RITA Intelligent Transportation Systems
Joint Program Office

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

Task 12 Final Report

Infrastructure and Vehicle DAS Functional Designs

(Appendix I)

May 15, 2008

Crash Avoidance Metrics Partnership (CAMP) Produced
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16. Abstract

The Cooperative Intersection Collision Avoidance System for Violations (CICAS-V) project aims to develop and field-test a comprehensive system to reduce the number of crashes at intersections due to violations of traffic control devices (TCDs; i.e., traffic lights and stop signs). The CICAS-V system provides a salient and timely in-vehicle warning to drivers who are predicted to violate a TCD, with the aim of compelling the driver to stop.

If the CICAS-V is tested during a field operational test (FOT) to determine the safety benefits, user acceptance, and unintended consequences, as well as validate basic operation of the system. Vehicle- and infrastructure-based data acquisition systems (DASs) were designed and developed to support the analysis of the CICAS-V system effectiveness. The purpose of this report is to provide the functional designs of both the vehicle and infrastructure DASs that will be used to collect data during the FOT.

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Executive Summary

The Cooperative Intersection Collision Avoidance System for Violations (CICAS-V) project aims to develop and field-test a comprehensive system to reduce the number of crashes at intersections due to violations of traffic control devices (TCDs; i.e., traffic lights and stop signs). The CICAS-V system provides a salient and timely in-vehicle warning to drivers who are predicted to violate a TCD, with the aim of compelling the driver to stop.

One of the CICAS-V project goals was to develop a system for testing during a future field operational test (FOT) to determine the safety benefits, user acceptance, and unintended consequences, as well as validate basic operation of the system. Vehicle- and infrastructure-based data acquisition systems (DASs) were designed and developed to support the analysis of the CICAS-V system effectiveness.

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 E-1 with further elaboration provided in the main body of this Task 12 Final Report.

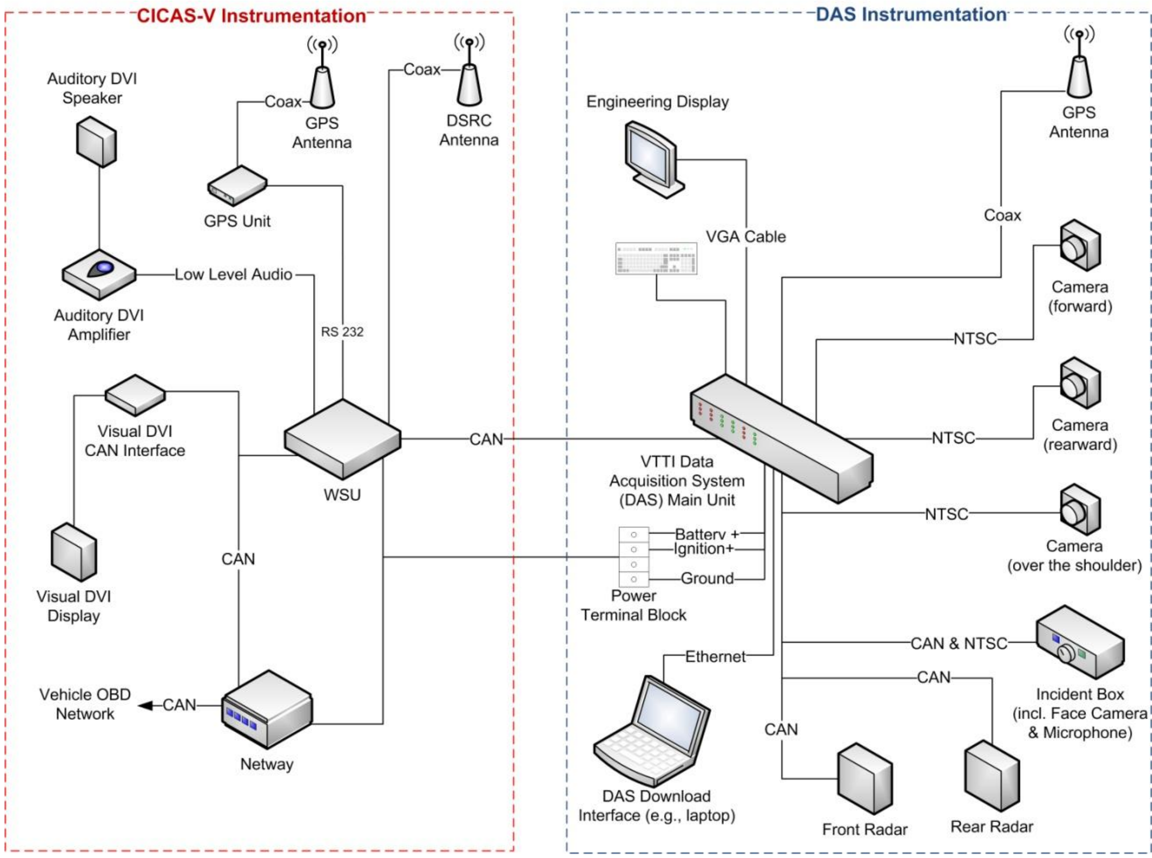

Figure E-1 – Vehicle DAS system schematic.

The infrastructure DAS is also based on the same VTTI DAS system. In accordance with the project statement of work, an infrastructure DAS was only developed for signalized intersections. It is depicted in Figure E-2 with further elaboration provided in the main body of this Task 12 Final Report.

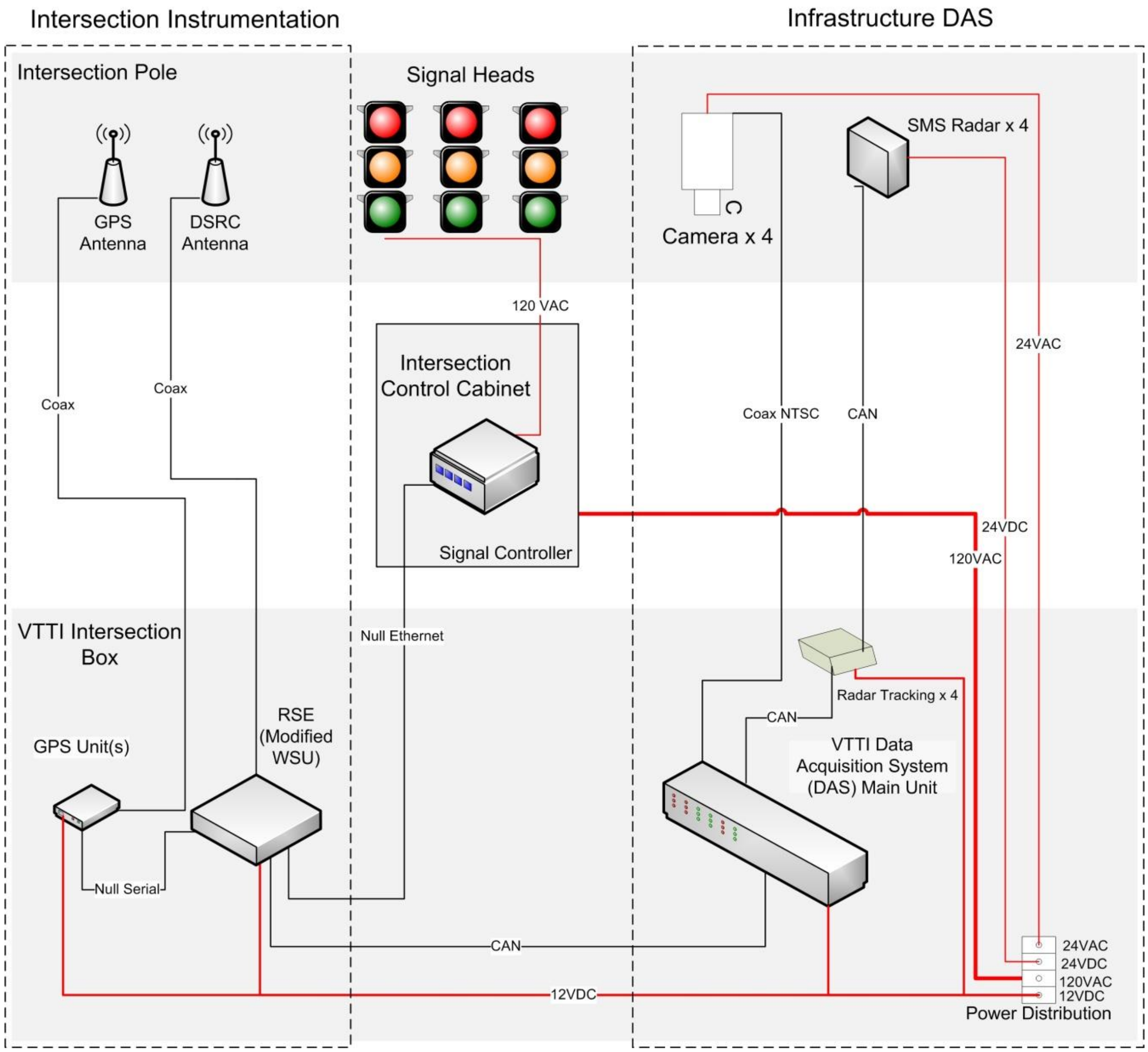

Figure E-2 – Infrastructure DAS system schematic.

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Acronyms

ACC	Adaptive Cruise Control
CAMP	Collision Avoidance Metrics Partnership
CAN	Controller Area Network
CCTV	Closed Circuit Television
CICAS-V	Cooperative Intersection Collision Avoidance System for Violations
DAS	Data Acquisition System
DSP	Digital Signal Processor
DSRC	Digital Short Range Communication
DVI	Driver-Vehicle Interface
EPIC	Embedded Platform for Industrial Computing
FMCW	Frequency Modulated Continuous-wave
FOT	Field Operational Test
GID	Geometric Intersection Description
GPS	Global Positioning System
GPSC	GPS Corrections
LED	Light-Emitting Diodes
OBD	On-Board Diagnostic
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
RSE	Roadside Equipment
SAN	Storage Area Network
SMS	Smart Microwave Sensors GMBH
SPaT	Signal Phase and Timing
TCD	Traffic Control Devices
USDOT	United States Department of Transportation
VTTI	Virginia Tech Transportation Institute
WSU	Wireless Safety Unit

1 Project Overview

The Cooperative Intersection Collision Avoidance System for Violations (CICAS-V) project aims to develop and field-test a comprehensive system to reduce the number of crashes at intersections due to violations of traffic control devices (TCDs; i.e., traffic lights and stop signs). The CICAS-V system provides a salient and timely in-vehicle warning to drivers who are predicted to violate a TCD, with the aim of compelling the driver to stop.

CICAS-V will be tested during a field operational test (FOT) to determine the safety benefits, user acceptance, and unintended consequences, as well as validate basic operation of the system. Vehicle- and infrastructure-based data acquisition systems (DASs) were designed and developed to support the analysis of the CICAS-V system effectiveness. The purpose of this report is to provide the functional designs of both the vehicle and infrastructure DASs that will be used to collect data during the FOT.

1.1 CICAS-V Description

As background to the design and development of the in-vehicle and infrastructure DASs, a brief description of the CICAS-V is provided. The CICAS-V contains several components working together to predict a TCD violation and provide the driver with a warning when appropriate. The CICAS-V is comprised of on-board equipment (OBE) and roadside equipment (RSE). Figure 1 provides a schematic illustration of the OBE components and communication pathways of the CICAS-V subsystems.

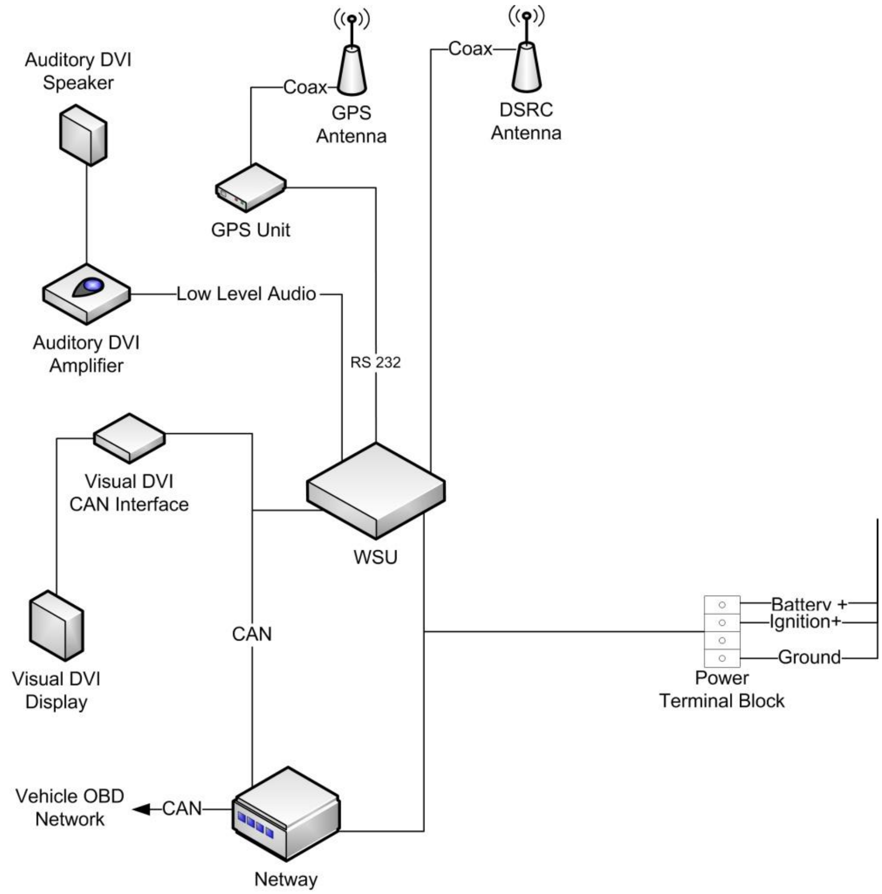

Figure 1 - CICAS-V OBE schematic.

The Wireless Safety Unit (WSU) is the central processing component of the CICAS-V network. The WSU receives data from the vehicle controller area network (CAN), the global positioning system (GPS), and dedicated short range communication messages (DSRC). Data from these sources are pre-processed and then evaluated in parallel by the threat assessment algorithm. If the algorithm predicts a violation, the WSU will activate the driver vehicle interface (DVI).

The vehicle CAN delivers data such as brake status, turn signal activation, and velocity to the Netway box. The Netway box, exclusive to each of the original equipment manufacturers (OEM), is used to translate OEM-specific CAN messages to a standard CAN format compatible with the WSU.

The GPS system provides longitude/latitude positioning data to the WSU. This allows the WSU to place the vehicle on a digital representation of the intersection called the Geometric Intersection Description (GID). GIDs may be stored on the WSU or obtained from the RSE through the DSRC channel. At signalized intersections, the vehicle is also matched with the appropriate signal phase and timing (SPaT) data provided by DSRC messages.

The WSU controls the three DVI modalities – auditory, visual, and haptic. The auditory warning is sent through the on-board line-out jack to an amplified speaker. The visual warning is activated on the WSU CAN network and displayed by a dash-mounted icon.

The haptic warning is sent over the CAN through the Netway box to the OEM brake controller. The DVI has three states: 1) an inactive state when the vehicle is not approaching an equipped intersection, 2) a visual-only indication when approaching an equipped intersection, and 3) a full warning mode that encompasses the visual, auditory, and haptic alerts.

The RSE portion of the CICAS-V is shown in Figure 2. The RSE utilizes a second WSU to transmit relevant information to the vehicle. The RSE transmits the GID, differential GPS corrections, and the SPaT information to the vehicle. The SPaT information is supplied to the RSE by custom firmware installed on the traffic signal controllers at the signalized intersections.

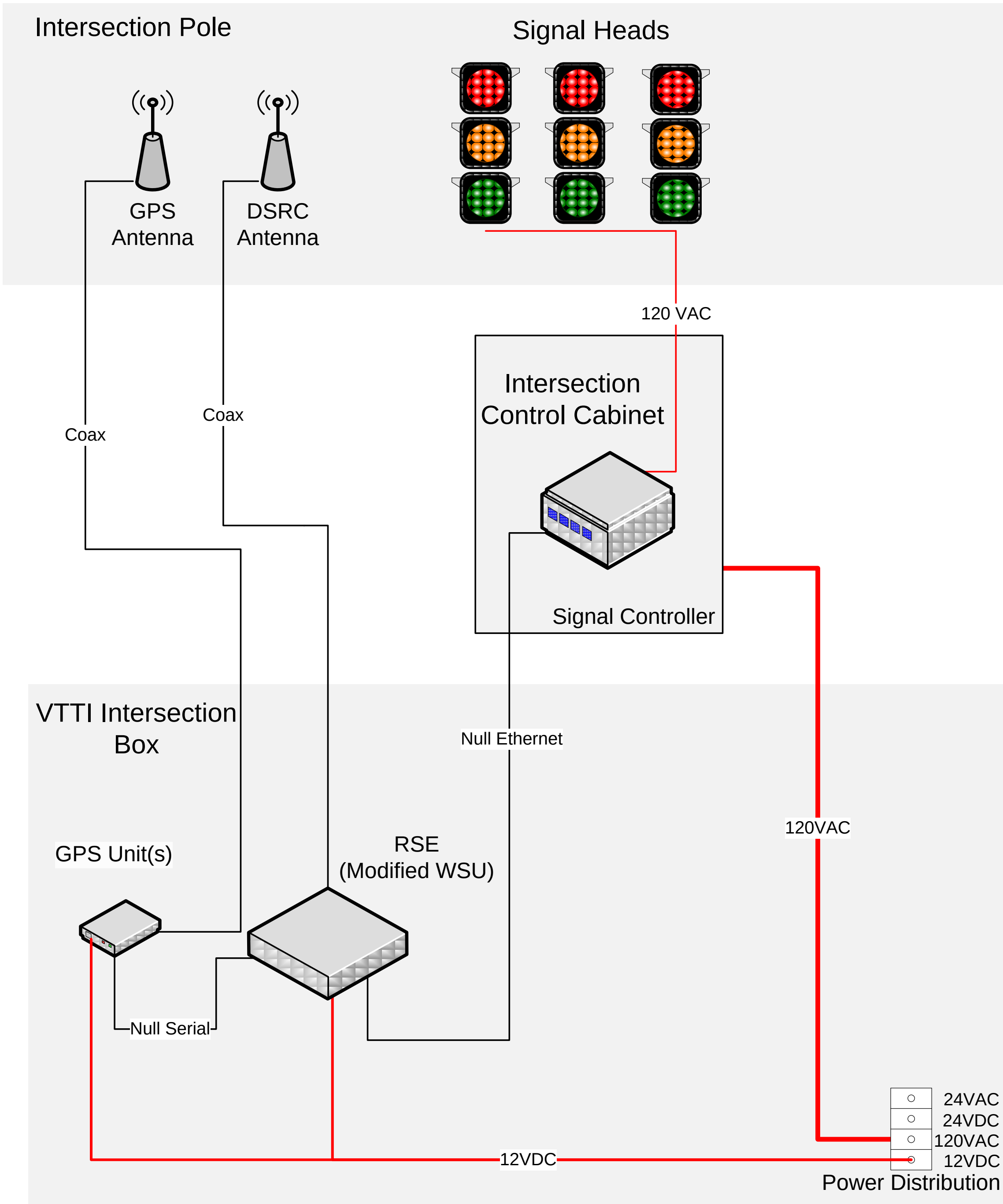

Figure 2 - CICAS-V RSE Schematic.

2 Vehicle DAS

The vehicle DAS is based on the high-performance, adaptable data collection system originally developed by the Virginia Tech Transportation Institute (VTTI) for the 100-Car Naturalistic Driving Study (100-Car Study; Dingus et al., 2006). The vehicle DAS has been refined through dozens of research projects over the last three years including Subtask 3.3 of the Phase I CICAS-V project (Perez et al., in review). The vehicle DAS is ideal for collecting a wide range of variables in a manner that is unobtrusive to the driver.

The vehicle DAS is composed of hardware, software, and data storage components. Each of these components is discussed in the following sections.

2.1 Vehicle DAS Variable List

The vehicle DAS variable list is provided in Appendix A. The vehicle DAS records data supplied by VTTI-installed sensors (i.e., radar) and the WSU communications interface. The WSU communication interface is a CAN pass through of the OEM production sensor data. Each OEM provided a programmed Netway CAN converter. The Netway converter translates the OEM specific sensor data into a common CAN format for the WSU application; which in-turn transmits a formatted data stream to the DAS. The vehicle DAS records all sensors and the WSU CAN output at a 10 Hz rate.

The collected variables provide the information necessary to reconstruct a vehicle's intersection approach and the driver's interaction with the CICAS-V. To assess the effectiveness and accuracy of the CICAS-V, algorithm-specific variables (i.e., speed, distance to stopbar, intersection type, braking, and signal state) are collected. These variables may be used for a variety of analyses (i.e., comparisons of warning to baseline events, assessments of warning timing, and evaluations of driver to DVI interactions).

Along with the CICAS-V variables, the DAS also records additional data that may be used to assess unintended consequences. For example, the radar data will allow researchers to see if the warning creates a greater potential for rear-end collisions based on the braking of the subject vehicle. In addition to the FOT variables (Appendix A), a series of diagnostic variables were also collected (Appendix B) to support Phase I efforts such as Task 11. These additional variables will not necessary be collected should an FOT be undertaken in the future.

2.2 Vehicle DAS Hardware Components

The vehicle DAS is used to record digital video and kinematic data from multiple sources. The system is built on an Embedded Platform for Industrial Computing (EPIC) single-board computer backbone with a custom-built interface stack capable of accepting and transmitting information to a variety of sensing components. This system of distributed data acquisition provides a flexible and maintainable system.

Figure 3 shows the configuration of the vehicle DAS as it is integrated into the entire CICAS-V instrumentation plan.

The vehicle DAS is tied into the CICAS-V through a single dedicated CAN cable connected to the WSU. This CAN connection transmits the CICAS-V application data from the WSU to the vehicle DAS in real time.

The vehicle DAS hardware includes several modular components. These include the main unit, custom in-house developed sensor modules, and the video/audio camera subsystem. Each component of the system has been carefully selected or specifically designed to operate within the vehicle environment.

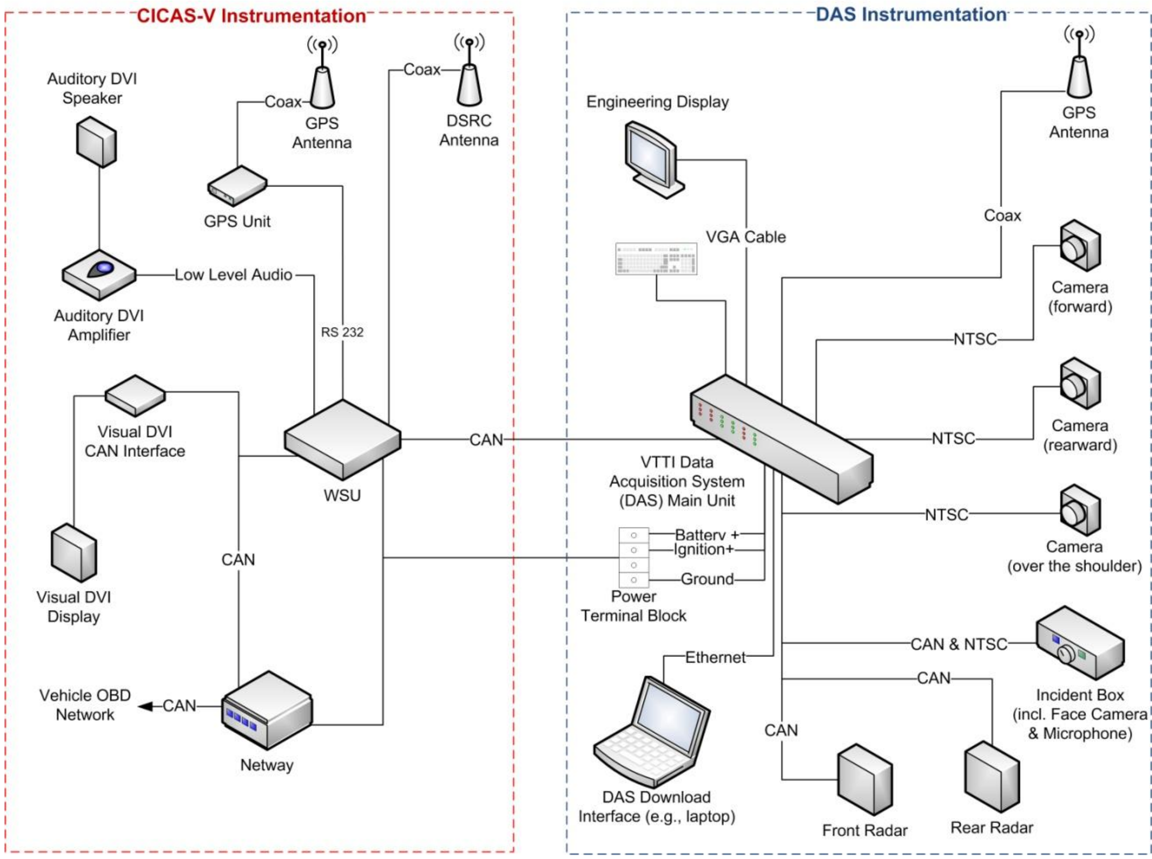

Figure 3 - Vehicle DAS system schematic.

2.2.1 Main Unit

The main unit of the VTTI data collection system is shown in Figure 4. The unit has been designed for unobtrusive mounting within many vehicle types. It contains an EPIC single-board computer, hard drive cradle, CAN communication, battery backup system, and several VTTI-developed sensor modules.

Figure 4 - Vehicle DAS main unit.

The main unit is mounted in the trunk under the vehicle's package shelf, leaving the majority of the trunk area available for use. The wiring for the system is run though the normal wire chases on the vehicle to all the various network nodes as well as to the cameras. Routing the wires behind the vehicle paneling reduces the possibility of damage to or disconnection of the system cabling.

Custom Linux-based software is used to choreograph real-time data collection, pre-processing, system management, and data storage. The software handles the synchronizing of the parametric and digital video subsystems allowing for post-collection analysis.

2.2.2 Video System

Four cameras are installed in the passenger compartment of the equipped vehicles. The placement of these cameras is unobtrusive while capturing the intended scene.

Figure 5a, Figure 5b, and Figure 5c display the cameras mounted in the vehicles. The camera used for the face, front, and rear system views (Figure 5a) uses multiple lens configurations to provide the appropriate field of view. The camera size is roughly 1" wide x 1" high which allows for easy concealment within the vehicle. The face camera is contained within the incident box (Figure 5b). The incident box provides a button that allows the driver to flag the data; which allows the driver to direct experimenter's attention toward an event. The incident box also contains an LED array to illuminate the drivers face at night. An additional camera (Figure 5c) is mounted over the driver's right shoulder and incorporates embedded infrared light-emitting diodes (LEDs) for nighttime illumination. The over-the-shoulder camera measures roughly 2" wide x 1.5" high. This camera is used to view the driver's hand placement on the steering wheel as well as to track driver interactions with the vehicle controls and instrument panel. The forward and rearward cameras obtain sufficient nighttime illumination from adjacent vehicle headlamps.

A
Camera used to capture the driver's face, forward road view and rear road view

B
Incident box containing face camera and LEDs to illuminate driver at night

C
Camera used to capture the driver's seated position and hand placement with LEDs for nighttime illumination

Figure 5 - In-vehicle cameras used.

The four video camera images are fed directly into a hardware MPEG 4 compression board. The board combines the four images into 720 X 480 pixel video for storage on the vehicle DAS hard drive. Figure 6 shows a sample of the four video views with the video frame number displayed in the top-left quadrant. For the purposes of the CICAS-V FOT, the compression rate has been set to approximately 6 Megabytes per minute.

Figure 6 - Sample video frame.

2.2.3 Front and Rear Radar

The front and rear radar units used in the vehicle DAS were produced by Smart Microwave Sensors GmbH (SMS). These units are Adaptive Cruise Control (ACC) radar units that have been redesigned by SMS to track objects surrounding the vehicle. Figure 7 displays the prototype radar unit. The radar is small enough to fit beneath the bumper fascias; thus producing a production-like fit and finish when installed. The physical dimensions of the radar are 105 mm wide x 94 mm high x 24 mm deep.

The modified SMS ACC radar provides a range of 200 m for the front-facing radar and 150 m for the rear-facing unit. The beam angle is +/- 8 degrees (far field) and +/- 20 degrees (near field) with an elevation angle of +/- 3 degrees. Both the front and rear radar units are capable of tracking up to 32 vehicles; however, for the purpose of reducing data storage, only the closest eight objects are recorded.

Figure 7 - SMS radar housing.

The radar operates in the 24 GHz frequency band and has been approved for use in the United States (compliant to FCC 15.245). The units utilize a Frequency Modulated Continuous-wave (FMCW) narrowband wave pattern with a maximum power output of less than 20 dBm. As other OEM ACC radar units may be installed on the test vehicles, it has been verified that the SMS radar units do not interfere with the factory radar.

2.2.4 Global Positioning System

The vehicle DAS system utilizes a low cost GPS, which is routed to the DAS using a custom developed GPS to CAN interface. The GPS is primarily used to set the system time and track the vehicle. The GPS can also be used as a backup speed sensor in cases where the network speed is unavailable. The antenna is placed on the rear package shelf, below the rear windshield (see Figure 8).

Figure 8 - Low cost GPS antenna.

2.3 Vehicle DAS Software

The vehicle DAS runs on a Linux operating system. The collection software is fully modular to allow new data modules to be included by creating software components to parse the CAN messages on any of three input ports.

The vehicle DAS collects data automatically with the ignition signal. The DAS continuously monitors the battery voltage and ignition signal and is able to begin and end data acquisition based on the vehicle's ignition status. If the battery voltage drops below a set threshold, the system turns off automatically and will not restart until the battery is charged to a suitable level.

A real-time engineering display monitors the current status of the data collection software and variables. This display interface is used as a device to validate the system operation following DAS installation in an FOT test vehicle. However, the display is not required for normal DAS operations when the vehicle is driven by a test participant during the FOT.

All variables that are written to the binary data file are available for viewing and are displayed in a text-based interface shown in Figure 9.

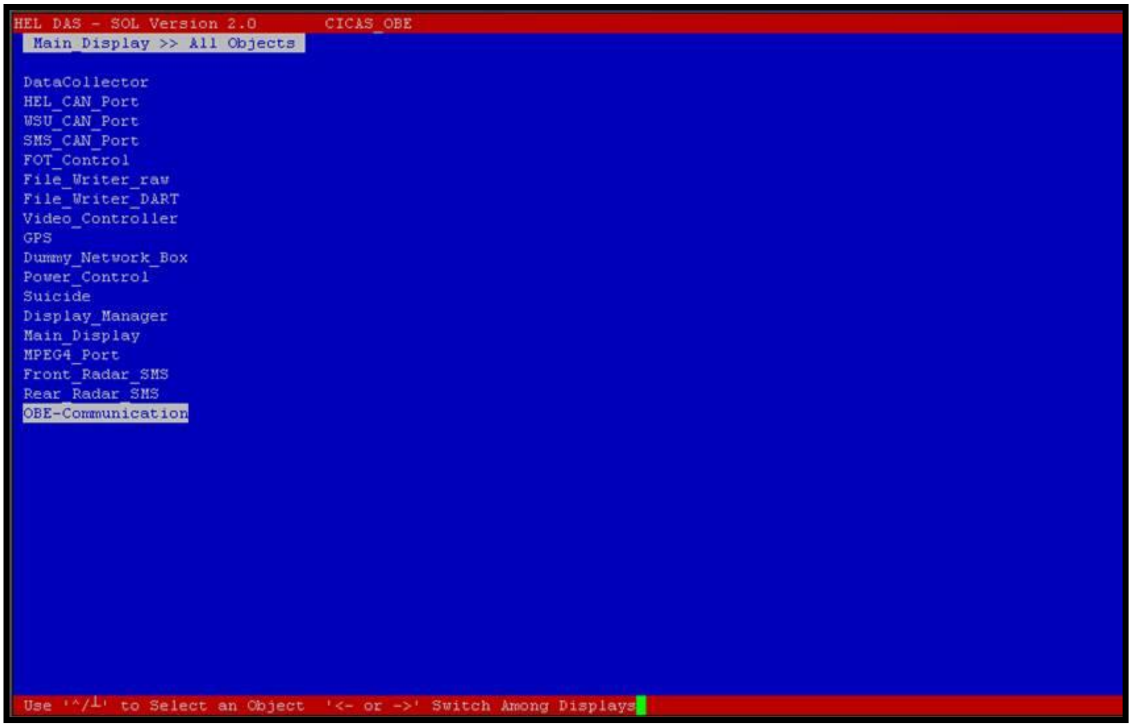

Figure 9 - Vehicle DAS engineering display.

2.4 Data Storage and Retrieval

During the FOT, data will be downloaded on regular intervals. To facilitate this, the data are stored on a removable hard drive within the main unit. A separate partition is available on the hard drive that contains all of the data and video files. A drive cradle and Linux drive reading tools are required to download the data.

An alternate method to access the data is to use an Ethernet crossover cable and a laptop computer. The laptop can then remotely log in to the vehicle DAS system to access data folders. This allows quick transfer of data without shutting down the system.

3 Infrastructure DAS for Signalized Intersections

The infrastructure DAS is based on the high-performance, adaptable data collection system originally developed by VTTI for the 100-Car Study (Dingus et al., 2006) and refined through dozens of research projects over the last three years including Subtask 3.2 of the Phase I CICAS-V project (Doerzaph et. al, in review).

3.1 Infrastructure DAS Variable List

The infrastructure DAS variable list is included in Appendix C. The infrastructure DAS collects data from roadside sensors and the RSE communications interface. The infrastructure DAS records all sensors at a 10 Hz rate.

The infrastructure DAS is used to log vehicle data for all approaches to the signalized intersection. These data are supplied by four radar units mounted on the intersection mast-arms. The radar units supply the range, speed, and acceleration of approaching vehicles in XY coordinates.

The infrastructure DAS data can be synchronized with the vehicle DAS through the SPaT, GID, and GPS Corrections (GPSC) message counters. With synchronized data sets, researchers will be able merge the two separate datasets to determine how a violation or warning impacted other vehicles at the intersection. The infrastructure DAS is comprised of hardware components, software, and data storage. Each of these components is discussed in the following sections.

3.2 Infrastructure DAS Hardware Components

Figure 10 shows how the infrastructure DAS integrates with the RSE. The infrastructure DAS receives data from the RSE on a dedicated CAN port. The RSE updates the infrastructure DAS whenever a DSRC wireless message is sent out. The messages included on the CAN link are the GID, SPaT, and GPSC time and message counter information.

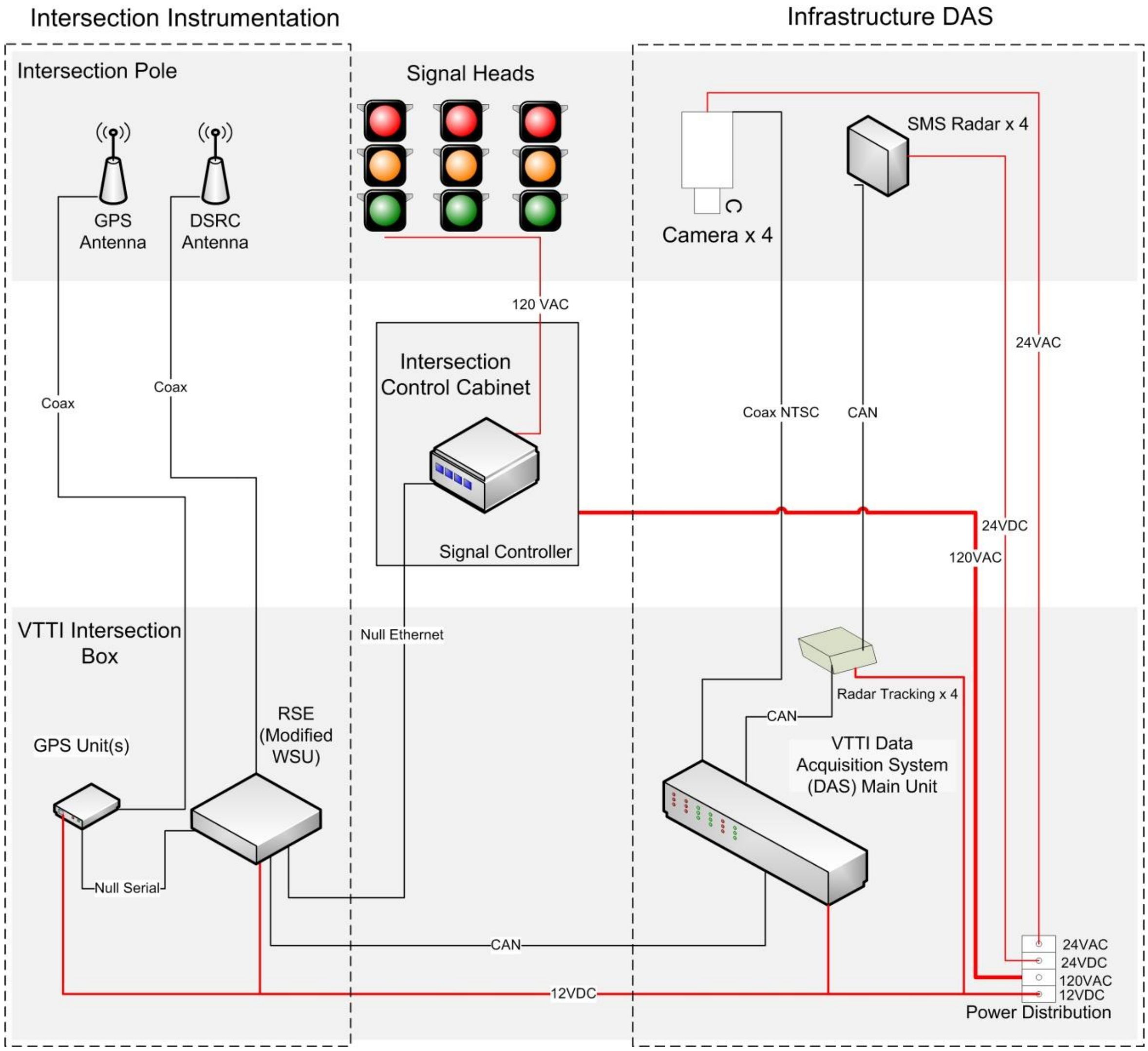

Figure 10 - Infrastructure DAS system schematic.

3.2.1 Main Unit

The main unit of the roadside DAS is shown in Figure 11. Similar to the main unit of the vehicle DAS, the main unit of the infrastructure DAS contains an EPIC single-board computer, hard drive cradle, CAN communication, battery backup system, and several VTTI-developed sensor modules. The unit is placed inside the intersection cabinet or an auxiliary cabinet located within communication range of the controller cabinet.

Figure 11 - DAS main unit.

3.2.2 Video System

The infrastructure DAS uses color day/night closed-circuit television (CCTV) cameras from Toshiba. An image of the camera without the housing is shown in Figure 12 (top). The Toshiba camera has a 1/3" CCD and is capable of resolving video down to 0.003 lux in black and white mode and 0.1 lux in color mode. The camera automatically switches from color to black and white depending on the ambient lighting conditions. The camera is located inside weatherproof housing and mounted directly above the radar unit at each approach (Figure 12, bottom).

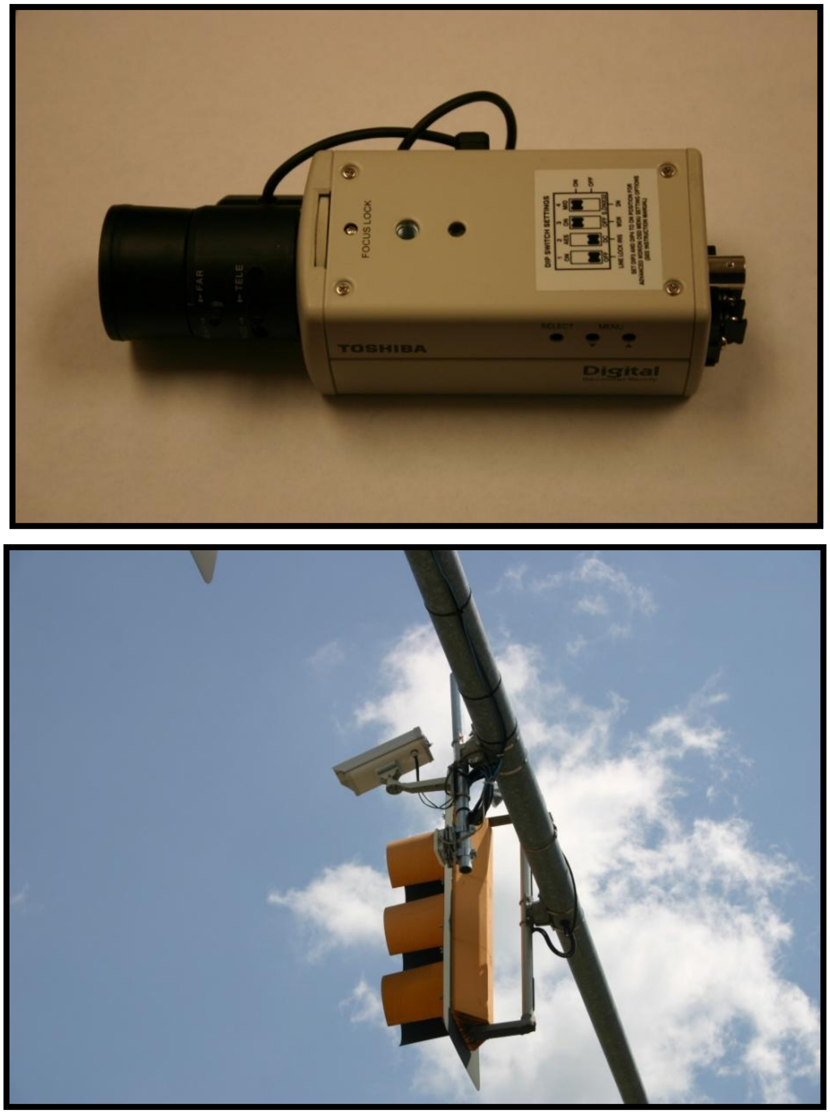

Figure 12 - The infrastructure video camera (top) and camera housing mount (bottom).

The video camera images for each approach are supplied directly into a hardware MPEG 4 compression board. The board combines the four images into a 720 x 480 pixel video for storage on the DAS hard drive. Figure 13 displays a sample frame of the video. Each quadrant in the image displays the video for one approach to the intersection. Similar to the vehicle DAS camera images, a video frame number is overlaid on the video for alignment with the parametric data. The video is used to validate the radar data for the individual approaches. The compression rate is approximately 6 Megabytes per minute.

Figure 13 - Infrastructure DAS sample frame capture.

3.2.3 Infrastructure Radar

The radar used in the infrastructure DAS was custom designed for the intersection application and calibrated to the specific sites at which they were installed. The radar units and tracking algorithms were jointly developed by VTTI and SMS. The tracking algorithms are adjusted to provide maximum functionality as vehicles approach the intersection. The radar mounting assembly is shown in Figure 14.

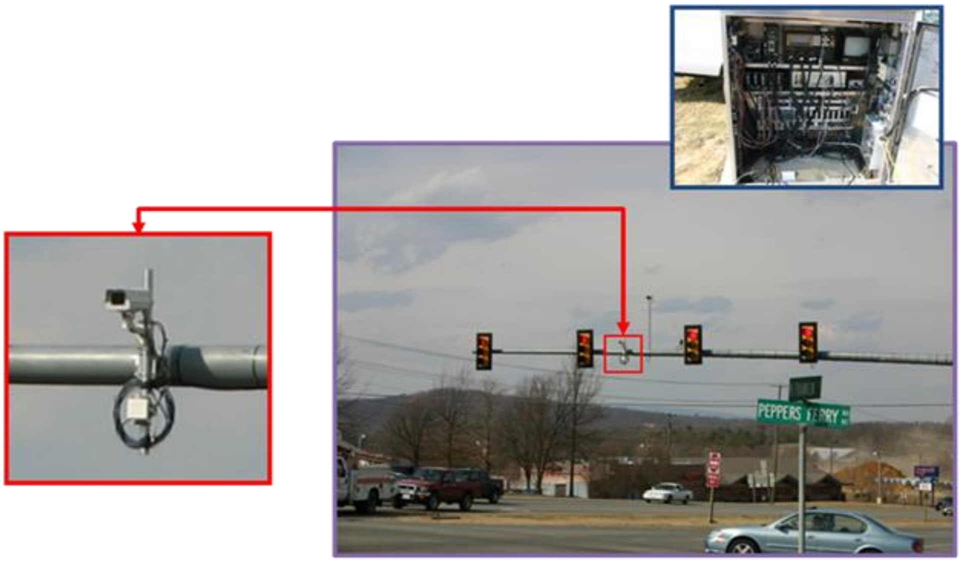

Figure 14 - Radar mounting assembly.

The radar systems operate in the 24GHz band with a transmit power of less than 20dBm. The radar complies with FCC 15.245 for use in the United States. Each unit has an advertised range of 0.5 m to 200+ m with an error of 0.5 m ±1% or better. Approach speed has a valid range of 0 – 100 m/s and an error less than 1%. A detailed field-based accuracy analysis of the installed radar is available in the Subtask 3.2 report (Doerzaph, et al, in review). A single radar unit is mounted on each of the four mast arms below the camera and aimed directly at the approaching traffic.

Each of the four sensors returns raw radar data over a CAN interface to the digital signal processor (DSP) located in the intersection control cabinet. A separate DSP performs the tracking computations for each of the four radar units. The tracking DSPs then provide the position, velocity, acceleration, length, and proprietary credibility statistics for up to 32 objects and 16 tracks of vehicles simultaneously (a maximum of 192 vehicles approaching the intersection at a given instant in time).

3.3 Infrastructure DAS Software

The infrastructure DAS collects data continuously. The infrastructure DAS software records when power is applied to the main unit at a 10 Hz data rate. The infrastructure DAS creates a new data and video file pair every 30 minutes. These smaller time windows are required due to the large amount of data being collected. One hour of data creates a compressed binary data file of 300 Megabytes.

3.4 Data Storage and Retrieval

Data are stored on removable hard drives at the installation sites. The average daily storage requirements for the raw data are approximately 20 GB. To retrieve the data, a trained technician shuts down the system and removes the data drive. The data drive is then replaced with an empty drive and the system is restarted. The technician validates the system operation and closes the cabinets.

4 Conclusion

The DASs developed during Task 12 utilize a suite of hardware sensors connected to a central processing unit through a distributed network. Each DAS monitors and records sensor outputs including the data streams provided by the OBE and RSE. These data are stored on the DASs until retrieval by the research staff.

The vehicle DAS permits researchers to reconstruct the intersection approaches of CICAS-V-equipped vehicles. In combination with the infrastructure DAS, researchers may also reconstruct the vehicles' interactions with adjacent traffic. If a FOT is performed in the future, the DASs will provide the data necessary to evaluate the CICAS-V application.

5 References

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6 Appendices

Appendix A: Vehicle DAS Variable List

Name	Operational Definition	Units
Header		
FileID	Unique numerical file ID	n/a
VehicleID	Unique numerical vehicle ID	n/a
SubjectID	Unique numerical subject ID	n/a
System		
Frame Number	Integer incrementing with each sample frame	n/a
Frame Overlay	Video frame number at the current data frame number (titled on video)	n/a
Global Positioning System (VTTI DAS Controlled)		
Week	Week number provided by GPS	week
Time of Week	Time from beginning of week as provided by GPS	ms
Latitude	Current latitude	decdeg
Longitude	Current longitude	decdeg
Altitude	Current altitude	m
GPS Speed	Speed as provided by GPS	m/s
Heading	Heading as provided by GPS	deg
GPSStatus	Position type (e.g. differential active)	n/a
Accelerometer (VTTI DAS Controlled)		
Raw X Acceleration	Longitudinal acceleration	g
Raw Y Acceleration	Lateral acceleration	g
Raw Gyro	Yaw rate	deg/sec
Forward Radar (repeated for each track up to 8 tracks)		
FrontRangeX(Track)	Longitudinal range to leading vehicles	m
FrontRangeY(Track)	Lateral range to leading vehicles	m
FrontSpeedX(Track)	Longitudinal speed of lead vehicle	m/s
FrontSpeedY(Track)	Lateral speed of lead vehicle	m/s
Rear Radar (repeated for each track up to 8 tracks)		
RearRangeX(Track)	Longitudinal range to following vehicles	m
RearRangeY(Track)	Lateral range to following vehicles	m
RearSpeedX(Track)	Longitudinal speed of following vehicle	m/s
RearSpeedY(Track)	Lateral speed of following vehicle	m/s
OBE Private CAN		
OBE status	A status message from OBE, may indicate which variables are valid	n/a
OBE High Accuracy GPS Position		
Status	Positioning quality: 0= No Position, 5= RTK positioning, 9=WAAS	n/a
Week		week
Time of Week		ms

Name	Operational Definition	Units
Latitude		decdeg
Longitude		decdeg
Altitude		m
GPS Speed		m/s
Heading		Deg
Map Matching		
Distance To Stopbar		cm
TTI		s
Present intersection ID		n/a
Present approach ID		n/a
Present lane ID		n/a
Signal Phase	Current Approach phase: 1=green, 2=yellow, 4=red	n/a
AmberTime Remaining		ms
Algorithm Output		
Warning Status	OBE warning status: 0=disabled, 1=no warning, 2=warning	n/a
Network Variables		
Odometer	Network reported odometer reading	m
Turn Signal Status		n/a
Brake Pedal Position		%
Throttle Position		%
Vehicle Speed		m/s
Ambient Temperature		
ACC		
Status		n/a
Set speed		
Brake torque		
Panic brake status		n/a
Pre-Charge Status		n/a
ABS Status		n/a
Stability Control Status		n/a
Horn		n/a
Seatbelt Engaged		n/a
Wiper Status		n/a
Accelerometer		
Longitudinal	Network reported longitudinal acceleration	g
Lateral	Network reported lateral acceleration	g
Gyro	Network reported yaw rate	
Misc		
Incident button status	0=inactive, 1=active	n/a
Video		
Forward	MPEG4 video stream (overlay Frame Number)	n/a
Rear	MPEG4 video stream	n/a
Face	MPEG4 video stream	n/a
Over Shoulder	MPEG4 video stream	n/a

Appendix B: System Development and Diagnostic Variables

Name	Operational Definition	Units
OBE Private CAN		
Hardware Watchdog Reset Counter		n/a
Active Masks1	Bit vector of network variables available for a given vehicle platform (not all variables are available on all vehicles)	n/a
Active Masks2	Bit vector of CAN network availability	n/a
OBE High Accuracy GPS Position		
OBE Errors		n/a
DAS Errors		n/a
Message not Received		n/a
Number of Satellites		n/a
SPAT Message Time		ms
SPAT Counter Type		cycles
GPSC Message Time		ms
GPSC Counter Type		cycles
GID Message Time		ms
GID Counter Type		cycles
OBE to DAS Heartbeat		n/a
GID Map Version		n/a
RSE PGS TOW		ms
Local GPS TOW		ms
GST Error Ellipse		m
Position Dilution of Precision		n/a
Horizontal Dilution of Precision		n/a
Local GPS Differential Age		s
Local GPS Solution Age		s
Local GPS Week Number		n/a
Local GPS Quality/Mode		n/a
Map Matching		
Intersection Type		n/a
Number of Approaches		n/a
Approach Likelihood		%
Vehicle Lane Position		n/a
Intersection Crossings		n/a
Road/Lane Level		n/a
Vehicle Off GID	Vehicle Off GID: 0=On GID, 1=Off GID	n/a
Signal Phase		
Left Turn Phase	Left Turn phase: 1=green, 2=yellow, 4=red	n/a
Right Turn Phase	Right Turn phase: 1=green, 2=yellow, 4=red	n/a
Pedestrian Phase	Pedestrian phase: 1=green, 2=yellow, 4=red	n/a
Time to next Phase		ms

Time to Left Phase		ms
Time to Right Phase		ms
Time to Pedestrian Phase		ms
Time from Pedestrian Phase		s
Network Variables		
Cruise Control		
Cruise Engaged		n/a
Cruise Override		n/a
Cruise Set Speed		km/h
Brakes Active		n/a
Intended Brake Switch		n/a
Driver Intended Brake Level		n/a
Vehicle Width		cm
Vehicle Length		cm
Wheel Velocity Left Front		rpm
Wheel Velocity Right Front		rpm
Wheel Velocity Left Rear		rpm
Wheel Velocity Right Rear		rpm
Tire Pressure Left Front		psi
Tire Pressure Right Front		psi
Tire Pressure Left Rear		psi
Tire Pressure Right Rear		psi
Headlight Status		n/a
Steering Wheel Angle		degrees
Gear Selected		n/a
Battery Voltage		volts
Accelerator Pedal Position		n/a
Accelerometer		
Vertical		g

Appendix C: Infrastructure DAS Variable List

Name	Operational Definition	Units
Header		
FileID	Unique numerical file ID	n/a
IntersectionID	Unique numeric intersection ID	n/a
System		
Frame Number	Integer incrementing with each sample frame	n/a
Frame Overlay	Video frame number at the current data frame number (titled on video)	n/a
Global Positioning System (VTTI DAS Controlled)		
Week	Week number provided by GPS	week
Time of Week	Time from beginning of week as provided by GPS	ms
GPSStatus	Position type (e.g. differential active)	n/a
Approach 1 Radar (repeated for each track up to N number of tracks max N of 32)		
Object ID(Track)	Unique ID for the track	ID
Range X(Track)	Longitudinal range to objects	m
Range Y(Track)	Lateral range to objects	m
Speed X(Track)	Longitudinal speed of object	m/s
Speed Y(Track)	Lateral speed of object	m/s
Acceleration X(Track)	Longitudinal acceleration of object	m/s^2
Acceleration Y(Track)	Lateral acceleration of object	m/s^2
Approach 2 Radar (repeated for each track up to N number of tracks max N of 32)		
Object ID(Track)	Unique ID for the track	ID
Range X(Track)	Longitudinal range to objects	m
Range Y(Track)	Lateral range to objects	m
Speed X(Track)	Longitudinal speed of object	m/s
Speed Y(Track)	Lateral speed of object	m/s
Acceleration X(Track)	Longitudinal acceleration of object	m/s^2
Acceleration Y(Track)	Lateral acceleration of object	m/s^2
Approach 3 Radar (repeated for each track up to N number of tracks max N of 32)		
Object ID(Track)	Unique ID for the track	ID
Range X(Track)	Longitudinal range to objects	m
Range Y(Track)	Lateral range to objects	m
Speed X(Track)	Longitudinal speed of object	m/s
Speed Y(Track)	Lateral speed of object	m/s
Acceleration X(Track)	Longitudinal acceleration of object	m/s^2
Acceleration Y(Track)	Lateral acceleration of object	m/s^2
Approach 4 Radar (repeated for each track up to N number of tracks max N of 32)		
Object ID(Track)	Unique ID for the track	ID
Range X(Track)	Longitudinal range to objects	m
Range Y(Track)	Lateral range to objects	m

Name	Operational Definition	Units
Speed X(Track)	Longitudinal speed of object	m/s
Speed Y(Track)	Lateral speed of object	m/s
Acceleration X(Track)	Longitudinal acceleration of object	m/s^2
Acceleration Y(Track)	Lateral acceleration of object	m/s^2
RSE Private CAN		
Signal Phase (1-8)	Signal Phase: 0=Unknown, 1=Green, 2=Yellow, 3=Red	n/a
SPAT Message Time		ms
SPAT Counter		cycles
GPSC Message Time		ms
GPSC Counter		cycles
GID Message Time		ms
GID Counter		cycles
Video		
Approach 1	MPEG4 video stream (overlay Frame Number)	n/a
Approach 2	MPEG4 video stream	n/a
Approach 3	MPEG4 video stream	n/a
Approach 4	MPEG4 video stream	n/a

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