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First Annual Report

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16. Abstract

The IVBSS program is a four-year, two phase cooperative research program being conducted by an industry team led by the University of Michigan Transportation Research Institute (UMTRI). The program began in November 2005 and will continue through December 2009 if results from vehicle verification tests conducted in the second year of the program indicate that the prototype system meets its performance guidelines and is safe for use by lay drivers in a field operational test planned for July 2008. The decision to execute Phase II of the program will take place in December 2007. The goal of the IVBSS program is to assess the safety benefits and driver acceptance associated with a prototype integrated crash warning system designed to address rear-end, road departure and lane change/merge crashes on light vehicles and heavy commercial trucks. This report describes accomplishments and progress made during the first year of the program (November 2005-December 2006). Activities during the first year focused on system specification, design and development and construction of the prototype vehicles.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

AASHTO	American Assoc. of State Highway and Transportation Officials
ACAS	Automotive Collision Avoidance System
AMR	Available Maneuvering Room
BSD	Blind Spot Detection
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CCD	Charge-Coupled Device
CDP	Concept Development Process
CFR	Code of Federal Regulations
CMOS	Complementary Metal-Oxide Semiconductor
CO	Contracting Officer
Co-PI	Co-Principal Investigator
COTR	Contracting Officer's Technical Representative
cRIO	Compact Reconfigurable I/O
CSW	Curve Speed Warning
CVO	Commercial Vehicle Operator
DAS	Data Acquisition System
DFR	Draft Final Report
DIU	Driver Interface Unit
DOORS	Dynamic Requirements Management program
DRDA	Division of Research Development and Administration
DVI	Driver-Vehicle Interface
FAD	Light-vehicle module for FCW, Arbitration, and DVI
FCW	Forward Crash Warning
FOT	Field Operational Test
FOV	Field of View
HIL	Hardware-in-the-Loop
HT	Heavy Truck
ICD	Interface Control Document
IMU	Inertial Measurement Unit
IMS	Independent Measuring System
IRB	Institutional Review Board
ISO	International Organization for Standardization
IVBSS	Integrated Vehicle-Based Safety Systems
LAM	Look Ahead Module

LCM	Lane-Change/Merge Warning
LDW	Lateral Drift Warning
LFAD	Light-vehicle module for LCM, FCW, Arbitration, and DVI
LV	Light vehicle
LVO	Light-vehicle operator
MDOT	Michigan Department of Transportation
MFVB	Multi-Function Vision Board
MLP	Most Likely Path
MUTCD	Manual of Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
NI	National Instruments
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
OPM	Operational Procedure Model
PDT	Product Development Team
PI	Principal Investigator
PXI	PCI eXtensions for Instrumentation
RDCW	Road Departure Crash Warning
RFA	Request for Application
SAM	Situational Awareness Module
SAVE-IT	SAfety VEhicles using Adaptive Interface Technology
SWF	Scalable Weighting Factor
TBD	To Be Determined
TTC	Time-To-Collision
TTLC	Time-To-Lane Crossing
TTE	Time-To-Event
TTW	Time-To-Warning
U.S. DOT	United States Department of Transportation
UM	University of Michigan
UMTRI	University of Michigan Transportation Research Institute
VOC	Voice of the Customer
VORAD	Vehicle Onboard RADar
VSA	Vehicle Stability Assist

1 Executive Summary

1.1 Introduction and Background

In November 2005, the U.S. Department of Transportation entered into a cooperative research agreement with an industry team led by the University of Michigan Transportation Research Institute to develop and test an integrated, vehicle-based, crash warning system that addresses rear-end, lane-change and roadway departure crashes for light vehicles and heavy commercial trucks. The program being carried out under this agreement is known as the Integrated Vehicle-Based Safety System program.

The goal of the IVBSS program is to assess the safety benefits and driver acceptance associated with prototype integrated crash warning systems. Preliminary analyses conducted by the U.S. DOT indicate that a significant number of crashes can be reduced by the widespread deployment of integrated crash warning systems that address rear-end, lateral drift, and lane change/merge crashes. [26 27 28] Such integrated warning systems have the potential to provide comprehensive, coordinated information, from which the individual crash warning subsystems can determine the existence of a threat and thus, provide the appropriate warning to drivers.

The IVBSS program is a four-year effort divided into two consecutive, non-overlapping phases of 24 months each. The UMTRI-led team is responsible for the design, build, and field-testing of the prototype integrated crash warning systems. This report summarizes work performed during the first year of the IVBSS program, and discusses contributions by UMTRI and its team members, emphasizing the design and development of the integrated system.

1.1.1 Crash Problem

Three crash warning subsystems are being integrated into each platform of the IVBSS program: forward crash warning, road departure warning, and lane-change/merge crash warning.

- Forward crash warning provides warnings to drivers to assist them in avoiding or mitigating rear-end crashes with other vehicles.
- Lateral drift warning consists of a system that warns drivers that they may be drifting inadvertently from their lane or departing the roadway. The light-vehicle platform also includes a curve speed warning subsystem.
- Curve-speed warning warns drivers that they may be driving too quickly into an upcoming curve and as a result might lose control and depart the roadway.
- Lane-change/merge warning warns drivers of possible unsafe maneuvers based on adjacent or approaching vehicles in adjacent lanes, and includes full-time side-object-presence indicators.

The three target crash areas addressed by the IVBSS program represent approximately 6,318,000 police-reported crashes that took place in the United States in 2003.[18] Of these crashes, 96 percent (6,060,000) involved at least one light vehicle, while heavy commercial trucks were involved in about 362,000 of these crashes. Collectively, rear-end, road departure, and lane-change crashes accounted for about 60 percent of all police-reported light-vehicle and heavy commercial-truck crashes, and approximately 50 percent of all crash-related fatalities. Figure 1 illustrates the crash problem for the three major crash types addressed in the IVBSS program for both light vehicles and heavy commercial trucks.

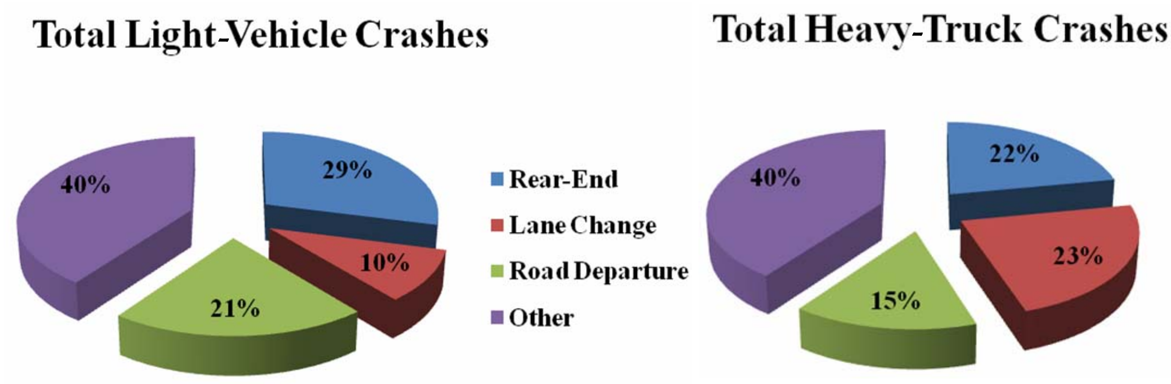


Figure 1. Breakdown of crash types in the United States (2003)

All the crash warning subsystems examined in the IVBSS program have undergone some level of previous development and evaluation. Major programs supported by the U.S. DOT, for example, have addressed forward crash warning, [3 4 14 15] road-departure crash warning, [16 17 20] and lane-change/merge systems. [21] These systems are also the most mature from a commercial and research evaluation standpoint. What differentiates the IVBSS program from previous efforts is that these subsystem are being evaluated as part of an integrated crash warning system, rather than independently. In order to realize the maximum potential benefits, the level of integration being undertaken in the IVBSS program is greater than that undertaken in any prior program of its kind.

The scope of systems integration on the IVBSS program includes the integration of sensor data across subsystems (data sharing), the arbitration of warnings based upon threat severity, and the development of an integrated driver-vehicle interface to ensure driver comprehension of warnings, reduction of driver workload, and reduction of driver reaction times. The overall integration effort should dramatically improve the IVBSS system performance relative to the standalone subsystems by increasing system reliability and reducing false warnings. As a result, consumer acceptance of crash warning systems in general might be expected to improve.

1.1.2 IVBSS Program Plan

The IVBSS team at the Department of Transportation includes representatives from the National Highway Traffic Safety Administration, the Research and Innovative Technology Administration—specifically, its Intelligent Transportation Systems Joint Program Office and the Volpe National Transportation Systems Center—the Federal Motor Carrier Safety Administration, and the National Institute of Standards and Technology.

The team led by UMTRI working on the light-vehicle platform includes Visteon Corporation, Honda R&D Americas, and Cognex Corporation. On the heavy-truck platform the partners are Eaton Corporation, International Truck, and Cognex Corporation. In addition, Con-Way Freight (a commercial trucking company) is working on the program with the expectation that it will soon be under contract to UMTRI to serve as the fleet through which the IVBSS field test is conducted. The involvement of industrial partners on the IVBSS program is seen to be critical, given the partners' technical knowledge of and ultimate ability to deploy actual systems into the U. S. vehicle fleet. Additional members of the team include Battelle Memorial Institute, which is assisting in the development of the heavy-truck driver-vehicle interface, and the Michigan Department of Transportation, which is providing technical support as it relates to the acquisition of crash and roadway geometry data.

The first year of the IVBSS program was comprised primarily of research, engineering, development, and verification efforts, including performance improvements to non-integrated crash warning systems that can be gained through sensor and data fusion, and improved warning effectiveness that can be generated by an integrated driver-vehicle interface. If the viability of the integrated systems can be demonstrated in the second year of Phase I, as determined by verification tests and performance criteria, then the program will proceed and the field operational test conducted using vehicles built early in Phase II.

1.1.3 Phase I – IVBSS Development

Figure 2 illustrates the timing and number of vehicles included in the program. In the first year, eight vehicles have been purchased or leased on which the developmental subsystems are being deployed. This includes six Honda Accord EXs (the make and model to be used in the FOT), one Chevrolet Suburban with an enclosed trailer that is serving as a surrogate for a class 8 tractor-trailer combination on the heavy-truck platform, and an International 8600 series tractor (the make and model to be used in the FOT). Development on the heavy-truck platform has initially taken place on the surrogate vehicle in order to allow various members of the team who do not hold commercial driver licenses to experience the systems under development.

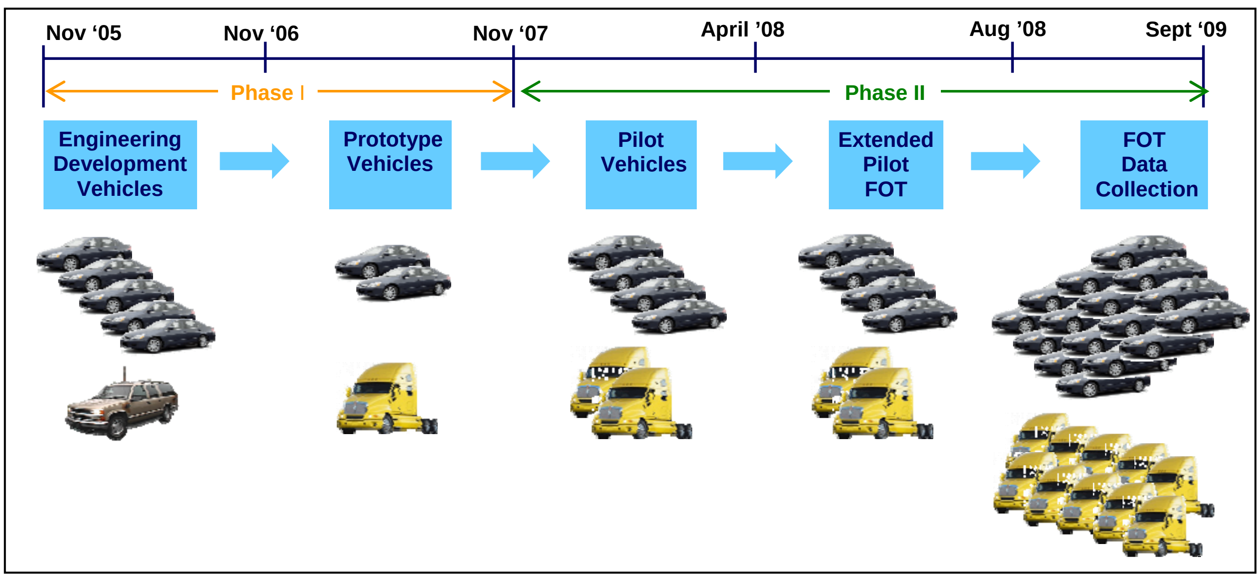


Figure 2. Approximate timing of IVBSS vehicle development and testing

Work in the first year of the IVBSS program focused primarily on system design, subsystem development, system performance guidelines, functional requirements, and verification test procedures. Because the subsystems being integrated were in varying stages of development at the beginning of the IVBSS program, Visteon, Eaton, and Cognex needed to complete development on some subsystems and refine others.

Specific first-year efforts included the development of the functional partitioning, system architecture, and interface control documents. Performance guideline and functional requirements documentation was also begun. Concepts of operation for the individual warning functions were developed and subsystem modeling was performed. The development vehicles purchased during the first year were outfitted with subsystem hardware and initial releases of software to allow for subsystem development. Preliminary work on the arbitration of warnings and integration of subsystems also began in the first year of the program and will continue into the second year.

The UMTRI-led team and the U.S. DOT worked extensively to develop verification test procedures that outline testing to be performed in the second year of the program. The results from these tests will serve as the basis of a decision on the likelihood of the integrated system's success and, therefore, whether to proceed with the field operational test.

The preliminary development and specification of the driver-vehicle interfaces (visual, audio, and haptic information provided to the driver) also began in the first year. This included the development of prototype hardware, followed by the design of a series of laboratory and driving simulator studies. To support the IVBSS development process, data acquisition systems that permit the collection of data from the developmental vehicles were also designed, and represented the initiation of a plan to develop future data acquisition systems to support the field operational test.

In the second year of Phase I, the physical integration of IVBSS into vehicles and subsystem refinement will continue, as will the development of verification test procedures and human factors testing to support the development of the driver-vehicle interfaces. Major tasks to be initiated in the second year of Phase I include the development and revision of threat assessment algorithms, the conduct of the verification tests (test track and on-road testing), analysis of the verification test data, jury drives, and detailed preparation for the pilot and field operational tests in Phase II.

1.1.4 Phase II – IVBSS Deployment and Analysis

In Phase II, the following activities will take place:

- Extensive pilot testing;
- Acquisition of the remaining vehicles;
- Building of the fleet of passenger cars and heavy trucks;
- Finalization of experimental design and protocol for the field test;
- Conduct of the field operational test; and
- Analysis of the results.

In the conduct of the field operational test, at least 108 passenger car drivers and 15 drivers of heavy trucks will be recruited. The actual field test will be conducted over a 12-month period and will collect extensive data on driver performance with, and without, warnings provided by the integrated safety system. Instruments used in assessing driver acceptance of IVBSS will also be developed and used in the conduct of the field test.

1.2 First-Year Accomplishments

1.2.1 Systems Architecture Development

System architecture development was also completed for both the light-vehicle and heavy-truck platforms in the first year. The systems architecture includes the partitioning of the IVBSS system into its major subsystems, specifies the sensors and software envisioned to reside in the subsystems, and identifies the hardware interfaces and communication protocols among the subsystems.

1.2.2 Sensor Suite Identification

Sensor suite identification involved the development of detailed descriptions of all sensors that make up IVBSS. Sensor type (vision, radar, inertial, and vehicle sensor) and specifications for these sensors were defined. The majority of sensors used in the IVBSS program are commercially available and intended for automotive and heavy-truck applications; however, all sensors were acquired and tested for the specific purposes of the IVBSS program.

1.2.3 DVI Option Space and Testing

The options available in the development of the driver-vehicle interfaces on the IVBSS program were identified and a series of human factors tests to examine design alternatives was initiated. This included identifying visual and auditory display requirements in addition to beginning the characterization of the warnings or messages themselves. Furthermore, extensive engineering development went into providing prototype hardware of the DVI to support IVBSS evaluation.

1.2.4 Preliminary Functional Requirements and Performance Guidelines

The preliminary functional requirements and system performance guidelines developed in the program's first year describe the anticipated IVBSS system functionality and the performance expected from the integrated system. Both the functional requirements and performance guidelines incorporate or reference existing requirements and standards where available.

1.3 First-Year Summary

Overall, the first year of IVBSS has been successful in the completion of several important engineering tasks that will prepare the program for a successful field operational test. In particular, significant progress has been made in the design and development of the IVBSS system architecture, the identification of sensors and equipment, preliminary DVI development and specification, system performance guidelines, and functional requirements. Additional tasks that began in the first year, and which continue into the second year of Phase I, include DVI testing, the development of verification test procedures, the construction of developmental vehicles, and preparation of data acquisition systems to support vehicle development. A high-level Gantt chart identifying major tasks on the IVBSS program is provided in Figure 3. (Specific program milestones and deliverables in support of these efforts are provided in Appendix A, with dates effective at the time of the completion of this report.)

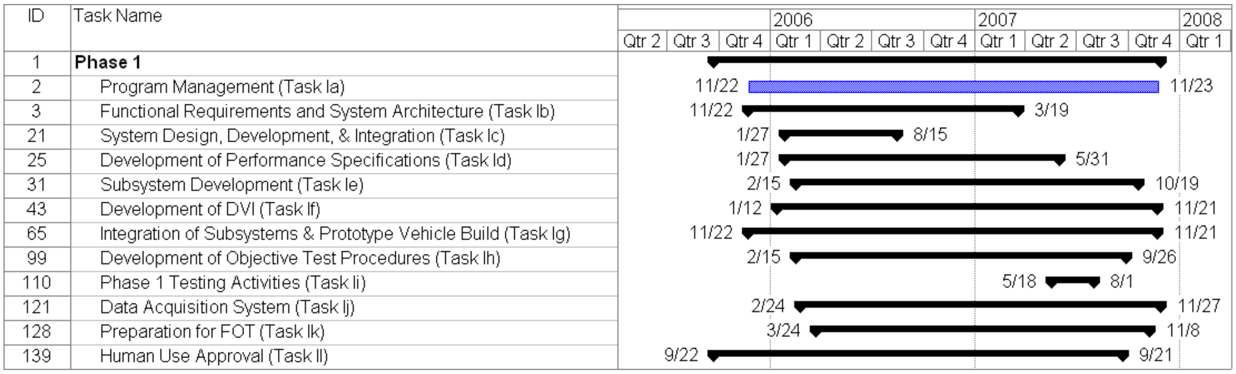


Figure 3. Major IVBSS program tasks

2 Introduction

This report documents the IVBSS program's first-year activities and accomplishments in the design and development of an integrated vehicle-based safety system under a cooperative agreement between U.S. DOT and a team led by UMTRI. The IVBSS program is a four-year, two-phase safety research effort aimed at accelerating deployment of integrated crash warning systems in the passenger vehicle and commercial truck fleets.

The objective of the IVBSS program is to develop a state-of-the-art, integrated, vehicle-based crash warning system that addresses rear-end, lateral drift, and lane-change/merge crashes and to assess safety benefits and driver acceptance of the system through field operational testing. Future widespread deployment of such integrated systems may offer significant benefits in reducing the number of motor vehicle crashes on the Nation's roadways. Crash reduction benefits specific to an integrated system can be achieved through a comprehensive and coordinated exchange of sensor data in order to more accurately determine the existence of a crash threat; in addition, the arbitration of warnings can be used to provide drivers with only the information that is most critical to avoiding crashes.

Three crash warning subsystems are being integrated into both light vehicles and heavy trucks in the IVBSS program: forward crash warning, lateral drift warning, and lane-change/merge crash warning. The light-vehicle platform also includes a curve speed warning subsystem.

- Forward crash warning warns drivers of the potential for a rear-end crash with another vehicle.
- Lateral drift warning warns drivers that they may be drifting inadvertently from their lane or departing the roadway.
- Lane-change/merge warning warns drivers of possible unsafe lateral maneuvers based on adjacent or approaching vehicles in adjacent lanes, and includes full-time side object presence indicators.
- Curve-speed warning warns drivers that they may be driving too quickly into an upcoming curve and as a result, might depart the roadway.

2.1 Crash Problem

The scope of the crash problem being addressed by the IVBSS program represents approximately 6,318,000 police-reported crashes that took place in the United States in 2003.[18] Of these crashes, 96 percent (6,060,000) involved at least one light vehicle and resulted in 1.5 million injuries and more than 19,000 fatalities. For the same time period, heavy commercial trucks were involved in about 362,000 crashes that resulted in 211,000 injuries and 1,100 fatalities. Collectively, rear-end, road departure, and lane-change crashes accounted for 60 percent of all police-reported light-vehicle and heavy-commercial-truck crashes. Perhaps the most striking description of the rear-end, road departure, and lane-change crash problem to be addressed by the IVBSS program is that these crash types account for approximately 50 percent, or 21,000 annual, crash-related fatalities. Figure 4 illustrates the crash problem for the three major crash types addressed in the IVBSS program for both light vehicles and heavy commercial trucks.

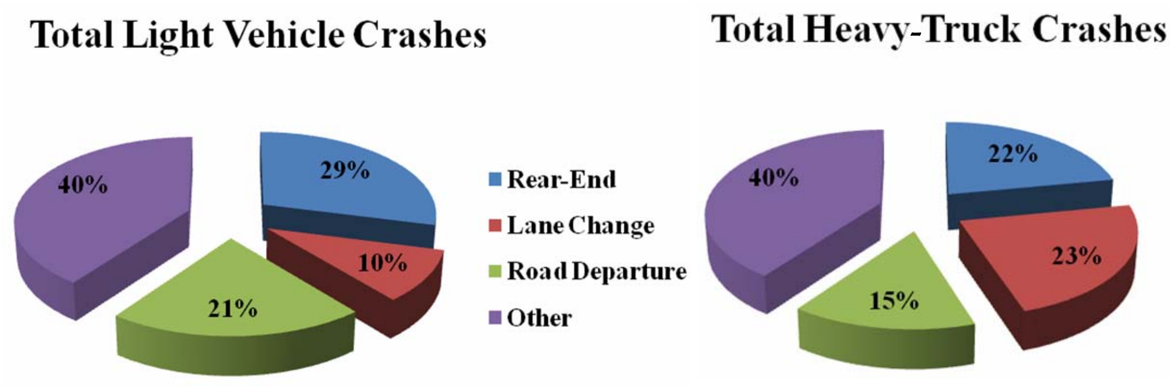


Figure 4. Breakdown of crash types in the United States (2003)

2.2 Program Purpose

The purpose of the IVBSS program is to assess the safety benefits and driver acceptance associated with a state-of-the-art integrated vehicle-based crash warning system. Preliminary analyses by the U.S. DOT indicate that a substantial number of police-reported crashes (48% or 1.6 million) can be addressed through the widespread deployment of integrated crash warning systems that address rear-end, lateral drift, and lane-change/merge crashes. The benefits of deploying integrated crash warning systems can be realized through the coordination and sharing of sensor data enabling crash warning subsystems to better determine the existence of a crash threat and issue useful warnings.

The IVBSS program has benefited from leveraging the work of several previous research programs on the development and deployment of crash warning systems. Information from these previous programs has aided in improving both the performance of specific crash warning subsystems and the integration effort by providing a more comprehensive understanding of benefits to be realized from sensor data sharing. The expectation is that the improvements in threat assessment and warning accuracy that can be realized through systems integration will, in contrast to a configuration of non-integrated warnings, result in increased consumer acceptance, the earlier introduction of integrated systems into the vehicle fleet, and a resulting reduction in crashes.

2.3 Previous Countermeasure Development

All of the crash warning subsystems being examined in the IVBSS program have undergone some level of previous development and evaluation, though not as part of an integrated warning system. Major U.S. DOT-sponsored programs have addressed the development and field testing of forward crash warning systems for light vehicles in the Collision Avoidance Metrics Partnership (CAMP) and Automotive Collision Avoidance Systems (ACAS) programs. The CAMP program developed performance guidelines for radar-based forward crash warning systems by characterizing the forward crash conflict and conducting studies on the timing of warnings to drivers. [14, 15] The ACAS program furthered the development of forward crash warning systems by deploying a system in a fleet of vehicles, and the data from this field testing was subsequently used to evaluate the safety benefits and user acceptance of the system .[3, 4] For heavy commercial trucks, U.S. DOT has also sponsored work on the development of operational requirements for forward crash warnings systems. [6]

The Run-Off-Road and Road Departure Crash Warning programs, also sponsored by U.S. DOT, have contributed extensively to the development of crash countermeasures for light vehicles by addressing road-departure crash warning systems, including curve speed warning. The Run-Off-Road program contributed to crash countermeasure design by studying the potential benefits of lane departure warning systems and characterizing the single-vehicle road departure crash threat. [19] The RDCW program built upon these previous efforts by developing and field testing a crash warning system that addressed lateral drift and curve speed crash conflicts. A 2006 report[16] summarizes the RDCW program, including an evaluation of the safety benefits and user acceptance for the road departure crash warning system. A program to develop operational requirements for lateral drift warning systems in heavy trucks has also been undertaken, [5] as has a field test of these lane departure warning systems. [6] Lastly, lane-change/merge crash warning system development has been supported to a lesser degree with the development of performance guidelines. [21]

2.4 Expected Benefits of an Integrated System

The IVBSS program differs significantly from previous efforts to develop crash countermeasures in that the primary goal is to identify the benefits of integrating three collision warning subsystems, each otherwise independently capable of presenting warnings to a driver, and to do so on two vehicle platforms. The scope of the systems integration task on the IVBSS program is greater than that undertaken in any prior program of its kind, and includes the integration of sensor data across subsystems (data sharing), the arbitration of warnings based on threat severity, and the development of an integrated driver-vehicle interface.

Integration should dramatically improve overall warning performance relative to the standalone subsystems by increasing system reliability, increasing the number of threats that can be accurately detected, and reducing false and nuisance warnings, thereby reducing crashes and increasing safety. In essence, individual subsystems will benefit from sensor data collected from the remaining subsystems. In addition, unlike stand-alone crash warning systems, the integrated system will be capable of detecting multiple threats that can be assessed and arbitrated to communicate only the most serious or immediate warning to the driver. Integration at the level of the driver-vehicle interface should offer significant benefits in the form of improved driver recognition of warnings, improved driver reaction times, and potentially reduced driver workload. Overall, the improvements that can be achieved with an integrated crash warning system should result in increased consumer acceptance and earlier adoption relative to standalone warning systems.

2.5 Program Approach

2.5.1 IVBSS Team Membership

UMTRI is serving as the prime contractor on the IVBSS program and is responsible for the management of the program. In addition, UMTRI is responsible for coordinating the development of the IVBSS system on both platforms, developing data acquisition systems, and, in Phase II, conducting the light-vehicle and heavy-truck FOTs. UMTRI’s Human Factors Division, with support from Battelle and in close collaboration with industry partners, is leading the experimental work on issues related to integrating the driver-vehicle interface. The Michigan Department of Transportation is also supporting UMTRI by assisting in the acquisition of crash and roadway geometry data to support analyses during the field operational test. Figure 5 illustrates the organizational structure of the partnership.

Visteon, with support from Cognex Corporation, is the lead system developer and systems integrator on the light-vehicle platform in the development of the lateral drift warning subsystem. Visteon is responsible for the development of the forward crash, lane-change/merge, and curve speed warning subsystems and the overall systems integration effort, including warning arbitration and hardware development for the driver-vehicle interface. Visteon is also providing digital map matching capabilities on the heavy-truck platform. Honda R&D is providing engineering assistance to Visteon and Cognex throughout the program in the integration of IVBSS into the passenger vehicles. This includes but is not limited to technical contributions in systems design and evaluation.

The industrial partners on the heavy-truck platform are Eaton Corporation, International Truck, Cognex, and Battelle. Eaton is serving as the lead system developer and system integrator on the heavy-truck platform, and is responsible for the development of the forward crash and lane-change/merge warning subsystems. Cognex is supporting Eaton in the development of the lateral drift and lane-change/merge warning subsystems, as well as collaborating on data fusion and system learning capabilities. International Truck is providing engineering assistance and will be responsible for installation of IVBSS into the heavy-truck fleet. Battelle is supporting Eaton in the development of the heavy-truck driver-vehicle interface and warning arbitration strategies. In addition, Con-Way Freight (a commercial trucking company) is currently cooperating on the program, with the expectation that it will soon be under agreement to serve as the heavy-truck fleet for conducting the IVBSS field test.

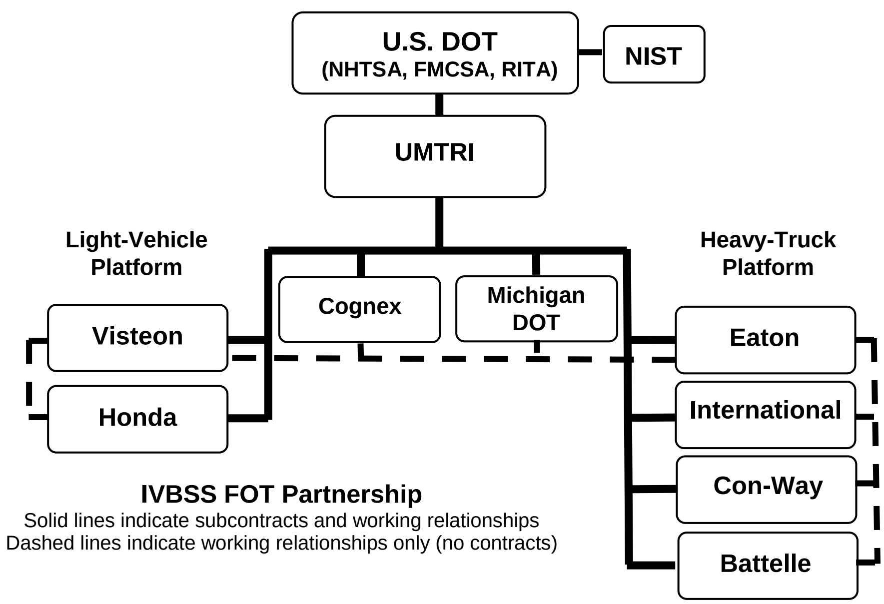


Figure 5. Organizational structure of IVBSS partnership team

The U.S. Department of Transportation IVBSS program team includes representatives from the National Highway Traffic Safety Administration, Federal Motor Carrier Safety Administration, Research and Innovative Technology Administration (Intelligent Transportation Systems Joint

Program Office), National Institute for Standards and Technology, and the Volpe National Transportation Systems Center.

The cooperative agreement is being administered by NHTSA. The U.S. DOT Research and Innovative Technology Administration's Intelligent Transportation Systems Joint Program Office is the sponsor of the IVBSS program, providing funding, oversight, and coordination with other U.S. DOT programs. FMCSA is assisting with the development and monitoring of the heavy-truck platform. The Volpe Center will be responsible for assessing system performance and viability in Phase I, as well as serving as the independent evaluator of results from the field operational test in Phase II. NIST is responsible for developing an independent data measurement system for use during verification testing, and subsequently analyzing the data.

2.5.2 Structure of the Program

IVBSS is a four-year cooperative agreement between the UMTRI-led team and the U.S. DOT that began on November 23, 2005. The program is evenly divided into two, non-overlapping phases of two years each, with efforts in Phase I primarily focused on system design, development, specification, and testing. Phase II includes the buildup of a vehicle fleet, the conduct of the field operational test, and subsequent analyses of system benefits and driver acceptance. The overall timeline for these major phases is shown in Figure 6.

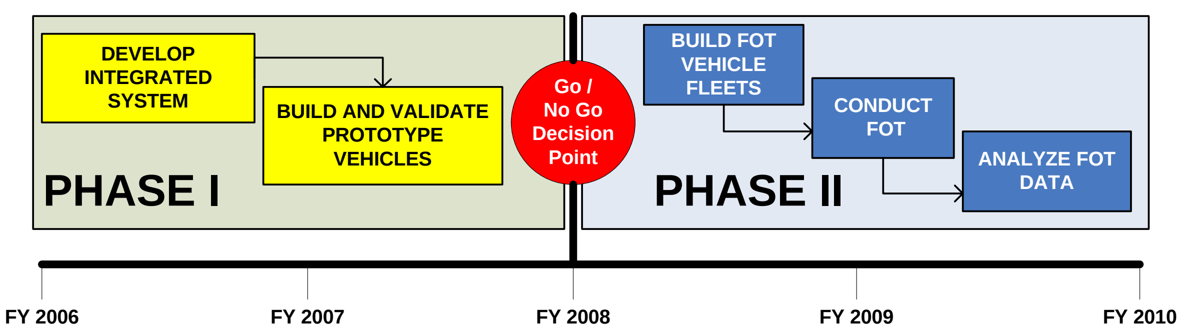


Figure 6. Overall timeline for IVBSS Phase I and Phase II

2.5.2.1. Phase I

The first year of the IVBSS program was comprised primarily of systems engineering and systems development. This includes performance improvements to non-integrated crash warning systems that can be achieved through sensor and data fusion and improved warning effectiveness associated with an integrated systems and an integrated driver-vehicle interface. Specific tasks on both the light-vehicle and heavy-truck platforms included developing system architectures, defining concepts of operation and functional requirements, describing the subsystems, identifying the sensors and hardware, and creating developmental vehicles.

Efforts in the second year of Phase I will concentrate primarily on building prototype vehicles to support verification testing, including the complete physical integration of IVBSS into both a passenger car and a heavy-truck. Verification testing will be performed on test tracks and public roads. Additional second-year efforts will focus on development and revision of threat assessment algorithms, analysis of data from the verification testing, jury drives, completion of the driver-vehicle interface tests, and detailed preparation for the pilot and field operational tests in Phase II.

2.5.2.2. Phase II

The second phase of the IVBSS program will involve study of system performance, user acceptance, and safety benefits, since it is only in the second phase that actual field operational testing is conducted. This phase includes three principal components: (1) building of the fleet vehicles, (2) field testing, and (3) system evaluation. Upon approval of the second phase of the program, the primary task will be to order sensors and related hardware to immediately begin the build of the vehicle fleet. This includes the installation of the complete IVBSS system into 16 passenger cars and 10 heavy trucks. During the build-up period, prototype vehicles will be used to begin pilot testing with unaccompanied drivers. Once the first fleet vehicles are complete and their performance verified the field operational tests will begin.

The field test will be conducted over a 12-month period for light vehicles and a 10-month period for heavy trucks, and will collect extensive data on driver performance with and without warnings provided by the integrated safety system. Subjective instruments used in assessing driver acceptance of IVBSS will also be developed and used in the conduct of the field test. An evaluation plan will be created early in the second phase to guide analysis of the FOT data, and analysis routines will begin while the field operational test is ongoing to expedite system evaluation and reporting at the end of the program.

2.6 First Year Accomplishments

The UMTRI-led team accomplished several important engineering tasks on both platforms in the first year of the IVBSS program. Significant progress was made in the development of the functional requirements and the design and development of the IVBSS system architectures. The functional requirements describe how the system is intended to operate, the circumstances under which it will present a warning, as well as when it will not warn the driver; the system architecture describes the physical connectivity of the hardware and exchange of data. Concepts of operation for the individual warning functions were developed and subsystem modeling was performed.

The team also identified the sensors and other equipment needed to implement IVBSS. Tasks that began in the first year include the development of performance guidelines, preparation of data acquisition systems to support vehicle development, and the construction of developmental vehicles. The development vehicles purchased this year were outfitted with subsystem hardware and initial releases of software to allow for onboard subsystem development. Initial efforts on the arbitration of warnings and integration of subsystems into vehicles began in the first year of the program, and will continue into the second year of the program.

In addition, the UMTRI-led team and the U.S. DOT began to develop verification test procedures, and will continue this effort into the following year. These procedures outline testing to be performed in the second year, the results of which will serve as the basis for a decision on the likelihood of the integrated system’s success and, therefore, whether to proceed with Phase II and the field operational test.

Finally, development and specification of the driver-vehicle interfaces on both platforms were accomplished in the first year of the program. This includes the development of prototype hardware, followed by a series of laboratory and driving simulator studies that began in the first year. Testing to identify desirable and recognizable warning characteristics was performed, and significant upgrades to the UMTRI simulator were made to support further testing. Refinement and testing of the driver-vehicle interfaces continue, and will be completed in the second year of the program.

2.7 Report Structure

The remainder of this report is organized as follows:

- Chapter 3 describes the light-vehicle platform, including system design, subsystem and driver-vehicle interface development, and system integration.
- Chapter 4 discusses the heavy-truck platform, including functional requirements, development of performance guidelines, subsystem and DVI development, and system integration.
- Chapter 5 covers the development of verification test procedures and Phase I testing.
- Chapter 6 details the DVI and simulator and laboratory testing.
- Chapter 7 describes the preparations for the field operational tests.
- Chapter 8 summarizes the major accomplishments of the first year research.
- Chapter 9 contains a list of references.
- Appendix A shows the milestones for each task in the project.
- Appendix B provides sample audio warnings issued by the driver vehicle-interface (on-line version only).

3 Light-vehicle Platform

The light-vehicle team is comprised of UMTRI, Honda, Visteon, and Cognex. The team will integrate curve speed warning, forward collision warning, lane-change/merge warning, and lateral drift warning systems into an integrated safety system with a unified driver-vehicle interface. The IVBSS system will be installed on the 2006 Accord EX for development and the 2007 Accord EX for field-operational-test deployment.

Visteon is the lead developer of the light-vehicle IVBSS countermeasure. Visteon is also responsible for leading systems engineering, vehicle integration, verification testing, and CSW, FCW, and LCM subsystem design. While UMTRI leads the DVI requirements capture process, Visteon will design the in-vehicle DVI accordingly. Furthermore, Visteon is responsible for arbitrating the warnings between each of the warning functions (CSW, FCW, LCM, and LDW). Cognex is responsible for LDW subsystem design and supports vehicle integration, verification, and DVI implementation activities. Honda provides engineering support for vehicle integration and has played a key role in the development and integration of specific elements of the DVI option space. UMTRI will provide the data acquisition system, lead the experimental design and conduct of pilot tests and the field operational test.

3.1 Functional Requirements and System Architecture

3.1.1 Overview

The functional requirements and the system architecture (Task 1.b) were developed during the first year of the program. Figure 7 shows this activity within the larger context of the Phase I systems engineering process. The crash problem, as described by the U.S. DOT was considered, along with previous and existing approaches to standalone crash warning systems. A system functional model was developed that described the functions and data flows necessary to address the target crash problem, as well as known operational scenarios (i.e., those that may lead to nuisance and false alerts). In parallel, the objectives, scope, and nature of IVBSS were defined, and, given the functional model, further functional requirements were derived. The system architecture was developed by aggregating the lower-level functions in a practical manner, recognizing the constraints of prototype hardware, and the interactions among functions. The steps on the right side of Figure 7 are described in later sections.

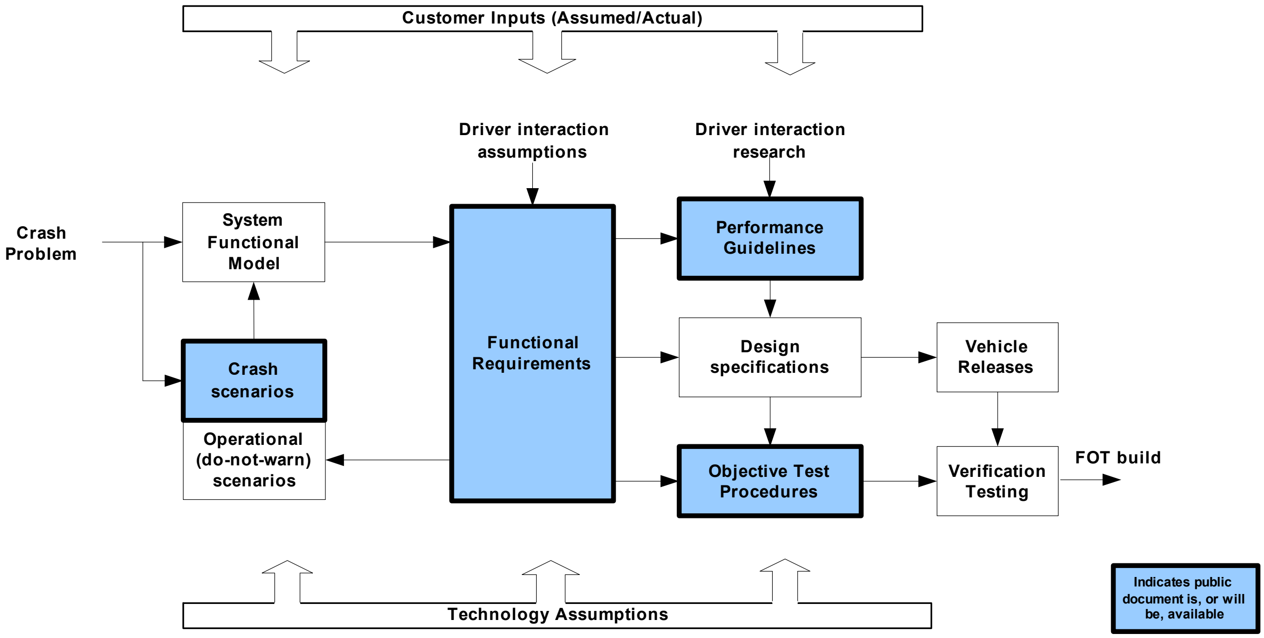


Figure 7. Systems engineering process for the light-vehicle platform

A preliminary functional requirements report for the light-vehicle platform was delivered and posted for public access.[10] The sections below describe the results of the functional requirements and system architecture efforts.

3.1.2 Functional Requirements

The first step in developing functional requirements was creating a detailed system functional model. Figure 8 shows the highest level of this model, which describes the relationship of the IVBSS system with the vehicle, driver, and environment. The IVBSS elements were further broken down into the six sub-functions (shown in Figure 9), which use data describing the roadway and targets (other vehicles), as well as data from the subject vehicle, in order to build an internal understanding of the driving situation. The threat of a potential crash is then assessed and decisions to issue IVBSS information to the driver are made. More levels of detail were developed than are shown here, and data flows among sub-functions were defined.

This process occurred in parallel with defining the objectives, scope, and primary strategy to be employed by IVBSS. The objectives of IVBSS are twofold: (1) maximize potential safety benefits by providing the driver with critical information, and (2) gain driver acceptance.

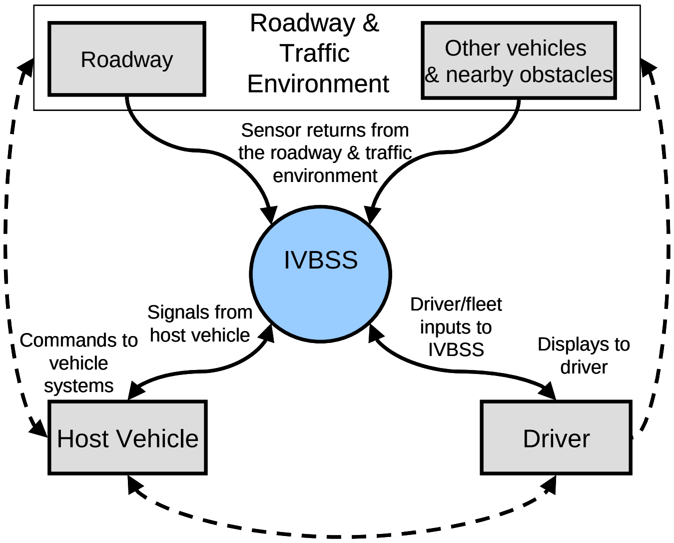


Figure 8. High-level system functional model

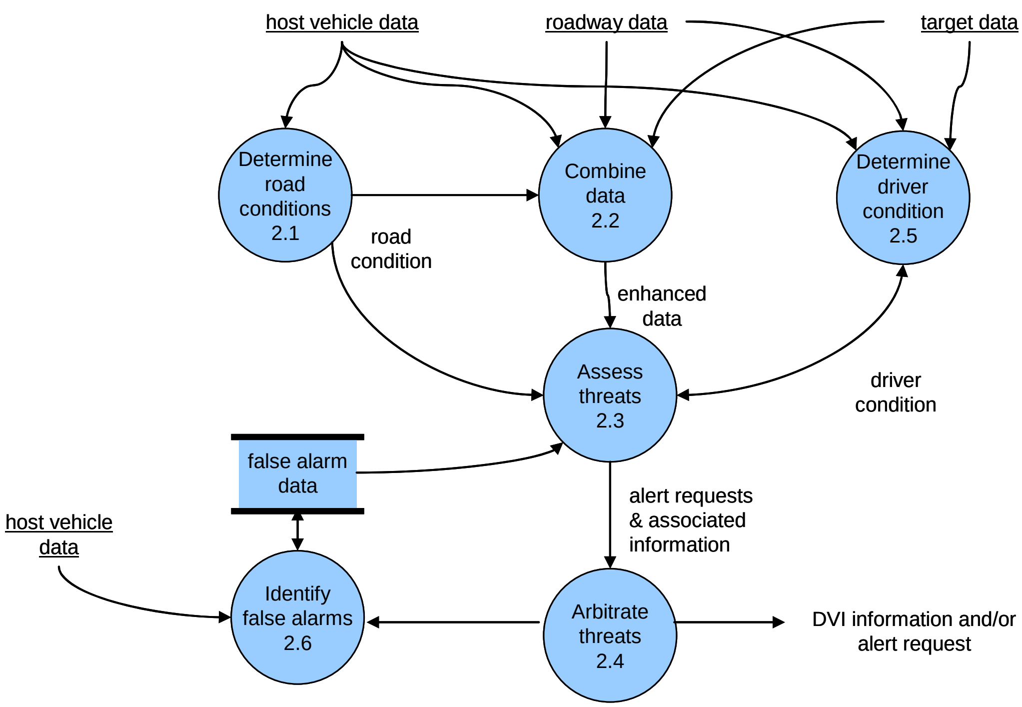


Figure 9. Mid-level system functional model showing selected IVBSS components

It was determined that two types of information would be provided: crash alerts and advisories. Crash alerts are audible, visual, or haptic displays that will be provided to help the driver be aware of an existing or quickly developing potential crash threat. Drivers are then responsible to decide whether and how to initiate an evasive maneuver. Advisories are less urgent warnings that are intended to assist the driver in decision-making to reduce the likelihood that a crash conflict will develop. IVBSS is, thus, a vehicle subsystem that supplements the driver's situational awareness. IVBSS will not assume control of the vehicle, so there is no ongoing control function (e.g., active cruise control or lane-centering assist) and no automatic crash-avoidance control (e.g., automatic braking).

Crash alerts were determined to be applicable to five hazardous situations. These pre-crash conditions correlate to a majority of traffic crashes:

- Subject vehicle is closing on a lead vehicle;
- Subject vehicle is traveling too fast for an upcoming curve;
- Subject vehicle is encroaching on a vehicle traveling in an adjacent lane;
- Subject vehicle is drifting off of the roadway; and
- A combination of two or more of the above.

A further development of these situations is encapsulated as two tables of key scenarios used for requirements development, both pre-crash scenarios and scenarios in which nuisance and false alerts are likely to occur. These tables were reported in the preliminary functional requirements document,[10] and were based on earlier work by the U.S. DOT.

IVBSS is an autonomous system that does not require other vehicles or the roadside to have additional equipment or capabilities. In this project, IVBSS must be implemented using technology that will be available and robust enough to conduct a field operational test in 2008. Lower-level functional requirements were developed for the five hazardous situations listed earlier. For each situation, requirements were levied for sensing, processing, and output to the driver. Descriptions and examples of these requirements are given in the following sections.

3.1.2.1. Sensing Requirements

IVBSS requires data in order to characterize the driving environment. This involves measurements from IVBSS sensors, communications with the vehicle, and use of static and dynamic onboard, or other, data sources. For each of the five hazardous situations listed earlier, requirements fall into five categories:

1. **Sensing subject vehicle information and driver-control inputs**: This stipulates the signals that IVBSS must obtain from the subject vehicle as well as IVBSS driver control inputs. For example, to address rear-end crashes, IVBSS must obtain subject vehicle speed, yaw rate, and driver brake switch. Other data may, of course, be desirable, including turn signal use, subject vehicle longitudinal acceleration, driver throttle control, wiper state, steering wheel angle, ambient temperature, and more.
2. **Sensing roadway geometry and characteristics**: This addresses the collection or acquisition of information about the roadway. For example, to address road-departure crashes, IVBSS must obtain data including: heading of the vehicle axes relative to the lane, position of the vehicle in the lane, determination of whether the lane edges are road edges, road curvature, upcoming road curvature, time rate of change of the lateral position of the vehicle relative to the road edge, and presence and geometry of upcoming roadway branches.
3. **Sensing objects and characterizing object type and motion**: This addresses identification and location of other vehicles that may pose a potential crash threat to the subject vehicle. For example, to avoid lane-change/merge crashes, IVBSS must detect and track same-direction vehicles in a field of regard that includes travel lanes adjacent to those in which the subject vehicle is traveling. In this case, the front edge of the field of regard shall be slightly

forward of the subject vehicle and the rear edge shall be a distance behind the subject vehicle that allows for addressing crashes in which adjacent-lane traffic is overtaking the subject vehicle. IVBSS must determine those vehicles' positions relative to the subject vehicle, laterally and longitudinally, and provide the relative speed in both lateral and longitudinal directions.

4. **Estimating road condition parameters**: Each warning function is required to obtain and use available data that may indicate low road friction.
5. **Sensing driver attributes**: In the second year, the light-vehicle platform will work toward incorporating individual driver behaviors into decisions about issuing crash alerts. The data necessary to support that activity is required to be available to the appropriate functions. For example, the FCW that addresses rear-end crashes will need headway- and speed-related measures that are thought to be potentially useful for this task.

3.1.2.2. Processing

Algorithms must be capable of processing the situational framework and determining that one or more of the hazardous situations are developing. The requirements for processing address situation characterization and threat assessment. Situation characterization is the determination of specific aspects of the driving situation needed by the system to ascertain that a potential crash threat exists. Given that a threat may exist, threat assessment for each warning sub-function generates an alert request that is sent to an arbitration function.

For each of the hazardous situations, a number of requirements were developed and documented.[10 12] For situation characterization to address rear-end crashes, for instance, there are requirements to address object classification, path prediction, and target selection. An example of object classification is that IVBSS must be capable of rejecting the vast majority of roadside objects (e.g., road signs and mailboxes) from consideration as potential threats.

Threat assessment requirements for the same type of crash alert stipulate a primary need to accommodate driver reaction times and typical emergency braking levels. There are several allowances in the threat assessment sections that recognize the central difficulty of managing nuisance and false alerts. This means that the system is allowed to postpone or suppress crash alerts when there is a reasonable possibility that the driver is aware of the situation or is intentionally maneuvering, or that the threat sensing has a significant amount of uncertainty.

3.1.2.3. Output

IVBSS must be capable of conveying this information to the driver in a timely and understandable manner. The full set of functional requirements developed during the first year of the program are contained in the preliminary functional requirements for the IVBSS light-vehicle platform document (Task 1.b). These requirements address crash alert displays, advisory displays, driver inputs into IVBSS, and system status messages. The purpose of the crash alerts is to prompt an unaware driver to adjust attention in a manner that immediately allows assessing the appropriate aspect of the driving situation. Eleven qualities of displays were proposed and an early down-selecting of the display modalities associated with the crash types was proposed. These were modified later and are presented in Chapter 6.

3.1.3 System Architecture

As described earlier, the IVBSS system architecture was derived from the functional model developed during the first year of the program. The first step was functional partitioning, the outcome of which is illustrated in part in Figure 10. The IVBSS system for light vehicles consists of six subsystems. At the top of the figure, four warning sub-functions each produce situational information and a request for driver alerts that address different crash types. To integrate these four systems into a seamless and intuitive driver interface, the arbitration subsystem is used to arbitrate and occasionally suppress alert requests that are received from the four sub-functions. The DVI subsystem presents information to the driver and also accepts driver inputs.

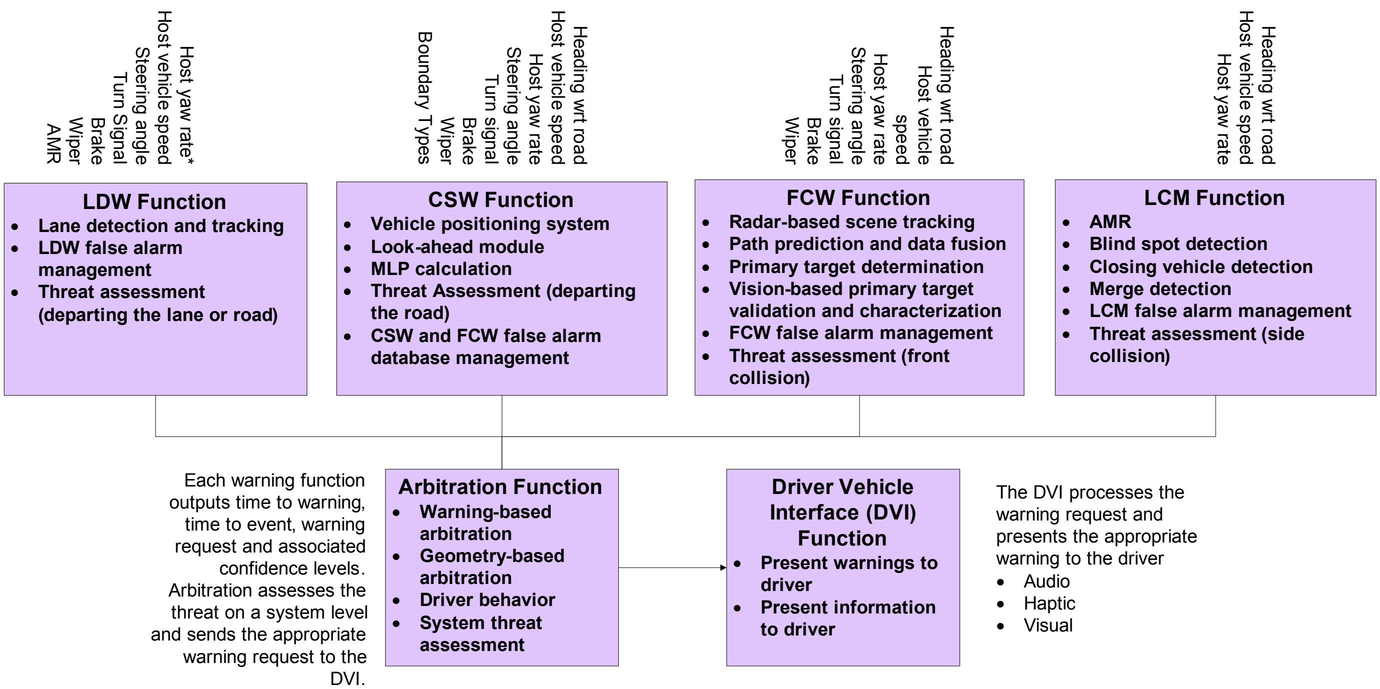


Figure 10. Light-vehicle functional partitioning

The implementation architecture was derived from the functional partitioning and data flow analysis. The resulting light-vehicle IVBSS architecture is depicted in Figure 11.

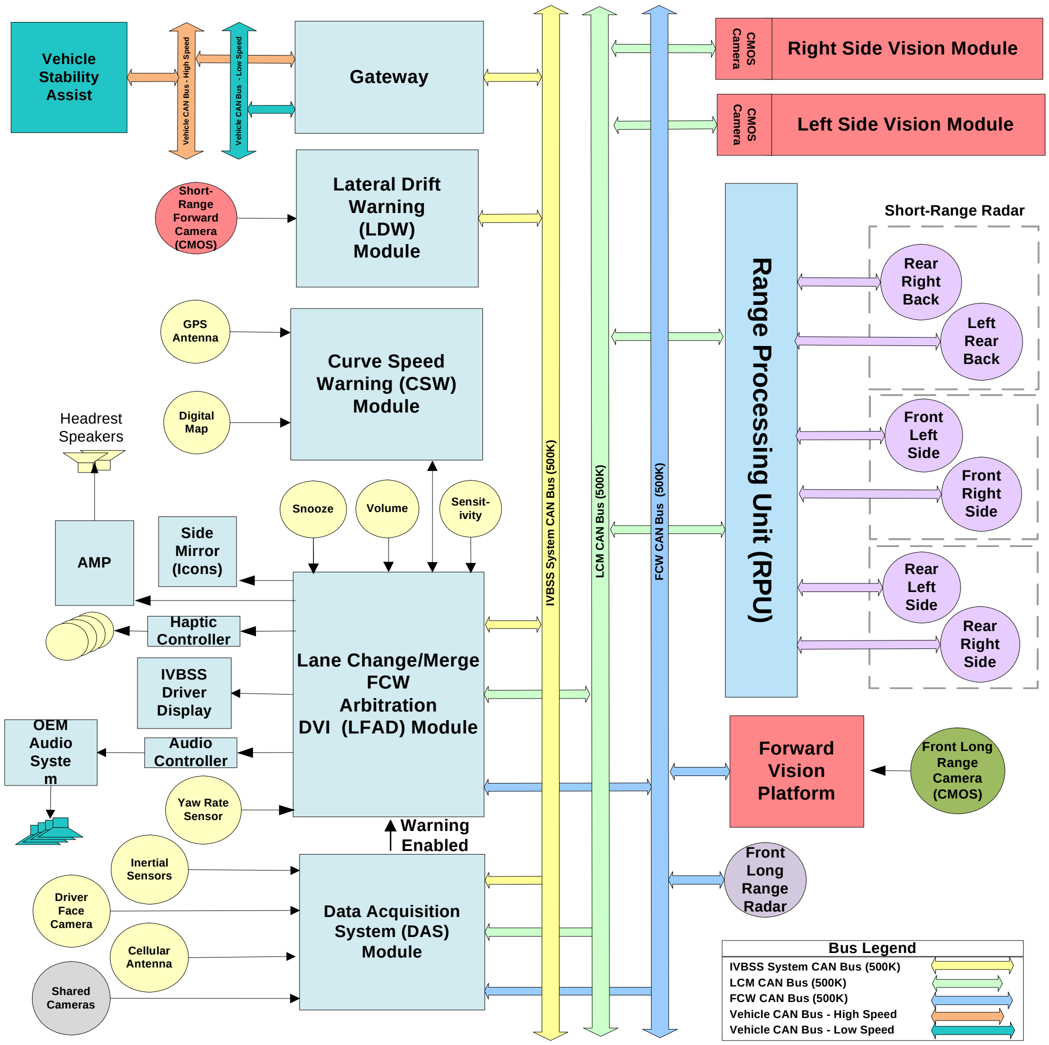


Figure 11. IVBSS system architecture

The three IVBSS CAN buses are shown as vertical features running up and down on the page. The five major elements to the left of the buses are:

- **Gateway**: Translates appropriate messages from two OEM data buses to one of the project CAN buses;
- **Lateral drift warning module**: Uses forward vision-based lane tracking and other signals from the CAN bus to broadcast LDW alert requests onto the bus;
- **Curve speed warning module**: Uses GPS, an onboard digital map, and other information to broadcast CSW alert requests onto a serial link to the LFAD module;
- **LCM/FCW/arbitration/DVI module**: A chassis that includes processors and other hardware on which LCM, FCW, arbitration, and DVI are hosted; and
- **Data acquisition system module**: A two-CPU module with peripherals that records data for analysis during development and the FOT.

The additional elements above the three IVBSS CAN buses include:

- Two vision-based modules that assist with LCM functionality on the left and right side of the vehicle (shown in the upper left corner);
- Another vision-based module shown in the upper right that assists FCW target selection; and
- Three pairs of short-range radars, with each pair communicating with the IVBSS CAN buses through a radar processing unit (RPU).

There are also several sensing and driver interaction elements associated with many of these elements. The individual subsystem functions are described in more detail in following sections.

3.1.4 Second Year Activities and Schedule

In the second year of the program, the functional requirements and vehicle architecture will be updated as required during the vehicle-level development phase. A final Phase I release will occur in November 2007 to incorporate design changes and key results. A revised public document on the functional requirements will be available in early 2008.

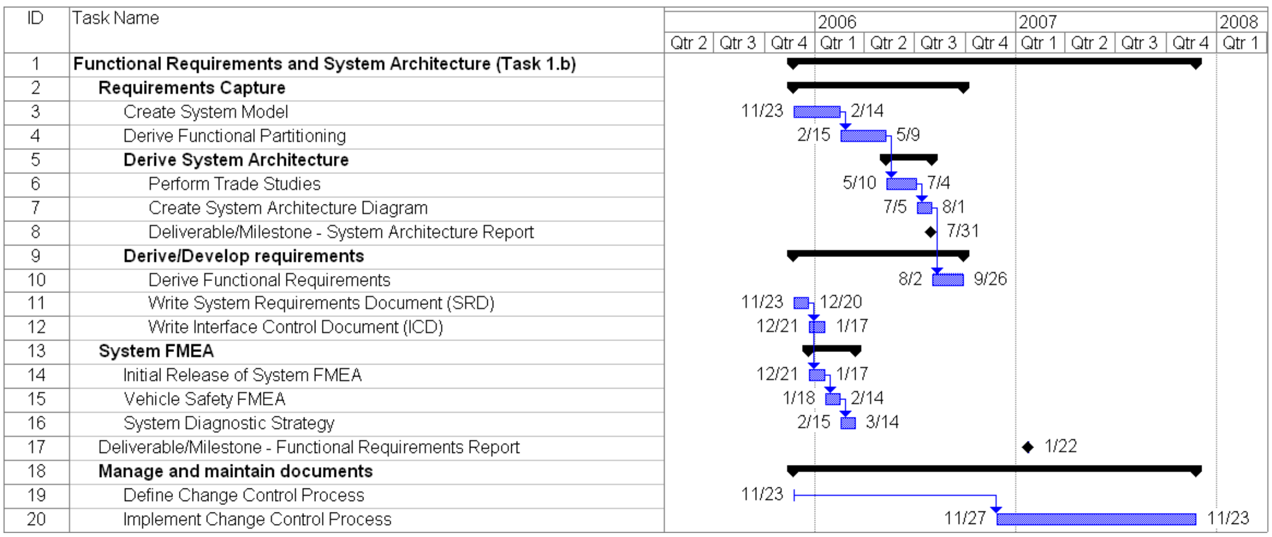


Figure 12. Light-vehicle schedule for functional requirements and system architecture

3.2 System Design, Development, and Integration

3.2.1 Overview

The output of the functional requirements and architecture tasks discussed previously is used by subsequent tasks. At the system level, the system design, development, and integration task creates and implements a vision for integrating the separate subsystems shown earlier in Figure 10. The goal of this task is a plan governing the actual design, development, and integration efforts that will lead to the prototype vehicles that are used in validation testing. The plan will describe the necessary tasks and success criteria for the stages of this process.

3.2.2 Design

Visteon used the concept development process to guide the team through the design, development, and integration of the IVBSS program (the system functional model was described earlier). Given that model and the functional requirements, the design process fills in the implementation of the detailed model, using the architecture and available tools. One output of this process is a detailed description of the signals exchanged between subsystems and shared with the data acquisition system.

3.2.3 Development

Development includes both subsystem- and system-level activities. Subsystem activities are discussed in section 3.4, while this section focuses on system issues. Communications will be verified in a static environment on the bench. Once the vehicles are built during the second year, the program will move into the vehicle-level development phase. The initial functional and performance guidelines will be analyzed and refined. Additionally, alternative DVI implementations will be tested and evaluated. At the end of the development phase, jury drives will be conducted as well as accompanied pilot testing to further refine the IVBSS system.

During the first year, the LDW system was developed on the bench and through vehicle testing. The FCW algorithms were developed using Simulink models. The CSW algorithms and software were updated, based on findings from the RDCW platform and were migrated to the new hardware platforms selected for IVBSS. The updates include software and map-based enhancements to improve the accuracy of predicting whether the subject vehicle will move onto an upcoming road branch (e.g., freeway exit ramp), as well as different approaches to the use of lane boundaries, turn signals, and other secondary signals to issue or suppress alerts. Both CSW and FCW systems have been installed on a Mercedes test vehicle for development. The LCM algorithms have been developed on the bench. An Accord EX has been equipped with the six short-range radar sensors in the installed position, as well as RPU modules for LCM development.

3.2.4 Integration

Integration addresses the installation of hardware on light vehicles and the resolution of any installation-related issues with system performance and reliability. One objective of the integration plan is to provide a vehicle that has the polish of an OEM vehicle, with driver controls and displays integrated in a manner that appears natural and is consistent with prevailing Honda design. The vehicle must be safe and reliable with prototype hardware secured and hidden from view. Recording devices such as cameras must not be intrusive or call attention to the experiment. Furthermore, integration for an FOT project must accommodate exchanges of prototype hardware, convenient access for software and hardware updates, and troubleshooting.

Six development vehicles will be built to incorporate the IVBSS system architecture on the 2006 Accord EX platform. These vehicles will be used for system development, jury drives, pilot testing, and system verification during Phase I. Upon approval to proceed to Phase II, an additional 12 vehicles (model year 2007) will be outfitted. Four of the development vehicles will be used as FOT vehicles, such that a 16-vehicle FOT fleet will be available.

Integration design was completed in the first year of the program. This included the wiring and power requirements, brackets, and miscellaneous components required to integrate IVBSS. All hardware was received to complete the first three development vehicles and the majority of the hardware was received to complete the remaining three development vehicles. The first development vehicle was completed in January 2007; vehicles #2 and #3 are currently being built.

3.2.5 Second-Year Activities and Schedule

Figure 13 shows the steps of the design, development, and integration plan (early subsystem development has already been discussed). In the second year, a series of system releases have been scheduled to install the IVBSS on light-vehicle development vehicles. This culminates in a vehicle verification activity using verification test procedures on the test track, as well as public on-road testing. By the end of the second year, all design, development, and integration activities will have been completed according to the overall schedule shown in Figure 13.

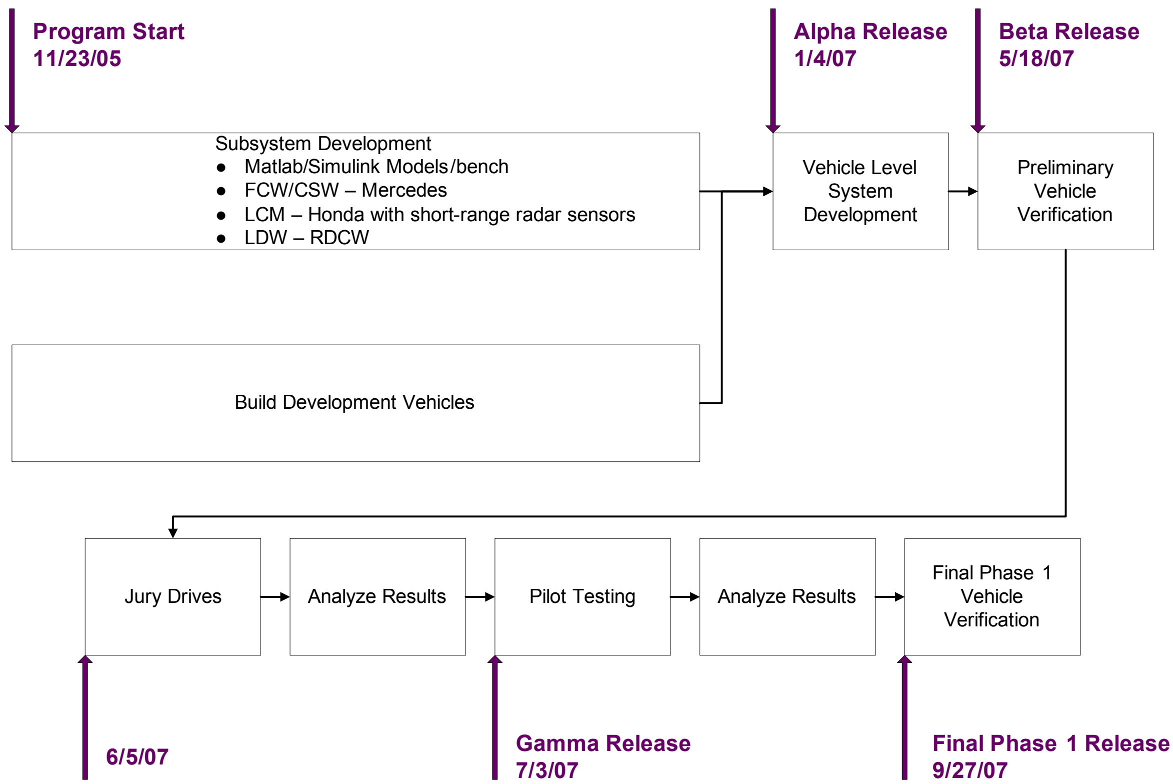


Figure 13. Overall light-vehicle development plan

3.3 Development of Performance Guidelines

Figure 7 illustrates the system engineering process; given the functional requirements, a set of performance guidelines will be developed and published in mid-2007. These will be quantitative and measurable performance metrics that are considered achievable and appropriate for the IVBSS system. As indicated in Figure 7, these guidelines drive details of the actual system implementation and will serve to guide the pass-fail criteria of verification testing to be conducted near the end of the second year. A preliminary set of guidelines will be released in mid-2007 and a final revised set following the completion of Phase I in early 2008.

3.3.1 Overview

The process of developing the preliminary guidelines is currently underway, building upon previous project reports that present preliminary functional requirements.[10] This effort will use previous guideline efforts for standalone crash warning systems, especially prior U.S. DOT projects[1 3 15 16 17 21] and ISO standards efforts (ISO 2002, 2004, and 2006). The focus, however, will be on the integration of these functions. In some performance areas, integration allows improvements in potential safety benefits through enhanced system awareness. In other areas, integration presents a challenge, especially in ensuring driver acceptance because the broad scope of IVBSS could yield more potential sources of false and nuisance alerts.

3.3.2 Integrated System Performance Guidelines

The performance guidelines will include specific bounds on system-level performance that may be observable by an independent observer. The purpose of these guidelines is not to describe system performance as built, but to express the acceptable and achievable performance considered necessary to achieve the highest functional objectives (i.e., safety benefit and driver acceptance). For example, for potential lane-change/merge crashes, guidelines will stipulate the geometric zones (using specific ranges) and a range of times-to-collision at which crash alerts are required, prohibited, or allowed. A set of operating speeds, road types and geometries, and environmental conditions are described in which the guidelines must be satisfied. The presentation of crash alerts and advisories are described, in terms of display modality and commonality and distinctions of displays for different potential crash threats.

3.3.3 Second Year Activities and Schedule

The integrated system performance guidelines document (Task 1.d) will be delivered by the end of the first quarter of 2007. This will be a preliminary set, with a final set provided after the completion of system development and testing at the end of Phase I.

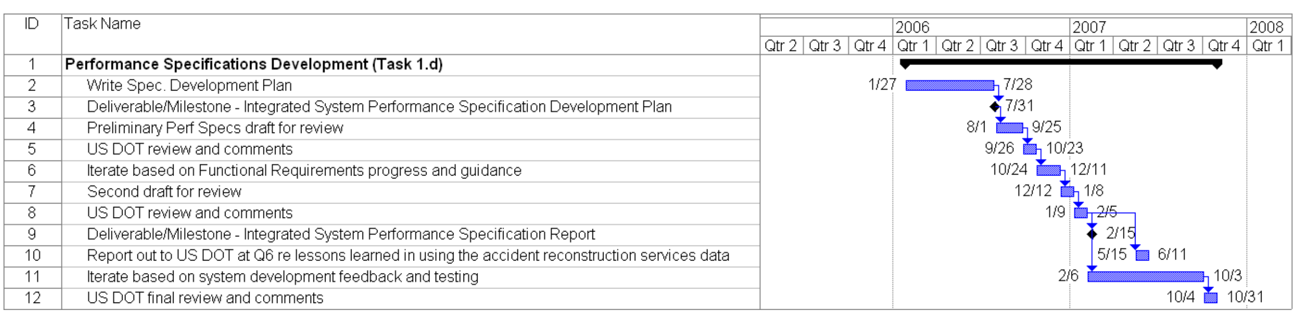


Figure 14. Light-vehicle schedule for performance guideline development

3.4 Subsystem Development

Subsystem development involves the design and implementation of the functions defined for each of the six subsystems described in Figure 10, which in turn resulted from functional partitioning.

3.4.1 Overview

The six subsystems have been developed somewhat independently on the bench, in the simulation environment, and on test vehicles (non-IVBSS-equipped vehicles). All of the hardware and sensors have been selected, designed, and developed to support the subsystem efforts. The following sections describe the sensor suite and detail the current status of subsystem development. Section 3.5 discusses the DVI subsystem, since there has been a separate and significant activity to incorporate human factors experiments into the design of the DVI.

3.4.2 Subsystem Descriptions and Sensor Suite

The sensor suite for the light-vehicle application of IVBSS consists of multiple vision, radar, inertial, and vehicle sensors and is depicted in Figure 15. The sensors and their applications are detailed in Table 1, with sensors associated with the warning sub-functions as primary or supporting sensors.. The light-vehicle platform includes seven radars (one long-range forward-looking 77-GHz radar, two rear-looking mid-range 24-GHz radars, and four side-looking short-range 24-GHz radars); four cameras; non-differential GPS with an onboard digital map; yaw rate gyroscope; and existing OEM vehicle data signals, such as speed, brake switch, turn signal status, etc. (Note: This does not include separate sensors that will be installed for the data collection effort to analyze the FOT data.)

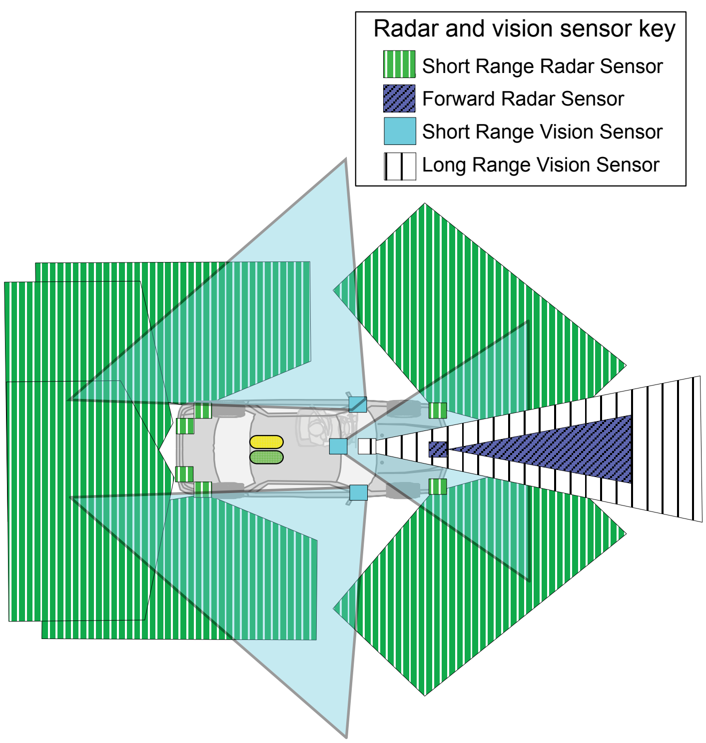


Figure 15. Light-vehicle sensor coverage overview (not to scale)

Table 1. Light-vehicle IVBSS sensor suite versus warning function

Sensor	LDW	FCW	LCM	CSW
Forward radar (1)		X*		
Side radars (2 each side)	X (AMR)		X*	
Rear radars (1 each side)	X (AMR)		X*	
Short-range forward vision (1)	X*	X	X	X
Long-range forward vision (1)		X		
Side/rear vision (left and right)	X (AMR)		X	
Vehicle yaw rate (1)	X	X	X	X
Vehicle data (speed, brake, turn, wipers, headlights, etc.)	X	X	X	X
GPS/dynamic database		X	X	X*

* = Primary sensor

The following addresses the separate subsystems including a subsystem overview, concept of operation, hardware, software, interactions with other systems, and status of subsystem development and major activities in the upcoming year.

3.4.2.1. Forward Collision Warning) Concept of Operation and Progress and Accomplishments

3.4.2.1.1. Subsystem Overview

FCW uses radar, vision, and other onboard and map signals to detect and identify vehicles that the subject vehicle may potentially strike. The radar provides several tracks that are processed to identify legitimate vehicle threats, and then a computation determines when to request a FCW alert. The arbitration subsystem considers the request in conjunction with any other existing or impending requests from other warning subsystems, and decides whether to provide a crash alert to the driver.

3.4.2.1.2. Concept of Operations

The forward collision warning system warns the driver when the vehicle is in danger of striking the rear end of another same-direction or stopped vehicle. The objective of this system is to warn the driver early enough to avoid the collision, while avoiding excessive nuisance alerts.
FCW system design attempts to address different forward collision scenarios such as:

- Subject vehicle (vehicle equipped with the system) is moving on a straight or curved road, and there is a slower, stopped, or decelerating lead vehicle in the subject vehicle’s current lane (straight or curved);
- Subject vehicle is moving on a straight or curved road following a lead vehicle. The lead vehicle changes lanes and a new slower, stopped, or decelerating lead vehicle appears in the subject vehicle’s current lane (straight or curved); and
- Subject vehicle is moving on a straight or curved road following a lead vehicle. The subject vehicle changes lanes toward a new slower, stopped, or decelerating lead vehicle.

In all of these scenarios the FCW is expected to warn the driver. The timing of the warning depends on the design tradeoff that is needed to minimize the number of nuisance and false alarms. The FCW system will not issue crash alerts in response to opposite-direction traffic, crossing-path traffic, or vehicles that are outside of the current subject vehicle travel lane.

3.4.2.1.3. Hardware

FCW processing occurs in the LFAD module, as previously described. FCW will use long-range Bosch radar to detect and track objects in the forward scene, and a CMOS long-range forward-looking camera to supplement the radar data for object validation and characterization.

3.4.2.1.4. Software

There are seven FCW software modules:

- **Radar-based scene tracking**: Tracks objects with respect to the subject vehicle;
- **Path prediction and data fusion**: Determines the upcoming geometry;
- **Primary target determination**: Determines the in-lane primary target that is considered the most likely to pose a crash threat;
- **Vision-based primary target validation and characterization**: Validates the choice of primary target, and includes verification that the target is a relevant vehicle;
- **Threat assessment**: Given the primary target, decides whether to issue an FCW crash alert request; and
- **FCW false alarm management**: Manages false alarms to reduce the nuisance alarm rate. Employs historical data including previous FCW alerts and subsequent driver responses.

3.4.2.1.5. Interaction with Other Subsystems

FCW uses information from other warning systems. For example, CSW map-matching and road characterization data is used to enhance forward situational awareness and to locate false alarm areas. Lane position information and vehicle data is also used. FCW also provides other subsystems with the predicted path data.

3.4.2.1.6. Development Activity

CAN and serial communications have been established between the FCW and other systems. FCW algorithms have been implemented in Matlab/Simulink and used in a simulation environment. For the simulation, real-world data has been used to develop and validate the algorithms. The algorithm models were then migrated to a rapid prototyping environment and installed on a test vehicle for further subsystem development on the road. FCW system development is well underway and interactions with other subsystems will begin once an integrated vehicle build is available.

The current algorithm development status is as follows:

- A radar-based FCW algorithm was implemented and is running in the vehicle;
- Vehicle detection and tracking has been implemented;
- Forward-radar sensor-track filtering was implemented based on a Visteon algorithm (filters 32 targets to eight targets);
- Vehicle-based target validation and characterization are nearing completion;
- Long-range vision algorithm development is underway;
- A fused FCW algorithm (vision and radar) is in progress, with completion expected in February 2007; and
- Interface protocol is complete and implemented for proper communications between FCW and the yaw rate sensor, forward radar sensor, vision platform, CSW, and the vehicle test platform.

3.4.2.2. Lateral Drift Warning Concept of Operation and Progress and Accomplishments

3.4.2.2.1. Subsystem Overview

LDW has the distinct advantage of being the only function addressed by the same technology solution across both light-vehicle and heavy-truck platforms. This cross-platform solution takes the form of the SafeTRAC lane tracking system from Cognex. A cross-platform approach allows advances made for one vehicle platform to be quickly and synergistically employed by the other. The approach also makes some activities common across the two platforms logistically more tractable (e.g., integration and validation testing).

3.4.2.2.2. Concept of Operation

The core sensor of the LDW subsystem is the forward-looking camera, which tracks lane boundaries of the road segment on which the subject vehicle is traveling. Information about the lane boundary positions and motion over time is used to estimate the subject vehicle's lateral position and velocity relative to the lane. This trajectory information is used to assess the threat of unintentionally drifting off the road, and, if the threat is high enough, to warn the driver of the danger.

Challenges of the LDW function include ambiguity about the driver's intentions and imprecision in the driver's lateral control of the vehicle. The latter is particularly significant in heavy trucks where there is little more than a foot of distance between the tire and the lane boundary, even when the vehicle is centered in the lane. However, the greatest of all challenges for LDW is consistently tracking the lane in the wide range of weather, lighting, and road conditions encountered by drivers in the real world.

3.4.2.2.3. Hardware

The commercially available SafeTRAC system consists of an LDW processing module with a driver interface and a small camera as shown in Figure 16.

Figure 16. Forward-looking LDW camera system hardware

The camera for the LDW subsystem is mounted near the top center of the windshield of the vehicle. The camera is mounted within the sweep of the windshield wipers, but outside the areas where the windshield wipers cause water to pool (Figure 17).

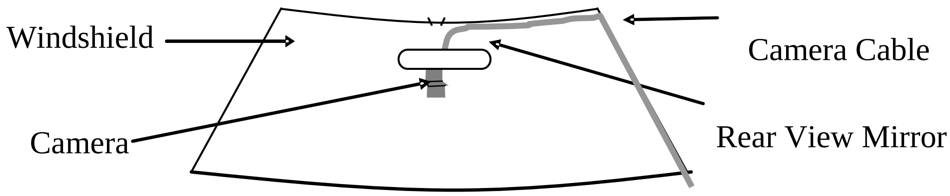


Figure 17. LDW forward camera-mounting location

The LDW module (1) is connected to the camera by a camera cable, (2) has a 12- to 24-volt power supply, and (3) is approximately 6 inches deep, 7.5 inches wide, and 2.5 inches tall. The LDW subsystem communicates over the IVBSS system CAN bus.

For Phase II, the LDW module and camera will migrate to a single-box solution, where the microprocessor, imager, and camera are housed in one unit. The footprint for the new LDW module for the FOT is approximately that of a typical electronic toll collection transponder unit.

3.4.2.2.4. Software

The LDW software builds on the successful LDW system fielded in the road departure crash warning field operational test program.[16] The overarching lesson from RDCW relating to the LDW subsystem was the need to maximize availability without an unacceptable rate of false alarms. A high-level overview of the software functionality is shown in Figure 18.

The software consists of three basic components. “Get image” is responsible for acquiring the image and selecting the region of interest. “Process image” is responsible for identifying key features in the image such as lane markings and then interpreting the locations of these features to determine key variables such as lateral position and lateral velocity. “Threat assessment” is responsible for determining when a warning should be issued based on the key variables. The primary output of these computations is the crash alert request (shown on the right side of the figure), with intermediate information for other subsystems resulting from image processing (outputs shown at the top of the figure).

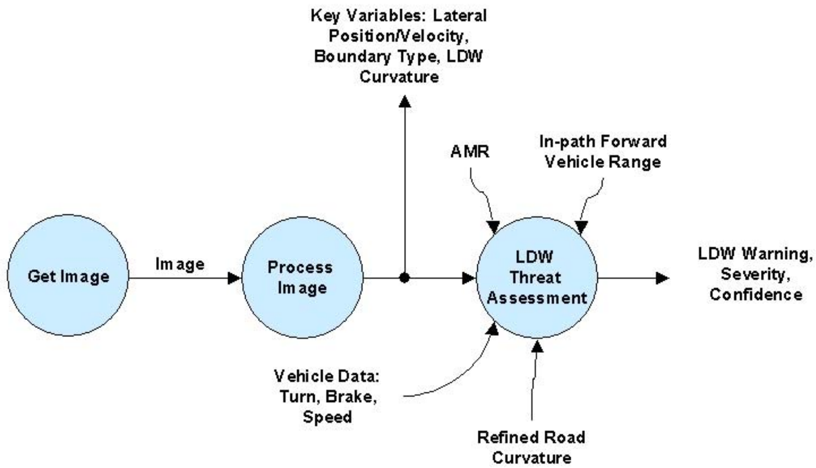


Figure 18. High-level LDW software overview

3.4.2.2.5. Interaction with Other Subsystems

LDW will have three types of interactions with the other IVBSS subsystems. These three main types of interactions and examples of each are listed below:

1) LDW will use information from the other subsystems to improve LDW performance.
   a. If the LCM subsystem detects a nearby object in an adjacent lane, the LDW warning threshold will be adjusted to warn earlier.
2) LDW will send information to the other subsystems so that they can improve their performance.
   a. Lateral velocity will be broadcast by the LDW subsystem. This information will be used by the LCM subsystem to delay warnings until there is lateral motion toward an occupied adjacent lane.
   b. Boundary type information will be broadcast by the LDW subsystem. The FCW subsystem can delay a warning if there is an adjacent lane (dashed boundary) that is unoccupied (LCM reports no adjacent obstacle).
   c. Vehicle position and lane-change information will be posted by the LDW subsystem. The FCW subsystem can use this data to improve its estimation of which radar returns are in the subject vehicle's path.
3) LDW and other subsystems will work together to improve situational awareness, e.g., refined curvature estimate.

3.4.2.2.6. Development Activity

During the first year of the IVBSS program, researchers implemented a three-pronged approach to meet the challenge of increased availability of:

- A new, more capable imager and processor (CMOS);
- Improved image processing algorithms that are accurate about – when to warn; and
- Improved false and nuisance alarm management to allow for accuracy – when not to warn.

The combination of switching to a CMOS imager and improving the low-level algorithms for addressing lighting extremes will help ensure that the LDW subsystem availability will increase and the false alarm rate will decrease as compared to RDCW. The new CMOS camera that will be used in the IVBSS LDW system can image both the bright and dark parts of the scene better than the CCD imager used in RDCW.

Figure 19 shows similarly promising results with the new camera in on-road experiments driving towards a setting sun, a situation that was found to be challenging for LDW during RDCW. Notice the “blooming artifacts” (bright vertical stripes) in the CCD image on the left. The new CMOS imager on the right is able to image the lane markers much more effectively, which will make tracking the lane easier for LDW.

Another major LDW activity this year has been to design a new imager, along with a new, more powerful image-processing microprocessor, into a small, ruggedized package that will be used on both light vehicles and heavy trucks. The new design, shown in Figure 20, mounts directly to the windshield.

During the second year, the hardware and software for the new LDW will be completed and tested, first in isolation and then after integration, as part of the larger IVBSS system.

Figure 19. Low-sun-angle tests of old CCD and new CMOS cameras

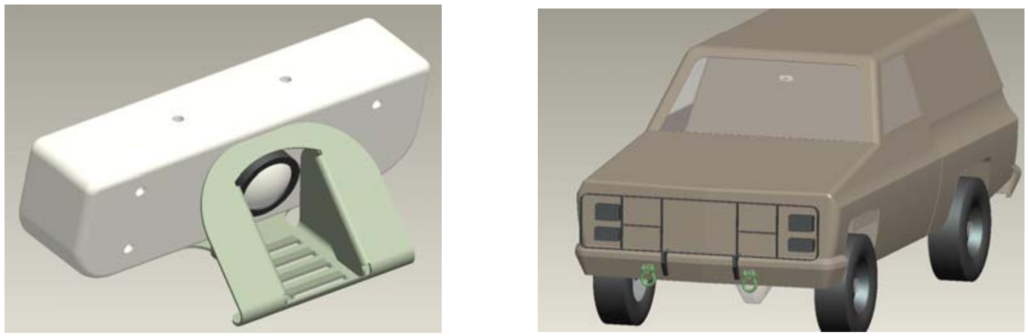


Figure 20. LDW camera and processor packaging, close-up and mounted on the windshield

3.4.2.3. Lane-Change/Merge (LCM) Concept of Operation and Progress/Accomplishments

3.4.2.3.1. Subsystem Overview

The lane-change/merge (LCM) subsystem addresses side-collision scenarios involving lane-change maneuvering of the subject vehicle or merging by the subject vehicle into an occupied lane. Side-looking radar is used to identify potential hazards in an adjacent zone extending from just in front of, to substantially rearward of, the subject vehicle. A crash alert is generated when a collision hazard exists in the adjacent zone, due to the lateral motion of the subject vehicle. Advisory information is provided by illuminating icons on the side mirrors when a same-direction moving vehicle is detected in, or may be moving into, the blind-spot zone.

3.4.2.3.2. Concept of Operations

Three basic functions comprise the LCM subsystem: (1) warning the driver of side-collision hazards due to subject vehicle lane-changes or merging, (2) informing the driver of same-direction traffic in adjacent lanes (within a blind-spot zone), and (3) providing lateral available maneuvering room (AMR) for use by other subsystems. Three short-range radar sensors are positioned on each side of the subject vehicle, providing obstacle data. The data is used to create an awareness of obstacles in the adjacent proximity zones that extend from 0.5 to 3 meters laterally from the side of the subject vehicle and run from approximately 3 meters forward of the front bumper to 18 meters rearward of the back bumper. (See reference 12 for more information.)

The blind-spot zone is a subset of the adjacent proximity zone that represents the area of the adjacent lane that is difficult for the driver to see, both directly by turning the head and indirectly via the side mirror. The blind-spot zone extends from 0.5 to 3 meters laterally from the side of the subject vehicle and runs from approximately the B pillar to 3 meters rearward of the back bumper. (See reference 12 for more information.)

The AMR function delivers a pair of outputs that quantify the available lateral distance from the subject vehicle to detected objects in the adjacent path or adjacent lane. The goal of this function is to optimize IVBSS warnings and improve the performance that standalone IVBSS features can provide. AMR will enable IVBSS systems to respond to environment factors beyond the detection capabilities of any single system.

3.4.2.3.3. Hardware

LCM algorithms will be housed in the LFAD module as previously described. Radar sensor data will be processed using three RPU modules, which will communicate with the LFAD module on a dedicated high-speed CAN bus (LCM CAN). Each RPU module will process the radar data and transmit the target information to the LCM as input to the LCM threat assessment module. The software model used is a modification of the already-developed Visteon blind-spot-detection algorithms and applications, which saved a significant amount of time to the overall LCM development time.

The two side-vision modules will also communicate with LFAD over the LCM CAN bus. For the light-vehicle IVBSS FOT, the LCM algorithms will migrate to three next-generation RPU modules designed and manufactured at Visteon. The next-generation RPU is under development. It will have a 32-bit dual-processor microcontroller architecture.

The Visteon multi-function vision board module with integrated CMOS camera is planned for the LCM subsystem. The MFVB module packaging constraints and lens selection for a side-looking system are being developed.

For the IVBSS program, vision is being considered to provide suitable location and tracking of other vehicles. The algorithms are being developed with vision incorporated under the assumption that vision will provide improved azimuth information and target characterization information to improve LCM threat assessment. The forward vision module will communicate directly to the LFAD (for FCW) over a shared high-speed CAN bus, which is shared with the long-range radar sensor. The vision module will provide primary target validation and characterization information to the LFAD.

3.4.2.3.4. Software

There are six basic software functions for LCM:

- Available maneuvering room estimation;
- Blind spot detection;
- Closing vehicle detection;
- Merge detection;
- LCM false alarm management; and
- Threat assessment.

3.4.2.3.5. Interaction with Other Subsystems

The LCM subsystem generates three outputs important to the IVBSS system. The primary function of the LCM subsystem is to warn drivers of lane-change and merge hazardous situations. The LCM subsystem supplies information on impending hazards to the arbitration subsystem. The arbitration subsystem is responsible for ensuring that IVBSS presents the most useful and timely warning to the driver, since multiple situations may occur simultaneously. Another function of LCM is to provide AMR to other subsystems.

3.4.2.3.6. Development Activity

In the first year of the IVBSS program, significant progress was made on the LCM algorithm development; specifically, the team has:

- Developed an expert-assisted LCM warning algorithm using an inference process that:
  - Handles imprecise input variables;
  - Provides robustness to measurement uncertainties; and
  - Incorporates driver experience and knowledge.
- Implemented core LCM warning algorithm based on radar sensor inputs;
- Simulated LCM algorithm using idealized data;
- Captured LCM and AMR functional and performance requirements and operational zones;
- Determined radar-sensor installation geometry;
- Supported bracket design;
- Determined key sensor-location parameters for software development;
- Initiated investigation of supplemental side-vision sensors;
- Developed simulation for radar signal processing;
- Captured in-vehicle LCM radar sensor data for analysis and offline processing; and
- Validated target detection and proper capture of target x-y coordinates.

For the second year of the program, the team will:

- Enhance LCM warning algorithm;
- Continue program implementation and simulation;
- Run LCM simulation with real data;
- Process radar sensor signals based on measured data using sensor data fusion, data clustering, and other signal processing methods;
- Test LCM warning system in-vehicle;
- Verify combined sensor data quality; and
- Finalize implementation plan for side vision.

3.4.2.4. Curve Speed Warning Concept of Operation and Progress/Accomplishments

3.4.2.4.1. Subsystem Overview

The CSW subsystem will extract data from the digital map and use lane tracking and detection information from the LDW module to assess the threat of losing control of the vehicle in an upcoming curve.

3.4.2.4.2. Concept of Operations

The CSW system warns the driver when the vehicle is traveling too fast for an upcoming curve. The objective of this system is to warn the driver early enough to avoid possible road departure at some point in the curve.

CSW system design attempts to address curves in both single and branching road geometries. In all of these road scenarios, the CSW will issue a warning if the driver exceeds the desired system-designated speed for the curve. CSW will not warn drivers for turns and intersections; it will also not warn for speeds less than the IVBSS-enabling speed.

The basic CSW system is navigation-based, using the navigation system to place the vehicle position on the map. It then uses the CSW algorithm to look ahead on the map, extract all possible driving path candidates, determine the intended driving path, performs a curvature calculation on the geometric data of this path, and finally perform a threat assessment based on vehicle speed and the road curvature ahead.

The intended driving path determination is achieved by designing a look-ahead module (LAM) that looks forward from the vehicle position to the look-ahead distance. The LAM determines the most probable path of the vehicle using information from vehicle positioning, lane information (provided by Vision), lateral velocity, and vehicle signals and state.

The IVBSS CSW design will have a special module to manage false alarms, which will attempt to detect some of the map database errors to suppress possible false alarms. It is also intended to build a false alarm database to mask some of the repeatable false alarms.

3.4.2.4.3. Hardware

The CSW algorithms and software will be integrated into the Prolificx TrakPod. The TrakPod is supplied as an OEM navigation module running the Windows CE 5.0 operating system, which allows system integrators and software developers to implement custom software solutions. The CSW module will communicate with the IVBSS system through an RS-232 serial connection to the LFAD module, and will have an external GPS antenna.

3.4.2.4.4. Software

There are six software modules:

- **Vehicle positioning system**: Locates the vehicle on the map;
- **Look-ahead module**: Extracts all possible road candidates;
- **Most likely path (MLP) calculation**: Determines the most likely path of the subject vehicle;
- **Curvature calculation**: Calculates the curvature of the MLP;
- **Threat assessment**: Assesses the threat based on road geometry and subject vehicle data; and
- **CSW and FCW false alarm database management**: Manages false alarms to reduce the nuisance alarm rate.

3.4.2.4.5. Interaction with Other Subsystems

The CSW subsystem provides the GPS latitude and longitude information to all other subsystems and will provide the road geometry and road attributes to the other subsystems.

3.4.2.4.6. Development Activity

The CSW algorithm is based on the road departure crash warning system developed for the field operational test deployment. Analysis of the RDCW data, both objective and subjective, revealed several areas of improvement for CSW that would significantly reduce the false alarm and nuisance alert rate. The improvements were incorporated into an enhanced algorithm and ported to new CSW hardware. The CSW subsystem is currently up and running on a test vehicle.
For the second year of the IVBSS program, the CSW algorithm will be tested in-vehicle with a fully equipped IVBSS system.

3.4.2.5. Arbitration Concept of Operation and Progress/Accomplishments

3.4.2.5.1. Subsystem Overview

The arbitration process is unique to IVBSS, a feature not found in standalone crash warning installations. Arbitration is necessary to manage the amount of information conveyed to a driver at any given time. Each subsystem is responsible for its own threat assessment and uses synergistic information from other subsystems to make its own treat assessment more robust and valuable. Arbitration continually monitors all subsystems to manage the DVI resources when multiple requests for DVI resources are likely to occur at, or very near, the same time.

The arbitration subsystem also incorporates knowledge of previous false-alarm situations, a driver behavior model, and road condition information to improve the overall system performance with regard to driver acceptance by eliminating some nuisance alarms. The module will identify subsystem threats, identify arbitrated false alarms, determine arbitrated road conditions, determine driver alertness and driver style, determine threat precedence, determine desired driver response, and issue appropriate warnings.

3.4.2.6. Concept of Operations

Threats develop or build over time, and arbitration monitors the subsystem looking for conflicts to be developing between subsystems, primarily lateral (to the side) or longitudinal (forward) threats such as the one shown in Figure 21. Until such time that conflicts between subsystems arise, arbitration passes DVI requests directly to the DVI subsystem. Once a conflict is identified, the arbitration subsystem determines the best warning to send to the driver. Arbitration is the only subsystem that can request the DVI subsystem to present a warning to the driver. To avoid conflicting warnings, arbitration must select a single warning to present at any given time, or present no warning at all if the driver is fully engaged in driving.

Figure 21 shows a complex situation that is handled by arbitration. In the figure, forward collision warning is circumvented by a lane-change/merge warning because a new path was identified.

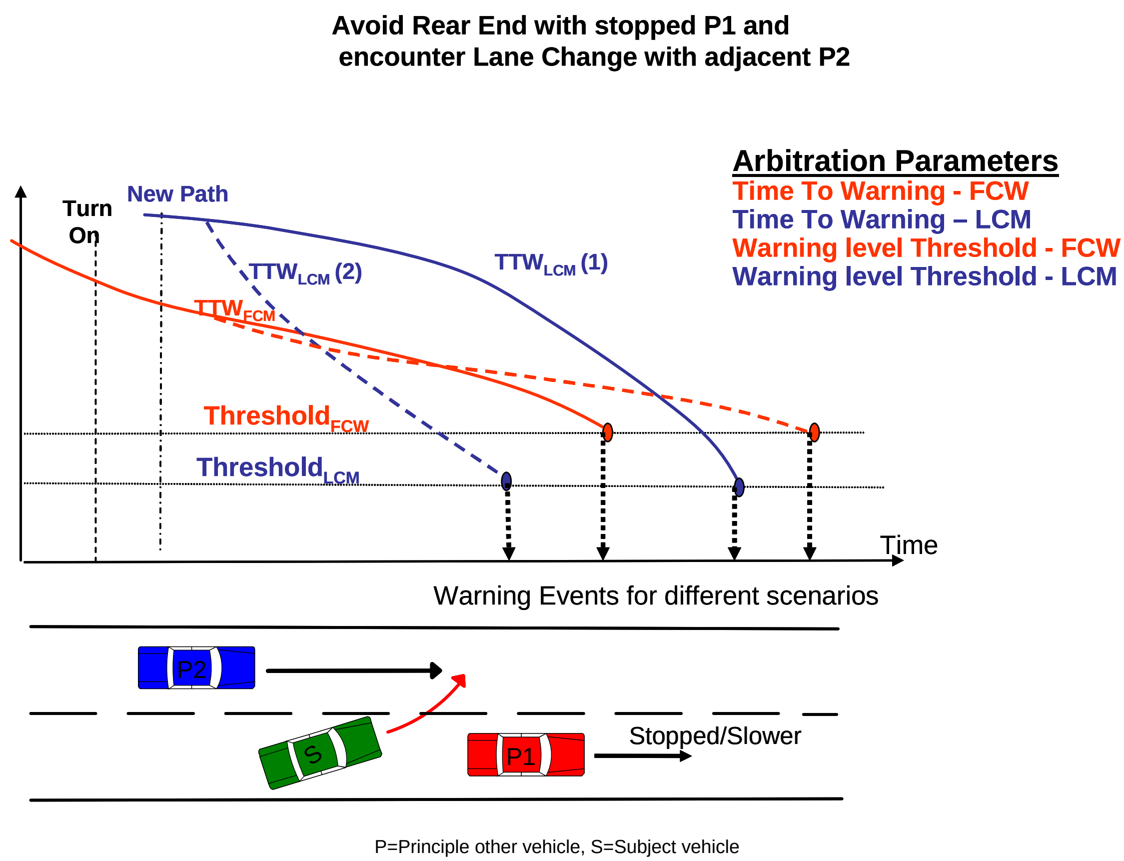


Figure 21. Concept of operations for arbitration

3.4.2.6.1. Hardware

For Phase I development, the arbitration algorithm will be run in the LFAD module. For Phase II FOT deployments, the algorithm will migrate with the DVI algorithm to a single cRIO.

3.4.2.6.2. Software

The prototype arbitration algorithm is being developed in a MatLab/Simulink environment using state flow diagrams (parallel and hierarchical structure for four-subsystem data analysis). Arbitration approaches are being examined to provide a candidate approach in the first quarter of 2007.

3.4.2.6.3. Interaction with Other Subsystems

Each of the four warning subsystems (FCW, CSW, LDW, and LCM) will transmit information of detected potential hazards to the arbitration subsystem for evaluation as a whole. Arbitration is the only subsystem to request the DVI subsystem to generate a warning. It will do so based on information provided by the four warning subsystems, including alert requests and estimates of the time-to-warning. If TTW is low and decreasing for two warning subsystems, it is an indication that arbitration must consider whether to suppress or delay one or both.

3.4.2.6.4. Development Activity

Development of the arbitration subsystem is in the initial model phase. Further model modifications are being explored as information formats of the other subsystems are finalized. Several optimizations and refinements of the arbitration algorithm are also being conducted. Initial values are set based on the driver behavior pre-analysis decision. A scaling approach defines a quantitative model of time-to-warning and time-to-event uni-modal reasoning for arbitration and threat assessment. The development team will examine further streamlining of this process.

In the second year of Phase I, the arbitration algorithm and software will continue to be developed to:

- Maximize real data processing from IVBSS subsystems;
- Analyze and classify driver style and driver alertness based on countermeasure activities;
- Analyze timing for warning- and geometry-based arbitration with DVI activity; parameters; and
- Create a simulation model of multiple-threat scenarios to aid in the overall design of the arbitration algorithm.

3.4.3 Second Year Activities and Schedule

In the second year, Phase I will conclude. All functional subsystem development activities will have been completed according to the overall schedule shown in Figure 22.

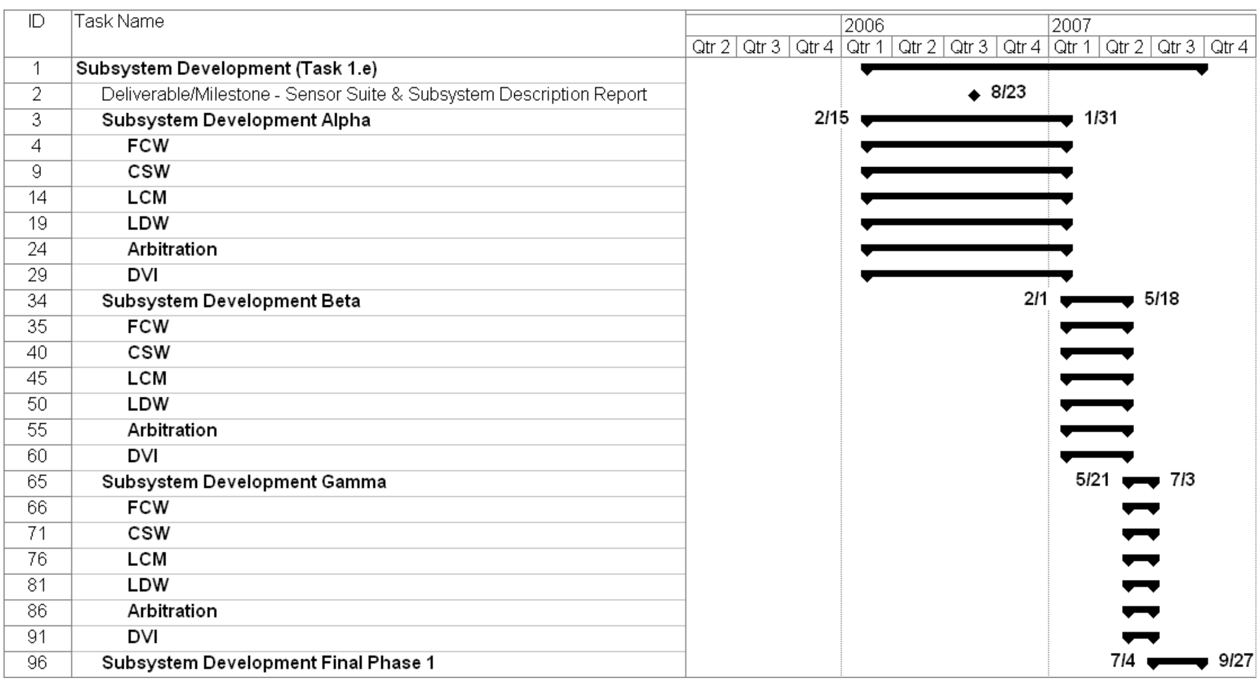


Figure 22. Light-vehicle schedule for subsystem development

3.5 Development of Driver-Vehicle Interface

Designing an integrated DVI that provides intuitive, effective, and driver-accepted information is one of the unique challenges of the IVBSS program. This design is based on experience from previous projects, simulator studies, and in-vehicle testing. This section addresses the development of DVI hardware and software capabilities onboard the vehicle that will host the eventual DVI design. Chapter 6 addresses the research program that will provide the basic insights into integrating these warning systems.

3.5.1 Overview

The general approach to designing the DVI for both the light-vehicle and heavy-truck platforms has been to design in hardware flexibility early in the system design and development stages. This allows human factors testing and evaluation to take place in parallel with the development of the IVBSS system, with the DVI team understanding any constraints there may be on the final implementation.

Early decisions regarding the types of hardware that will be available to the DVI team on the two platforms were made, and a team of human factors experts worked directly with the IVBSS systems design and development teams to ensure that the hardware selection met the anticipated needs based upon the outcome of the human factors testing. This involved making some early assumptions regarding the scope of the DVI, based on some fundamental human factors principals, to allow the programs DVI and systems development teams to proceed in parallel. The following describes the DVI option space and current status of the light-vehicle DVI hardware development.

3.5.2 Light-vehicle DVI Option Space

A preliminary specification of the modality of crash alerts and advisories was developed as shown in Table 2 and Table 3. These tables reflect a preliminary view of IVBSS; however, ongoing human factors experiments may result in revisions that will be included in the final design. These tables drive an option space (required technical capabilities) for the DVI hardware and software onboard the vehicles. The option space must include the following:

- Visual displays in the cabin and on the side rearview mirrors;
- Audible displays including the ability to provide left- or right-directional cues;
- Haptic cues in the driver’s seat; and
- Brake pulse capability.

Table 2. Preliminary crash alerts for the light-vehicle platform

Type of Crash Conflict	Crash Alert Auditory Component	Crash Alert Haptic Component	Crash Alert Visual Indicator
Striking rear-end of vehicle ahead	Audible cue A (optional)	Brake pulse A	Visual cue A
Curve-over speed crash	Audible cue A or B (optional)	Brake pulse A	Visual cue B
Drifting out of lane – No object identified as crash threat (optional)	None	Haptic vibration in seat –Directional	Visual cue C
Drifting off road – No object identified as crash threat	None	Haptic vibration in seat – Directional	Visual cue C
Drifting off road or out of lane – Object identified as crash threat	Audible cue C – Directional	Haptic vibration in seat – Directional	Visual cue C
Lane-change crash or merging crash	Audible cue C – Directional	Haptic vibration in seat – Directional	Visual cue C or D

Table 3. Preliminary advisories for the light-vehicle platform

Type of Information	Advisories (Visual Only)
Forward object – Potential threat	Forward target detected (optional)
Forward roadway curve	Information regarding upcoming curve (optional)
Side object – Potential threat	Indicator or icon when vehicle in side-object zone (optional)

To host these capabilities, the light-vehicle LFAD module houses the LCM, FCW, arbitration, and DVI modules. LFAD consists of a National Instruments PXI controller with two compact reconfigurable input-output modules (cRIOs) and will be used for development. The DVI will migrate to the cRIO-embedded target (shared with arbitration) for the IVBSS FOT vehicle.

The DVI module interfaces are shown in Figure 23, and include interfaces for accepting driver inputs, providing IVBSS driver information (visual, audible, and haptic), and exchanging data with other subsystems and the vehicle through a project CAN bus. The figure shows capabilities for interfaces and is not intended to describe the final design of the DVI. Three visual cues will be provided: (1) an OEM text and icon display on the center stack above the audio system and HVAC controls, (2) icons on both side-view mirrors, and (3) icons displayed by reflecting LED lights off the windshield. Audible cues will be delivered through the driver headrest speakers, with right-left directionality. Haptic cues can be provided in the driver seat pan (with right-left directional capabilities) and through brake pulses.

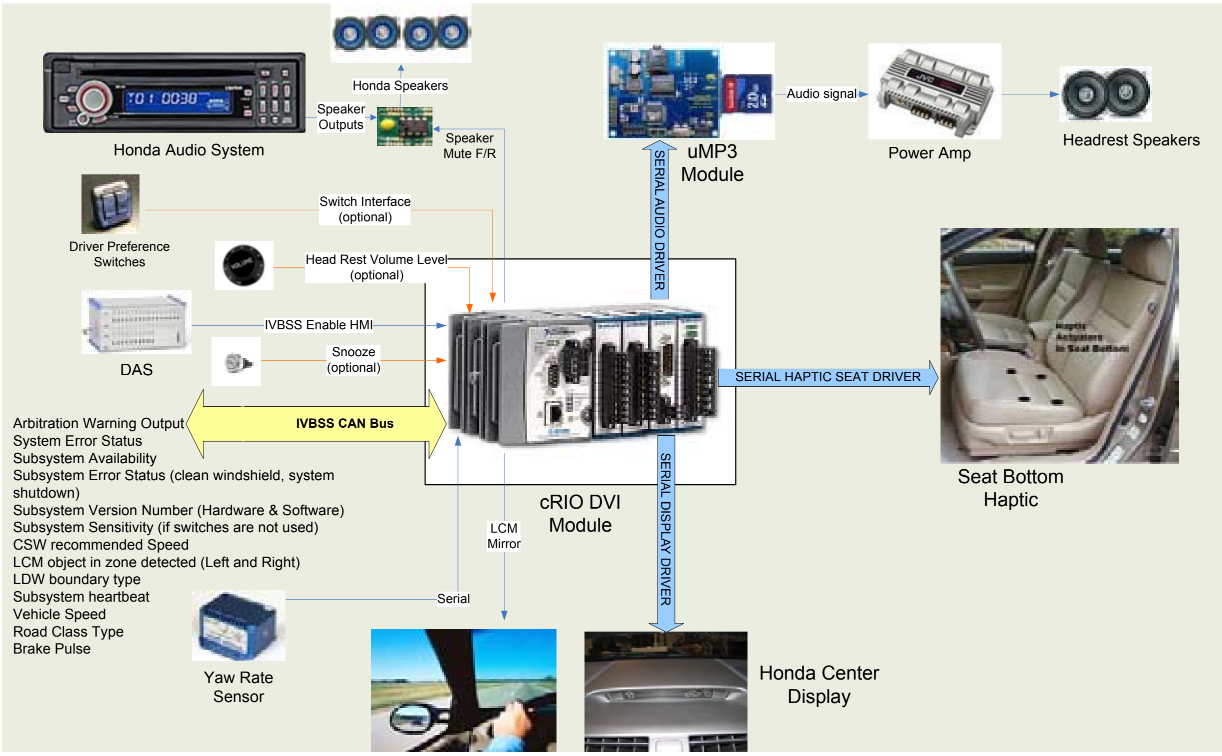


Figure 23. Driver-vehicle interface block diagram

Driver inputs that will be possible to implement include:

- Driver preference switches (for adjusting crash alert timing);
- Driver audio volume control (for headrest speakers);
- Driver temporary IVBSS mute button (to suppress unwanted alerts for a brief period); and
- An input to configure the DVI in a demonstration mode.

The light-vehicle development vehicles will be built with all of the hardware described in the following sections.

3.5.2.1. Driver Control Interface

This section addresses the implementation of the driver input options.

3.5.2.1.1. Driver Preference Switches

There will be two double-pole and double-throw driver preference switches. Each switch will have three positions for driver preference: low, medium, and high. One sensitivity switch could be used for longitudinal adjustment (FCW and CSW) and the other for lateral adjustment (LDW and LCM). Depending on the output of the DVI experimental work and considerations, it would also be possible to use only one switch (or no switches). The DVI module will monitor the status of the driver preference switches and report the settings over the IVBSS system CAN bus.

3.5.2.1.2. Head Rest Volume
An ITT Canon switch is also being used for the volume. The driver will be able to select from one of three predefined volume levels (low, medium, and high), but will not be allowed to turn the volume off completely.

3.5.2.1.3. Temporary Mute Button
All vehicles will be built with a temporary mute (or snooze) button, which, when pressed, will suppress warnings for two minutes. Subsequent button presses will be allowed to suppress warnings in two-minute increments, up to six minutes total or three button presses. This allows drivers to silence the system when in unusual circumstances that are leading to multiple false or nuisance alerts, such as in an unusually complex construction zone. This time increment range is selected using engineering judgments and experience regarding the typical duration of such circumstances, and with a desire to avoid silent operation for long time periods, which may have an impact on safety benefits.

3.5.2.1.4. Demo Mode
The DVI subsystem will allow the DVI to be exercised in a static mode to enable the demonstration of the system functionality. The activation of the demonstration mode will be through a series of button presses during key-on; additional hardware will not be required.

3.5.2.2. IVBSS Displays
This section addresses the hardware and software that allows presentation of IVBSS crash alerts and advisories.

3.5.2.2.1. IVBSS Driver Display (Center Stack)
The custom IVBSS display will be mounted in the center stack using a modified Honda HVAC and radio display housing, and a Noritake VF dot matrix display. It will dim with the vehicle dim thumbwheel position consistently with other Honda components mounted in the IP. At a minimum, the IVBSS display would be capable of providing the following information to the driver:

- System enabled or disabled;
- Current setting of driver preferences (lateral and longitudinal);
- Service required message (system failure);
- Clean windshield message (to prompt the driver to remove debris or dirt that is blocking the forward IVBSS camera views);
- Subsystem availability to provide crash alerts (LDW-left and LDW-right unavailable shall be unique);
- Volume setting;
- Auditory status of IVBSS cues (temporarily muted or audible);
- Advisory of the maximum travel speed that may be comfortable for the upcoming curve; and
- Advisory that confirms detection and tracking of a forward target.

3.5.2.2.2. LCM Icon in Side-View Mirror
The development vehicles are built with a multi-colored LED assembly in the side-view mirror. The assembly contains two LEDs that have the capability of illuminating in either red or yellow.

A separate mobile unit will be built that can be installed on any of the development vehicles after the builds for testing. The unit will have changeable gels so that many options can be studied. The two major study topics are: (1) two icons (blind spot detection and closing zones) versus a single icon and (2) icon selection. If a single-zone icon is selected, a third study will be required to determine what is included in the zone indication.

3.5.2.3. IVBSS Audio

3.5.2.3.1. IVBSS Amplifier

IVBSS employs a JVC KS-AX3300 two-channel, 65 W automotive amplifier. The amplifier is driven directly from the MP3 player (left and right analog inputs).

3.5.2.3.2. MP3 player

The Rogue Robotic MP3 module and SD flash cards for the MP3 audio card will be trunk-mounted. The audio signal output from the MP3 player will be fed directly to the IVBSS amplifier; however, the MP3 will communicate with the DVI module serially.

3.5.2.3.3. Speakers

All vehicles will be built with additional speakers in the driver's headrest and will be controlled via a dedicated IVBSS amplifier.

3.5.2.3.4. Interface to Honda Audio System

The Honda radio controls the Honda speakers. A low-power 5-volt relay controlled by an output from the cRIO digital I/O will be activated when an audible warning is presented to the driver. The relay would only affect the Honda front speakers, resulting in the volume of the front speakers being lowered by 7-8 dBA.

3.5.2.4. IVBSS Haptic Interface

3.5.2.4.1. Brake Pulse

The development vehicles will be built with a haptic brake pulse for forward warnings. The Visteon design team has been working with Honda to create a specialized vehicle stability assist modulator, which will accept commands from the IVBSS system to apply pressure to the brakes. The system is designed with several fail-safe settings, the most noteworthy of which is that both the duration of the pulse and the magnitude of the pressure request are limited.

For development, the brake pulse algorithm is currently running on a cRIO module installed in an Accord EX that has been equipped with the new modulator. The algorithm will vary as a function of speed such that the feel of the brake pulse is consistent over the entire speed range. Several pressure values and durations are being evaluated.

3.5.2.4.2. Haptic Seats

All of the driver's seats have been modified with four haptic motors and one controller on the underside of the driver's seat. The haptic controller communicates serially with the DVI. The haptic controller has a unique communications protocol that has been previously implemented on RDCW. The haptic motors will be activated for LDW cautionary warnings (drift over dashed line without object in adjacent lane), and will be directional (left and right).

3.5.2.5. Development Activity

During the first year of the IVBSS program, the DVI option space was defined. All DVI hardware was selected or designed accordingly. Specifically, during this period:

- Center console panels were modified to integrate the Noritake 240x16 dot matrix display;
- The interface between the cRIO I/O hardware and all DVI components was defined;
- The audio mute circuit was designed and tested;
- The framework software was developed for the DVI to drive the dot matrix display, the audio interface, and the haptic seats;
- The brake pulse interface (IVBSS to VSA module) was defined, designed, and tested; and
- A DVI bench was fabricated and included a seat with haptic motors and headrest speakers installed, the IVBSS driver display, and the audio module.

3.5.3 Second-Year Activities and Schedule

For the second year of the program, the DVI option space will be fully tested and evaluated, and the final design will be set.

3.6 System Integration, Build of Prototype Vehicles, and Verification Testing

This task addresses installing IVBSS on a fleet of development and FOT vehicles.

3.6.1 Overview

The 2006 Accord EX is the vehicle platform for the IVBSS development program. The 2007 model will be the vehicle platform for the IVBSS FOT fleet. Phase I includes the integration of IVBSS on six development vehicles; four of these will be converted into FOT vehicles during Phase II. Phase II will involve installing the IVBSS system on an additional 12 FOT vehicles.

3.6.2 Light-Vehicle Prototype Build Plan

The buildup of the first three development vehicles was started in this performance period and will be completed in early 2007, while the last three vehicles will be completed by mid-2007. The IVBSS system is complex, requiring over 35 components to be designed and installed, not including the hardware required to mount the components to the vehicle or the power distribution hardware. Figure 24 shows the overall integration plan for the IVBSS system. The items to be installed were introduced in earlier sections of this report. Notable in this figure, however, are a few items, such as the DAS cabin camera, that will be integrated only into one development vehicle, but into all the FOT vehicles. Special cases such as this are due to either the fact that some items are not needed until the FOT (such as some DAS-related items), or that integration is supporting a decision about whether to pursue a particular hardware approach. An example of the latter is that the brake pulse capability is not being installed in all development vehicles until a final determination is made.

The majority of the IVBSS components are trunk-mounted. A special trunk rack has been designed that houses the various IVBSS components. The rack is on a track and can move

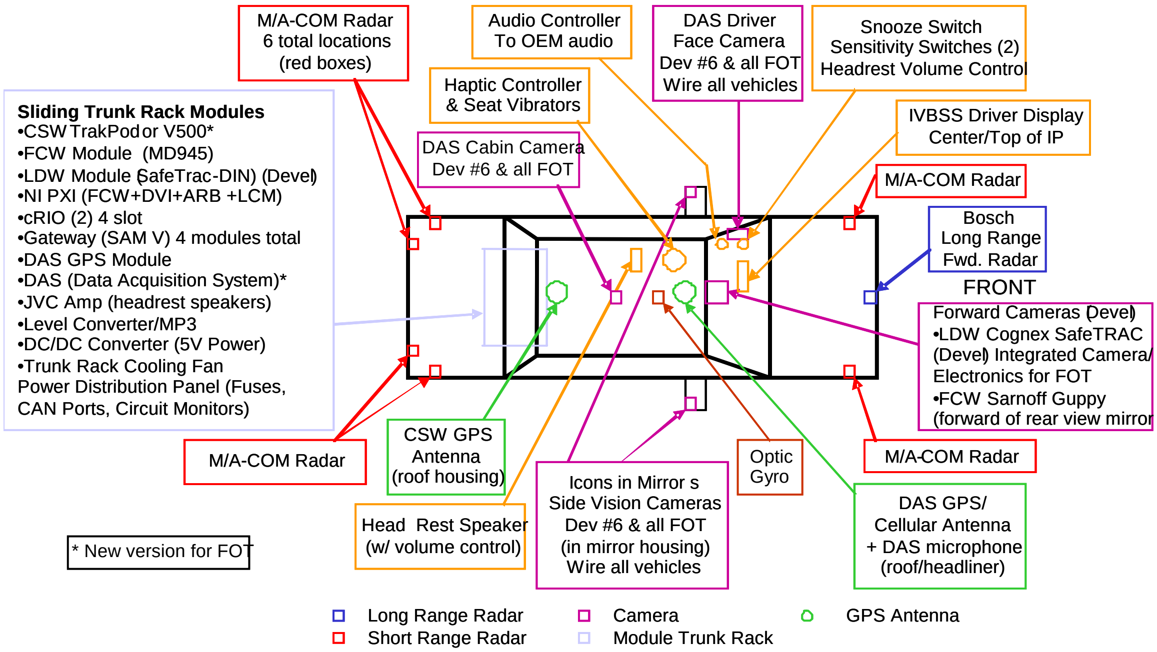


Figure 24. IVBSS module, sensor, and camera placement in vehicle

toward the rear of the trunk to provide easy access to the components during development. Components will be inaccessible to the FOT participants, with a false back made to bar any access from the trunk. The access panel in the back seat will be permanently locked. For development, however, the access panel will provide CAN drops for all of the CAN busses.

3.6.2.1. FCW Subsystem

The FCW algorithm runs on the LFAD module, which is trunk-mounted. The yaw rate sensor will also be mounted in the trunk. The forward radar will be mounted behind the front fascia. The long-range FCW camera is mounted on the windshield, behind the rearview mirror. The FCW vision module also is trunk-mounted.

3.6.2.2. LDW Subsystem

The LDW module is mounted in the trunk, while the short-range LDW camera is mounted on the windshield, behind the rearview mirror.

3.6.2.3. LCM Subsystem

Figure 25 shows the six short-range radar sensors for the LCM subsystem in the vehicle-installed position. LCM algorithms are running on the LFAD module, which is installed in the trunk. The three RDU modules that interface with the radar sensors are also installed in the trunk.

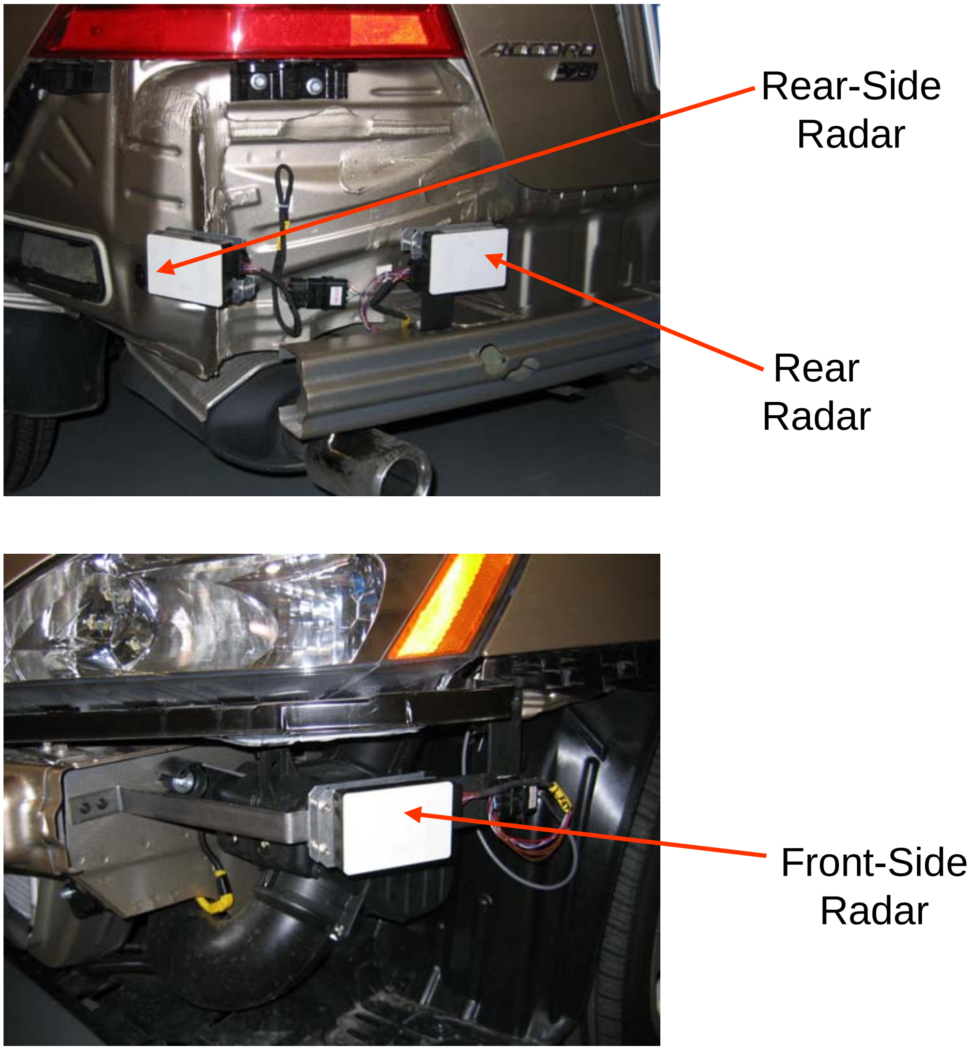


Figure 25. LCM short-range radar sensors

3.6.2.4. CSW Subsystem

The CSW module and associated components are trunk-mounted.

3.6.3 *Second-Year Activities and Schedule*

All six IVBSS development vehicles will be completed in the second year.

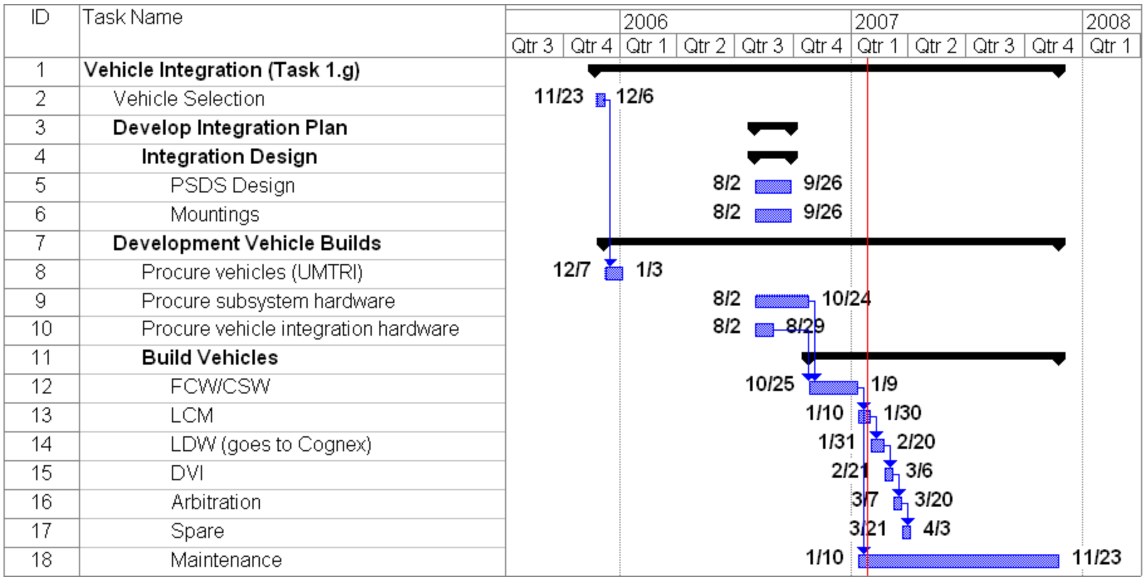


Figure 26. Schedule for light-vehicle system integration and prototype building

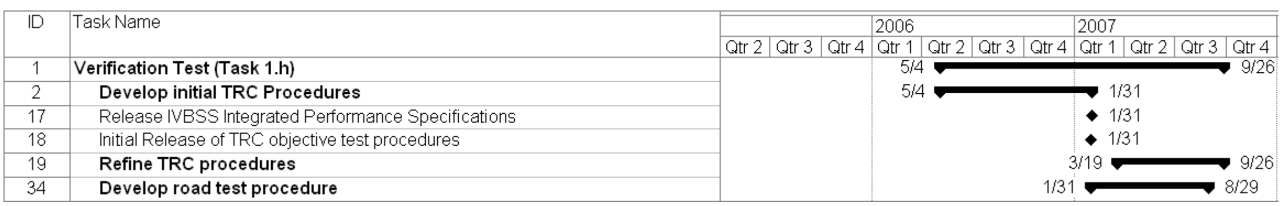


Figure 27. Schedule for light-vehicle verification testing

4 Heavy-Truck Platform

The heavy-truck platform team is comprised of partners from UMTRI, Eaton Corporation, Cognex Corporation, and Battelle Memorial Institute. The team is working to integrate forward collision warning, lane-change/merge warning, and lateral drift warning systems into an integrated safety system on a class 8 tractor for field operational test deployment. Key results from the first year include not only technical accomplishments for the integrated suite of sensors and the integrated system of warning functions and interface, but also team dynamics alignment to better serve the mission and the U.S. DOT.

This section documents the first year's progress on the IVBSS heavy-truck platform. Details are provided for the major elements of the effort, including functional requirements and system architecture, system design and integration, performance guidelines, subsystem and sensor suite details, driver-vehicle interface development, and prototype vehicle builds and development.

4.1 Functional Requirements and System Architecture

The functional requirements and system architecture (Task 1.b) were both developed during year 1. Figure 28 shows the heavy-truck activity within the larger context of the Phase I systems engineering process. The process shown is slightly different from that followed by the light-vehicle team. The heavy-truck team first considered the crash problem and developed an extensive list of crash scenarios and operational scenarios, along with parameters to populate examples of those scenarios. The scenarios were used to directly develop functional requirements, without the use of the system functional model employed by the light-vehicle team. The remainder of the process is

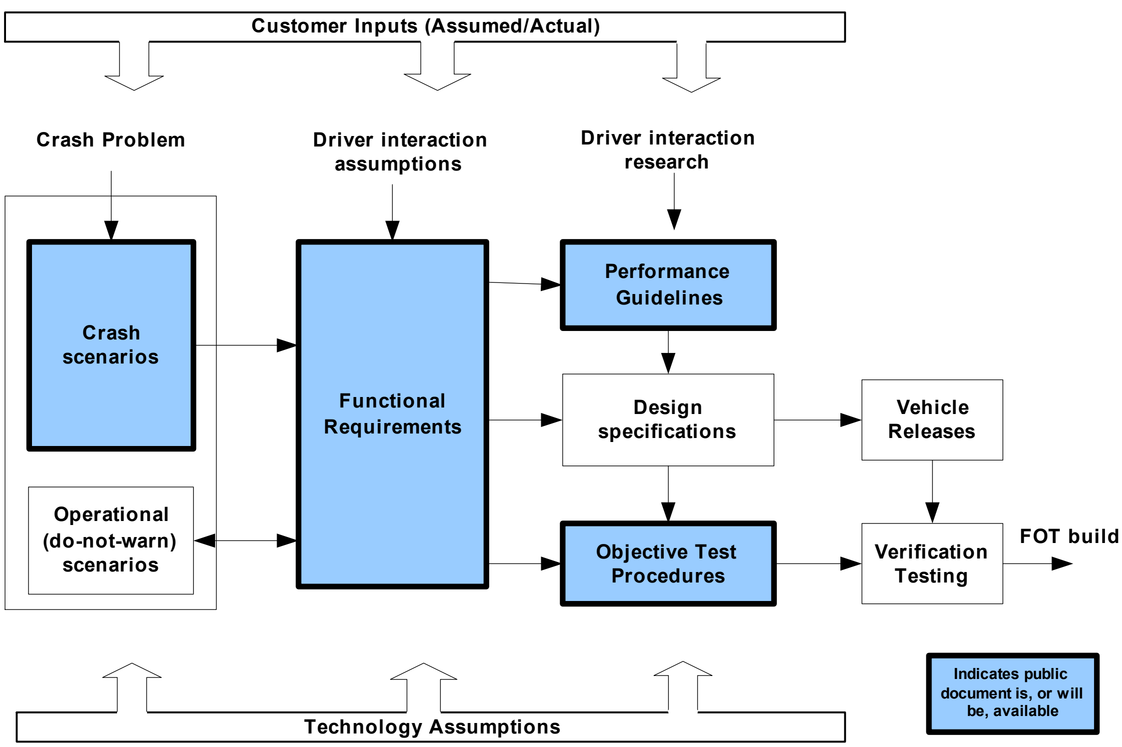


Figure 28. System engineering process for the heavy-truck platform

similar to that described in section 3.1. A preliminary functional requirements report for the heavy-truck platform was delivered and posted for public access.[11]

This process has considered collision warning technologies that have been incorporated and investigated under earlier major U.S. DOT programs, such as lane-change/merge systems,[20] road departure systems,[16 19] and forward collision warning systems.[3 4 14 15] The following sections describe some of the key results of the functional requirements and system architecture efforts.

4.1.1 Overview

IVBSS provides information to the driver to assist in avoiding or reducing the severity of the following four crash types:

- Rear-end crashes where the subject vehicle strikes the rear of a primary other vehicle;
- Road-departure crashes where the driver of the subject vehicle allows the unintentional lateral drift of that vehicle, ultimately taking the vehicle off the road;
- Lane-change/merge crashes where: (1) the subject vehicle intentionally changes lanes and collides with a vehicle that had been moving in the same direction, or (2) the subject vehicle intentionally merges into traffic and collides with a same-direction vehicle; and
- Crashes that involve two or more of the above pre-crash conditions.

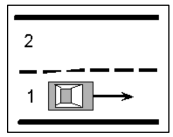
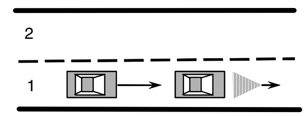
Information about the driver's situation is provided in two forms, crash alerts, and crash advisories. The timing of crash alerts is intended to allow drivers who are unaware of the potential approaching threat to have enough time to react, assess the situation, and decide whether to initiate and complete an evasive maneuver that avoids (or greatly reduces the severity of) a crash . In an integrated system, it is important to address multiple crash scenarios and manage the timing and presentation of that information in a manner that reduces both driver confusion and perception of nuisance.

Overall, it is recognized that an aware driver remains the best decision maker about whether, and how, to conduct such maneuvers. The IVBSS system will not provide automatic control of the vehicle and will not prohibit other systems that do employ active control of the vehicle. Other constraints stated in section 3.1.2 also hold for the heavy-truck platform.

4.1.2 Functional Requirements

The preliminary functional requirements document, which was developed by the heavy-truck team, has been updated and improved through the course of the first year. To focus the requirements development process, the initial activity involved a critical identification and rationalization of the scenarios involved. This involved identifying possible pre-crash and nuisance-alert scenarios and attaching to each scenario a set of attributes to assist with requirements development and validation. Most scenarios were drawn from earlier programs that were referenced above. Early assessment matrices for this task segmented the scenario space by crash type, crash statistics, kinematic properties, warning options, likely driver behavior, and potential commercial viability. The matrix shown in Table 4 indicates some of the attributes that were considered. By analyzing a set of scenarios, it was possible to consider the various functionalities and operating conditions and generate functional requirements and the system architecture.

Table 4. Scenario classification analysis matrix for heavy trucks

Classification	Scenario	Details			
Picture					
Description	No POV's within "warning range" of SV, SV follows an **accelerating** POV	SV appoaches stopped vehicle, SV approaches slower vehicle moving at constant speed, SV approaches decelerating vehicle. From IVBSS RFA it may include uneven road surface-"The intent of the uneven surface is to cause the SV to shake and bounce and possib			
Fusion Opportunity (Synergy)					
Source: CAMP, ACAS, RDCW, IVBSS-RFA, IVBSS-VOLPE= ("Crash Imminent Test Scenarios for Integrated Vehicle Based Safety Systems" document)	**New**	**IVBSS-RFA**			
Sub-Scenario Description		Constant Slower Speed POV	Decelerating POV	Stopped POV	Constant Slower Speed POV - uneven surface
Response Description					
Warning Notes		IVBSS RFA-"The FCWS should detect the POV at a minimum "X" feet and provide an alert to the driver no later than "Y" seconds time to collision". "For this alert (slow constant speed POV), when the POV is within three seconds or 220 feet (whichever is l			
Row(s) of Sheet "Warnings" related to this scenario		4,5,7,8			
Log nuisance alert					
Build digital map database					
Other					
IVBSS Example Specifications for Objective Tests for HD					
Subject Vehicle Velocity (mph)	_	30 (30,60,60,	30 (45,60)	33 (55)	50 (50)
SV Acceleration (g)	_	0	0	0	0
POV1 Vehicle Velocity (mph)	_	20 (10,50,30, 15)	30 (45,60)	0	15 (30)
POV1 Vehicle Range (longitudinal distance to SV)	_	variable	(1 s HW for -.15g, 2s HD for -0.3 g)	variable	

The preliminary functional requirements document was made available to the public on the UMTRI website [11]. The heavy-truck version is very similar to the light-vehicle platform version and includes the same type of requirements as discussed in section 3.1.2.

The heavy-truck and light-vehicle teams worked separately on the requirements, but discussed differences between the respective results; examples of these differing requirements include:

- The heavy-truck platform includes a requirement for alerts based on smaller headway times, while the light-vehicle platform does not include such headway-based crash alerts.

This is because the braking capabilities of heavy trucks cannot always compensate for sudden decelerations by passenger vehicles if the headway is small; appropriate headways thus provide a safety margin. Conversely, a passenger vehicle is assumed to have braking capability comparable to almost any deceleration capability a preceding vehicle may have.

- More consideration of nuisance alerts is necessary for light-vehicle systems, since typical operating environments and driving styles may lead to more nuisance scenarios with customers who are less tolerant of them. Heavy-truck operations typically include more freeway exposure than that seen in the light-vehicle fleet, and while decisions to acquire safety technology are almost entirely economically based for heavy trucks, the light-vehicle market includes a major element of driver preference. Furthermore, light vehicles engage in more lane changes, passing maneuvers, and turns per mile of exposure than do heavy vehicles, which increases the chances of inducing unwanted nuisance alerts.

There will be a final release of the functional requirements document in early 2008. Advances will be made in the areas of driver-vehicle interface requirements, arbitration, and the management of multiple-threat scenarios.

4.1.3 System Architecture

The heavy-truck IVBSS was partitioned into major subsystems and their supporting sensors and software, with a definition of the interfaces and communications between the subsystems. The sensor suite for the heavy-truck IVBSS function consists of multiple vision, radar, inertial, and vehicle sensors that are mostly commercially available, off-the-shelf sensors. These are depicted in Figure 29. The system will also use sensory information from the vehicle CAN bus, such as vehicle speed and brake and vehicle status indicators. In addition to the IVBSS sensors, the data acquisition system will use supplemental sensors for FOT data collection and analysis purposes.

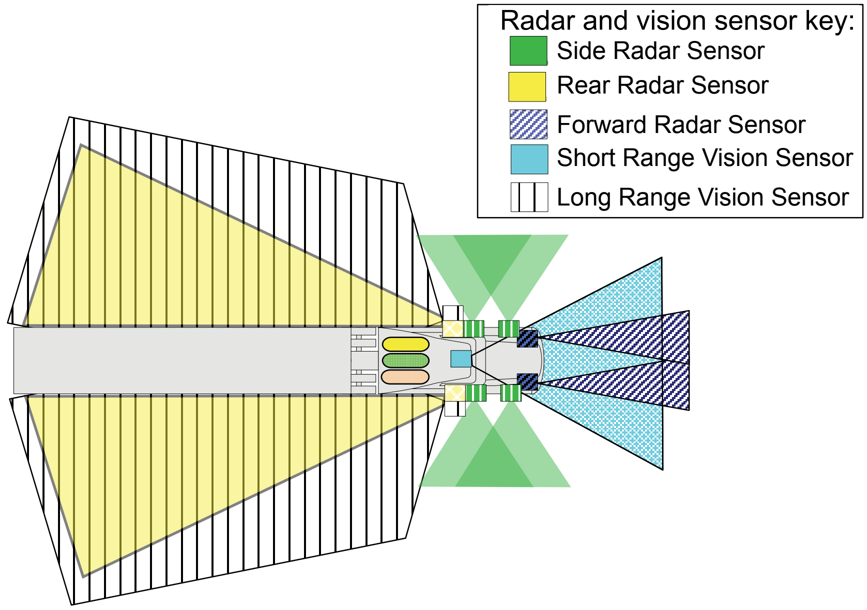


Figure 29. Heavy-truck sensor suite overview (not to scale)

Table 5 summarizes the major sensor elements and identifies those that play primary and supporting roles for the warning functionalities. Forward collision warning uses two forward-looking radar units, lane departure warning uses a single forward-looking camera, and lane-change/merge warning employs a fusion of rear-looking cameras, rear-looking radar, and side radar. Additional information regarding the sensors is as follows:

- **Short-range forward-looking camera**: A short-range forward-looking camera mounted in the vicinity of the top center of the windshield. The camera and dedicated video processing hardware will be based on the Cognex SafeTRAC lane-tracking hardware unit. The azimuth field-of-view of the camera is 38 degrees and the imaging field is up to approximately 25 meters ahead of the subject vehicle.
- **Long-range rear-looking cameras**: Two long-range rear-looking cameras mounted in the vicinity of the tractor side mirrors. The charge-coupled-device cameras will have dedicated video-processing hardware; however, whether they will be monocular, binocular, or stereo camera units will be determined at a later date. The decision regarding the specific camera hardware (monocular or stereo) will be based on the ability of the video processing algorithms to identify side obstacles when using either hardware configuration. It is hypothesized that the stereo configuration provides depth information that may improve the performance of side obstacle identification; however, the extent of the benefit over a monocular configuration is unknown at this time.
- **Short-range side-radar**: Four Eaton (BackSpotter) 5.8-GHz radar units mounted on the heavy-truck platform, two on the left side of the tractor and two on the right. The radar units will detect the presence of objects adjacent to the subject vehicle at a maximum detection range of at least 4 meters and an azimuth field-of-view of 100 degrees.
- **Forward radar**: Two TRW AC20 forward-looking 77-GHz radar units mounted in the vicinity of the tractor headlights will estimate range, range rate, and azimuth of multiple objects ahead of the subject vehicle at a maximum detection range of at least 150 meters and an azimuth field-of-view of 11 degrees. The units will provide dedicated onboard target tracking and FCW warning software.
- **Rear-facing radar**: Two M/A COM C3 SLR rear-looking 24-GHz radar units mounted in the vicinity of the tractor side mirrors will estimate range, range rate, and azimuth of multiple objects adjacent to the subject vehicle at a maximum detection range of at least 30 meters and an azimuth field-of-view of 40 degrees. The units will provide dedicated, onboard target tracking.
- **GPS sensor**: A GPS sensor will determine the position of the subject vehicle. Positional information will be used in conjunction with a dynamically created digital map to provide information related to false alarms, roadside objects, and roadway geometry.
- **Inertial sensors**: A yaw rate sensor will estimate the yaw angle and rate relative to the longitudinal travel of the subject vehicle. A tri-axial accelerometer will estimate the acceleration of the vehicle along three axes.

Table 5. Heavy-truck IVBSS sensor suite versus warning function

Sensor	LDW Sensors	FCW Sensors	LCM Sensors
Forward radar		X*	
Side radar	X (AMR)		X*
Rear radar	X (AMR)		X*
Short-range forward vision	X*		X
Long-range rear vision	X (AMR)		X
Vehicle yaw rate	X	X	X
Vehicle XYZ acceleration	X	X	X
Vehicle data (speed, brake, turn, wipers, headlights)	X	X	X
GPS/dynamic database		X	X

* = Primary sensor

This sensor suite has been installed on the initial engineering development, a Chevrolet Suburban SUV (also known as the "mule" vehicle), and represents a tractor-only solution for sensing. The tractor-only sensor configuration is important for the project and for realistic commercial viability. For a typical fleet operation, there may be three or more trailers out in the field for any given tractor. Furthermore, those trailers will tend to not be "married" to a given tractor. This simplification of architecture has greatly simplified the execution and management of the FOT in Phase II. Additionally, this system architecture has been finalized and implemented on the mule vehicle allowing it to capture datasets for playback and algorithm development and refinement; it will also be used to iterate the system architecture through the second year activity in time for final review and release. The Suburban was selected so that anyone on the development team could drive the vehicle without requiring a commercial driver's license.

The schematic diagram of the heavy-truck IVBSS system hardware architecture is shown in Figure 30. The architecture is based on a four-CAN bus communication infrastructure that facilitates sharing of all sensor data and subsystem module information. The four CAN buses are: (1) the camera/side radar/DVI bus (CAN 1); (2) the J1939 vehicle CAN bus; (3) the forward radar data bus (CAN 2); and (4) the rear radar data bus (CAN 3).

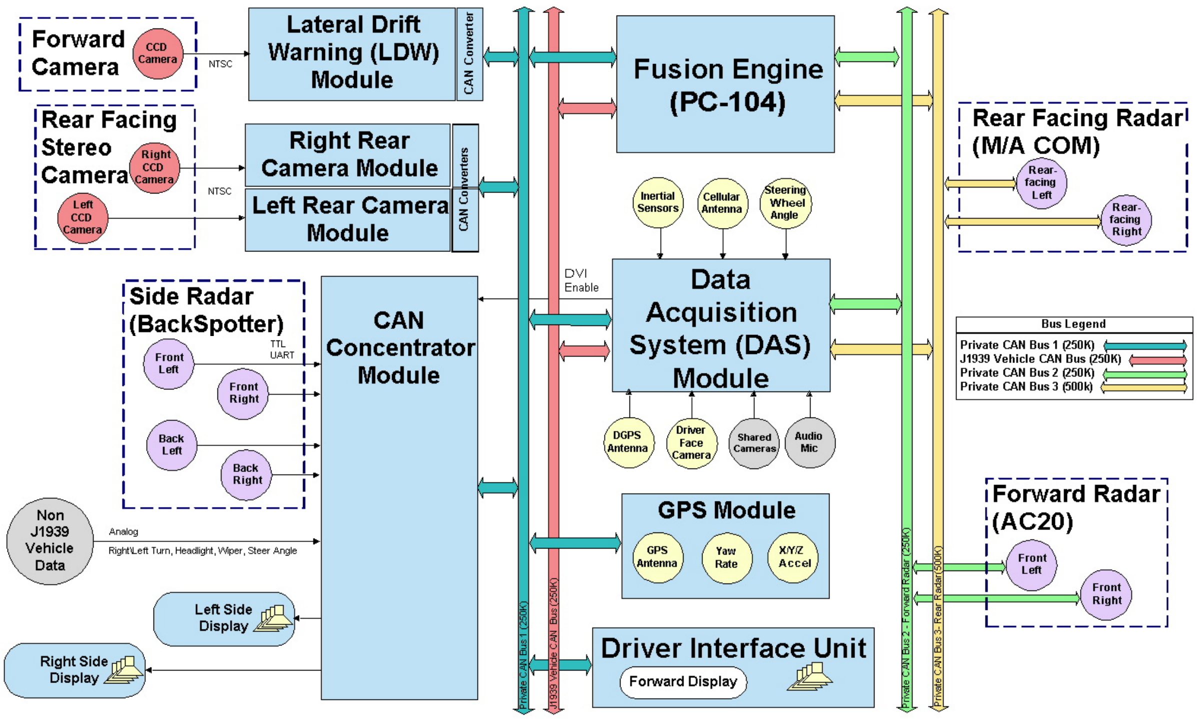


Figure 30. Schematic diagram of the system hardware architecture

As depicted in Figure 30, the two rear-facing radar units (M/A-COM C3 SLR) and the two forward-facing radar units (AC20) each have their own dedicated bus due to the relatively large amount of data provided by the radar sensors.

The camera data is provided on a private CAN bus and contains LDW warning information, lane information, and information relative to the presence of vehicles or obstacles next to the subject vehicle; it will not include raw video data. For Phase I of the program, the forward- and rear-facing cameras will be CCD cameras, each with its own dedicated vision processing hardware and CAN converter interface hardware. The forward camera and LDW module essentially comprise the Cognex SafeTRAC product. For Phase II, the forward camera will likely be CMOS and internal to the LDW module. The LDW module in Phase II will also have a native CAN I/O interface. The forward-camera system is monocular; the rear-facing camera systems may be monocular or combination binocular and stereo camera units.

The CAN concentrator module is a custom-designed hardware unit used to collect and translate the side-facing proximity radar sensor data, the DVI enable signal from the DAS, and vehicle data (not provided on the vehicle bus) onto the private CAN bus 1. The concentrator module also translates DVI output messages from the CAN bus 1 to the side displays. As indicated in Figure 30, the primary forward display (driver interface unit), will communicate directly on CAN bus 1. The GPS module is a custom-designed hardware unit using low-cost, commercially-available GPS, yaw rate, and tri-axial accelerometer sensors. It will interface to CAN bus 1 and be located toward the roof of the tractor cab for optimal GPS signal reception.

The fusion engine interfaces with all four system buses. It is the primary hardware component and executes the majority of the IVBSS fusion, warning, and arbitration algorithms. The fusion engine is based on a PC-104 stack and uses the rapid prototyping tools from Mathworks to rapidly transition from software and simulation development to real-time testing on board the experimental and prototype vehicles.

With the exception of the LDW-related algorithms, the heavy-truck software takes the form of a centralized software architecture, where the majority of the software is executed on the main PC-104-based processor, the fusion engine. Most of the sensor hardware modules, however, have their own resident signal processing and conditioning software that preprocesses or extracts information from the sensor data before transmission to the fusion engine. For example, all vision processing algorithms will be executed on the camera modules. The radar sensors will also perform preliminary radar signal processing, data association, and target tracking algorithms using onboard processing capabilities.

Currently, the software architecture is composed of the following components: 1) a lateral-drift warning SW module that provides lane detection and tracking, false alarm management, and threat assessment; 2) a forward-radar SW module that provides scene tracking, primary target determination, and threat assessment; 3) a rear-camera SW module that provides adjacent vehicle detection and characterization; 4) a rear-radar SW module that provides scene tracking adjacent to the subject vehicle; and 5) the fusion engine SW module that provides radar filtering and fusion, host state estimation and path prediction, roadway geometry estimation, LCM threat assessment, available maneuvering room estimation, warning based arbitration, system threat assessment, dynamic database management (for false alarms, roadside obstacles, and other roadway information), system management, diagnostics, and I/O signal conditioning.

4.1.4 Second Year Activities and Schedule

The final review and release of the functional requirements and system architecture documents is scheduled for the end of Phase I. Iteration based on system development feedback, verification testing information, and feedback from report-out at briefings will provide refinement prior to the final draft review and release.

ID	Task Name
1	**Functional Requirements & System Architecture (Task 1.b)**
2	**Functional Requirements**
3	Scenario Identification
4	Preliminary draft for review
5	US DOT review and comments
6	Iterate to refine outline & format
7	Second draft for review
8	US DOT review and comments
9	Deliverable/Milestone - Functional Requirements Report
10	**System Architecture**
11	Req's- Selection of sensor suite, decide stretch goals
12	Define sub system requirements
13	System Architecture - detailed development
14	Deliverable/Milestone - System Architecture Report

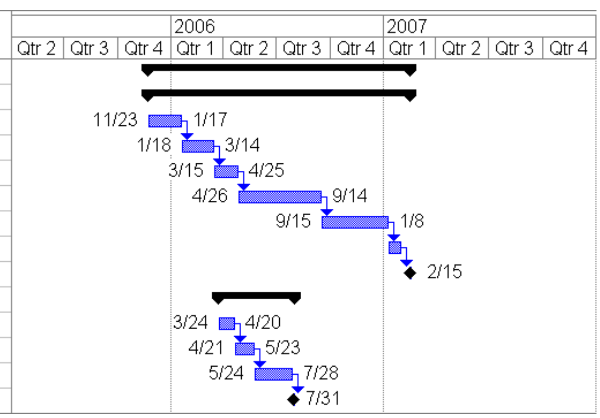


Figure 31. Heavy-truck schedule for functional requirements and system architecture

4.2 System Design, Development, and Integration

Plans for the design and vehicle builds, along with verification testing within the integration effort were completed in the first year. System design, development (including subsystem development and check-out), and integration (with subsystem and data fusion) activities were considered and planned; the plan governs the actual efforts that will result in the prototype vehicles (Suburban mule vehicle, bronze class 8 tractor, and gold class 8 tractor) that are being used in system verification and concept testing. This plan and approach follow accepted processes for quality and development.

4.2.1 Overview

The work plan governing the design, development, and integration approach and methodology for the creation of the IVBSS system was also completed in the first year. This plan supports the hardware and software combination that will provide warning functions, arbitration, and the DVI, as well as the vehicle builds for Phase I; the simulation, bench-test, and development activities used for algorithm development were also completed (see Table 6). Using simulation and bench-test environments in concert with the actual vehicle test mules and prototype platforms allows the team to quickly investigate new ideas through the review of a portfolio of data playback libraries, analysis of performance, and the monitoring of improvement on key system parameters.

Table 6. Support vehicles for mule activity and prototype use in Phase I

Vehicle	Function
Suburban "mule" truck	Permits non-CDL engineers to acquire data and validate system design
Class 8 "bronze" truck	Engineering test platform, but clean enough to back up the "gold" truck
Class 8 "gold" truck	Clean development vehicle as specified in the RFQ to be delivered for all verification testing

The overall plan being implemented in Phase I, pending any adjustments due to coordination of testing with the light-vehicle platform, addresses the subsystem development aspects in preparation for the system-level development and incorporates the vehicle build insertions at the appropriate time points. This task, in the form of the system design, development, and integration plan for IVBSS, was completed in the first year.

4.2.2 Design

A systems engineering approach was used to subdivide the heavy-truck system into relevant subsystems. This uses a top-down process, and, subsequent to the design and development of the subsystems, a bottom-up approach to combine the subsystems into a fully functioning and integrated system ready for verification and testing. The design process was guided by the functional requirements and system performance guidelines, which form the basis of the design. Much of the earlier work in the separate subsystem technologies and capabilities is being used as the starting point, with integration of those subsystems as a primary focus. The subsystems were also designed to easily combine into one integrated system.

The design effort included elements of sensor suite selection and system architecture development. Upon definition of the architecture, and given that this architecture will adjust over time to incorporate new ideas and solutions as needed, the exercise of decomposing the interface between levels of components was conducted to provide a structured understanding of the <Input

– Process – Output> scenario. This allowed the various team subgroups to work on their respective sections with the expectation that all subsystems would later be integrated. The input-output sets were documented in the interface control document, which was used by both the heavy-truck and light-vehicle teams.

4.2.3 Development

The general development process was mentioned previously and documented in the report. On the desktop are the simulation and hardware-in-the-loop benchtop tools and methods. On the vehicle, to be used on test tracks and roadways, are the experimental mule and prototype development tools and methods.

Within the simulation environment, scenarios and associated kinematic conditions, as well as specific vehicle dynamic models, can be loaded and virtually tested to develop concepts for warning function algorithms. Further, within the fully three-dimensional models, the characteristics of the sensors and their base performance (including warning alerts, tracking, and key sensor parameters) can be loaded and tested to understand performance in a structured manner. This environment allowed the development team to work concepts and introduce perturbation and noise levels to test limits and performance under the library of scenarios. Verification by running scenario libraries was conducted in an automated fashion, shortening the timeframes for development. Tools for the simulation environment include CarSim, TruckSim, Simulink, Stateflow, and other toolbox components. The verification test scenarios have been simulated in the CarSim environment. This approach will be especially useful to avoid unsafe conditions in on-road tests.

The hardware-in-the-loop bench environment development effort is parallel with the simulation environment. Since IVBSS subsystem communication will occur over CAN communications, the bench has been set up to configure the subsystems and supporting signal conditioning into a benchtop IVBSS system. The Suburban mule vehicle has been outfitted with the full complement of sensors and hardware to allow datasets to be captured and archived for playback through the hardware-in-the-loop benchtop IVBSS. With this playback capability, the bench environment provides a convenient, safe, and repeatable platform to develop and test fusion and arbitration algorithms for implementation in the follow-on prototype vehicles, as well as the Suburban mule vehicle during development and refinement. The bench environment is a PC with Simulink, Stateflow, xPCTarget, and other toolbox elements, where xPCTarget allows downloading the system models into a real-time unit that forms the fusion processor, which is known in the system architecture as the “fusion engine.” In coordination with the bench and simulation environments, the team uses data visualization tools to overlay visualized radar data on video data for radar sensor validation; it can also capture libraries of vehicle scenario data for real-time playback into the bench system, and to view and modify system parameters either on-vehicle or on-bench.

The Suburban mule allows non-CDL drivers to conduct field testing. The mule also allows the team to run trials, work out system and subsystem bugs, and determine that all aspects of the system, as well as the DVI and DAS, are compatible and ready for verification testing and prove-out.

Finally, development effort continues for the DVI hardware and design for integration development. UMTRI is responsible for the characteristics of the DVI, and the development team is responsible for providing enabling hardware and software in the form of the physical device that supports the UMTRI effort for the testing and FOT phases. This hardware design is complete and the prototype hardware is pending release in the short term through the commercial arm of the Eaton (Vehicle Solutions Business Unit, VORAD group).

4.2.4 Integration

As the development effort migrates to useable hardware and software that can be implemented first on-bench, then in the Suburban mule, and finally in the bronze and gold tractors, the integration effort will migrate the subsystems from the bench and mule vehicle to the prototype vehicles. Risks in this migration were planned as gaps that will be addressed in the course of verification testing and refinement, and through design and development review during the course of the migration.

Prototype hardware installation and design were addressed through robustness testing and checkout. Electrical and thermal checkout will determine low and high voltage levels, noise on communication levels, vibration levels, mounting endurance and stability, and self-diagnostic capability for sensor and communication fault levels. Track and roadway testing will allow system operational verification in real driving environments, while integration activities will continue into the second year.

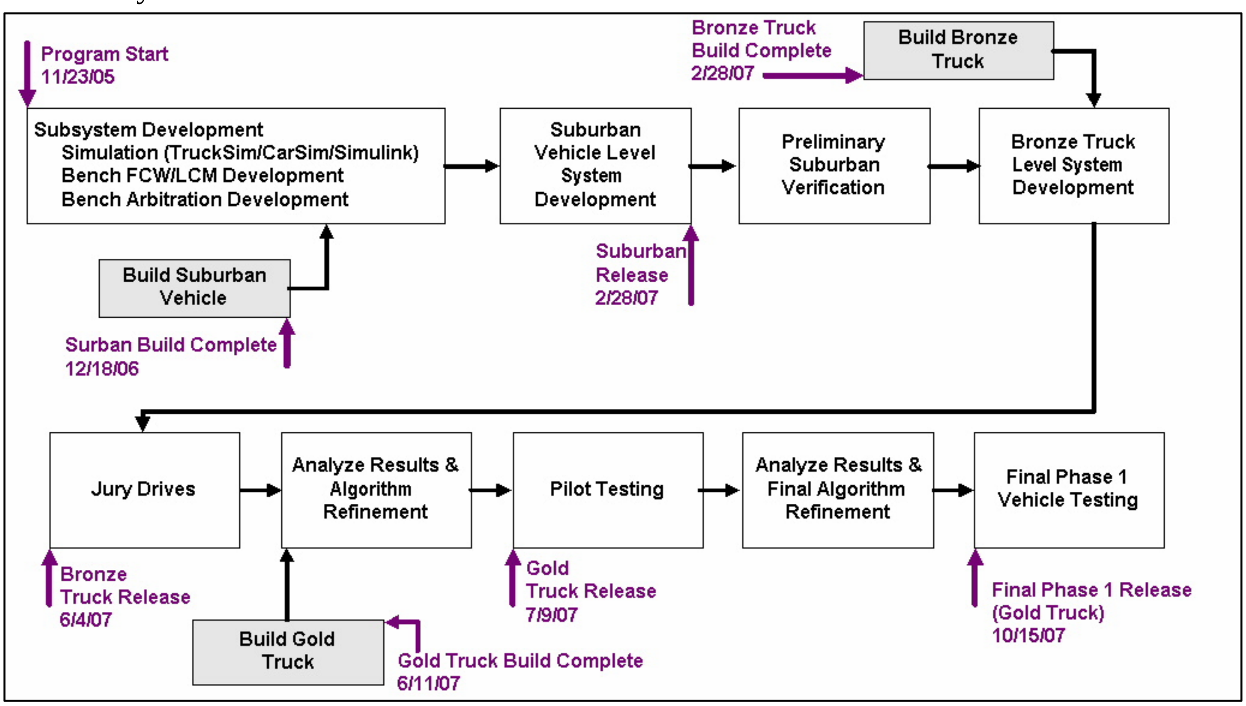


Figure 32. Overall heavy-truck development plan flow

4.3 Development of Performance Guidelines

Figure 28 showed that system performance guidelines were developed from the preliminary requirements. The performance guidelines consist of quantitative and verifiable performance measures for IVBSS system functions in key driving scenarios. The process of deriving guidelines was similar to that described in section 3.3, and included references from previous pubic research programs as well as ISO standards and corporate knowledge from the commercially available Eaton Vorad and Cognex systems.

4.3.1 Overview

The process contained in the plan moves from initial guidance, through a set of parallel refinement steps, to a specification that links to the functional requirements. The heavy-truck team employs a systems engineering process that uses the "voice of the customer" (VOC) process to drive system requirements identification, evaluation, and capture. In this systems engineering process, the VOC for the IVBSS program is represented by the potential known or envisioned pre-crash scenarios, accompanied by associated historical crash statistics to help understand essential priority. Further, U.S. DOT, working with independent technical consultation, has provided a refined set of potential pre-crash scenarios including crash statistics.

Once these scenarios and statistics provide a clear understanding of the inputs to the program, and VOC needs and concerns are addressed, the next step will be the identification and consolidation of the system functional requirements. The functional requirements document characterizes, in straightforward language, the system behavior in response to pre-crash scenarios. The functional requirements should not contain specific values for system component specifications or number values for scenario condition parameters; they should, however, contain sufficient qualitative content to clearly understand and predict what the integrated system should be doing in response to upcoming traffic or pre-crash situations, including specific warning content. The functional requirements document could also contain additional information about the characterization of the system that is somewhat scenario-independent, such as weather-conditional behavior, system operational status, or diagnostic status. The goal of the functional requirements is to guide and aid in the development of the integrated system performance guidelines, verification test procedures, and test plans that will implemented during the verification of the prototype vehicle IVBSS systems and used in the development and execution of the FOT. Thus, there is traceability that extends throughout the requirements-capture process, from scenarios through to functional requirements, integrated system performance guidelines, verification test procedures, and verification testing.

The integrated system performance guidelines document follows the essential backbone of the functional requirements document, making explicit the relevant and associated physical parameters to be linked to the qualitative characteristics contained in each of the functional requirements. Since the IVBSS program primarily concerns the integration of certain subsystems that had been previously tested under separate conditions, the performance guideline development process seeks to clearly articulate the integrated, system-level performance at the highest level of specificity, following systems engineering methods and practices. This is true under scenario conditions that essentially test the separate subsystem and functional warning schemes, as well as when probing the integrated multiple scenarios schemes, which can be serially or simultaneously combined.

The final IVBSS Heavy-truck Performance Guidelines Report is scheduled for completion at the end of Phase I. Iteration based on system development feedback and verification testing information will provide refinement prior to the final draft review and release.

4.3.2 Integrated System Performance Guidelines

The performance guidelines report was written in accordance with the functional requirements developed by the IVBSS heavy-truck team based on crash scenarios developed by the Volpe Center, ISO standards (ISO 15623, 2002; ISO 17361, 2005; and ISO 17387, 2006), results from projects such as RDCW[16] and ACAS,[3] and other related publications.[5 6 23 25] Specifically, this document defines what data must be collected, the accuracy of the data, functions of the algorithms, and necessary system outputs in terms of signals, reliability, consistency, and robustness.

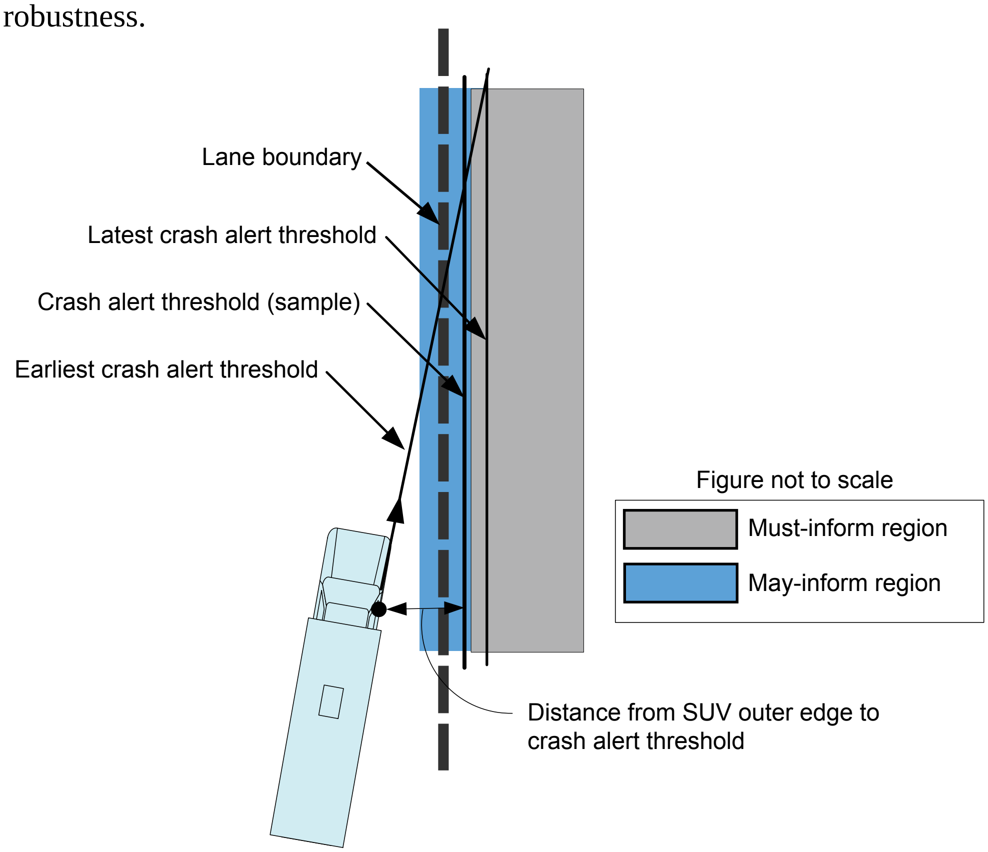


Figure 33. Lateral-drift crash alert timing concepts

The integrated system performance guideline document defines commonly used terms and performance guidelines, and includes references upon which the performance guidelines were defined. A sample integrated system performance guideline addresses the timing of crash alerts when a vehicle may be drifting from the roadway (Figure 33 illustrates such a scenario). A crash alert may be provided in a zone that encompasses the road edge, but also includes some portion of the lane itself, as well as areas beyond the lane edge. IVBSS must provide crash alerts at some point beyond the lane edge. This is called the “must-inform” zone, as shown in Figure 33. The guidelines make allowances for suppressing or delaying crash alerts in this situation based on measured information that indicates a significant possibility that one or more of the following is true: (1) the driver is aware of the perceived conflict; or (2) the driver intends to initiate a maneuver, or is maneuvering, such that the potential conflict could be resolved through the maneuver.

More details are available in the heavy-truck preliminary performance guidelines report[13] that will be published in final form in early 2008.

4.3.3 Second Year Activities and Schedule

The integrated system performance guideline development plan is also complete, and the final report will be delivered (Task 1.d) in early 2007.

The final review and release of the IVBSS Heavy-Truck Performance Guidelines Report is scheduled for the end of Phase I. Iteration based on system development feedback and verification testing information will provide refinement prior to the final draft review and release.

ID	Task Name
1	**Performance Specifications Development (Task 1.d)**
2	Write Spec. Development Plan
3	Deliverable/Milestone - Integrated System Performance Specification Development Plan
4	Preliminary Perf Specs draft for review
5	US DOT review and comments
6	Iterate based on Functional Requirements progress and guidance
7	Second draft for review
8	US DOT review and comments
9	Deliverable/Milestone - Integrated System Performance Specification Report
10	Report out to US DOT at Q6 re lessons learned in using the accident reconstruction services data
11	Iterate based on system development feedback and testing
12	US DOT final review and comments

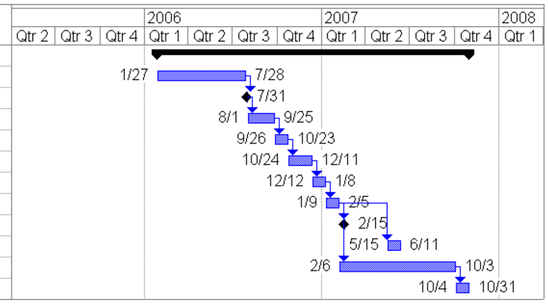


Figure 34. Heavy-truck schedule for performance guideline development

4.4 Subsystem Development

As noted earlier, the four major subsystems are forward crash warning, lane-change/merge warning, lateral drift warning, arbitration, and the DVI. The following section details the subsystems as they relate to arbitration and development progress; the DVI is discussed in more detail in section 4.5.

4.4.1 Overview

The subsystems on the heavy-truck platform were developed leveraging existing commercial programs and products. However, substantial development efforts were required for both subsystem performance and for integration of the systems into a cohesive system. Development occurred using simulation, on the bench, and in the mule vehicle, and will continue on the engineering tractor to be built in early 2007.

4.4.2 Subsystem Descriptions and Sensor Suite

4.4.2.1. Forward Collision Warning Concept of Operation and Progress and Accomplishments

The forward collision warning capability will provide imminent and cautionary alerts to help drivers avoid striking other vehicles from behind or to reduce the severity of such collisions. The primary sensors of the FCW subsystem are a pair of long-range, forward-looking TRW AC20 77-GHz radar units. Several other sources of information are fused together with the forward-looking radar data to improve the accuracy of in-lane object detection and the proper assessment of the threat posed by the vehicle or obstacle.

The FCW system will use a pair of AC20 radar units mounted near the tractor headlights to provide sufficient detection coverage in front of the vehicle, in particular for close vehicle cut-in scenarios. The mounting location is also ideally suited for detection of small vehicles, such as motorcycles, which typically ride in the tire track lateral lane position to avoid grease and debris that tend to accumulate near the lane center. The sensors have a field-of-view of 11 degrees and an approximate range of 150 meters. The AC20 radar units will communicate radar track data to the fusion engine on their own dedicated CAN bus.

The AC20 radar units are the primary sensors of the FCW subsystem. The unit has onboard processing hardware that will estimate target track data assigned to specific vehicles and objects. A set of evolving parameters is associated with each track: track identification number, relative distance, relative rate (radial velocity), estimated relative acceleration, angular position, and track confidence level. The set of tracks will be managed according to the girth and depth of vehicle tracks (i.e., entry and exit from the radar FOV). Each AC20 can track up to eight vehicles simultaneously at a data rate of 40 ms.

To reduce the amount of data communicated to the fusion engine, each AC20 radar unit will execute its own forward-collision-warning algorithm. Using the vehicle speed and yaw rate information provided to the AC20, the warning algorithm will assess all track information, distinguish between in-path and out-of-path obstacles, and calculate the associated threat level. The FCW-related software executing on the fusion engine will fuse several sources of information, including warning information from each AC20, roadway geometry information, lane boundary information, AMR, and host kinematic state information. The FCW subsystem will use this information to provide an enhanced FCW warning and an associated severity and confidence measure. The FCW-specific software processing executed in the fusion engine consists of two main components: FCW data fusion and FCW threat assessment. The FCW subsystem also uses information provided by two additional processing components: roadway geometry and host state estimation.

The FCW data fusion component merges the forward collision data provided by the two AC20 radar units. The forward collision data includes: FCW threat level, FCW priority and critical target information (track identification number, relative (radial) distance, relative rate (radial velocity), estimated acceleration, and angular position). The critical target is the closest in-path obstacle or vehicle. The FCW warning algorithm executed on each AC20 is based on the relative kinematic parameters of the subject vehicle and critical target developed and refined by Eaton VORAD for the heavy-duty truck market over the last decade.

The FCW threat assessment component provides a final fused FCW warning and an associated severity and confidence measure using information related to the lane boundary type, AMR, position-specific false alarm information, refined road curvature, and the host state. The FCW information is subsequently used by the system warning arbitrator.

Upcoming roadway geometry or curvature is useful for processing both image data and radar data. The roadway geometry estimation component uses several sources of information for estimating the upcoming road curvature: visually-estimated curvature from the LDW subsystem, vehicle yaw rate and speed, and roadway data stored in a dynamic database from previous traversals of the same road. IVBSS combines information from these sources and generates a refined curvature estimate that is more accurate than any individual curvature. The refined estimate is calculated in the fusion engine and sent to the LDW module to improve LDW, as well as LCM, performance.

The host-state estimation component estimates the subject vehicle's kinematic state and predicts its future path or trajectory. Information used for estimation includes: LDW relative lane data (lateral position and velocity, heading), vehicle inertial sensor data (yaw rate, x/y/z acceleration, speed), and vehicle operational indicators (turn signal, brake, accelerator). The host state and predicted path are used internally in the fusion engine for both the FCW and LCM subsystems.

Technical progress on forward collision warning includes:

- Performance was analyzed and fine-tuned on the AC20 tracking and collision warning algorithms using a class 8 tractor ("Big Red") in July through November, in advance of the Eaton AC20 product deployment in Q2, 2007. Results confirm acceptable performance of the tracking algorithms in terms of data accuracy, temporal response, and latency.
- Performance of the twin AC20 radar sensors was analyzed using the Suburban mule vehicle in November and December. Results indicate that the combined forward radar field-of-view is more than sufficient for meeting the program requirements, and that it is possible to fuse the two radar units to improve measurement accuracy.
- Communication and display capability were demonstrated using the FCW system warnings using the Suburban forward display in November and December.
- Simulation testing of the FCW subsystem, using base FCW warning algorithms that were created and verified, was demonstrated in November and December.

4.4.2.2. Lateral Drift Warning Concept of Operations and Progress and Accomplishments

The concept of operations for the LDW is the same for heavy trucks as light vehicles, and due to the cross-platform synergy afforded by the SafeTRAC lane tracker, the progress for the first year outlined in the light-vehicle LDW subsystem description (p. 28), also applies to heavy trucks. The LDW subsystem is based on the commercially-available SafeTRAC lane departure warning system from Cognex. SafeTRAC consists of a processing module with a driver interface and a small camera mounted on the windshield of the vehicle.

The LDW subsystem was integrated into the vehicles used in the RDCW program. Similarly in IVBSS, LDW will be integrated into the vehicle and use the same driver-vehicle interface as the other subsystems. LDW will be further integrated with the other subsystems to improve the functionality of both LDW and the other subsystems.

4.4.2.3. Lane-Change/Merge Concept of Operations and Progress and Accomplishments

The LCM warning function advises or warns the driver of an impending crash with another vehicle occupying a proximity zone in the adjacent lane, on either side of the subject vehicle, when changing lanes, turning, or passing a vehicle. The primary sensor information for the LCM subsystem is provided by four short-range, side-looking radar sensors and a pair of rear-looking radar sensors. A pair of rear-looking cameras will augment LCM functionality.

For rear-looking radar development, the following progress has been made:

- Data collection using M/A-Com radar (and video data for overlay) has been accomplished using Big Red. The M/A-Com data was analyzed and Kalman filtering algorithms were developed to improve state estimation and to identify and remove trailer reflection characteristics. Results confirm the tractor-only solution will meet or exceed system functional requirements, i.e., no trailer sensors are required.
- BackSpotter side radar was mounted on the Suburban mule vehicle and functionality was tested using the side display units. Results indicate that the use of two BackSpotter radar units on each side of the Suburban along with the M/A COM radar provide sufficient adjacent-lane coverage along the side of both the Suburban and trailer.

The M/A-Com radar investigations are shown in Figure 35, which indicates mounting locations for the rear-looking radar and cameras. The calibration and alignment of the rear-looking radar units are shown in Figure 36 with results indicating that the alignment required is physically acceptable in the field and provides sufficient adjacent lane coverage both alongside and approximately 9 meters behind the typical longest trailer configuration.

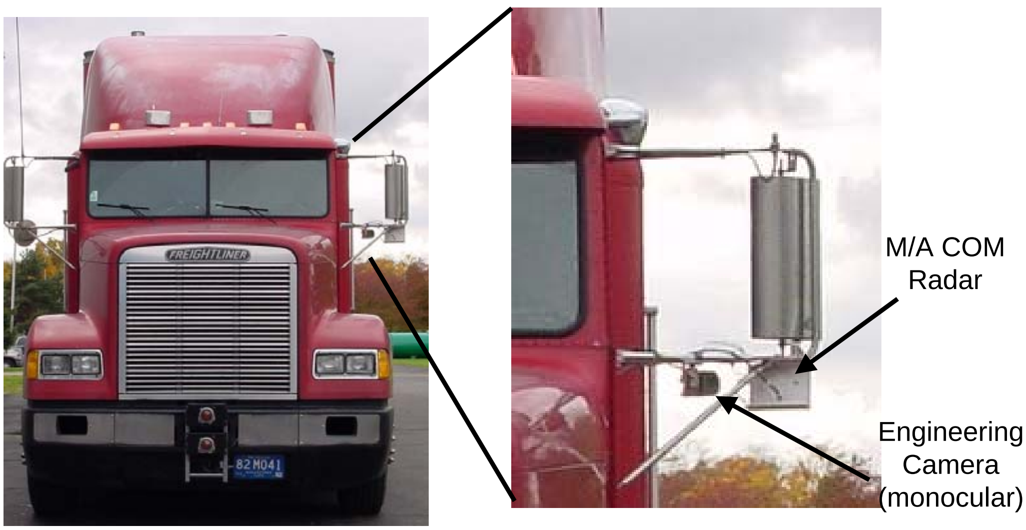


Figure 35. “Big Red” with M/A-Com radar and camera mounting

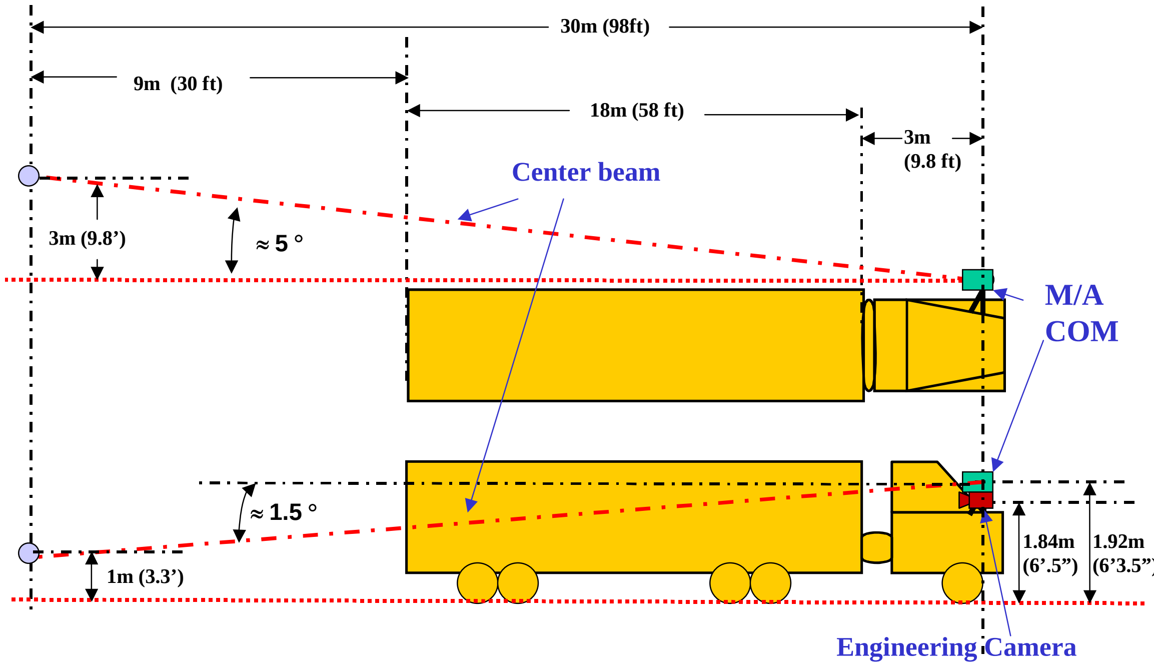


Figure 36. M/A-Com radar mounting and rear radar coverage

As part of the heavy-truck LCM development process, the IVBSS team has been pursuing the application of video technology to address the challenging problem of side sensing for LCM. The concept of operations involves detecting vehicles in lanes adjacent to the tractor-trailer by using two pairs of cameras (one pair mounted on each side of the cab looking backwards and to the side). The pairs of cameras on each side of the cab allow the range to adjacent vehicles to be computed directly, based on slight differences in their appearance in each image (similar to the way the human brain estimates depth from the different views provided by two eyes).

Stereovision has the potential to provide accurate, low-cost, high-resolution and wide field-of-view data about the presence of vehicles or other objects adjacent to the vehicle, making it a promising replacement for or adjunct to radar-based side sensing.

The stereo video sensor the IVBSS team is investigating is sold by Cognex for controlling the opening and closing of external doors at retail businesses. Sensor results so far are encouraging. As shown in Figure 37, vehicles and stationary objects adjacent to the subject vehicle can be detected at a range equivalent to the back of the trailer.

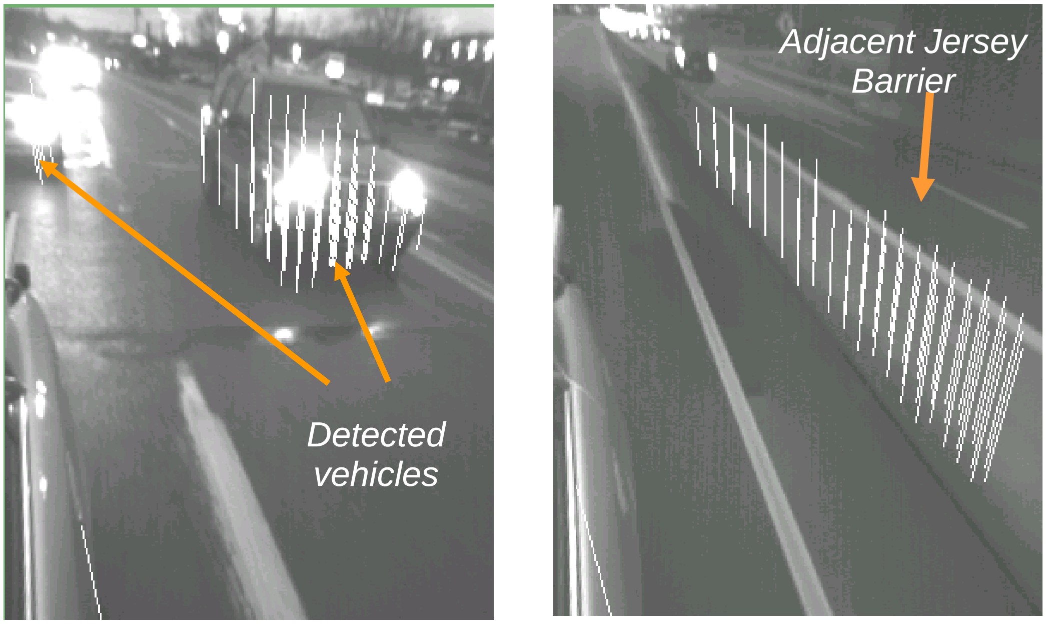


Figure 37. Side vision detection results for moving vehicles and stationary targets

Stereo side vision activities for the second year will focus on improving detection of adjacent objects and suppressing false returns, followed by software and hardware integration and validation testing.

4.4.2.4. Arbitration Concept of Operation and Progress and Accomplishments

To avoid overloading the driver with information, an arbitration system will play a critical role in IVBSS. First, it will arbitrate among forward collision, lateral drift, and lane-change/merge collision warning signals based on the severity of each threat. It will also support the DVI, which may include status information during times of low collision conflict as well as urgent warnings of an imminent collision. The arbitration unit is unique to an integrated warning system.

The primary input to the arbitration subsystem is the warning severity and confidence of the three warning subsystems (FCW, LDW and LCM). The arbitration algorithms will also rely heavily on input from human factors and DVI studies and information for adjusting threat priorities, managing temporal aspects of the warnings, and, most importantly, determining the appropriate warning mechanisms and modalities for integrated scenarios. The arbitration algorithms will also make use of contextual and temporal databases.

The formalized arbitration framework is referenced as a time-varying probabilistic optimization problem. Generated warnings minimize overall risk posed to the driver while systematically balancing false positive and false negative behavior. Key components involved are vehicle trajectory estimation and subject vehicle driver-behavior models and statistics. Two methods for predicting host trajectory using heavy-truck driver statistics have been investigated. Results indicate that by statistically applying data related to SV maneuvers, the unpredictable behavior of the driver can be partially accounted for, improving the estimation of the probability of a collision.

The arbitration framework has been adapted to system specifics, including items such as sensor and subsystem outputs, and latency. In general this modified approach provides the following:

- Quantification of the propagation of sensor errors and subsystem confidence measures;
- Arbitration that essentially occurs naturally (within the framework) and is less reliant on complex rules-based arbitration schemes; and
- A more rigorous analysis and adjustment of the trade-offs between false positive and negative alarms and system warning aggressiveness.

Arbitration development is primarily being conducted on the bench and will then migrate to the vehicle environment.

4.4.3 Second Year Activities and Schedule

Many first year activities will be carried over and completed during the second. The schedule for subsystem development (Task 1.e) is shown in Figure 38.

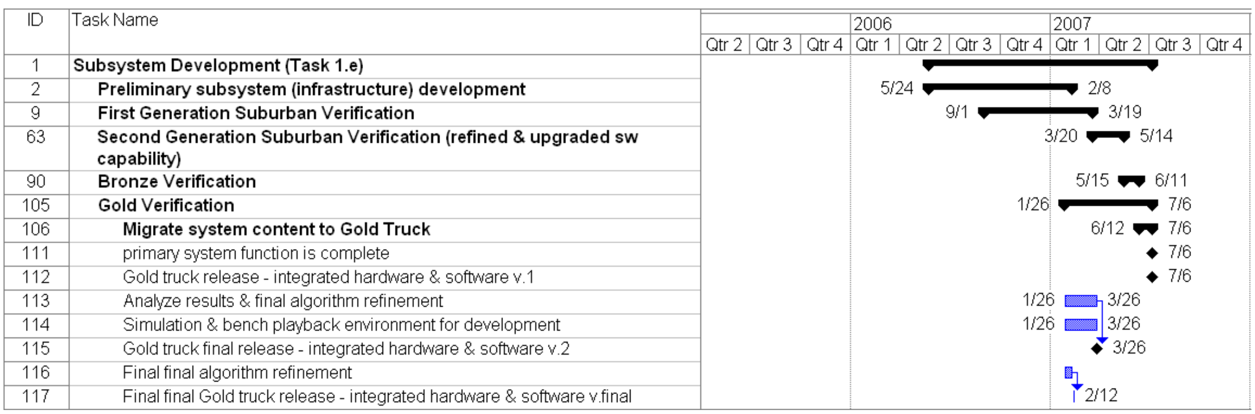


Figure 38. Heavy-truck schedule for subsystem development

4.5 Development of Driver-Vehicle Interface

This section addresses the subsystem aspects of the DVI, in terms of physical embodiment for hardware and software capability. Chapter 6 addresses the DVI from the human factors perspective, in terms of the science and investigations involved.

4.5.1 Overview

The general approach to designing the DVI for both the light-vehicle and heavy-truck platforms has been to design in hardware flexibility early in the systems design and development stages, thereby allowing human factors testing and evaluation to take place in parallel with the development of the IVBSS system. Early decisions regarding the types of hardware that will be available to the DVI team on the heavy-truck platform have been made, and the DVI team is working directly with the IVBSS systems design and development team to ensure that the hardware selection meets the anticipated needs based on the outcome of the human factors testing. This involves making some early assumptions regarding the scope of the DVI, based on some fundamental human factors principals, to allow the programs DVI and systems development teams to proceed in parallel.

The ultimate decision regarding selection of the final DVI configuration is a joint effort of UMTRI, the heavy-truck team, the vehicle manufacturer, and U.S. DOT and its partners. The decisions will take into consideration the following factors: (1) whether the approach is safe and effective based on simulator and in-vehicle testing; (2) the feasibility of the implementation from technical, financial, and schedule perspectives; and (3) what the market for crash warning systems seems to desire.

4.5.2 Heavy-Truck DVI Option Space

This section describes the dimensions considered in the development of the DVI warning space. Table 7 shows the warning strategy matrix.

Table 7. IVBSS heavy-truck DVI warning strategy space

Warning Type	IVBSS Warning	Desired Driver Response	Desired Driver Attention	Haptic Modality	Auditory Modality	Visual Modality
FCW	Hazard ahead	Decelerate vehicle and possibly steer to avoid threat based on driver's observations	Forward	Unlikely	Forward sound source from DVI	Red collision warning LEDs on DVI, collision warning LCD display on DVI (informational only)
LDW	Drifting across a lane boundary	Steer back into lane	Forward	Unlikely	Directional, from side of threat, using speakers (crossing solid or dashed) controll-ed by DVI	Informational only, e.g., status and availability or "clean window" message and possible "move left/right" graphic on LCD of DVI
LCM	Entering occupied lane	Steer back into lane	Forward with appropriate side verification	Unlikely	Directional, from side of threat, us-ing speakers controlled by DVI	Always visible, directional "adjacent occupied" indicator near each side view mirror.

The DVI warning space includes both a headway warning system and an imminent collision detection system. The headway warning system provides drivers with graded cautionary warnings when headway time to a forward object drops below four established thresholds (3, 2, 1, and 0.5 seconds). These headways were selected based on field experience of safe headway distances, as well as consideration of possible preceding vehicle decelerations and the heavy truck's braking capability. The forward collision system provides collision warnings whenever a significant risk of collision is detected.

The physical embodiment of the DVI that has been designed and is currently being prototyped for use in the heavy truck is shown in Figure 39 (the class 8 heavy-truck cockpit is depicted).

Figure 39. Heavy-truck DVI space in truck cockpit

4.5.3 *Second-Year Activities and Schedule*

The DVI hardware was designed, and preliminary prototypes were delivered to the team; in the second year, prototypes are expected for use in integration with the system for verification testing.

4.6 System Integration, Build of Prototype Vehicles, and Verification Testing

The integration effort migrates the IVBSS hardware and software from the bench to the Suburban mule vehicle, and finally to the bronze and gold tractors. This section details progress on the integration effort.

4.6.1 *Overview*

The three vehicles to be built during Phase I include: (1) the engineering mule vehicle (a Suburban SUV), (2) the bronze tractor (shown in Figure 35), and (3) the gold tractor ("bronze" and "gold" are the team's terms for the engineering development tractor and the prototype installation tractor, respectively). The mule vehicle was built and operational in the first year of the project. The bronze and gold tractors will be operational in, respectively, the first and second quarters of 2007.

For the FOT fleet, an additional 10 vehicles will be built in Phase II. These will be new tractors purchased by the fleet operator that participates in the field operational test. The gold tractor will serve as a backup tractor to address the necessity that the tractors must remain in service during the entirety of the FOT.

4.6.2 Heavy-Truck Prototype Build Plan

Since the heavy-truck IVBSS is being developed as a system, the integration section covers primarily progress on the vehicle build-up activity; vehicle integration progress during the first year includes:

- **Suburban**
  - All sensors and hardware have been installed on the Suburban mule vehicle.
  - Communication has been established among all components and initial testing of FCW and LDW functionality has demonstrated acceptable performance to date.
  - All sensors have been calibrated and aligned and are ready for data collection in January 2007.
- **Bronze class 8 tractor**
  - Bronze lease has been secured.
  - The team has taken delivery of the vehicle (model 8600i, which is similar to the expected FOT vehicles).
  - No hardware or sensor issues are expected in terms of availability and timing.
- **Gold class 8 tractor**
  - This vehicle is likely to be the 8600 platform, commonly used in the day cab for fleet operation.
- **Procurement strategy**
  - Parts for three vehicles need to be procured, and one spare of each sensor and component for bench testing and functional spare.

Figure 40 illustrates the Suburban with a trailer, the twin AC20 radar units, and the side radar, while Figure 41 shows the placement of the Eaton DVI.

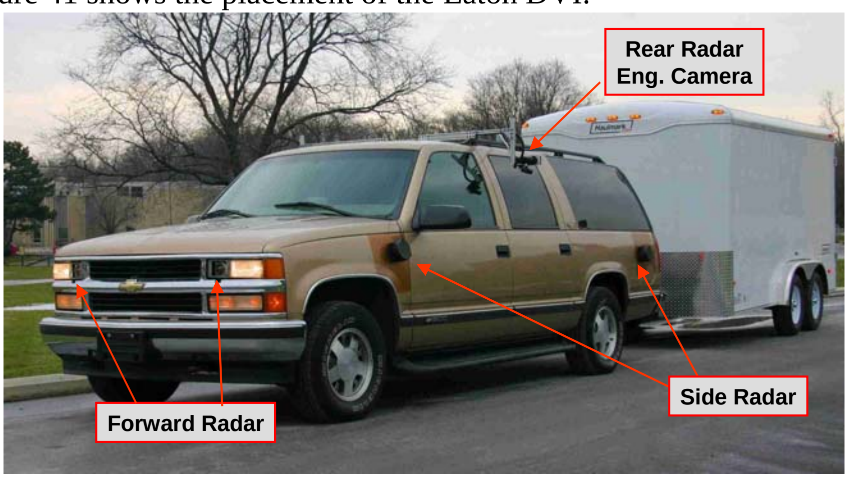


Figure 40. Suburban mule vehicle with trailer

Figure 41. Suburban mule vehicle with DVI

4.6.3 Second Year Activities and Schedule

The schedule for heavy-truck system integration and prototype builds (Task 1.g) is shown in Figure 42.

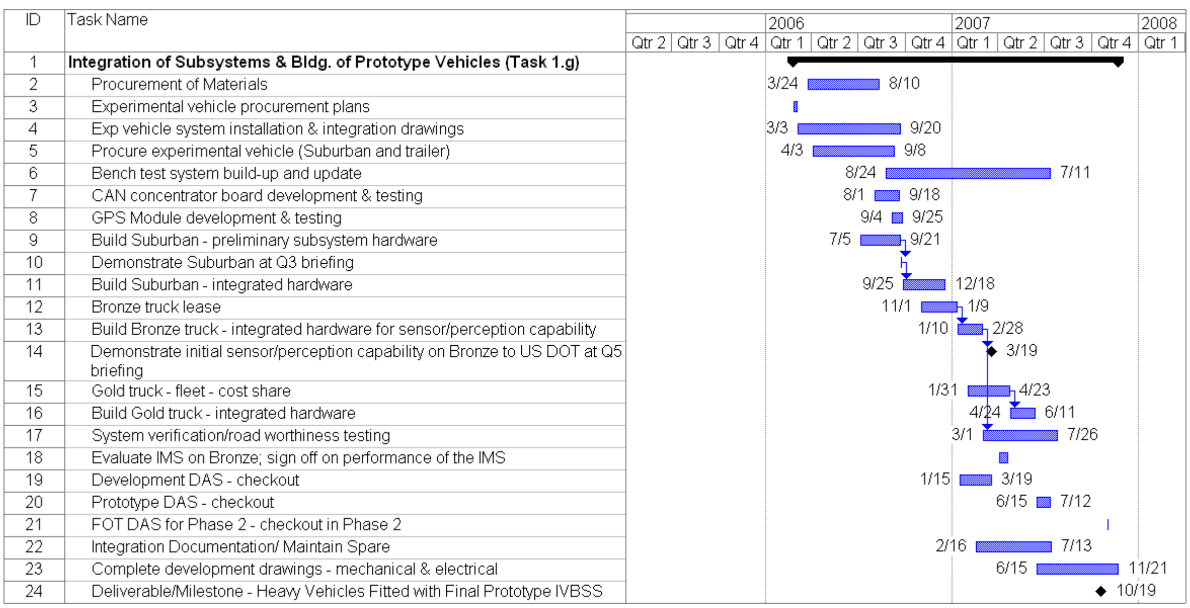


Figure 42. Schedule for heavy-truck system integration and prototype building

Projected second year activities include:

- Installing IVBSS hardware on the bronze tractor;
- Obtaining the gold tractor and installing IVBSS hardware;
- Performing system verification and road worthiness testing;
- Performing checkout of the development and prototype data acquisition systems;

- Documenting the integration including development drawings (mechanical and electrical);
- Maintaining the spare tractor; and
- Delivering the official heavy truck fitted with the final prototype IVBSS.

5 Development of Verification Test Procedures and Phase I Testing

In collaboration with U.S. DOT, team members from both platforms are in the process of developing test procedures to verify that the prototype integrated system satisfies performance guidelines and will serve as a suitable system for conducting a series of pilot and field operational tests in Phase II of the program. Both platforms will, at a minimum, include the following:

- Extensive test-track and on-road procedures;
- Test scenarios and specifications, such as speeds, closing rates, road geometry, etc.;
- Pass/fail criteria for evaluating system performance; and
- A set of measurement variables that will be used to evaluate system performance when compared to an independent measurement system installed on the test vehicle.

5.1 Overview of the Verification Test Procedures

Verification test procedures fall into two broad categories, closed-course test track and on-road tests. The test-track procedures are further broken down as engineering and no-warn tests. In order for the program to proceed into Phase II (field operational test), the system must pass these required tests. For verification purposes, the required tests will be performed with the IVBSS subject vehicle equipped with an additional sensing system to provide an independent method of performance and sensor verification. The independent measurement system will be provided and installed by the National Institute of Standards and Technology.

The required tests can be subdivided into multiple categories: (1) one for each of the subsystem technologies; (2) one that considers conflict scenarios where multiple threats are present; and (3) an arbitration algorithm is used to provide an appropriate warning or series of warnings to the driver. All of the multiple threat procedures for both platforms are required tests, and, as such, have associated pass-fail criteria.

Engineering tests will evaluate and test the system, and will also be used to determine system limitations. Although these tests are compulsory, the results of the engineering tests will not be used to determine whether or not to proceed into the second Phase of the program. Each of the subsystem technologies has one or more associated engineering tests. No-warn tests will also be run on the test track and are designed to verify that the system does not issue warnings that the driver might perceive as a false or nuisance alarm. All required tests, engineering tests, and no-warn tests will be conducted under the controlled conditions of a closed-course test track. A summary of the tests that will be performed during the Phase I testing task is provided in Section 5.4 of this document.

On-road testing is a combination of both scripted and naturalistic driving. The test is scripted in that the driver follows a pre-defined route containing a range of roadway and environmental characteristics selected to expose the system to many common driving scenarios. The test is naturalistic in that the driver will be instructed to perform maneuvers in a normal manner. That is, this test is not designed to characterize the system in a real-world environment by purposely eliciting warnings, but rather to accurately reflect the type of alerts and alert rates that a driver might be exposed to while driving in a mix of routine situations. The results from the test will be analyzed to assess the system availability overall and by road type, and to measure and characterize the following system and subsystem performance metrics as they pertain to alerts:

- Number of alerts and alert rates;
- Timing, distance to obstacle and closure rates;
- Validity (valid/false);
- Helpfulness (meaningful/annoying); and
- Appropriateness (intended/missed).

All verification testing on test tracks will be performed at the Transportation Research Center test facility in East Liberty, Ohio, or the Dana Test Center in Ottawa Lake, Michigan. The on-road testing will be performed in southeastern Michigan.

5.2 Status of Verification Test Plan

A set of test procedures for both platforms has now been defined and agreed upon by the IVBSS team and U.S. DOT. Currently, researchers for both platforms are developing documents that detail how each test will be performed and evaluated. The test procedures for each platform include the following:

- A test definition and purpose;
- A test concept showing initial, transitional, and warning conditions along with conflict resolution for the safe execution of the tests;
- A set of performance measures and rules to evaluate if the test was run according to the procedure;
- A set of pass/fail criteria to Judge if the warning system functioned according to design as well as the measures used to determine if the system passed the test;
- A detailed list of standard test conditions and any deviation of a given test from that standard protocol;
- Details of how to stage the test; and
- Driving instructions for the IVBSS vehicle driver and each confederate vehicle driver.

5.3 Vehicle and Hardware Descriptions

Verification testing will be performed using one of the fully-equipped IVBSS development vehicles for both platforms. The hardware for collecting the performance data has not been finalized. Both platforms will use the onboard IVBSS data acquisition system (DAS) for collecting and archiving the objective data that will be used to evaluate the performance of the system and given to the U.S. DOT for comparison with data collected by the independent measuring system (IMS). In some cases, the confederate vehicles may also be equipped with instruments to aid in the staging of the test and to expedite the execution of the tests.

5.4 Summary of Verification Tests

This section describes the tests that will be used to verify that the prototype integrated system meets its design requirements and is ready for use in the field operational test planned for Phase II.

5.4.1 Rear-End Crash Threat Tests

The 12 rear-end crash threat scenarios are as follows:

- Scenario 1: This test is intended to verify the appropriateness of an FCW when the SV approaches, from behind, a slower moving POV (P) in the center of the same lane. In this test the SV and P1 are traveling at a constant speed with a speed differential between the SV and P1 of at least 8.9 m/s (20 mph).

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

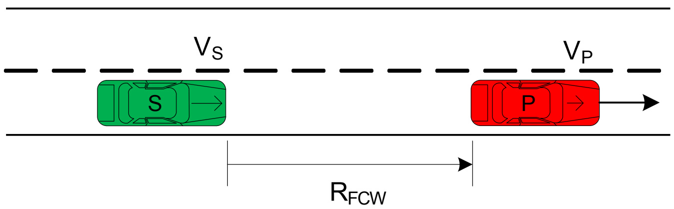


Figure 43. Rear-end crash scenario 1

- Scenario 2: This test is intended to verify the appropriateness of an FCW when the SV approaches from behind (with a short headway time gap), a modestly slowing POV (P) in the center of the same lane.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P,Ax_P=Principle other vehicle speed, deceleration, R_{FCW}=FCW warning range

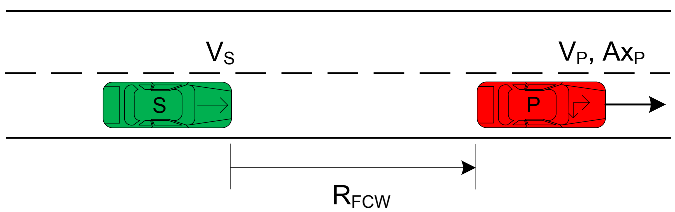


Figure 44. Rear-end crash scenario 2

- Scenario 3: This test is intended to verify the appropriateness of an FCW when the SV approaches from behind (with a large headway time gap), an aggressively slowing POV (P) in the center of the same lane.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P,Ax_P=Principle other vehicle speed, deceleration, R_{FCW}=FCW warning range

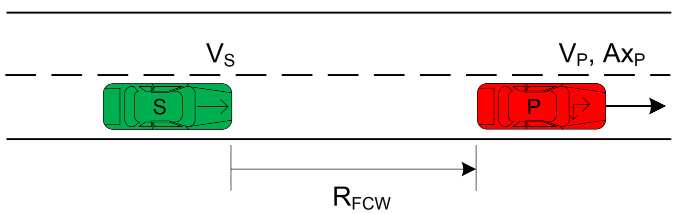


Figure 45. Rear-end crash scenario 3

- Scenario 4: The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a stopped vehicle approached at moderate speed.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

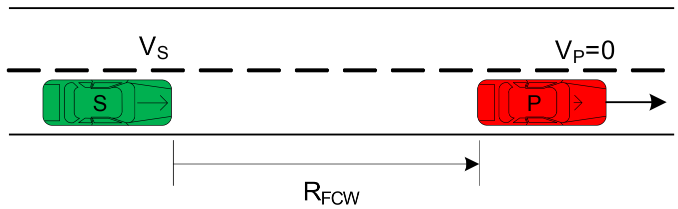


Figure 46. Rear-end crash scenario 4

- Scenario 5: The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a stopped vehicle approached at low speed.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

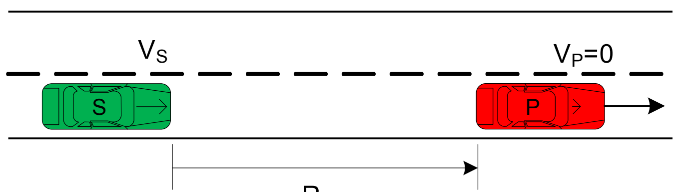


Figure 47. Rear-end crash scenario 5

- Scenario 6: This test is intended to verify the timeliness detecting a new in-path vehicle and the appropriateness of an FCW when the SV changes lanes to approach from behind a moderately slower moving P. The SV should complete its lane change just before entering the system's forward warning zone.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

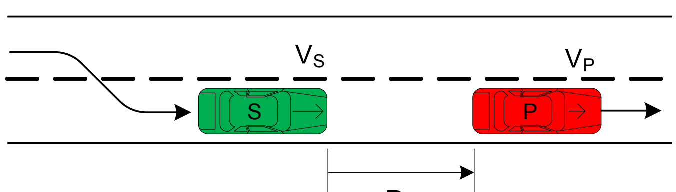


Figure 48. Rear-end crash scenario 6

- Scenario 7: The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a stopped vehicle in a curve to see if the system is able to determine the stopped vehicle to be in the same lane and therefore a threat.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

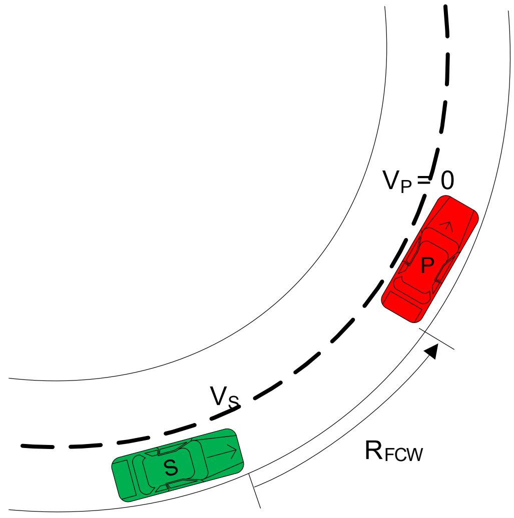


Figure 49. Rear-end crash scenario 7

- Scenario 8: The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a slower vehicle in a curve to see if the system is able to determine the slower vehicle to be in the same lane and therefore a threat.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

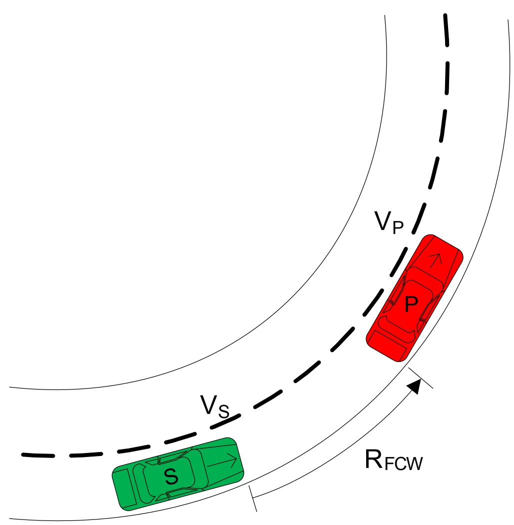


Figure 50. Rear-end crash scenario 8

- Scenario 9: This test is intended to verify the appropriateness of an FCW when the SV approaches a slower moving motorcycle that is traveling behind a same-speed truck. The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to detect smaller in-path vehicle near larger vehicles and issue timely warnings.

P1/P2=First/second principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, $V_{P1/P2}$=First/second principle other vehicle speed,
R_{FCW}=FCW warning range

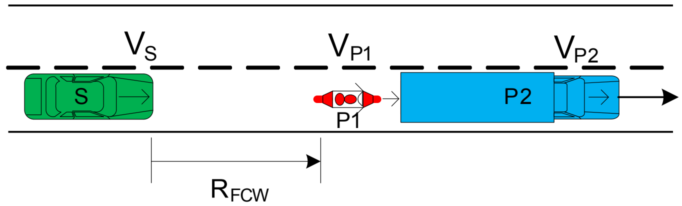


Figure 51. Rear-end crash scenario 9

- Scenario 10: This test is intended to verify the timeliness detecting a new in-path vehicle and the appropriateness of an FCW when a slower moving POV changes lanes in front of the SV. The lane-change/cut-in by the POV should occur within the forward-conflict region of the FCW system on the SV.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

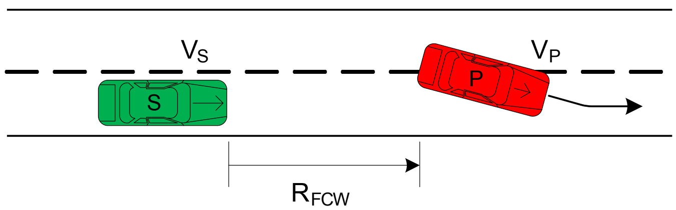


Figure 52. Rear-end crash scenario 10

- Scenario 11: This test is intended to verify the timeliness detecting a new in-path vehicle and the appropriateness of an FCW when a slower POV is suddenly revealed after the cut-out of an intermediate vehicle.

P1/P2=First/second principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, $V_{P1/P2}$=First/second principle other vehicle speed,
R_{FCW}=FCW warning range

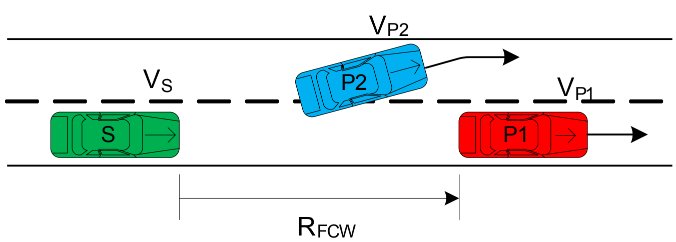


Figure 53. Rear-end crash scenario 11

- Scenario 12: This test is intended to verify the appropriateness of an FCW when the SV approaches, from behind and from long range, a slower moving motorcycle in the center of the same lane. This test especially explores the ability of the countermeasure to detect and issue timely warnings for smaller in-path vehicles.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, R_{FCW}=FCW warning range

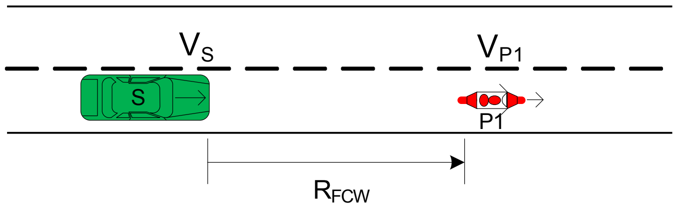


Figure 54. Rear-end crash scenario 12

5.4.2 Lane-Change Crash Threat Tests

The six lane change threat scenarios are as follows:

- Scenario 1: This test is intended to verify the appropriateness of a warning when the right-side blind zone is occupied by a vehicle. The SV driver gives a turn signal and begins to change lanes to the occupied right adjacent lane. Physically the POV is positioned with its front bumper behind the SV driver. Both vehicles are traveling at the same forward speed.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed,
V_P=Principle other vehicle speed, $LatV_S$=Subject vehicle lateral speed, $LatR_{LCW}$=Lateral warning range

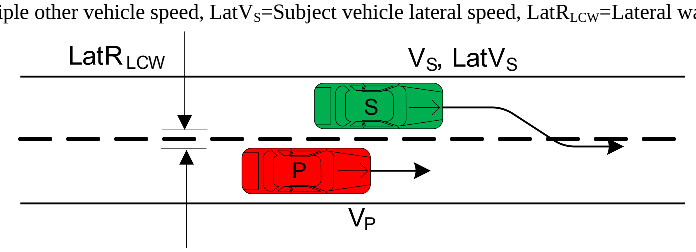


Figure 55. Lane-change crash scenario 1

- Scenario 2: This test is intended to verify the appropriateness of a warning (when and if it is issued) when the SV signals and begins to change lanes to the left while the adjacent lane is occupied by another vehicle such that the front bumper of the POV is behind SV driver. In this test both vehicles, traveling at the same forward speed are negotiating a large radius curve (~300 m).

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed,
V_P=Principle other vehicle speed, $LatV_S$=Subject vehicle lateral speed, $LatR_{LCW}$= Lateral warning range

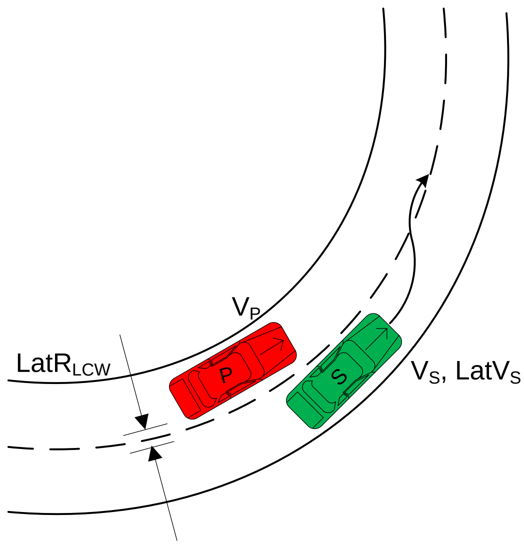


Figure 56. Lane-change crash scenario 2

- Scenario 3: This test is intended to verify the appropriateness of a warning when the SV signals and begins to merge into a lane that is occupied by another vehicle located in the blind spot of the SV driver. In this test both vehicles are traveling at the same forward speed. The test determines whether the countermeasure's required lane change merge warning is consistent with the warning requirements when the lane marker is not available.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed,
V_P=Principle other vehicle speed, $LatV_S$=Subject vehicle lateral speed, $LatR_{LCW}$= Lateral warning range

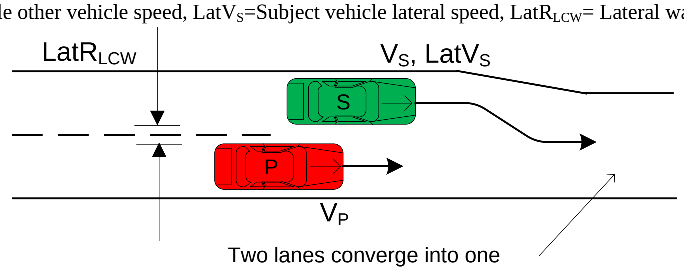


Figure 57. Lane-change crash scenario 3

- Scenario 4: This test is intended to verify the appropriateness of a warning (when and if it is issued) when the SV signals and begins to change lanes too soon after passing the vehicle in the left lane. In this test SV vehicle is traveling a little faster than the POV.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed,
V_P=Principle other vehicle speed, $LatV_S$=Subject vehicle lateral speed, $LatR_{LCW}$= Lateral warning range

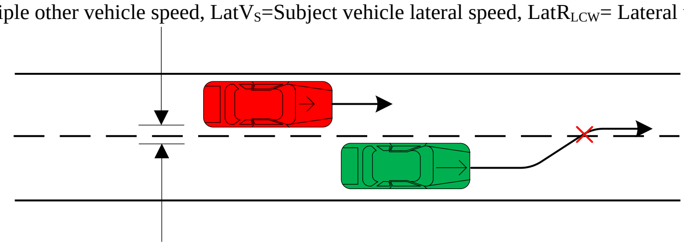


Figure 58. Lane-change crash scenario 4

- Scenario 5: This test is intended to verify the appropriateness of a warning when the SV changes lane and encounters an approaching POV.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed,
V_P=Principle other vehicle speed, $LatV_S$=Subject vehicle lateral speed, $LatR_{LCW}$= Lateral warning range

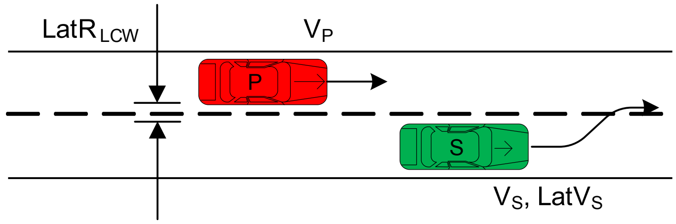


Figure 59. Lane-change crash scenario 5

5.4.3 Road Departure Crash Threat Tests

The seven road departure crash threat scenarios are as follows:

- Scenario 1: This test is intended to verify the appropriateness of an LDW when the SV drifts at a slow rate toward an opposing-traffic lane as designated by a double solid lane boundary. The lateral velocity of the SV relative to the boundary markers should be between 0.2 and 0.4 m/s.

S=Subject vehicle, V_S=Subject vehicle speed, $LatV_S$=Subject vehicle lateral speed,
$LatR_{LDW}$= Lateral warning range

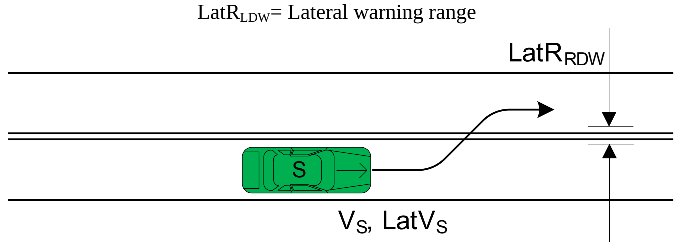


Figure 60. Road departure crash scenario 1

- Scenario 2: This test is intended to verify the appropriateness of an LDW when the SV drifts at a high rate toward a clear shoulder as designated by a solid lane boundary. The lateral velocity of the SV relative to the boundary markers should be between 0.6 and 0.8 m/s.

S=Subject vehicle, V_S=Subject vehicle speed, $LatV_S$=Subject vehicle lateral speed,
$LatR_{LDW}$= Lateral warning range

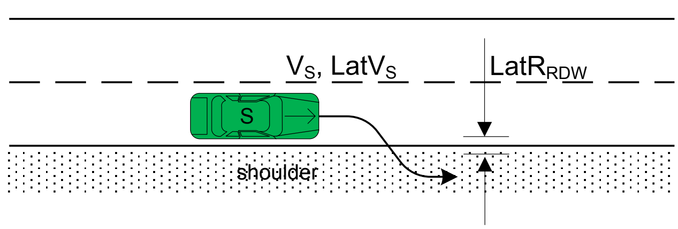


Figure 61. Road departure crash scenario 2

- Scenario 3: This test is intended to verify the appropriateness of an LDW when the SV driving at low speed drifts at a low lateral speed toward a clear shoulder (designated by a solid lane boundary) on a curve with a small radius (~200 m). The lateral velocity of the SV relative to the solid white boundary marker should be between 0.2 to 0.4 m/s.

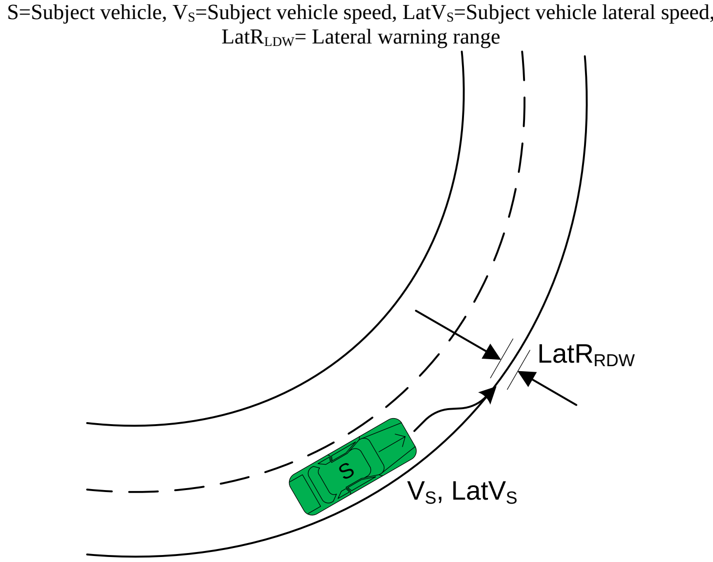


Figure 62. Road departure crash scenario 3

- Scenario 4: This test is intended to verify the appropriateness of an LDW when the SV driving at high speed drifts at a low lateral speed toward a clear shoulder (designated by a solid lane boundary) on a curve with a large radius (~ 300 m). The lateral velocity of the SV relative to the solid white boundary marker should be between 0.2 to 0.4 m/s.

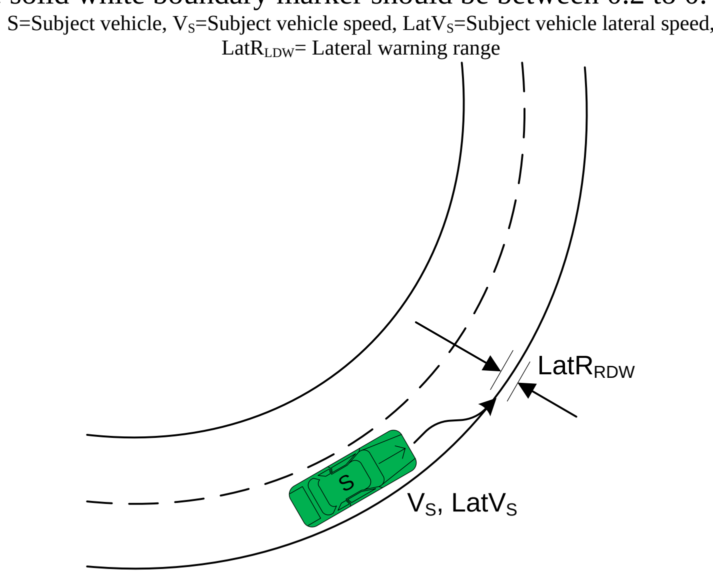


Figure 63. Road departure crash scenario 4

- Scenario 5: This test is intended to verify the appropriateness of an LDW when the SV drifts at a low lateral speed toward an adjacent jersey barrier to be placed one meter from lane marker. The lateral velocity of the SV relative to the barrier should be between 0.2 to 0.4 m/s.

S=Subject vehicle, V_S=Subject vehicle speed, LatV_S=Subject vehicle lateral speed, LatR_{LDW}= Lateral warning range

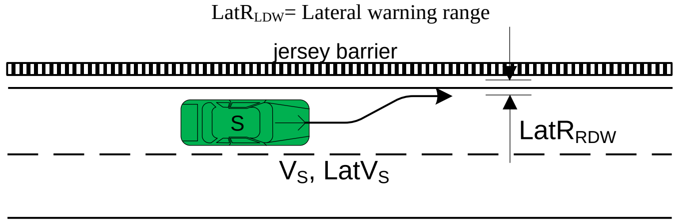


Figure 64. Road departure crash scenario 5

- Scenario 6: This test is intended to verify the appropriateness of a curve speed warning (CSW), when the SV driving at excessive speed encounters a small radius curve in warm/dry condition.

S=Subject vehicle, V_S=Subject vehicle speed, R_{CSW}= Curved speed warning range

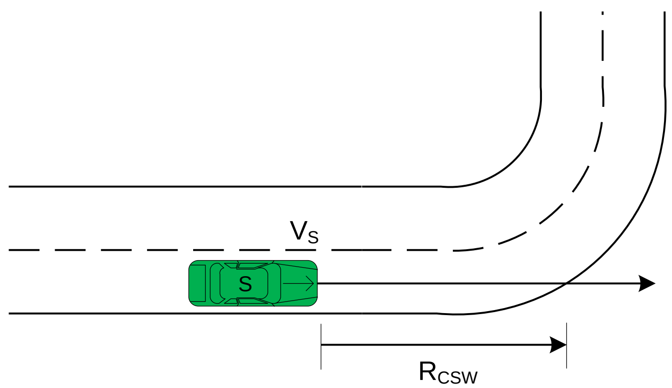


Figure 65. Road departure crash scenario 6

- Scenario 7: This test is intended to verify the appropriateness of a curve speed warning (CSW), when the SV driving at excessive speed encounters a small radius curve in cold or wet condition.

S=Subject vehicle, V_S=Subject vehicle speed, R_{CSW}= Curved speed warning range

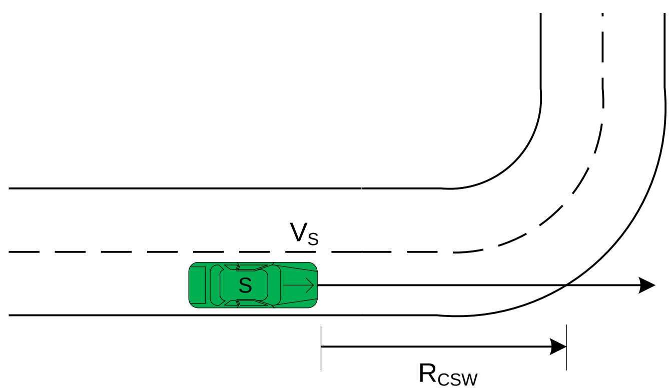


Figure 66. Road departure crash scenario 7

- Scenario 8: This test is intended to verify the appropriateness of a warning when the SV begins to change lanes to the left without signaling, while the adjacent lane is occupied by another vehicle that is located such that the POV rear bumper is in front of the SV driver. In this test both vehicles are traveling at the same forward speed.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed,
V_P=Principle other vehicle speed, $LatV_S$=Subject vehicle lateral speed, $LatR_{LCW}$= Lateral warning range

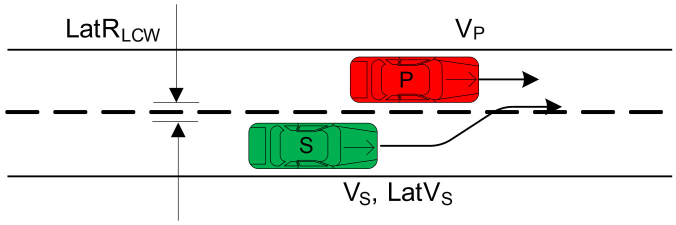


Figure 67. Road departure crash scenario 8

5.4.4 Multiple-Threat Tests

The three multiple-threat scenarios are as follows:

- Scenario 1: This test is intended to verify the appropriateness of an FCW and LCW when the SV approaches a slower P1 while there is an adjacent P2 that prevents the SV from changing lanes to maneuver around P1. In this test the SV and P2 are traveling at the same forward speed. This test determines whether the countermeasure's required alert occurs giving the SV sufficient threat awareness of the multiple threats.

P1/P2=First/second principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, $V_{P1/P2}$=First/second principle other vehicle speed,
$LatV_S$=Subject vehicle lateral speed, R_{FCW}=FCW warning range, $LatR_{LCW}$= Lateral warning range

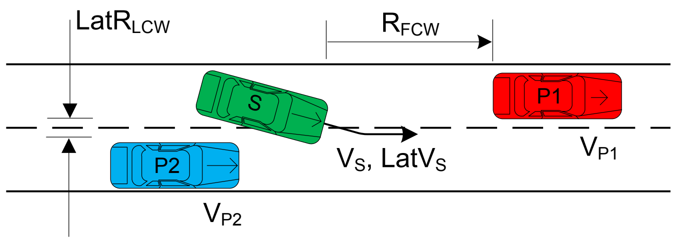


Figure 68. Multiple-threat crash scenario 1

- Scenario 2: This test is intended to verify the appropriateness of an LCW followed by an FCW when an adjacent P2 prevents the SV from changing lanes to go around a slowing P1. This test determines whether the countermeasure's required alert occurs, giving the SV sufficient threat awareness of the multiple threats. It will also show, that the IVBSS Warning System will not suppress critical warnings due to multiple threats occurring.

P1/P2=First/second principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed,
$V_{P1/P2}$=First/second principle other vehicle speed, Ax_{P1}= First principle other vehicle deceleration
$LatV_S$=Subject vehicle lateral speed, R_{FCW}=FCW warning range, $LatR_{LCW}$= Lateral warning range

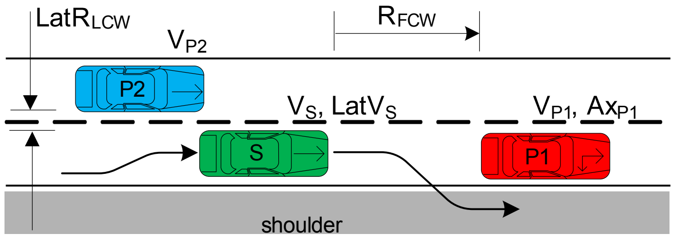


Figure 69. Multiple-threat crash scenario 2

5.4.5 No-Warn Threat Tests

The eight no-warn threat scenarios are as follows:

- Scenario 1: The purpose of this test is to verify that the IVBSS system does not issue a warning in a close-following situation, where SV is driving behind a POV with a constant 1-second headway gap.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed, $T_{headway}$=Time headway gap

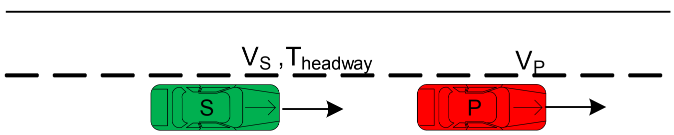


Figure 70. No-warn threat scenario 1

- Scenario 2: The purpose of this test is to verify that the IVBSS system does not issue a warning when SV passes a stopped POV in the adjacent lane, when both the vehicles are in a curve.

P=Principle other vehicle, S=Subject vehicle,
V_S=Subject vehicle speed, V_P=Principle other vehicle speed

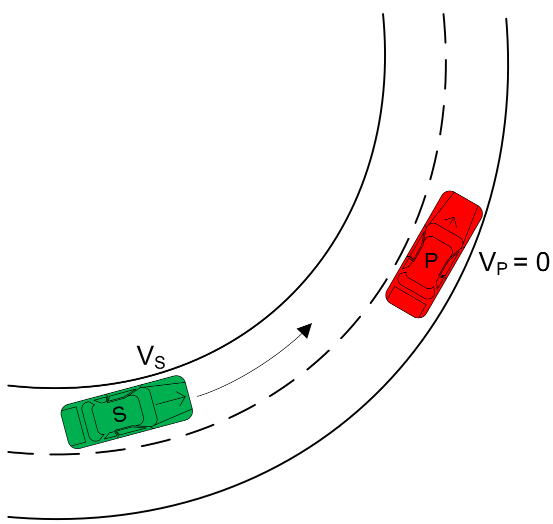


Figure 71. No-warn threat scenario 2

- Scenario 3: This test determines whether or not IVBSS system allows for close cut-in lane changes by a faster-moving POV without warning, as commonly experienced during naturalistic driving.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed, V_P=Principle other vehicle speed, $T_{headway}$=Time headway gap

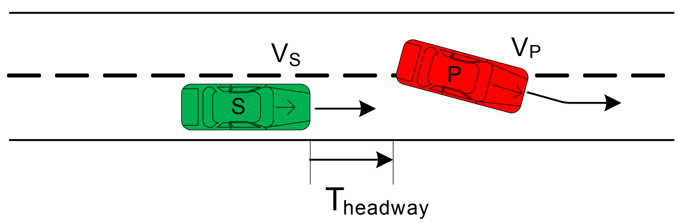


Figure 72. No-warn threat scenario 3

- Scenario 4: The purpose of this test is to verify that the IVBSS system does not issue a warning when SV approaches from behind and passes between two slower moving large vehicles in adjacent lanes.

P1/P2=First/second principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed, $V_{P1/P2}$=First/second principle other vehicle speed

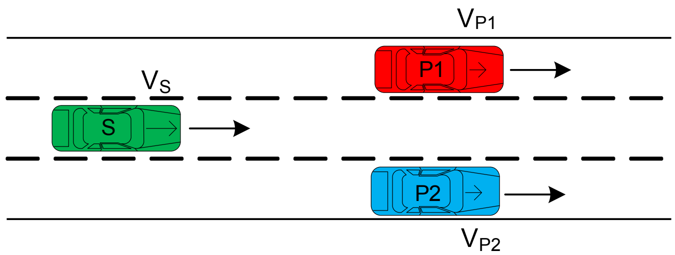


Figure 73. No-warn threat scenario 4

- Scenario 5: This test is intended to verify that no warning is issued for poor lane keeping, when SV is weaving within the lane, with a continuous barrier on the left with clear lane markings.

S=Subject vehicle, V_S=Subject vehicle speed, $LatV_S$=Subject vehicle lateral speed

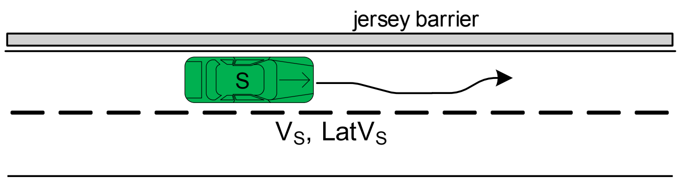


Figure 74. No-warn threat scenario 5

- Scenario 6: The purpose of this test is to verify that the IVBSS system does not issue a warning when the SV driver changes lanes in front of a slowly approaching POV in an adjacent lane. Since the POV driver has adequate time to react to the SV lane-change due to both the range between the POV and rear of the SV and the slow closing rate between the vehicles, a warning should not be issued to the SV driver.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed, V_P=Principle other vehicle speed, $T_{headway}$=Time headway gap, $LatV_S$=Subject vehicle lateral speed

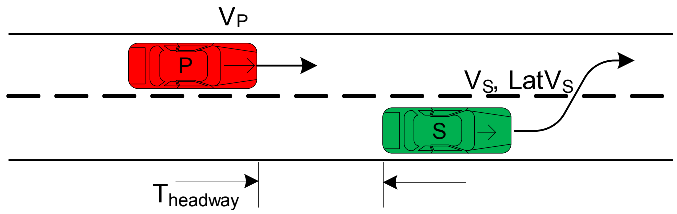


Figure 75. No-warn threat scenario 6

- Scenario 7: The purpose of this test is to verify that the IVBSS system does not issue a warning during a lane change for vehicles that are two lanes over and not a threat.

P=Principle other vehicle, S=Subject vehicle, V_S=Subject vehicle speed, V_P=Principle other vehicle speed, $LatV_S$=Subject vehicle lateral speed

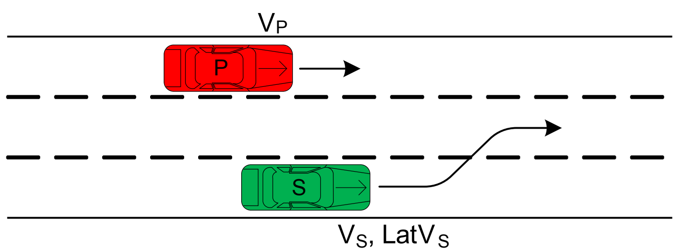


Figure 76. No-warn threat scenario 7

- Scenario 8: This test is intended to verify the appropriateness of a curve speed warning system that no CSW warning is given when the SV driving at safe speed encounters a small radii curve in warm/dry condition.

S=Subject vehicle, V_S=Subject vehicle speed

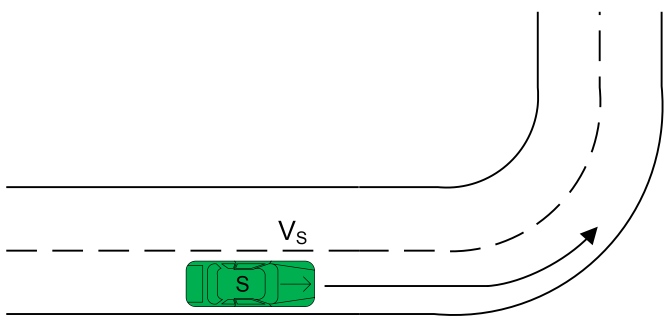


Figure 77. No-warn threat scenario 8

5.5 Verification Test Schedule

The light-vehicle and heavy-vehicle verification test schedules are shown in Figures 78 and 79, respectively. A similar Gantt chart, Figure 81 shows the heavy-truck verification test schedule. Both figures show the major schedule items for the development of the verification test procedures and Phase I testing. For both platforms, the first year of the program focused on developing the initial procedures. The light-vehicle program makes the TRC facility the focus of the effort when planning the execution of the procedures. For heavy-truck, the TRC, Dana, and Eaton Marshall test-track facilities will be used.

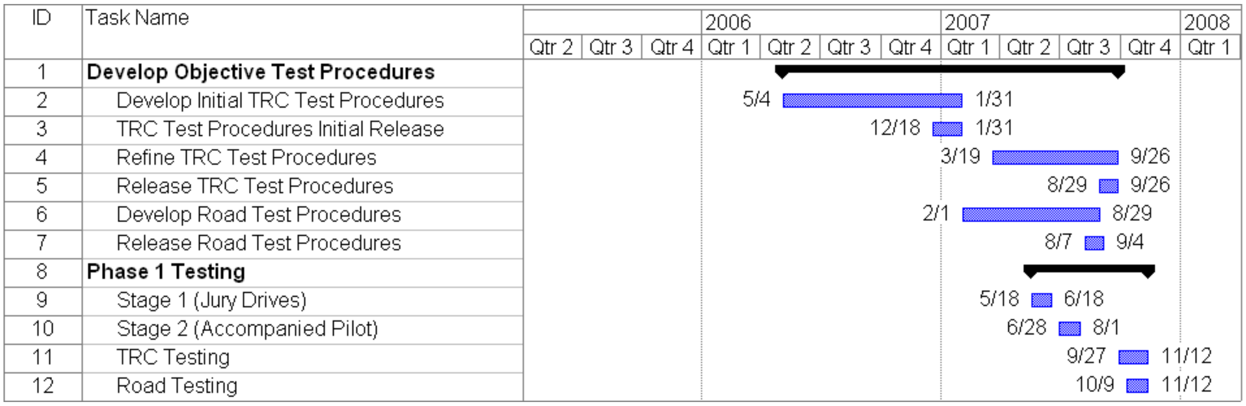


Figure 78. Light-vehicle verification test procedures and Phase I testing

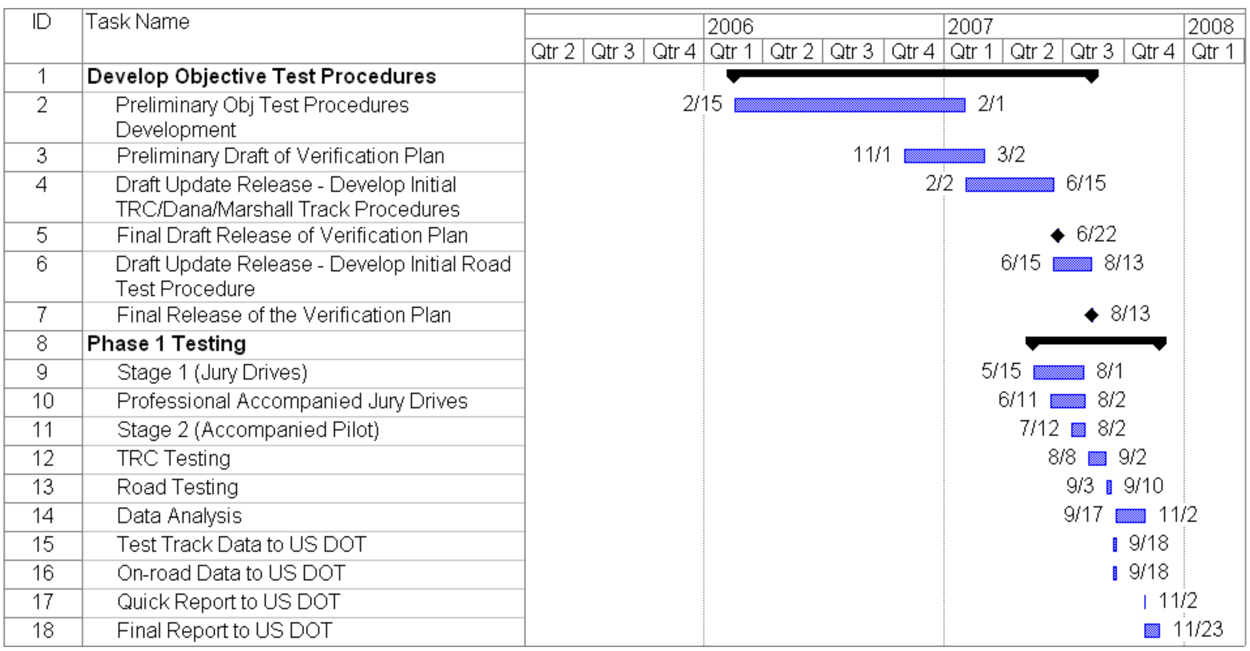


Figure 79. Heavy-truck verification test procedures and Phase I testing

5.6 Verification Test Schedules (Track and Road)

Test-track and on-road testing for the light-vehicle platform will be coordinated with that for heavy trucks, such that all program participants may observe any of the testing. Test-track testing will commence at the end of September 2007. On-road testing will begin immediately after completion of the test-track testing.

5.7 Second Year Activities and Schedule

The verification test plan and documentation will be completed during the second program year. The test plan will also be updated to include findings from the vehicle-level development occurring during that year. All tests will be verified at the track or on-road, respective of the specific test. The test plan will be executed beginning in September 2007. The resulting data will be analyzed and a test report generated. The results will be used to determine whether or not the IVBSS program will proceed into Phase II.

6 DVI and Human Factors Simulator/Laboratory Testing

6.1 Overview

The objective of the driver-vehicle interface simulator and laboratory testing is to establish warning system characteristics that result in both safe and effective DVIs. The design of an integrated crash warning system differs significantly from that of a single, standalone system in that the warnings must be distinguishable from one another. A single system simply has to present a warning that is readily detected and acted upon. A good warning tells the driver what is wrong and what to do, in an unambiguous and rapidly interpreted manner.

The team's approach to designing the DVI for both the light-vehicle and heavy-truck platforms was to design in hardware flexibility early in the system design and development stages. This allowed human factors testing and evaluation to take place in parallel with the development of the IVBSS system, with the DVI team understanding any constraints there may be on the final implementation (e.g., limits on file sizes for auditory warnings, visual display location, and the use of color).

Flexibility was built into the DVI by not constraining what can be presented to drivers. For example, in the simulator, the auditory information is a WAV file that is played by the program running the warning module. By changing the file name (which can be done at the last minute before testing), literally any sequence of tones, speech, or other sounds can serve as the warning. In terms of the haptic interface, changing the haptic output of any of the eight seat vibrators is a matter of changing a single string that specifies the on and off durations and intensity of each vibrator. Visual information, which is presented by a BASIC program that specifies the JPEG or text shown and its location and length of its display, is also easily modified.

Early decisions were made regarding the types of hardware that will be available to the DVI team on the two vehicle platforms, and a team of human factors experts worked directly with the IVBSS systems design and development teams to ensure that the hardware selection met the anticipated needs based upon the outcome of the human factors testing. This involved making some early assumptions regarding the scope of the DVI, based on some fundamental human factors principals, to allow the DVI and systems development teams to proceed in parallel. For example, there was a strong desire for the heavy-truck DVI to use existing hardware, which included a tone generator with limited capabilities, speakers with limitations, and LEDs on the A-pillar. It was also apparent that haptic feedback through the seat would be difficult to accomplish in a truck because of the suspension and air seat. For the light-vehicle DVI, however, the warning sounds could be generated using MP3 files, for which there are few limitations.

Engineering constraints and engineering tests paralleled the experimental work. For example, a special speaker system that provided localized sound to the light-vehicle driver, but not to passengers, was considered. The thought was that with a high false alarm rate, frequent warnings would be disturbing to passengers.

Preparation for the DVI simulator testing began with a review of the existing literature. The literature database created for this project contains 76 journal articles, proceedings papers, and technical reports. These were helpful in identifying test methods and conditions to examine, and in providing insights into warning characteristics such as warning modality, multiple alarms, alert reliability, responsiveness, and localization. The localization study (experiment 1, subtask 4) particularly benefited from the assembled body of literature. However, for matters of perceptual confusion, the literature was not very helpful in predicting which particular warning would be understood. Most of the human factors testing and DVI development work to date has concentrated on standalone systems (i.e., what constitutes a good auditory warning regardless of the application), or has not taken into consideration the potential for confusion with other warnings, the uncertainty of drivers when multiple warnings are present, or what is needed to mitigate uncertainty. Therein lies the challenge facing the design of an integrated warning system, and the importance of DVI testing and development in a simulator environment.

Identifying the human factors issues to examine in simulator testing was based on consideration of the human factors literature on warnings and knowledge of engineering issues that would arise as implementation proceeds. As a consequence, seven research questions emerged:

1. When and how should warnings be shared/differentiated (e.g., FCW and CSW, LDW and LCM)? How does that depend on factors such as having a common action in response to the warning (brake/slow down, stay in your lane), the collision potential/severity of the outcome (crash target present/absent), and, possibly, the warning reliability/nuisance alarm frequency?
2. When sequencing co-occurring warnings:
    a. Should only one warning be presented because the second will delay the driver's response? ***or***
    b. Should the second warning be presented with a delay (and what should that delay/lockout be)? ***or***
    c. If the second warning is of higher priority, should it preempt the first, and, if so, how (fade out the first, immediately start the second, provide delay/lockout and then start, etc.)?
3. How well do drivers respond to the set of warnings for the IVBSS? Are any confused or misunderstood?
4. What is the time course of driver actions to respond to single and multiple warnings, both when the warnings are unique to the situation and when multiple situations lead to the same warning (such as a common warning for LDW and LCM)? Of particular interest is where drivers look.
5. How does the tradeoff between warning system processing time (to start to inform the driver) and warning accuracy affect driver responses to warnings?
6. How does auditory warning effectiveness vary with warning sound characteristics (loudness, pitch, speed) in sound environments representative of each vehicle platform?
7. For sounds that involve periods of silence (or pauses), are responses deferred to coincide with silence? What is the optimal number of repetitions?

These seven questions were mapped into five experiments, the first of which had five subparts (see Table 8).

Table 8. Sequence of experiments

Experiment	Question/ Topic	Central Theme	Procedure	System
Exp 1/Jury selection	Auditory warning characteristics (Q6)	Characterize sound environment of light vehicle and heavy truck; select sounds best suited to environment, five sub-tasks	*Jury evaluations:* (sub-task 1) of masking of warnings, (2) of sound appropriateness, (4) Localization of candidates sounds *RT evaluations* (sub-task 3) confusability of ensemble, (5) repeating sounds	All
Exp 2	Time course, method (Q3, Q4)	How people respond (where and when they look) suggests warning presentation modality and content.	Collect eye fixations, steering and brake data, etc. to initial warnings (includes uninformed warnings)	FCW, LDW, CSW, maybe LCM
Exp 3	Shared warnings (Q1, Q3)	If two warnings (FCW, CSW) lead to the same response, should the warning be the same?	Collect steering and brake data, etc. for shared warnings and unique warnings	All
Exp 4	System time/acc. tradeoff (Q3, Q5)	Warnings that are delayed may be more accurate. What tradeoff is "best?"	Use full set of candidate warnings, vary accuracy and delay of each warning, collect steering and brake data, etc.	All
Exp 5	Co-occurring warnings (Q2)	When two warnings occur at the same time, should one be delayed and by how much?	Create situations to trigger two warnings. Sometimes present both, sometimes present in priority order, with delays. Collect steering and brake data, etc.	All

To experimentally address the above questions, it was apparent that the UMTRI driving simulator needed significant upgrading. Additionally, enhanced tools to support warning evaluation were needed. Simulator testing was chosen for the initial effort because of the need to present potentially life-threatening situations where the outcome would not be fatal, and to be able to do so repeatedly and consistently. Furthermore, it would have been difficult to obtain permission to test a crash warning system on the road that had not been first evaluated in the laboratory.

Key simulator enhancements included the following:

- **Increasing field of view**. Prior to this project, the UMTRI simulator had a 120-degree field of view, which was inadequate for lane-change/merge scenarios for which warnings were needed. Therefore, side screens, projectors, and image generators were added resulting in a 200-degree field–of-view.
- **Adding an eye fixation system**. Work was also done to synchronize the clock for the system with the driving simulator.
- **Adding a seat shaker**. Midway through development, a special seat shaker was added to simulate brake pulses.

- **Developing software to convert warning parameters**. Certain types of warnings to be evaluated, as well as the range of their physical characteristics, were apparent, but the specific parameters were unknown. Software was developed to convert a string of warning parameters (sound file name, number of repetitions, time between repetitions) into a warning.
- **Developing crash scenarios**. The project required developing of a large number of crash scenarios (merging, cut-ins, etc.) for which simulator code did not previously exist.

6.2 Experiments

6.2.1 E1: Auditory Warning Selection

Unlike visual displays, auditory warnings do not require a driver to look at a display in order to detect the alert. Auditory warnings are also relatively inexpensive to design and integrate into a collision warning system and represent a fairly conventional DVI approach to deliver a warning notification to a driver. Identifying the best choice of warning sounds for a system in which multiple crash warnings may be needed is a difficult undertaking because sound can vary in many independent dimensions, producing infinite possibilities. The approach taken here is to divide the investigation into parts that may provide some guidance in selection of sounds characteristics that may be applied to crash warnings.

The following selection criteria should be applied to warning sound selection:

- **Sounds should be easily noticed**. To be noticed, a sound must be audible over the background noise levels of the light vehicle or heavy truck.
- **Sounds should be minimally annoying**. A warning should not startle a driver by being too loud or having too harsh an onset. It should also avoid masking other potentially relevant sounds in the cabin.
- **Sounds should be quickly identifiable**. That is, they should be sufficiently distinctive so they are not confused with other non-warning sounds or with other sounds in the crash warning suite.
- **Sounds should be easily associated with a crash scenario**. Highly urgent sounds should be matched with highly urgent warning circumstances. If possible, natural sounds might be selected that can be readily associated with a crash scenarios (i.e., auditory icons)., care should be taken, however, to ensure that these sounds are not easily confused with sounds in the natural environment.

The auditory warning experiments are divided into five experimental subtasks as follows:

- E1.1: Sound environment characterization;
- E1.2: Acoustic properties affecting sound perception.
- E1.3: Evaluation of learnability, confusability, and response efficiency of sound suites;
- E1.4: Localization of sounds; and
- E1.5: Effects of repetition and silence on driver response.

The following sections briefly describe and summarize the results of studies E1.1-E1.5.

6.2.1.1. Experiment E1.1 — Sound Environment Characterization

The purpose of this investigation was to describe the general sound environment likely to be found in the light-vehicle and heavy-truck environments to ensure that warning sounds would be sufficiently loud to be heard over background noise levels, and sufficiently different from existing sounds (e.g., belt reminders, key reminders) that the chance of confusion would be minimized.

Ambient sound levels were collected for a representative heavy truck, a representative day-cab configuration operating at 70 mph, and the target light vehicle, a 2007 Accord EX. Each vehicle was driven at representative highway speeds with the windows closed. Existing warning sounds present on the Accord were sampled; these sounds were generally temporal variations of a high-pitched (2048 Hz) sine wave. Examples of these sounds are provided in Appendix B. The heavy-truck samples were lower in fundamental pitch (around 660 Hz) than the light-vehicle. Variations of the basic sound were produced by altering the base duration of the sound pulses.

6.2.1.2. Experiment E1.2 — Acoustic Properties Affecting Perceived Urgency

This experiment examined how several acoustic properties of a sound affect a listener's perception of the urgency, annoyance, and noticeability of the sound. This is based on previous work by Tan and Lerner[21] in which prospective warning sounds were evaluated on multiple attributes (e.g., annoyance, loudness, and urgency). In the current study, sound samples were created that varied on several dimensions in a fractional design in order to model the relationships between each factor and subjective impressions of urgency, annoyance, and noticeability. In addition, several "standard" sounds were included to obtain benchmarks for each of the subjective evaluations.

The objective of this study was to understand how acoustic sound characteristics affect a person's subjective impression of each dimension to match sounds to subjective ratings of crash scenario urgency and to determine which acoustic features are most salient in affecting subject impressions. In this study, 24 subjects evaluated a set of 32 sounds. Of the 32 sounds, 24 were abstract sounds generated programmatically using CSound scripts generated by a Python script, which, in turn, was driven by a SAS-based stimulus table to produce an orthogonal design. Sounds were varied on the basis of timbre, harmonic and inharmonic content, pitch, pulse speed, onset speed, pulse count, single- or multi-pitch contour, and rhythmic evenness. The remaining eight sounds were adopted from previous crash warning projects (ACAS and RDCW), existing products (VORAD), and prior auditory warning studies and served to provide a context for the generated sounds.

The results indicate that all three subjective judgments are highly correlated. Thus, a sound that is judged as very urgent is also likely to be judged as annoying. The overall results suggest that the most influential sound characteristics that affect perceived sound urgency are:

- Multi-pitch contour—decreased rated urgency;
- Pulse count (3, 5, 7)—increased rated urgency;
- Pulse speed—increased rated urgency; and
- Onset time—short onset increased rated urgency, long onsets decrease rated urgency.

Each IVBSS prospective crash scenario (FCW, CSW, LDW, and LCM) was rated by participants and ranked based on its assigned urgency score (shown in Figure 80). Participants were provided a brief verbal description of each scenario and asked to recall any incidents or near incidents from their own driving experience that matched each scenario, and then to rate the urgency of the circumstance. Drivers rated LCM as the most urgent scenario and LDW as the least urgent. This suggests that drivers perceived the two lateral warnings as the extremes of the tested stimulus series.

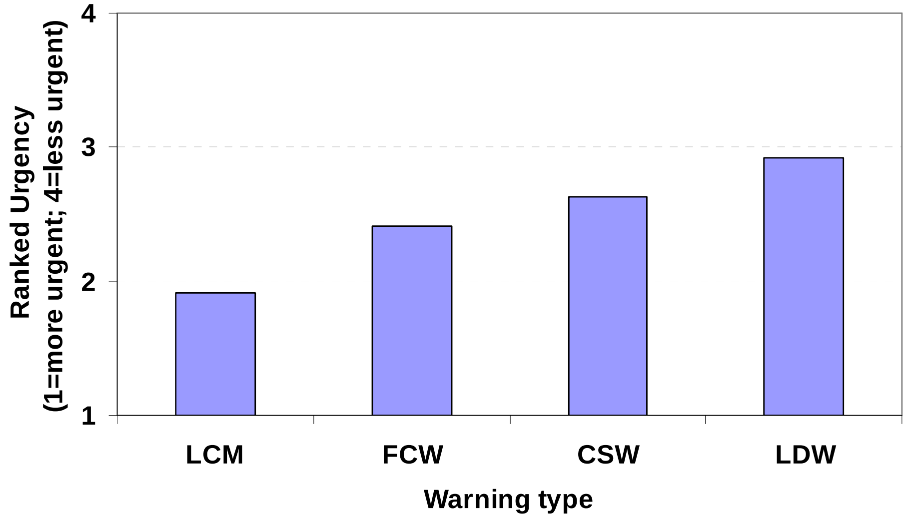


Figure 80. Average ranked urgency by scenario (lower numbers indicate greater urgency)

6.2.1.3. Experiment E1.3 — Warning Suites

In this study, three candidate suites of four warning sounds will be investigated for their learnability, confusability, and response efficiency. Each suite represents a worst-case imminent-warning interface with respect to complexity of the sound environment. Indeed, simpler interfaces might ultimately be adopted that distinguish fewer imminent crash scenarios. The approach used in this exercise was to develop a maximally-complex sound environment in order to reveal differences in the sound suites. Learnability was assessed by measuring the number of learning trials to reach a response accuracy criteria, confusability was determined by examining how often sounds within suites are mistaken for other warnings, and response efficiency was determined by measuring how quickly a correct choice reaction time is made for the warning sounds in each suite.

The three sound suites investigated include the following (examples of each set of sounds are provided in Appendix B):

- **Hybrid auditory icons (urgent)**. This set includes an abstract FCW sound, a honking-horn LCM sound, a squealing-tire sound for CSW, and an abstract sound meant to resemble a rumble strip for LDW.
- **Hybrid auditory icons (lower urgency)**. This set was derived from the first set, but manipulated to reduce the urgency by lowering pitch and slowing the pulse speed.
- **Abstract sounds**, arranged by modeled urgency (derived from experiment E1.2), were also developed.

Twenty-four subjects were run this study, and each suite of sounds was tested within a block of trials. Suite presentation was counterbalanced across subjects, and the task was for each subject to indicate (by a key-press) which of four crash scenarios are signaled by one of the randomly selected sounds in the suite.

6.2.1.4. Experiment E1.4 — Sound Localization

This study will examine the degree to which sound localization is improved by modifying some characteristics of the warning sounds. In general, human sound localization is based on binaural differences in sound amplitude and on temporal differences due to staggered arrival times of a sound to each ear. Sound localization cues that are consistent with the lateral direction of a detected threat are expected to reduce threat detection time. For IVBSS warnings, the placement of a warning sound source will only coarsely identify the left or right location of a potential threat; they are not intended to accurately represent the spatial position of a threat. A recent study[2] suggests that sounds containing noise components may be more easily localized than sounds that do not. In this study, sounds associated with crash warnings that reflect left or right threats (LDW and LCM) will be modified to include noise components to determine if localization benefits are observed.

6.2.1.5. Experiment E1.5 — Silent Intervals and Sound Repetitions

This study will examine the degree to which intervals of silence between sound repetitions affect the response time of a subject. There is some evidence from cell phone use[19] that an action in response to an auditory signal (e.g., a ringing phone) could be synchronized to periods of silence such that a response is withheld until a silent interval. It is unknown whether this result generalizes to collision warnings, but if it does, it may have serious consequences for the design of auditory warnings.

6.2.2 E2: Time Course for Various Test Conditions

The time course experiment has been designed to address three sets of questions:

1. How do drivers actually respond to real, nuisance, and false warnings, and especially, where do they look? Two states are being considered: (1) the first time or the first few times a particular warning is presented (“surprise or uninformed driver” conditions) and (2) after drivers have been fully informed of its functioning.
2. How is the warning presentation strategy affected by:
   a. The presence and absence of a distracting task?
   b. The use of occlusion to increase visual demand?
3. How well do drivers respond to the set of warnings for IVBSS developed in the simulator? Are any warnings confused or misunderstood?

In this experiment, subjects will be trained in performing a distracting task while driving. A variety of the alert types (true, false, and nuisance alerts) will be presented for all four crash warning subsystems. Subjects will also be trained on each of the warning systems including learning how and when they are triggered. Subjects will drive and perform the distracting task with each warning presented several times, with the goal of having at least two occurrences of each type of warning (true, false, nuisance) for each warning subsystem.

6.2.3 E3: Shared Warnings

The shared warnings experiment has been designed to address two sets of questions:

1. When and how should warnings be shared/differentiated (e.g., FCW and CSW, LDW and LCM)? How does that depend on having a common action in response to the warning

(brake/slow down, stay in your lane), the collision potential/severity of the outcome (crash target present/absent), and, possibly, the warning reliability/nuisance alarm frequency?

2. In the simulator, how do drivers respond to a set of potential warnings for IVBSS? Are any warnings confused or misunderstood?

The primary dependent measures were the brake actuation times for each scenario and test condition. If the system-specific warning provides additional useful information, that utility should be reflected in reductions in accelerator release time (for CSW and FCW) and steering response time (for LDW and LCM). Crash-related measures were also collected (number of crashes, TTC, and closest point of approach).

6.2.4 E4: System Time or Accuracy Tradeoff

The time or accuracy tradeoff experiment has been designed to address two sets of questions:

1. How does the tradeoff between warning system processing time (to start to inform the driver) and warning accuracy affect driver responses to warnings?
2. In the simulator, how well do drivers respond to the set of warnings for IVBSS? Are any warnings confused or misunderstood?

The focus of this experiment will be on the time it takes from when the system has enough information to provide a warning until it presents the warning. Given that response times are on the order of approximately one second, the response times should be accurate to 100 ms. Using a margin of error of 2 leads to 50 ms intervals for estimation. Additional processing time may allow for improved warning accuracy and a potential reduction in the number of nuisance or false alarms.

6.2.5 E5: Co-Occurring Warnings

The co-occurring warnings experiment has been designed to address two sets of questions:

1. When sequencing co-occurring warnings:
   a. Should only one warning be presented because the second will delay the driver's response? ***or***
   b. Should the second warning be presented with a delay (and what should that delay or lockout be)? ***or***
   c. If the second warning is higher priority, should it preempt the first, and if so, how (fade out the first, immediately start the second, provide delay and then start, etc.)?
2. In the simulator, how well do drivers respond to the set of warnings for IVBSS? Are any warnings confused or misunderstood?

There are four primary factors (potential independent variables) to consider: (1) how many alarms are presented (one or two) and if two alarms are presented (2) which warning has higher priority, (3) which warning arrives first and by how much time, and (4) the reliability/confidence of each warning. Subjects will drive a complex simulator world, but with modifications to the geometry and traffic to specifically trigger multiple alarms. As with other studies, a mixture of true, nuisance, and false alarms is desired.

6.2.6 Environmental Characterization

The two platforms to be used, the Accord EX and an International 8600 series tractor, will require that the cabin environments be sufficiently characterized, particularly for environmental noise levels and the types of auditory tones that might already exist in the vehicles. To a large degree, particularly on the light-vehicle platform, this has already occurred.

This characterization is required to ensure that the auditory warnings developed as a result of the simulator testing are sufficiently different from existing tones so as not to be confused with existing tones. However, the effects of the environment in which they are implemented can dramatically alter the *in situ* characteristics. Factors such as the dynamic range of the vehicle's speakers and sound attenuation due to in-cabin trim can affect the perceived characteristics of auditory signals. Additional work has also been performed to characterize the visual displays and labeling of controls and displays in the cabins. Matching the existing use of colors, fonts, font sizes, and luminance levels for self-luminous displays all contribute significantly to making IVBSS an integral part of the vehicle from the perspective of the driver.

6.2.7 Jury Selection

The jury selection process is largely one in which potential warning characteristics, both appearance and timing, can go through a "down-select" process to narrow and refine system characteristics. A fully-integrated IVBSS system will be evaluated by all program participants, including UMTRI, U.S. DOT, NIST, and Volpe. It is a subjective analysis of system performance whose feedback is used to enhance the system design. The process will consist of a prescribed route with prescribed maneuvers.

The drive will encompass a variety of roads, including class 1-5 roads, unmapped areas (e.g., parking lots), and paved and unpaved roads. The testing will also consist of subjectively evaluating the IVBSS system on a non-prescribed route. In each case the specific attributes of IVBSS will be examined. The system will be measured on performance, functionality, and acceptability of the DVI. This testing will provide feedback on design changes to be incorporated prior to the first exposure of the system to lay drivers. The in-vehicle jury selection will take advantage of instrumented development vehicles on both platforms. Some of the jury selection efforts will have to take place on the test track, using prescriptive maneuvers.

6.2.8 Pilot Testing

Pilot testing will engage lay passenger-car and commercial-truck drivers on accompanied drives to evaluate the IVBSS functionality and the DVI. Specifically, pilot testing will attempt to demonstrate the IVBSS system in a naturalistic setting and in the presence of a researcher who is experienced with the system. Pilot testing will use instrumented development vehicles to allow detailed evaluation of events that drivers naturally experience. Subjective evaluations of the system will also be obtained. The main goal of pilot testing will be to determine if the DVI for IVBSS is readily understood by drivers, but it will also provide insight into whether the IVBSS design is viable based on reactions to performance and functionality. The results of pilot testing come early enough in the system development process to allow feedback to influence system adjustments to warning algorithms and the DVI. A route will be selected such that specific attributes of IVBSS can be demonstrated through naturally-occurring events. The route will also encompass a variety of roads and traffic conditions. There will be no prescribed maneuvers in pilot testing.

6.3 Accomplishments

During the first year, considerable progress was made toward developing both a safe and effective DVI for the light-vehicle and heavy-truck platforms. DVI development began with a literature review and preliminary findings from the literature concerning localization of warnings helped to inform and guide the development of Experiment 1. Experiment 1 was partially completed and resulted in identifying preliminary sound characteristics for warnings.

Additionally, Institutional Review Board approvals were obtained for all of the human factors experiments. While not completed during the first year, most of the work to develop the driving simulator scenarios was performed. To a large degree, these scenarios will be shared by experiments 2 to 5 (to be conducted in the second year). In these experiments, scenarios are designed so that any vehicle could pose a threat, and threats can come from the front and sides. Furthermore, scenarios have been designed in such a way that a vehicle maneuver can result in a threat, such as a lane change revealing a parked vehicle ahead, whereas other times there were no negative consequences.

The same basic dependent measures related to driving will be used in all major experiments, including: accelerator release time, brake actuation time, steering response time, and minimum time to collision. Both objective and subjective measures will be included, with the most appropriate objective measure depending upon the type of warning system in question.

6.4 Second Year Activities and Schedule

All of the tasks outlined in the above, with the exception of the first two subtasks in the auditory warning selection experiment and the initial environmental characterization of the vehicles, will take place in the second year of the program. Figure 81 illustrates the development schedule for the DVI.

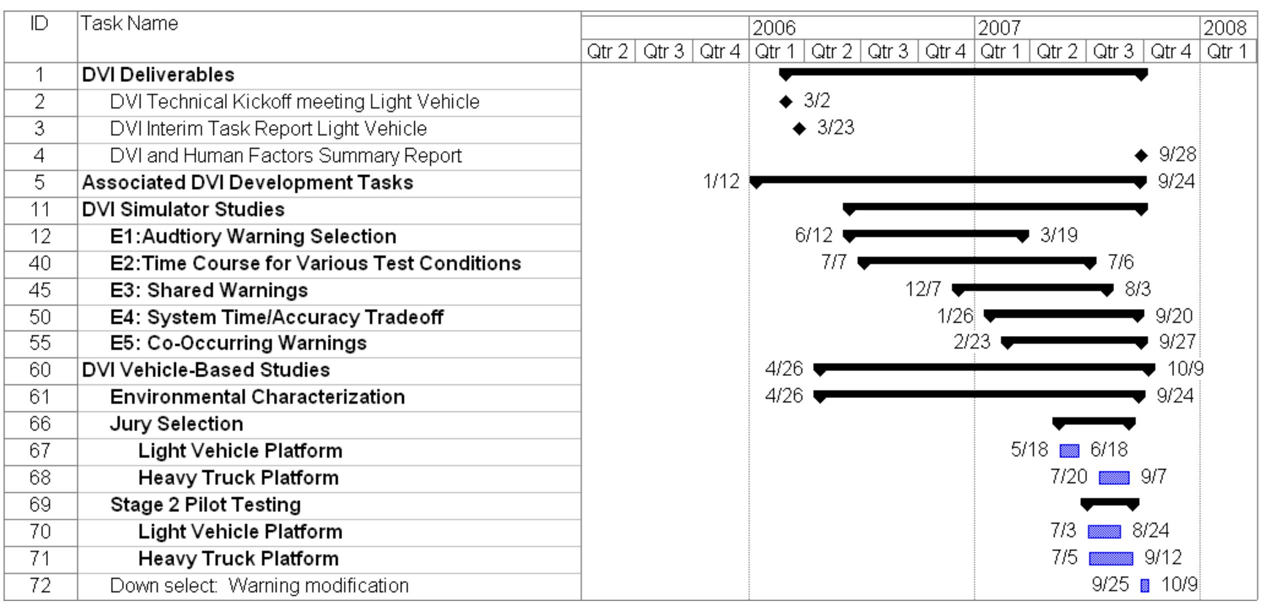


Figure 81. Schedule for development of driver-vehicle interface

While progress has been made in the areas of examining the literature, driving scenarios, and experiments for the simulator, and in conducting experiment 1, there remains a great deal of work to be performed in year 2 of Phase I. These efforts will include completion of the simulator studies and jury drives involving system developers, vehicle manufacturers, and U.S. DOT representatives. First and foremost is the completion of the simulator studies, followed by evaluating DVI characteristics during jury drives. The yet-to-be-completed simulator experiments will inform the design of the DVI—which sounds are readily associated with various warnings; which sounds are confused; where haptic feedback should and should not be used; if warnings for different hazards can be the same if the driver response is the same; and what types of delays of warnings do not degrade performance. Jury drives will be the first opportunity for most members of a large development team to experience the DVI in the vehicle. Feedback from the jury drives, both formal and informal, will be used to assess DVI design characteristics and warning strategies. A final report describing all of the DVI efforts will be submitted once all of the studies have been completed and the data analyzed, before the end of Phase I.

7 Field Operational Test Preparation

Preparation for the field operational test, which takes place in Phase II of the program, will begin in the second year. Some work has already occurred, however, including early development of the data acquisition system, as it is needed to support the development of the IVBSS systems in the second year. As the second year of Phase I progresses, there will be an increasing emphasis on field test preparations, as outlined in section 7.2.

7.1 Data Acquisition System

The development schedule of the data acquisition system (Task 1.j) is shown below.

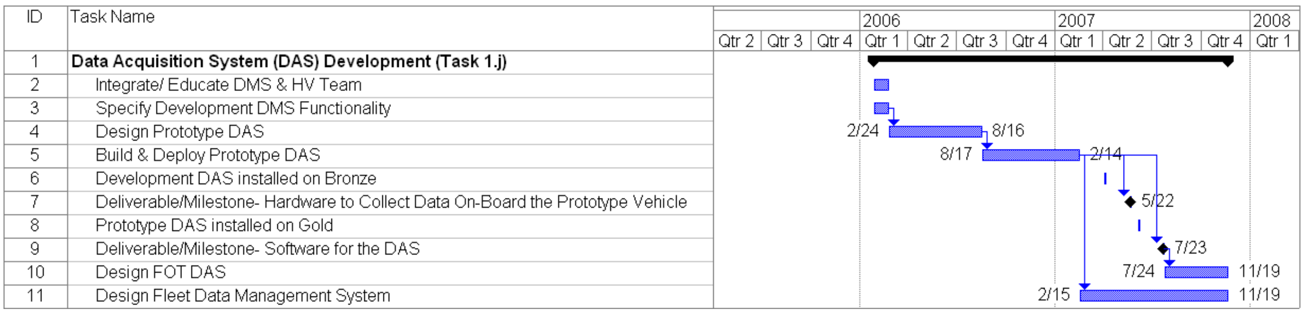


Figure 82. Schedule for development of data acquisition system

7.1.1 Overview

The data system development activity (Task 1.j) is to create hardware and software and to deploy networking operations to capture data from onboard IVBSS vehicles during both Phase I development and verification efforts and Phase II FOT experiments. This activity includes:

- Data capture to support Phase I engineering development of the IVBSS systems on the light-vehicle and heavy-truck platforms;
- Data capture during Phase I verification testing, including some cooperative elements to assist the U.S. DOT's designated organizations to collect independent data during these tests;
- Data capture during pilot testing in Phases I and II;
- Data capture during both the extended pilot FOT and the final FOT during Phase II;
- Data capture and transfer to support remote monitoring of the test fleets in order to ensure proper performance of the IVBSS system and appropriate usage of the test vehicles by the test participants (both project phases);
- Creation and management of data archives from both the Phase I development and testing efforts and the major testing efforts in Phase II;
- Support of analysis task needs for the UMTRI project team during all phases of the project;
- Sharing of key elements of the data archive with the independent evaluator and other representatives identified by the U.S. DOT;
- Ability of the entire UMTRI team to remotely access data for both development purposes and to assist in the conduct and analysis of the major tests; and
- Ability of the U.S. DOT and its contractors to monitor the progress of the FOT fleet usage and system performance remotely, and in near real time.

The data system can be described as two integrated systems. The first system is the onboard data acquisition system module that collects data that is generated by IVBSS, the subject vehicle, and "FOT sensors" (sensors and devices that serve the data collection purposes but do not contribute to the IVBSS functionality). The second system is the data management and analysis system, which is a set of software, networking, and hardware elements that are used to manage the DAS units remotely, to manage data already onboard the DAS units, to load and manage archived data into enterprise-grade servers, and to enable post-processing and visualization of data. While the onboard DAS is a new generation that builds upon designs used in previous U.S. DOT field operational tests, the DMAS represents major innovation in networking to support such projects.

There will be three generations of DAS modules and two generations of the DMAS during the project, as shown in Table DAS.1. The three generations of DAS modules include an initial deployment of five modified units from the RDCW project to support the engineering development efforts at Eaton, Cognex, and Visteon. Those DAS units will augment the engineering teams' ability to collect data – all teams will have primary data collection systems that provide traditional data support and visualization. The DAS modules are added because of the improved data-search capabilities and the turnkey operation that allows secondary issues to be identified and resolved. For example, an intermittent issue is more easily identified when the data is archived in a query-able database format.

The second generation of DAS modules will be the prototype DAS units, which will include the same hardware and software components as the DAS units that will eventually be fielded in Phase II for both the light-vehicle and heavy-truck platforms. The prototype DAS units may not have all the final hardware packaging and wireless communications that will be implemented for Phase II.

The third generation of DAS modules will be the FOT DAS units. These will be used in Phase II and will have complete hardware packaging and wireless communications.

The DMAS will have two generations; Table 9 shows that both the development DAS and Phase I prototype DAS modules will be used in conjunction with a DMAS network that includes remote servers at each of the three development team facilities. UMTRI will be able to remotely administer and manage the data on those servers, as well as the DAS module itself, and duplicate the data at UMTRI if necessary. Thus when the development teams revise the data produced by their IVBSS system or subsystems, UMTRI can reconfigure the DAS to collect the data and reconfigure the databases to reflect the changes.

The second generation of the DMAS for Phase II operations will use essentially the same concept except that the remote server location will be the heavy-truck fleet terminal.

Table 9. Generations of DAS modules and DMAS networks

Generation of DAS Modules	DAS Module Description	Features of DAS Module	DMAS Remote Server Locations	Primary Server Location and Communications
Development	Modified RDCW FOT units (4 LV, 1 HT)	Possible limits on radar, vision capabilities	Eaton (Southfield, MI), Cognex (Pittsburgh, PA), Visteon (Van Buren, MI)	UMTRI (Ann Arbor, MI) Manages via VPN
Phase I prototype	Prototype of Phase II units (2 each for LV, HT)	Up to seven radars, four cameras	Same as above	Same as above
Phase II	Phase II units (18 LV, 11 HT)	Final packaging	HT fleet location (Romulus, MI)	UMTRI; Remote data via cell modems, wireless, VPN. Team access via VPN and web.

Figure 83 shows a schematic of the onboard DAS module and its interfaces. The primary sources of data include:

- The IVBSS data buses (four CAN buses on the light-vehicle platform, and two CAN buses and a J1939 bus on the heavy-truck platform);
- Camera signals from the LDW camera on both platforms, and possibly other IVBSS cameras;
- Camera signals from cameras that are installed only for analysis purposes;
- FOT sensors, including accelerometers and GPS on both units, and possibly steering wheel angle on the heavy vehicle system;
- Battery power and ignition switch state;
- Remote wireless data transfer (cellular data network connection for the light-vehicle platform and wireless LAN for the heavy-truck platform); and
- Ethernet connection for downloading data and communicating remotely (via the VPN network) to the DAS module.

The onboard DAS module will collect data on the following types of information:

- Driver’s vehicle-control activity (e.g., brake switch, throttle, wipers, turn signals, lights, etc.);
- Subject vehicle state (e.g., speed);
- IVBSS intermediate information;
- IVBSS crash alerts, advisories, and system status information;
- Driver inputs to IVBSS (e.g., driver preference for alert timing);
- GPS information;
- All radar information (seven radars on the light-vehicle platform and six radars on the heavy-truck platform);
- Video information from five cameras per platform (forward scene, driver’s face, cabin activity, external scene to the left-side and the rear, external scene to the right-side and rear of the vehicle); and
- Environmental information (e.g., road type, ambient temperature, precipitation, lighting, etc.).

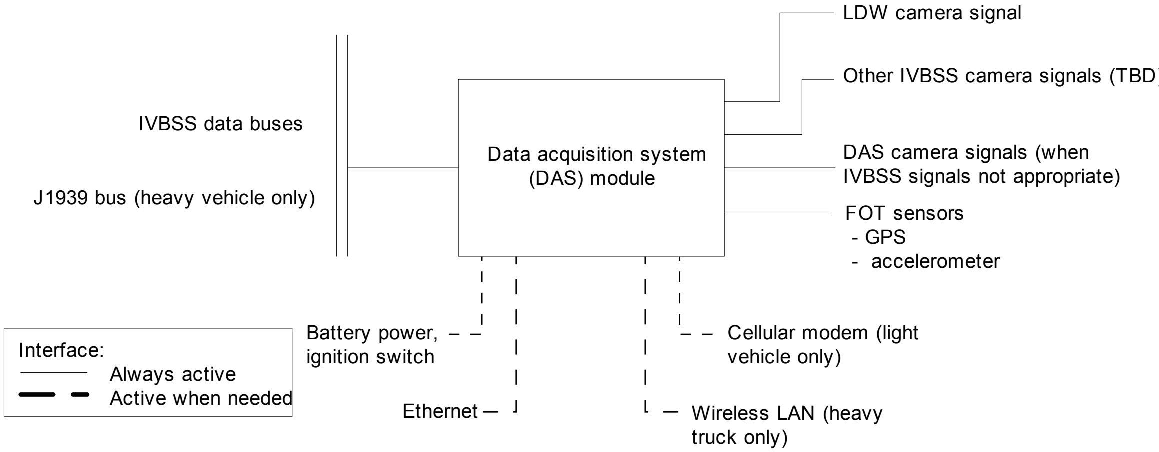


Figure 83. Onboard DAS module and its interfaces

Numerical data will be collected at rates of 10 Hz or faster; for example, several of the radars operate at 40 Hz. Video data will be collected at rates up to 10 Hz, although the frame rates are a function of the driving circumstances and occasionally of the state of the IVBSS alert levels.

The main challenge will be the hardware selection of video data cards to handle five camera scenes. Typically UMTRI uses adaptive video collection approaches to facilitate efficient data collection and, more importantly, rapid and convenient access to video data. Furthermore, the requirement is for random access to any image in the database and to avoid typical compression approaches that use not only spatial compression (across an image), but temporal compression approaches (across successive images). The "five-second rule" says that an analyst should be able to view video data associated with any instant in the experiment within five seconds of a software request. The challenge in this project has been to migrate from software compression that allows these freedoms to finding a suitable hardware compression approach that preserves these convenient analysis features.

Figure 84 shows a simplified view of the paths for data movement associated with the data management and analysis system. Data from vehicles can be transferred into the data archive by wireless communications or direct downloads either at UMTRI or at remote locations, such as the development team's facility or the heavy vehicle fleet. Conversely, UMTRI can remotely reconfigure the DAS at those locations, enabling iteration on the definition of the data archive and maximizing efficiency of operations.

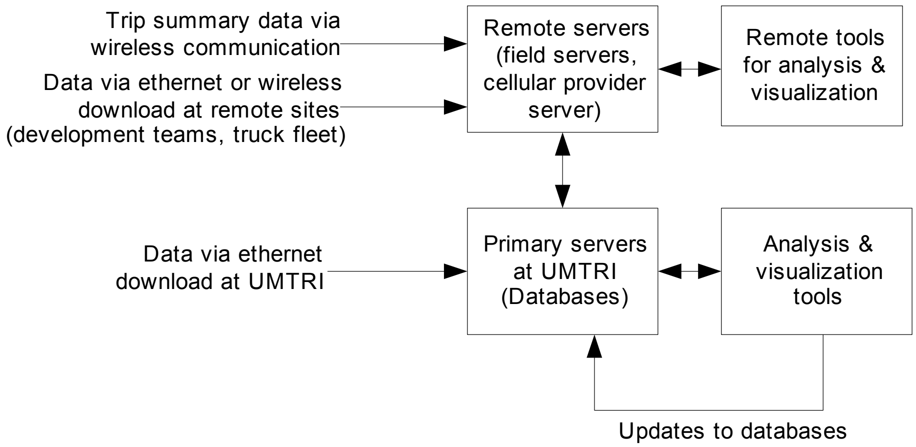


Figure 84. Schematic of data movement paths

7.1.2 Status of the Prototype DASs

The development DASs to support Phase I development efforts are available for test vehicles. The first units will be installed in February 2007 on the light-vehicle platform and in March 2007 on the heavy-truck platform. Three computer servers have been acquired for the DMAS and work is ongoing to coordinate arrangements for the virtual protocol networking.

The prototype DAS architecture and design have been determined, except for details of the video-capture system. Hardware has been selected and acquired, and software revisions to accommodate IVBSS-unique features have largely been made.

The DAS system will be composed of two CPUs: one dedicated to video data capture and the other dedicated to recording data collected from the IVBSS and vehicle data buses and ancillary sensors. This system will be similar in concept to units previously described in the final reports of previous passenger-vehicle FOTs conducted by UMTRI. The hardware will be comprised almost entirely of new hardware with updates in software to accommodate unique requirements of the IVBSS systems and experiment, such as interfacing with the four identical light-vehicle radar units that all broadcast CAN messages with identical header IDs.

7.1.3 Prototype DAS Delivery Schedule

The team will finalize video hardware selections in early 2007, as data collection requirements for video data collection mature, and as the technology development teams finalize their selections for video capture.

The prototype DAS units are scheduled for completion in June 2007.

7.1.4 Field Test DAS Development

The final generation of DAS slated for Phase II activities will be almost identical to the prototype DAS units, except that the hardware packaging and wireless networking will become finalized. Since the heavy-truck fleet is now known and the associated packaging constraints can be addressed, the decisions about packaging can likely be made in early summer 2007.

The greatest challenge for this generation of the DAS will be acquiring hardware and then fabricating enough units within the four-month period between the start of Phase II and the beginning of the extended pilot FOT.

7.2 Second Year Activities and Schedule

Key elements of the second year's activities include the continued refinement of the DAS to its final generation, as outlined above, and the initiation of joint efforts with the independent evaluation team with regard to the FOT experimental design, subjective and objective data plans, and the submission of an FOT plan.

While the default experimental design was described in the original technical proposal for award of the program, UMTRI, who will be responsible for conducting both the light-vehicle and heavy-truck FOTs, is open to changes to the initial design based upon ensuring that the needs of the U.S. DOT and the independent evaluator are met. Attributes such as the duration of the exposure to the IVBSS system by participants is of particular interest to all program contributors. Power analyses that have already been performed by the independent evaluator will factor heavily into evaluating the optimal experimental design, and will be supplemented by data regarding alert rates obtained in the second year.

Additional elements of FOT planning that will be addressed in the second year include development of draft subjective instruments to support pilot testing, and to identify a host of subjective and objective instruments and measures that will be used, in part, to characterize the participants in the FOT. The subjective instruments, questionnaires, will be developed by UMTRI with significant consideration made to the needs of the independent evaluator. Similarly, the objective measures and instruments (driving records, visual acuity, and demographic information) will also be led by UMTRI with significant contributions from the independent evaluator.

Initiation of the IRB application for approval to conduct the FOT is not likely to begin until after the second year, as approval for stage 2 testing will be obtained and will serve as the prototype for seeking IRB approval for the FOT. In other words, any challenges associated with obtaining IRB approval for the FOT that might reasonably be anticipated will be worked out in obtaining IRB approval for stage 2 testing. In general, based on significant experience with similar IRB applications, obtaining approval is not seen to pose any significant challenges.

8 Conclusions

The first year of the IVBSS program was both challenging and rewarding. The program has been largely successful in accomplishing several key systems engineering and development tasks. The first year provided the foundation upon which the remainder of the program will be based in that sound engineering was necessary to ensure satisfactory vehicle performance of IVBSS during verification testing and well into the field operational test. This required significant consideration of the level of integration being achieved on both the light-vehicle and heavy-truck platforms. Though slightly different in their initial approaches, both the light-vehicle and heavy-truck platform teams performed the necessary systems engineering to define their respective functional partitioning, system architectures, performance guidelines, functional requirements, and concepts of operation.

Additional accomplishments in the first year of the program included the preliminary development and specification of the driver-vehicle interfaces, as well as associated laboratory and simulator studies, the acquisition of developmental vehicles, and initial installation of the subsystem hardware into developmental vehicles.

The scope of the integration task of the IVBSS program is greater than that undertaken in any prior program of its kind, and so faced many unique considerations. The design of warning subsystems could not take place in isolation, but instead had to account for the many contributions and requirements of IVBSS as a whole. Despite developing two very different vehicles, the light-vehicle and heavy-truck platform teams were able to take advantage of one another's strengths and joint considerations to tackle the significant challenges in systems development. Overall, as a result of considerable effort by all team members, IVBSS is well-positioned to carry out the second year activities – and to ultimately proceed successfully into Phase II.

Building off of the first year's accomplishments, efforts in the second year of Phase I will concentrate on the construction of prototype vehicles to support verification testing. Verification testing will be performed on test tracks and public roads to verify that the integrated system is operating as intended and specified. Data from verification testing will be analyzed and jury drives will be conducted. The second year of the program will also include the development and refinement of the IVBSS threat assessment algorithms and warning arbitration, completion of the driver-vehicle interface testing, and detailed preparation for the pilot and field operational tests in Phase II.

The UMTRI-led team was fortunate to have worked closely with the U.S. DOT and its partners throughout the first year of the program, particularly in the development of verification test procedures, and wishes both to acknowledge the U.S. DOT's contributions and look forward to continued collaborative efforts on IVBSS.

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Appendix A: Complete Project Schedule

The milestones for the project are shown in the figures below.

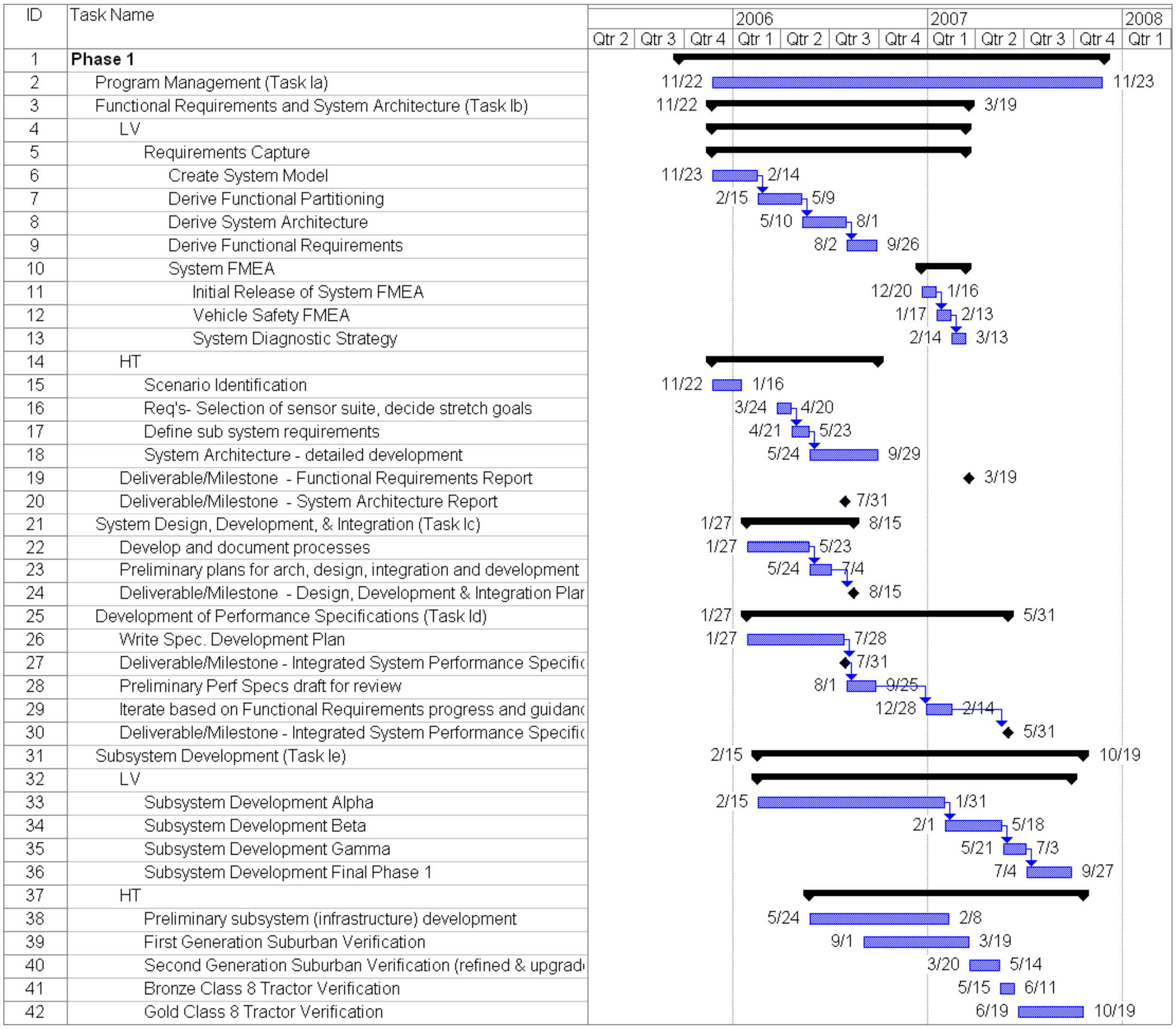

Figure 85. Milestones and deliverables undertaken in the first year (part 1)

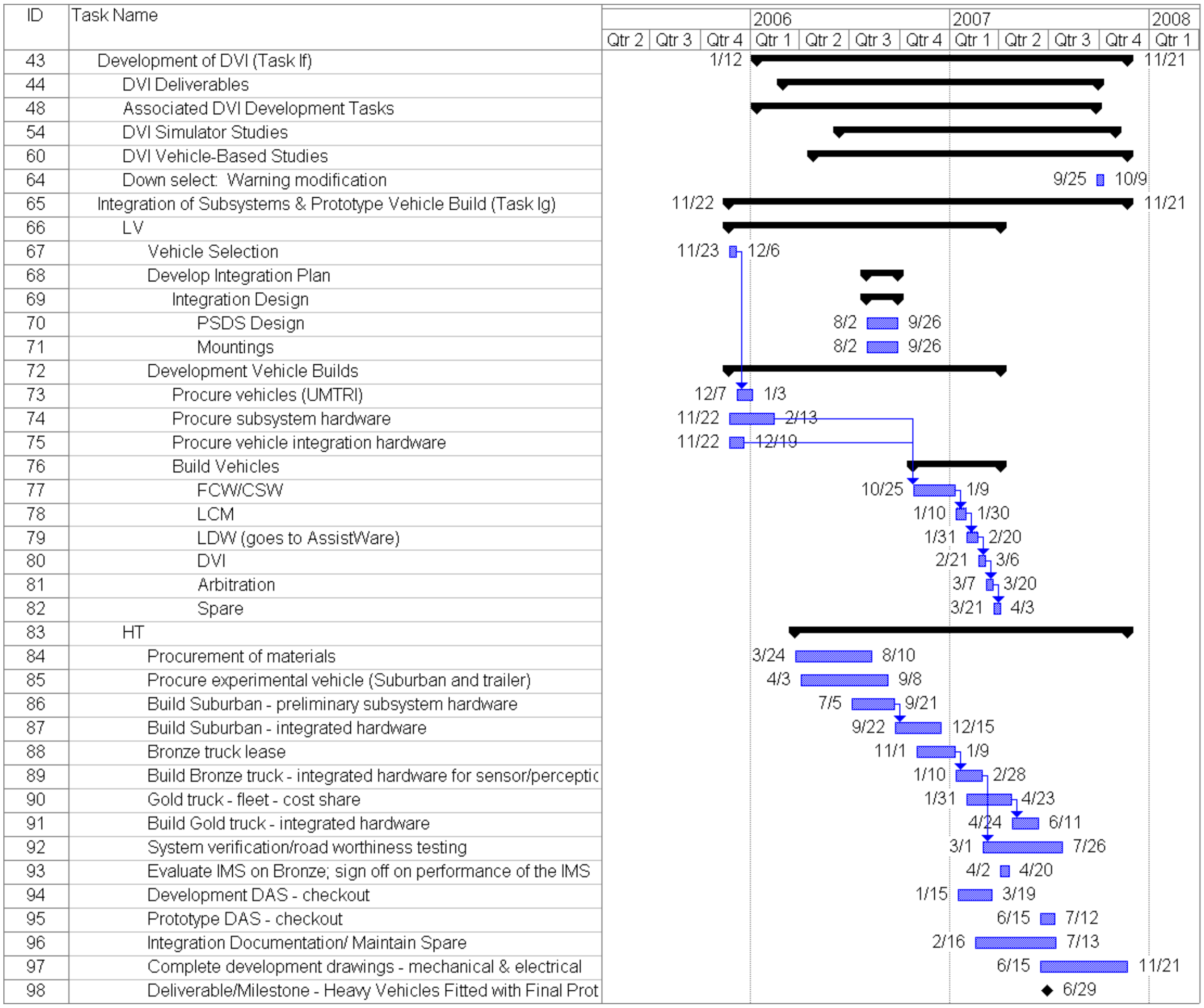

Figure 86. Milestones and deliverables undertaken in the first year (part 2)

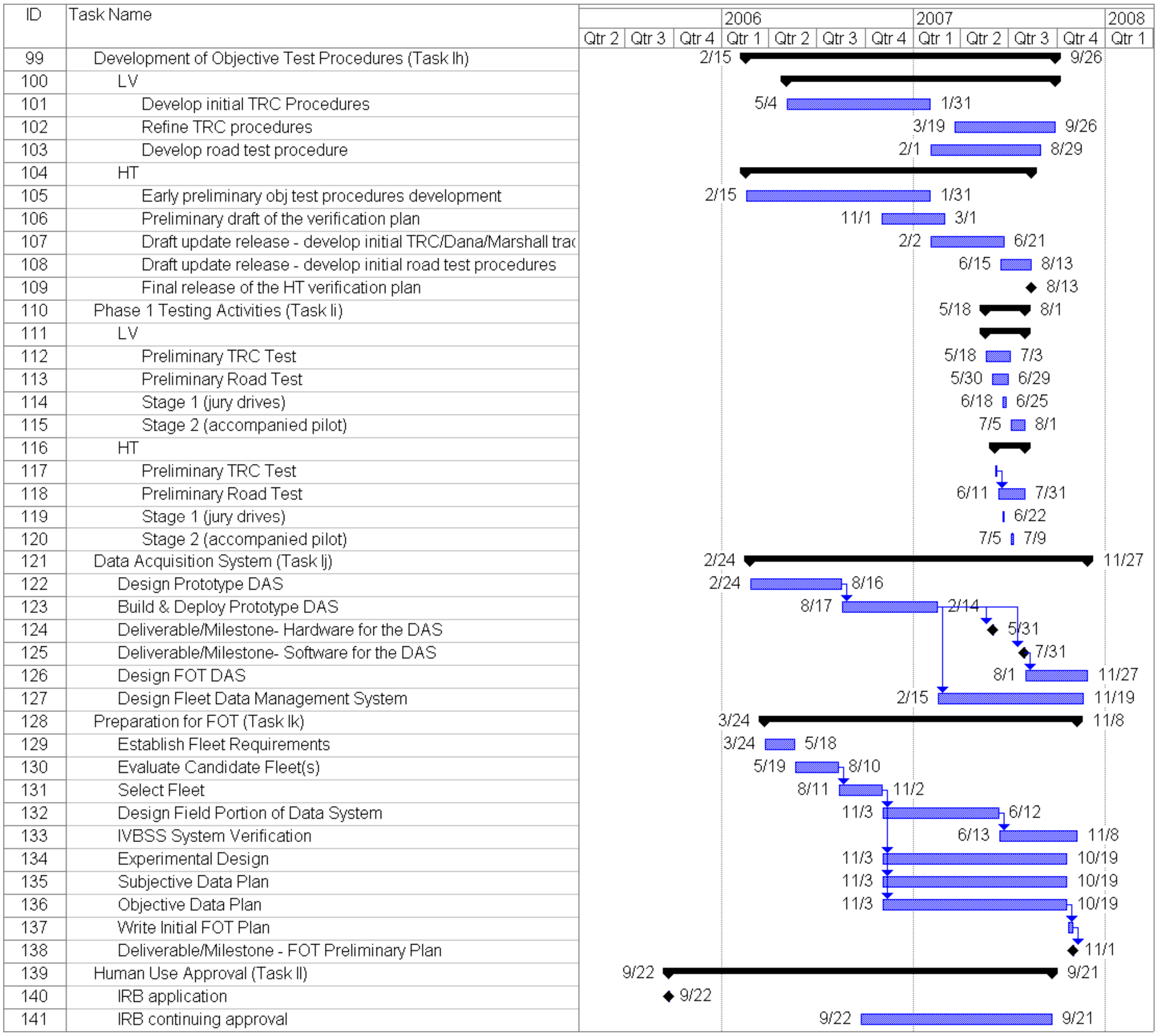

Figure 87. Milestones and deliverables undertaken in the first year (part 3)

Appendix B: Driver-Vehicle Interface Warning Sounds

B.1 Existing Sounds

Examples of sounds tested on the 2007 Accord EX include:

- Safety belt reminder Play
- Key in ignition Play
- Parking Play
- Lights on; door open (2048 Hz followed by 1650 Hz) Play

B.2 Experiment E1.3—Warning Suites

Three candidate suites of four warning sounds were investigated for learnability, confusability, and response efficiency.

- **Hybrid auditory icons (urgent)**:

  - FCW Play

  - LCM Play

  - CSW Play

  - LDW Play

- **Hybrid auditory icons (lower urgency)**:

  - FCW Play
  - LCM Play
  - CSW Play
  - LDW Play

- **Abstract sounds**:

  - FCW Play
  - LCM Play
  - CSW Play
  - LDW Play

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