RITA Intelligent Transportation Systems
Joint Program Office

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

Task 3 Final Report
Human Factors Research

(Appendix A)

October 28, 2008

U.S. Department of Transportation
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16. Abstract

The Cooperative Intersection Collision Avoidance Systems for Violation (CICAS-V) project aims to develop and test a system to reduce the number of crashes at intersections due to violations of stop light and stop sign traffic control devices. The CICAS-V presents a timely and salient in-vehicle warning to those drivers who are predicted to violate a stop light or a stop sign. The warning is designed to elicit behavior from drivers by motivating them to respond appropriately to avoid a violation and a potential intersection crash if cross traffic is present.

Task 3 of the CICAS-V project includes four subtasks directed at the design, development, and evaluation of the driver-vehicle interface (DVI) and warning algorithm:

- 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).
- Subtask 3.2: Naturalistic Infrastructure-Based Driving Data Collection and Intersection Collision Avoidance Algorithm Development (Doerzaph et al., in print).
- Subtask 3.3: Test of Alternative Driver-Vehicle Interfaces (DVI) on the Smart Road (Perez et al., in print).
- Subtask 3.4: Human Factors Pilot Test of the CICAS-V (Neale et al., in print).

A brief description of each Subtask is presented. This description includes a discussion of the method, results, and implications for the design of the CICAS-V warning system. A detailed discussion of each subtask is found in individual subtask reports.

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Acronyms

CAMP: Crash Avoidance Metrics Partnership

CAN: Controller area network

CICAS: Cooperative Intersection Collision Avoidance System

CICAS-V: Cooperative Intersection Collision Avoidance System for Violation

DVI: Driver vehicle interface

DAS: Data acquisition system

FOT: Field operation test

GID: Geometric intersection description

GPS: Global positioning system

HF: Human factors

OBE: On-board experimenter

OEM: Original equipment manufacturer

PBA: Panic brake assist

RSE: Roadside equipment

SPaT: Signal phase and timing

TTI: Time to intersection

VDOT: Virginia Department of Transportation

VTTI: Virginia Tech Transportation Institute

WSU: Wireless safety unit

Metric Conversions

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1 Introduction

The Cooperative Intersection Collision Avoidance Systems for Violation (CICAS-V) project aims to develop and test a system to reduce the number of crashes at intersections due to violations of stop light and stop sign traffic control devices. These crashes account for thousands of injuries and fatalities in the United States every year (National Highway Traffic Safety Administration, 2006). Drivers running stop-controlled and red-phased signalized intersections cost over $7.9 billion in economic loss each year (Najm et. al., 2007). To reduce the frequency of these crash types, the CICAS-V presents a timely and salient in-vehicle warning to those drivers who are predicted to violate a stop light or a stop sign. The warning is intended to elicit behavior from drivers by motivating them to respond appropriately to avoid a violation and a potential intersection crash if cross traffic is present.

The CICAS-V project consists of fourteen tasks involving the complete design, development, and testing of the CICAS-V. Task 3 includes four subtasks directed at the design, development, and evaluation of the driver-vehicle interface (DVI) and warning algorithm. It also encompasses the evaluation of the data acquisition systems (DASs) to be used for a field operational test (FOT). These subtasks and the primary objective of each are as follows:

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).

> *Objective*: Classify driver behaviors and driving conditions associated with stop-controlled and signalized intersection violations, and identify how observed driver behaviors and driving conditions could support the development of a CICAS-V.

Subtask 3.2: Naturalistic Infrastructure-Based Driving Data Collection and Intersection Collision Avoidance Algorithm Development (Doerzaph et al., in print).

> *Objective*: Develop and evaluate warning assessment algorithms for the CICAS-V prototype.

Subtask 3.3: Test of Alternative Driver-Vehicle Interfaces (DVI) on the Smart Road (Perez et al., in print).

> *Objective*: Determine the physical DVI that would be integrated into the CICAS-V FOT prototype.

Subtask 3.4: Human Factors Pilot Test of the CICAS-V (Neale et al., in print).

> *Objective*: Perform a pilot test of the CICAS-V to: a) refine the CICAS-V warning algorithm; b) to ensure equipment readiness for a full-scale FOT; c) evaluate the DVI in an on-road study; and d) make recommendations for refinement of the CICAS-V in preparation for a final FOT release.

Each of these four subtasks was designed to provide supporting data for recommendations to develop the CICAS-V. The first three tasks overlapped in sequence to enable recommendations to be made across subtasks, as well as to influence other relevant tasks. Subtask 3.4 was subsequently conducted with input from the first three subtasks.

For each of the four subtasks, a brief description of the method, results, and implications for the design of the CICAS-V warning system are presented. The reader is referred to the individual Subtask reports for more detailed information.

2 Subtask 3.1: Mining of the 100-Car Naturalistic Driving Database

2.1 Subtask 3.1 was conducted: 1) to classify driver behaviors and driving conditions associated with stop-controlled and signalized violations; and 2) 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).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.

2.2 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.

2.2.1 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.

2.2.1.1 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.

2.2.1.2 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 (i.e., through the same intersections) on their daily commute and the intersection familiarity leads to more aggressive approach behavior and an increased number of violations.

2.2.1.3 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 (e.g., 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, and 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.

2.2.1.4 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.

2.2.2 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.

2.2.2.1 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.

2.2.2.2 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 introduce 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.

2.2.2.3 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.

2.2.2.4 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.

2.2.3 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 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.

2.4 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.

3 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).

3.1 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 1). An approaching vehicle first enters the monitored region of the intersection at time T_o. 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.

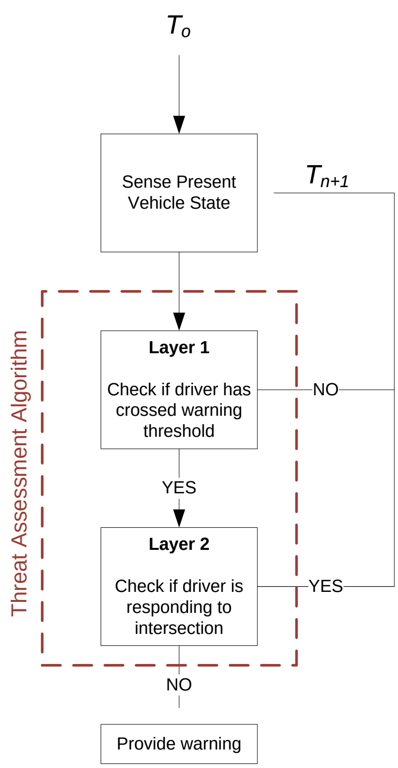

Figure 1 Top-level algorithm architecture.

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.

3.2 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 though 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.

3.3 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.

4 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).

4.1 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 1.

Table 1 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 was therefore 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: 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); and 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, a 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.

4.2 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 2 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 2 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.
6	**Speech with Brake Pulse**	**2.44**	**Naturalistic distraction**	**17 (94%)**	**1 (6%)**	N.A.
7	Beep Tone with Brake Pulse and PBA	2.24	Naturalistic distraction	5 (50%)	5 (50%)	0
8	**Speech with Brake Pulse and PBA**	**2.24**	**Naturalistic distraction**	**16 (89%)**	**2 (11%)**	**1**
9	**Speech with Brake Pulse and PBA**	**2.04**	**Naturalistic distraction**	**7 (78%)**	**2 (22%)**	**0**
10	**Speech with Brake Pulse and PBA**	**1.84**	**Naturalistic distraction**	**3 (33%)**	**6 (67%)**	**1**
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 2. 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.

4.3 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.

4.4 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.

5 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).

5.1 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.

5.1.1 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.

5.1.2 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: 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 "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”, presented at 72.6 dBA via the front speakers, measured at the location of the driver’s head. The visual warning (Figure 2) 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 2 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).

5.1.3 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 3.

Table 3 Summary of turn maneuvers for Pseudo-Naturalistic Study experimental method.

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

5.1.4 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, distracting 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.

5.2 Subtask 3.4 Results

5.2.1 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 4). Of those drivers, 14 received a total of 50 CICAS-V warnings over the course of their drives.

Table 4 Distribution of drivers by age and gender who experienced Stop-Controlled Algorithm 1.*

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

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

A review of the warnings indicated that all of the drivers who experienced alerts with Stop-Controlled Algorithm 1 received them at 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, 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.

5.2.2 Stop-Controlled Algorithm 2 Results

A total of 72 drivers completed the Pseudo-Naturalistic Study protocol equipped with Stop-Controlled Algorithm 2 (Table 5). 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 5 Distribution of drivers by age and gender who experienced Stop-Controlled Algorithm 2.*

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

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

5.2.3 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 6.

Table 6 Distribution of drivers by age and gender who experienced Signalized-Warning Algorithm during the Pseudo-Naturalistic Study.*

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

5.2.4 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 7.

Table 7 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
Total	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 8.

Table 8 Comparing demographics of compliant drivers for Subtask 3.2 SRS and Subtask 3.3 Study 6.

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

Subtask 3.3 Study 6	Male	Female	Total
Young	3	3	6
Middle	3	2	5
Old	3	3	6
Total	9	8	17

The alert timing and driver braking behavior data obtained in the two studies is compared in Table 9. 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 9 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.

5.2.5 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.

5.2.6 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 average, 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.

5.3 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 imp

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 that 1) the visual display was not designed into the original instrument panel configuration and was added later; 2) drivers had little time with the vehicle (two to three hours) to become accustomed to the display; 3) the speech and brake pulse modalities are very effective; and 4) for the purposes of conducting an FOT, the visual display can be viewed as a secondary indicator to the speech and brake pulse warning modes and could be modified to improve conspicuity.

5.4 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, reflecting four software upgrades and several incorporated system refinements. Therefore, it is recommended that a small study be conducted prior to an FOT to test the upgraded software.

Also, this study was conducted in the small metropolitan region of Blacksburg, Virginia. In this area, the GPS coverage was adequate for testing the system, the state 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.

6 References

Dingus, T.A., Klauer, S.G., Neale, V.L., Petersen, A., Lee, S.E., Sudweeks, J., Perez, M.A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z.R., Jermeland, J., & Knipling, R.R. (2006). *The 100-car naturalistic driving study, phase II – Results of the 100-car field experiment.* (Contract No. DTNH22-00-C-07007). Washington, DC: National Highway Traffic Safety Administration.

Doerzaph, Z.R., Neale, V.L., Bowman, J.R., Viita, D.C., & 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* (Cooperative Agreement No. DTFH61-01-X-00014). Washington, DC: National Highway Traffic Safety Administration.

Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., & Shulman, M. (1999). *Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems* (Report No. DOT HS 808 964). Washington, D.C.: National Highway Traffic Safety Administration.

Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J., & Ramsey, D.J. (2006). *The impact of driver inattention on near crash/crash risk: An analysis using the 100-Car naturalistic driving study data* (Contract No. DTNH22-00-C-07007, Task order 23). Washington, DC: National Highway Traffic Safety Administration.

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 11 Final Report: Objective Tests*. Washington, DC: National Highway Traffic Safety Administration.

Najm, W.G., Smith, J.D., & Yanagisawa, M. (2007). Pre-Crash Scenario Typology for Crash Avoidance Research (Report No. DOT HS 810 767). Washington, D.C.: National Highway Traffic Safety Administration.

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.

National Highway Transportation Safety Administration. (2006). *Traffic Safety Facts – 2004* (Report No. DOT HS 809 919). Washington, D.C.: National Highway Traffic Safety Administration.

Perez, M. A., Neale, V. L., Viita, D., Wiegand, K., & 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.* (Cooperative Agreement No. DTFH61-01-X-00014). Washington, DC: National Highway Traffic Safety Administration.

Stone, S.R., Neale, V.L., Wiegand, K., Doerzaph, Z.R., & Maile. M. (In Print). *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*. (Cooperative Agreement No. DTFH61-01-X-00014). Washington, DC: National Highway Traffic Safety Administration.

Sudweeks, J., Neale, V. L., Wiegand, K., Bowman, J., Perez, M., & Maile, M. (In Print). *Cooperative Intersection Collision Avoidance System 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.* (Cooperative Agreement No. DTFH61-01-X-00014). Washington, DC: National Highway Traffic Safety Administration.

Swets, J.A. (1996). *Signal detection theory and ROC analysis in psychology and diagnostics: Collected papers*. Mahwah, NJ: Erlbaum.

Zimmerman, K. and Bonneson, JA. (2005). *Investigation of the time-into-red for red-light-related crashes.* 84th Annual Meeting of the Transportation Research Board (CD-ROM), Washington, D.C.

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