made for the small FOT (based on detecting CICAS-V effects on vehicle deceleration) and for the medium FOT (detecting changes in the number of near violations). The resulting sample sizes (i.e., required number of subject drivers) were then used to estimate the number of test vehicles and test duration per subject, using the stated number of signalized intersections and an overall test duration of 52 weeks.

**Table 12: FOT Alternatives**

<b>FOT</b>	<b>No. of Subjects</b>	<b>Individual Subject Data Collection</b>	<b>No. of Signalized Intersections</b>	<b>No. of Cars</b>	<b>Overall Duration of Data Collection</b>
Small	90	5 wks	20	10	52 wks
Medium	108	12 wks	20	27	52 wks
Large	204	12 wks	24	49	52 wks

The estimation of the expected number of alerts was based on several data sources (Table 13)

**Table 13: Estimation of Expected Number of Violations at Intersections**

<b>Data Source</b>	<b>Number of Alerts per 100K Intersection Crossings</b>
VTTI's Quick Analysis of Subtask 3.2 Signalized Data	126
Volpe's Sacramento Study	6 – 29
Subtask 3.1 Data	42
Other Literature	17 - 401

For the purposes of evaluating the alternative FOT designs, the minimum and maximum number of violations per 100,000 intersection approaches was selected as 5 and 50. The number of near violations was determined from Subtask 3.1 data. The relationship between violations and near-violations is roughly 1:10. Based on those data, the expected number of intersection crossings and alerts for different FOT sizes are (Table 14)

**Table 14: Expected Number of Alerts for Medium and Large FOT Expected Number of Alerts for Medium and Large FOT**

<b>FOT Size</b>	<b>Intersection Crossings</b>	<b>No. of Subjects*</b>	<b>Violations High Estimate</b>	<b>Violations Low Estimate</b>	<b>Near Violations High</b>	<b>Near Violations Low</b>	<b>Total Alerts** High</b>	<b>Total Alerts** Low</b>
Medium	129,600	108	65	6	648	65	713	71
Large	293,760	204	147	15	1,469	147	1,616	162

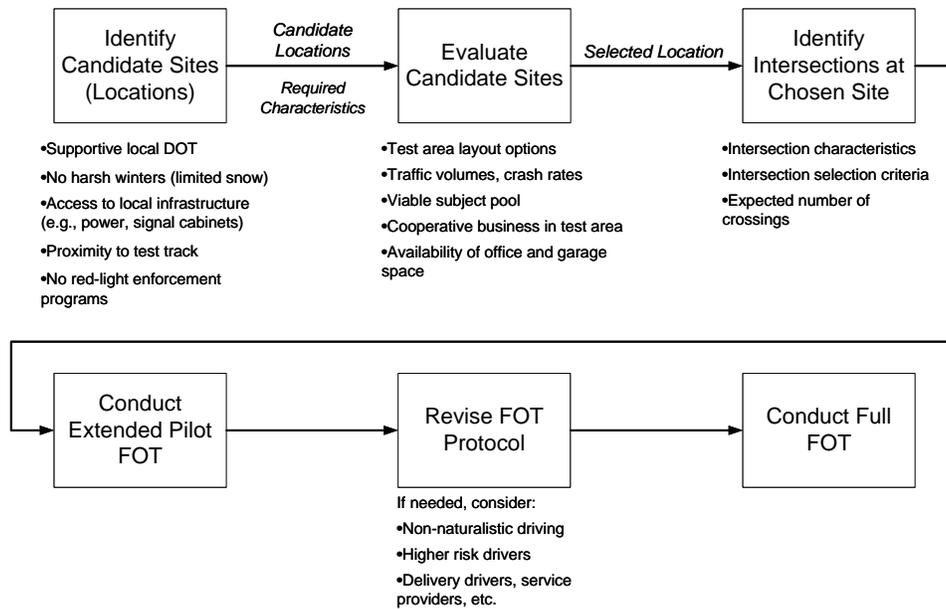
The small FOT was not viable for estimating user acceptance and unintended consequences due to insufficient number of alerts, although in conjunction with a significant modeling effort this FOT design likely would have generated enough data to estimate the safety benefits of CICAS-V. Because all three research questions (i.e., safety benefits, user acceptance and unintended consequences) could not be addressed with this design, it was not considered further.

The medium-sized FOT requires additional modeling to determine the safety benefit since near-violations will need to be extrapolated to estimate the number of violations for the benefits analysis. The medium-sized FOT, using the high estimate for alert rate would also permit user acceptance and unintended consequences to be examined. However, using the low estimates, the medium FOT does not yield enough alerts to accurately determine user acceptance, unintended consequences and safety benefits.

The large FOT, using the high violation rate estimate, provides sufficient data to address the questions regarding user acceptance and unintended consequences. In addition, this design does not require additional modeling to estimate the number of violations, thereby, increasing confidence levels as compared to either of the smaller FOT designs. Using the low estimates, the large FOT may need some modeling to answer the safety benefits question but the expected number of alerts is still high enough to address the questions about user acceptance and unintended consequences.

The large FOT, relative to the medium FOT, is significantly more likely to yield sufficient data for addressing the FOT evaluation goals. Therefore, the work in Task 13 focused on planning the large FOT.

The process for selecting an FOT site is shown in Figure 24.



**Figure 24: FOT Site Selection Process**

An initial pool of candidate locations that satisfies the initial selection criteria such as a supportive local DOT, no harsh winters with limited snow, no red-light enforcement cameras, etc, will then be analyzed as to whether it supports a test area layout that would maximize daily intersection crossings and whether it would support the logistics requirements of the FOT. Also, the intersection characteristics and satisfying the intersection selection criteria are being taken into account for the final site selection. After this step is completed, the intersections will be instrumented and the extended Pilot FOT will be conducted. After the extended Pilot FOT the FOT protocol will be revised if necessary and the full FOT will be conducted.

The extended Pilot FOT will use 24 signalized intersections and 50+ stop sign controlled intersections, 6 vehicles and 12 drivers. Each driver will drive the vehicle for 6 weeks. The duration of the data collection is 12 weeks (two vehicle cycles).

The full FOT will use 24 signalized and 50+ stop sign controlled intersections, 51 test vehicles and 204 drivers. Each driver will drive the vehicle for 12 weeks. The first three weeks the system will be inactive but data will be collected (baseline). After that the subjects will drive the vehicle for nine weeks with the system active. The total duration of the data collection is 52 weeks (four vehicle cycles). All drivers participate in the “surprise trial” study (task 3.3 and 3.4) on a test track, following their participation in the FOT.

The expected number of intersection crossings is:

- Signalized: 587,520 (24 intersections \* 2/sday \* 5days/wk \* 12 wks \* 204 drivers)
- Stop Sign: 34,272 (2 stop signs/day \* 7 days/wk \* 12 wks \* 204 drivers)

It is expected that this FOT will generate sufficient information for an extensive cost/benefit analysis and to address the three research questions.

The work in this task is reported in the Task 13 Final Report (Kiger et al., In Print).

### **2.14 Task 14: IRB Approval**

The objective of Task 14 was to secure the approval of an Institutional Review Board for the experiments with human subjects. This approval was required to protect the rights of the naïve drivers that participated in the four subtasks comprising the human factors research in Task 3. All necessary approvals were received for the tests in a timely manner.

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#### **HUMAN FACTORS REPORTS (TASK 3)**

##### Subtask 3.1

Sudweeks, J., Neale, V. L., Wiegand, K., Bowman, J., Perez, M. and Maile, M. (In Print). *Cooperative Intersection Collision Avoidance Systems Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Subtask 3.1 Report: Mining of the 100-Car Naturalistic Database to Determine Factors Related to Intersection Violations and Near Violations*. Washington, DC: National Highway Traffic Safety Administration.

##### Subtask 3.2

Doerzaph, Z. R., Neale, V. L., Bowman, J. R., Viita, D. C., and Maile, M. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Subtask 3.2 Interim Report: Naturalistic Infrastructure-Based Driving Data Collection and Intersection Collision Avoidance Algorithm Development*. Washington, DC: National Highway Traffic Safety Administration.

##### Subtask 3.3

Perez, M. A., Neale, V. L., Kiefer, R. J., Viita, D., Wiegand, K., and Maile, M. (In Print). *Cooperative Intersection Collision Avoidance Systems Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Subtask 3.3 Interim Report: Test of Alternative Driver-Vehicle Interfaces on the Smart Road*. Washington, DC: National Highway Traffic Safety Administration.

##### Subtask 3.4

Neale, V. L., Doerzaph, Z.R., Viita, D., Bowman, J., Terry, T., Bhagavathula, R., and Maile, M. (In Print). *Cooperative Intersection Collision Avoidance Systems Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Subtask 3.4 Interim Report: Human Factors Pilot Test of the CICAS-V*. Washington, DC: National Highway Traffic Safety Administration.

## **SYSTEM ENGINEERING REPORTS**

### **Task 4: Conops**

Maile, M., Ahmed-Zaid, F., Caminiti, L., Lundberg, J., Mudalige, P., Pall, C., Garrett, J. K., Kaiser, J. L., Mixon, L. T., and Smith, G. D. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Concept of Operations*. Washington, DC: National Highway Traffic Safety Administration.

### **Task 4: High-Level Requirements Specification**

Maile, M., Ahmed-Zaid, F., Caminiti, L., Lundberg, J., Mudalige, P., Pall, C., Garrett, J. K., Kaiser, J. L., Mixon, L. T., and Smith, G. D. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) High-Level Requirements Specification*. Washington, DC: National Highway Traffic Safety Administration.

### **Task 5: System Architecture Description**

Maile, M., Ahmed-Zaid, F., Caminiti, L., Lundberg, J., Mudalige, P., Pall, C., Garrett, J. K., Kaiser, J. L., Mixon, L. T., and Smith, G. D. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) System Architecture Description*. Washington, DC: National Highway Traffic Safety Administration.

### **Task 5: System Requirements Specification**

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### **Task 6: System Performance Specs. (Vehicle & Infrastructure)**

Maile, M., Ahmed-Zaid, F., Caminiti, L., Lundberg, J., Mudalige, P., Pall, C., Garrett, J. K., Kaiser, J. L., Mixon, L. T., and Smith, G. D. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) System Performance Specification - Vehicle*. Washington, DC: National Highway Traffic Safety Administration.

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## **SYSTEM DEVELOPMENT AND TESTING REPORTS**

### **Task 7: Objective Test Procedures**

Maile, M., Ahmed-Zaid, F., Basnyake, C., Caminiti, L., Kass, S., Losh, M., Lundberg, J., Masselink, D., McGlohon, E., Mudalige, P., Pall C., Peredo, M., Popovic, Z, Stinnett, J., and VanSickle, S. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Task 7 Final Report: Objective Test Procedures*. Washington, DC: National Highway Traffic Safety Administration.

### **Task 8: Prototype Build and Testing**

Maile, M., Ahmed-Zaid, F., Basnyake, C., Caminiti, L., Kass, S., Losh, M., Lundberg, J., Masselink, D., McGlohon, E., Mudalige, P., Pall C., Peredo, M., Stinnett, J., and VanSickle, S. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Task 8 Final Report: Prototype Build and Testing*. Washington, DC: National Highway Traffic Safety Administration.

### **Task 10: Prototype Development**

Maile, M., Ahmed-Zaid, F., Basnyake, C., Caminiti, L., Kass, S., Losh, M., Lundberg, J., Masselink, D., McGlohon, E., Mudalige, P., Pall C., Peredo, M., Stinnett, J., and VanSickle, S. (In Print). *Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Task 10 Final Report: Integration of Subsystems, Building of Prototype Vehicles and Outfitting of Intersections*. Washington, DC: National Highway Traffic Safety Administration.



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