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Third Annual Report

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16. Abstract

The Integrated Vehicle-Based Safety Systems (IVBSS) program is a five-year, two-phase cooperative research program being conducted by an industry consortium led by the University of Michigan Transportation Research Institute (UMTRI). The goal of the program is to assess the safety benefits and driver acceptance associated with a prototype integrated crash warning system designed to address rear-end, roadway departure, and lane change/merge crashes for light vehicles and heavy commercial trucks.

This report describes accomplishments and progress made during the third year of the program (June 2008 to May 2009) and activities planned for the following year. Accomplishments detailed in this report include making refinements to the integrated crash warning system, conduct of additional verification testing and extended pilot tests, the analysis of data, and the construction of the fleet of 26 research vehicles.

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Table of Contents

1 EXECUTIVE SUMMARY 1
Introduction and Background 1
IVBSS Program Plan 1
Phase I…… 1
Phase II 2
Third-Year Accomplishments 2
Conclusions 4
2 INTRODUCTION 5
2.1 Program Approach 6
2.1.1 IVBSS Team Membership 6
2.1.2 Structure of the Program 6
2.2 Report Structure 7
3 LIGHT-VEHICLE PLATFORM 8
3.1 Systems and Hardware Developments 8
3.2 Systems and Hardware Modifications 9
3.2.1 Hardware Modifications 10
3.2.2 Software Modifications 11
3.2.3 Vehicle Builds 12
3.2.4 Data Acquisition System and Database Development 14
3.3 Verification Tests 15
3.3.1 Track-Based Verification Test 15
3.3.2 On-Road Verification Tests 15
3.4 Extended Pilot Test 17
3.4.1 Purpose 17
3.4.2 Methodology 17
3.4.3 Results 18
3.4.4 Application of the Results 21
3.4.5 Conclusions 21
3.5 Field Operational Test 22
3.5.1 Purpose 22
3.5.2 Methodology 22
3.6 FOT Status 23
4 HEAVY-TRUCK PLATFORM 24
4.1 Systems and Hardware Developments 24
4.1.1 System Development 24
4.1.2 Hardware Integration Design Refinement 24
4.1.3 Software Revisions 25
4.2 Vehicle Builds 26
4.2.1 Data Acquisition System and Database Development 29

4.3 Verification Test ... 29
4.3.1 Track-Based Verification Testing ... 30
4.3.2 On-Road Verification Testing ... 30
4.4 Extended Pilot Test ... 32
4.4.1 Purpose ... 32
4.4.2 Methodology ... 32
4.4.3 Results ... 32
4.4.4 Application of the Results ... 34
4.4.5 Summary ... 35
4.5 Field Operational Test ... 35
4.5.1 Purpose ... 35
4.5.2 Methodology ... 36
4.6 Heavy-Truck FOT Status ... 37
5 INDEPENDENT EVALUATION ... 39
5.1 Approach ... 39
5.1.1 Safety Benefits ... 39
5.1.2 Driver Acceptance ... 39
5.1.3 System Capability ... 40
5.1.4 Video Processing ... 41
5.1.5 Data Mining ... 42
5.1.6 Data Viewer and Logger ... 42
5.2 Accomplishments and Schedule ... 43
5.3 Follow-on Activities ... 44
6 PROJECTED FOURTH YEAR ACTIVITIES ... 46
6.1 Conduct of Field Test Operations ... 46
6.2 Data Analysis Plans ... 46
6.3 Data Analyses ... 47
7 REFERENCES ... 49

List of Figures

Figure 1. Major program tasks 4
Figure 2. Activity timeline for the light-vehicle platform during the third year 9
Figure 3. Data acquisition system 10
Figure 4. Final front grille with integrated radar shield 11
Figure 5. Driver-vehicle interface changes 12
Figure 6. Light-vehicle fleet builds timeline 13
Figure 7. The light-vehicle fleet 14
Figure 8. Breakdown of alert rates by system function 16
Figure 9. LDW availability by travel speed 17
Figure 10. Travel by test participants 19
Figure 11. Relative rates of occurrence of each alert type (all drivers) 19
Figure 12. Alert rates per distance traveled for the 12 individual participants 20
Figure 13. Schedule of light-vehicle releases and returns 23
Figure 14. Hardware modifications 25
Figure 15. System integration process 27
Figure 16. FOT vehicle integration site 27
Figure 17. Exterior view of vehicle sensors 28
Figure 18. Heavy-truck driver-vehicle interface 28
Figure 19. Schedule of heavy-truck builds 29
Figure 20. Breakdown of alert rates by system function 31
Figure 21. LDW availability by travel speed 31
Figure 22. Alert rate per 100 miles by EPT driver 33
Figure 23. Nuisance alert rate per 100 miles as function of alert and route type 34
Figure 24. Schedule of heavy-truck vehicle releases including baseline and treatment periods 37
Figure 25. Block diagram of independent evaluation tasks 41
Figure 26. Snapshot of the multi-media data viewer 43
Figure 27. Gantt chart of independent evaluation tasks 43
Figure 28. Phase II project schedule (1) 50
Figure 29. Phase II project schedule (2) 51

List of Tables

Table 1. Overall results of track tests for the light-vehicle system 15
Table 2. Participant responses to selected post-drive questions (11 participants) 20
Table 3. List of extended pilot test suggested improvements 21
Table 4. Overall results of Phase II track tests for the heavy-truck system 30
Table 5. Accumulated total and enabled distance as of April 30, 2009, for each tractor 38

List of Acronyms

AVI	Audio Video Interleaved
BSD	Blind Spot Detection
CDL	Commercial Driver's License
CSW	Curve Speed Warning
DAS	Data Acquisition System
DVI	Driver-Vehicle Interface
EPT	Extended Pilot Test
FCW	Forward Crash Warning
FMCSA	Federal Motor Carrier Safety Administration
FOT	Field Operational Test
IMU	Inertial Measurement Unit
IVBSS	Integrated Vehicle-Based Safety Systems
LCM	Lane-Change/Merge Warning
LDW	Lateral Drift Warning
MPEG	Motion Picture Experts Group
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
P&D	Pick-up and Delivery
POV	Principal Other Vehicle
RITA	Research and Innovative Technology Administration
SQL	Structured Query Language
UMTRI	University of Michigan Transportation Research Institute
TRC	Transportation Research Center
U.S. DOT	United States Department of Transportation

1 Executive Summary

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 in a multi-year program to develop and test an integrated, vehicle-based, crash warning system that addresses rear-end, roadway departure, and lane-change/merge crashes for light vehicles and heavy commercial trucks. The program being carried out under this agreement is known as the Integrated Vehicle-Based Safety Systems 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 the number of crashes can be significantly reduced by the widespread deployment of integrated crash warning systems that address rear-end, roadway departure, and lane change/merge crashes.[1] The scope of the systems integration effort conducted during the program included sharing sensor data between subsystems, warning arbitration based on threat severity, and development of an effective driver-vehicle interface. Such 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 provide the appropriate warning to drivers. It is anticipated that the integration will result in increased system reliability, fewer false warnings, improved driver reaction time and response to warnings, and increased driver acceptance.

The IVBSS program is a five-year effort divided into two consecutive, non-overlapping phases. This report covers Phase II (June 2008 - May 2009) activities, and emphasizes final development of the integrated system, verification testing, vehicle builds, and other products and processes that the program has generated.

IVBSS Program Plan

The IVBSS team is managed by the National Highway Traffic Safety Administration with funding provided by the Intelligent Transportation Systems Joint Program Office of the Research and Innovative Technology Administration. Other Federal Government team members include the RITA's Volpe National Transportation Systems Center (Volpe Center), the Federal Motor Carrier Safety Administration, and the National Institute of Standards and Technology.

The UMTRI-led light-vehicle platform team includes Visteon Corporation, Honda R&D Americas, and Takata Corporation, while the heavy-truck platform partners are Eaton Corporation, International Truck and Engine Corporation, Takata Corporation, Con-way Freight, Inc., and the Battelle Memorial Institute. The involvement of industrial partners in the program is seen to be critical, given their technical knowledge of such systems and their ability to commercialize and deploy actual systems into the U. S. vehicle fleet.

Phase I

During Phase I of the program (November 2005 - May 2008), several key accomplishments were achieved. The system architectures were developed, sensor suites were identified, human factors testing in support of the DVI development was conducted, and prototype hardware to support system evaluation was constructed. Phase I also included the development of functional requirements and system performance guidelines, which were distributed to industry stakeholders for comment. Multiple prototype vehicles were built and evaluated, including jury drives[1] and accompanied pilot testing. Verification test plans were developed in collaboration with the U.S. DOT and the tests were conducted on test tracks and public roads. Extensive program outreach included two public meetings, numerous presentations and booths at key industry venues, and one-on-one meetings. Finally, preparation for the field operational test began, including the design and development of a prototype data acquisition system. Vehicles to be used to conduct the FOTs were procured, and a field operational test plan was submitted. A detailed description of accomplishments made during Phase I can be found in the Integrated Vehicle-Based Safety Systems Phase I Interim Report.[2]

Phase II

Phase II (June 2008 – October 2010) consists of continued system refinement, building a fleet of vehicles equipped with the integrated warning system, extended pilot testing, conduct of the field operational tests, and program outreach to public and private stakeholders.

Third-Year Accomplishments

System Development

Refinements to the integrated crash warning system hardware and software continued to be made on both platforms. The majority of changes were made to enhance system performance and reliability. Specific improvements reduced instances of false alerts, improved the consistency of system performance, and provided system diagnostics to support the conduct of the extended pilot and field operational tests.

Fleet Builds

The process of installing the integrated crash warning system into 26 research vehicles (16 passenger cars and 10 commercial trucks) began, and was completed during this period. Each of the vehicles underwent significant modifications in order to accommodate the installation. On the light-vehicle platform alone, almost 600 new circuits were added. All the sensors necessary for the operation of the integrated system, as well as those necessary to collect data for conducting analyses, needed to be installed in a manner that they would survive months of daily use.

Data Acquisition and Database Development

Twenty-eight data acquisition systems were developed to support data collection during the field operational tests. The systems are installed in each vehicle as a complement to the warning system and function as both data processing devices as well as permanent recorders of the numerical and video data collected. The DAS is a turn-key component requiring no actions by the participants and consists of four subsystems, which include a main computer, video

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[1] A jury drive is a series of structured and unstructured test drives conducted by system developers and other team members in order to evaluate system performance and prospective approaches to the system design. Feedback is collected from the participants, and the results are used to make design decisions.

processor, power controller, and cellular communications unit. A cellular-based remote monitoring system was developed to monitor vehicle status and diagnose problems and failures in the field. Data retrieval procedures and protocols were developed, as well as a relational database structure to house the approximately 1 million miles of driving data to be collected.

Verification Testing

Track-based and on-road verification tests were conducted for both platforms. The tests were performed to assess any impact of software changes made in Phase II and to ensure system readiness to proceed into the extended pilot tests and the full-scale field operational tests.

Human Subjects Approval Process

Approval to use human subjects in the conduct of the extended pilot and field operational tests was obtained from the Behavioral Sciences Institutional Review Board at the University of Michigan. These approvals covered both the light-vehicle and heavy-truck platforms.

Extended Pilot Testing

Two extended pilot tests were conducted for both the light-vehicle and heavy-truck platforms. Both tests provided evidence that the system performance and driver acceptance were sufficient to justify proceeding with the conduct of the field operational tests. The results from these tests were also used to improve system performance and enhance functionality prior to the conduct of the field operational tests. These tests were invaluable in improving the systems ultimately fielded and also served as an opportunity to dry-run test questionnaires, driver instructional material, and driver recruitment procedures.

Field Operational Testing

During this period, the light-vehicle and heavy-truck field operational tests were launched successfully. The heavy-truck test began in February 2009 with a representative sample of 20 commercial drivers drawn from Con-way Freight's Ann Arbor terminal. This field test will end in December 2009 after approximately 10 months of continuous data collection using 10 instrumented commercial trucks. The light-vehicle test was launched in April 2009 and will be completed in May 2010. This field test will collect naturalistic driving data from 108 licensed drivers over 12 continuous months, using 16 instrumented passenger cars.

Program Outreach

A number of outreach activities provided industry stakeholders with regular updates on the program and its status. This included presentations at the following professional meetings: the 15th World Congress on Intelligent Transportation Systems, Lifesavers Conference, Society of Automotive Engineers World Congress, and the Society of Automotive Engineers Heavy-Truck Handling, Dynamics and Controls Symposium. In addition, team members directly briefed members of the Alliance of Automotive Manufacturers, and provided numerous opportunities for industry representatives to experience the light-vehicle system first-hand through a series of demonstration drives and vehicle loans to industry representatives.

Conclusions

The third year culminated in the successful launch of the field operational tests for both the light-vehicle and heavy-truck platforms. System performance and reliability were improved early during the start of Phase II; and extended pilot testing provided additional data and insights that led to system improvement. Preliminary results from the field tests indicate that the integrated systems are performing as intended; the tests should provide a significant volume of data that will enable determination of safety benefits of large-scale system deployment. Major program tasks from the third year are shown in Figure 1.

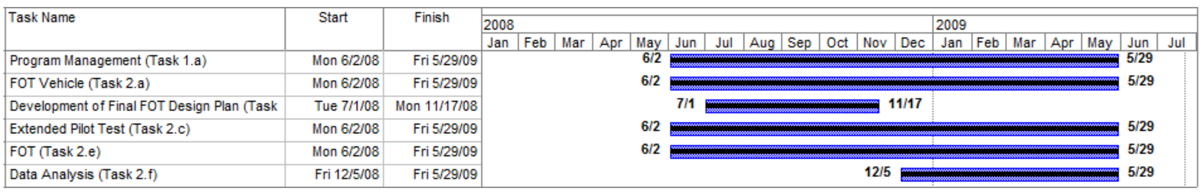

Figure 1. Major program tasks

2 Introduction

This report describes activities and accomplishments in the development and testing of an integrated vehicle-based safety system during the third year of the IVBSS program. The goal of the program is to develop a state-of-the-art, integrated, vehicle-based crash warning system that addresses rear-end, roadway departure, 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. Crash reduction benefits specific to an integrated system can be achieved through a coordinated exchange of sensor data to determine the existence of crash threats. In addition, the arbitration of warnings based on threat severity can be used to provide drivers with only the information that is most critical to avoiding crashes.

Three crash-warning subsystems have been integrated into both light-vehicle and heavy-truck systems: forward crash warning, lateral drift warning, and lane-change/merge crash warning. The light-vehicle platform also includes a curve speed warning subsystem. Below is a description of the subsystems:

- Forward crash warning (FCW) warns drivers of the potential for a rear-end crash with another vehicle;
- Lateral drift warning (LDW) warns drivers that they may be drifting inadvertently from their lane or departing the roadway;
- Lane-change/merge (LCM) crash 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; and
- Curve speed warning (CSW) warns drivers that they may be driving too quickly into an upcoming curve and, as a result, might depart the roadway.

Preliminary analyses by the U.S. DOT indicate that 61.6 percent (3,541,000) of police-reported light-vehicle crashes and 58.7 percent (424,000) of police-reported heavy-truck crashes can be addressed through the widespread deployment of integrated crash warning systems that address rear-end, roadway departure, and lane-change/merge crashes. Information from previous research 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 improvements in threat assessment and warning accuracy can be realized through systems integration, relative to single function, stand-alone systems. Integration has the potential to also improve overall warning performance relative to the single function, stand-alone subsystems by increasing system reliability, increasing the number of threats that can be accurately detected, and reducing false and nuisance warnings.[2] It is anticipated that this will translate into reduced crashes and improved safety, in addition to increased driver acceptance and earlier introduction of integrated systems into the marketplace.

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[2] A nuisance warning is one that is triggered by an appropriate stimulus and is consistent with the warning system design intent, but individual drivers may consider it unnecessary under certain driving situations. A false warning is one issued without an appropriate stimulus and is inconsistent with the warning system design intent.

2.1 Program Approach

2.1.1 Team Membership

UMTRI is the prime contractor for the program and is responsible for its management, coordinating the development of the integrated crash warning system on both platforms, developing the DAS, and conducting the FOTs. Visteon is the lead system developer and systems integrator on the light-vehicle platform. Honda R&D Americas is the light-vehicle manufacturer and is providing engineering assistance throughout the development process. Eaton Corporation is the lead system developer and integrator on the heavy-truck platform, while International Truck and Engine Corporation is providing engineering assistance, and supported system installation. Takata Corporation supported both the light-vehicle and heavy-truck platforms by providing vision-based lane detection technology. The Battelle Memorial Institute supported Eaton in the development of the heavy-truck driver vehicle interface and warning arbitration. Con-way Freight is the heavy-truck fleet participating in the field test, and the Michigan Department of Transportation is supporting UMTRI by assisting in the acquisition of crash and roadway geometry data to support the analyses.

The U.S. DOT IVBSS team is managed by the National Highway Traffic Safety Administration, with funding provided by the Intelligent Transportation Systems Joint Program Office of the Research and Innovative Technology Administration. Other Federal Government team members include the RITA's Volpe National Transportation Systems Center (Volpe Center), the Federal Motor Carrier Safety Administration, and the National Institute of Standards and Technology.

The Volpe Center is responsible for the independent evaluation of the integrated crash warning systems. The goals of the evaluation are to estimate potential safety benefits from widespread deployment of the systems, determine driver acceptance, and characterize the system capability using data collected during the field tests. The Volpe Center's role also includes providing support in the conduct and analysis of system verification tests and assessment of system readiness for full-scale field testing.

2.1.2 Structure of the Program

The IVBSS program is executed under a cooperative agreement between UMTRI and the Department of Transportation. The program began in November 2005, and is divided into two non-overlapping phases. Phase I (November 2005-May 2008), consisted of systems engineering and systems development. This included defining concepts of operation and functional requirements, developing system architectures, identifying the sensors and hardware, describing subsystems and constructing development vehicles. It also included publication of functional requirements and system performance guidelines, development and conduct of verification test procedures, and studies addressing the design of integrated driver-vehicle interfaces. A complete description of Phase I activities can be found in Integrated Vehicle-Based Safety Systems (IVBSS) Phase I Interim Report.[2]

This report covers the first year of Phase II, which began in June 2008. Phase II includes continued system refinement, the construction of the FOT vehicle fleets, additional verification testing, conduct of the extended pilot and field operational tests, and data analyses to determine safety benefits and driver acceptance.

2.2 Report Structure

The remainder of this report is organized as follows:

- Chapters 3 and 4 describe activities relating to preparing for and launching the field operational tests for the light-vehicle and heavy-truck platforms, respectively.
- Chapter 5 covers the independent evaluator's role and activities.
- Chapter 6 discusses tasks planned for the fourth year of the program.
- Appendix A includes the Phase II project schedule.

3 Light-Vehicle Platform

3.1 Systems and Hardware Development

Activities during this period included refinement of the integrated system, verification testing, construction of the FOT fleet, conduct of the extended pilot test, and launch of the FOT.

The schedule for these activities is shown in Figure 2. There were two key milestones during this period: extended pilot verification testing in October 2008 and the FOT launch in April 2009. Before verification testing could be performed, however, the vast majority of development work and final hardware modifications needed to be completed and tested. In order to launch the FOT, the extended pilot test and the fleet construction activities had to be finished, as well as some adjustments to the software and, to a much lesser degree, the hardware. The extended pilot test served as a dress rehearsal for the field test so that any issues in design and implementation or the experimental process and systems could be identified and corrected before the field test began.

A description of these activities is provided in the following sections. Final development work and fleet construction are detailed in Section 3.2; verification testing is discussed in Section 3.3. The extended pilot test methodology and findings are given in Section 3.4. Plans for the light-vehicle FOT and the current test status can be found in Sections 3.5 and 3.6, respectively.

Task Name	Start	Finish
FOT Vehicle (Task 2.a)	**Tue 4/1/08**	**Mon 5/31/10**
Light-vehicle	**Tue 4/1/08**	**Thu 6/11/09**
Procure Fleet Vehicles	Tue 4/1/08	Mon 4/28/08
Prototype DAS build	Tue 4/15/08	Mon 5/5/08
Subsystem Design	Tue 4/1/08	Fri 8/22/08
Calibration	Tue 4/1/08	Fri 8/22/08
Vehicle Integration and Safety Analysis	Tue 4/1/08	Thu 6/19/08
IVBSS software revisions	**Mon 6/2/08**	**Fri 8/22/08**
Extended pilot software and hardware release	**Mon 6/2/08**	**Wed 3/18/09**
Continued algorithm and subsystem devel	**Mon 6/2/08**	**Wed 3/18/09**
Final vehicle integration of the IVBSS	**Mon 6/2/08**	**Thu 6/19/08**
Data definitions of variables	Fri 6/13/08	Thu 8/28/08
Primary & secondary data signals verified (dictionary)	Wed 6/11/08	Fri 4/10/09
Vehicle builds	**Fri 6/20/08**	**Tue 4/7/09**
Batch 1 LV1-LV4 (Extended Pilot)	Fri 6/20/08	Mon 10/6/08
Batch 2 LV5-LV8	Mon 9/8/08	Tue 12/9/08
Batch 3 LV9-LV12	Mon 10/13/08	Thu 1/29/09
Batch 4 LV13-LV16 (Retrofitted Development Ve	Mon 12/8/08	Tue 4/7/09
ICD Freeze	Fri 8/22/08	Fri 8/22/08
Eta Release	Tue 9/9/08	Tue 9/9/08
Calibration Signoff	Tue 9/9/08	Fri 9/26/08
FOT DAS in vehicle check-out	Wed 9/24/08	Mon 10/6/08
Vehicle Rollout (upfit/check-out/mileage)	**Tue 10/7/08**	**Mon 5/11/09**
LV 1 to 4	Tue 10/7/08	Mon 11/10/08
LV 5 to 8	Wed 12/10/08	Thu 3/19/09
LV 9 to 12	Fri 1/30/09	Thu 3/5/09
LV 13 to 16	Wed 4/8/09	Mon 5/11/09
Agreement with DOT on video rates and events	Fri 8/1/08	Tue 9/2/08
First FOT DAS build (DAS 2)	Thu 10/2/08	Thu 10/2/08
First FOT DAS builds (DAS 2 and DAS 3)	Mon 9/22/08	Fri 10/10/08
DAS builds for FOT	**Mon 10/13/08**	**Thu 4/30/09**
Remaining data signals verified	Wed 9/24/08	Thu 6/11/09
Verification	**Wed 4/9/08**	**Fri 1/16/09**
brake pulse testing	Wed 4/9/08	Thu 4/10/08
cold soak	Mon 1/12/09	Thu 1/15/09
ignition cycling test	Fri 1/16/09	Fri 1/16/09
Extended Pilot Verification	**Fri 9/5/08**	**Fri 10/31/08**
FOT Vehicle Prep for Ext. Pilot	Mon 10/27/08	Fri 11/14/08
Subsystem Tuning based on Extended pilot data	Mon 2/16/09	Wed 3/18/09
Populate FADB for CSW for FOT	Fri 3/6/09	Wed 3/25/09
Theta Release	Thu 3/19/09	Tue 4/7/09
Mini-verification (if required)	Fri 4/3/09	Thu 4/9/09
Update Fleet with Theta	Fri 4/10/09	Thu 4/16/09
Milestone: Completed FOT vehicles	Mon 5/11/09	Mon 5/11/09
Milestone: Additional light vehicle for NHTSA	Thu 6/4/09	Thu 6/4/09
Extended Pilot Test (Task 2.c)	**Fri 7/25/08**	**Mon 3/16/09**

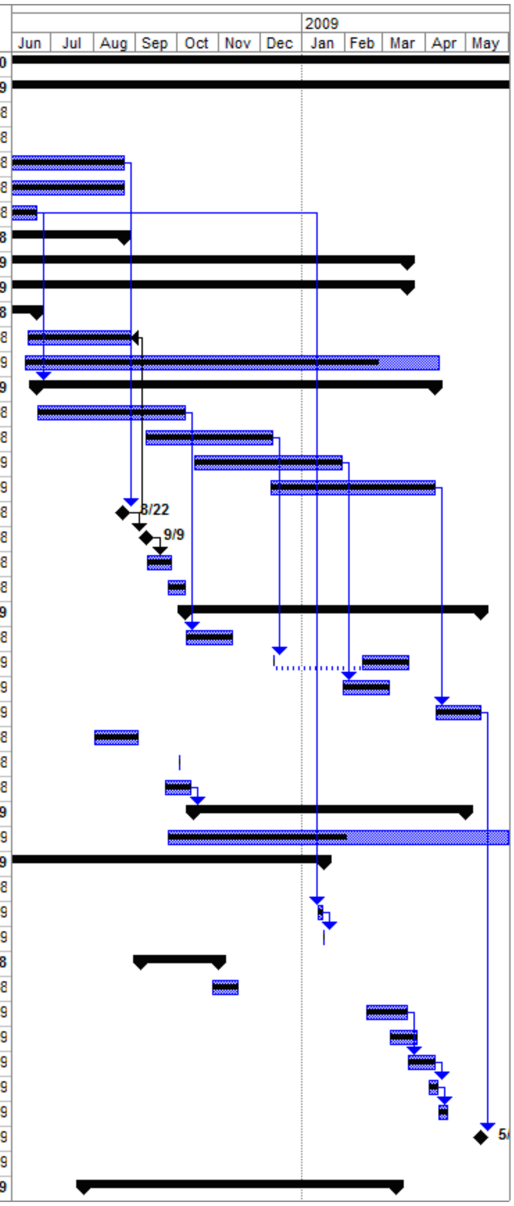


Figure 2. Activity timeline for the light-vehicle platform during the third year

3.2 Systems and Hardware Modifications

Development work included hardware and software modifications, as well as construction of the FOT fleet; these are each addressed in order below. Visteon served as the prime system developer and system integrator for the light-vehicle platform, with the lane departure system design and delivery completed by Takata Corporation. UMTRI provided the data acquisition system and associated sensors. Honda R&D Americas provided assistance in the system integration through information and expertise about the vehicle platform, as well as modifications to the brake systems to allow brake pulse cues to be provided. The U.S. DOT was involved in the verification test development and data analysis, while NIST provided an independent measurement system and supported the verification tests and data analysis.

3.2.1 Hardware Modifications

The light-vehicle test platform is a 2006/2007 Honda Accord EX with the prototype crash warning system integrated into the base vehicle, along with data collection equipment also installed.

Several hardware modifications were completed and implemented in the third year. A new electronics rack was installed in the trunk of the FOT vehicles. This rack consumes less space and allows the test participants more storage in the trunk. The rack also holds hardware components, including some that underwent significant changes:

- Migration of certain warning system functions, warning arbitration, and DVI functions to a smaller and more capable hardware platform; and
- New generation data acquisition system module, shown in Figure 3.

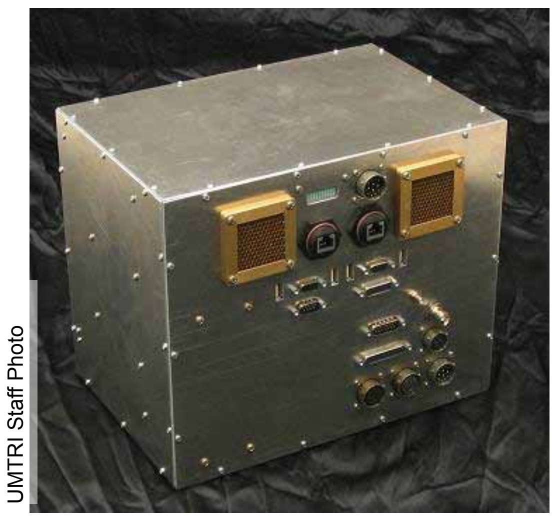


Figure 3. Data acquisition system

In addition, the light-vehicle grille was modified to allow the forward radar to be installed behind it with a radar-transparent surface for protection from debris and weather effects. Figure 4 shows the modified grille design. Other hardware modifications included migration of the lane departure warning unit to a different platform – still installed on the front windshield – with a modified enclosure. New hardware also included a set of sensors to capture data to support the evaluation of the extended pilot and field operational tests. These included a camera to capture the driver's face, a cabin camera to observe driver actions, as well as two rear-facing cameras to obtain views of the driver's blind-spot or any overtaking vehicles. An inertial measurement unit (IMU) was installed to measure vehicle motion, and a differential GPS antenna and cellular modem antenna were also installed for this purpose.

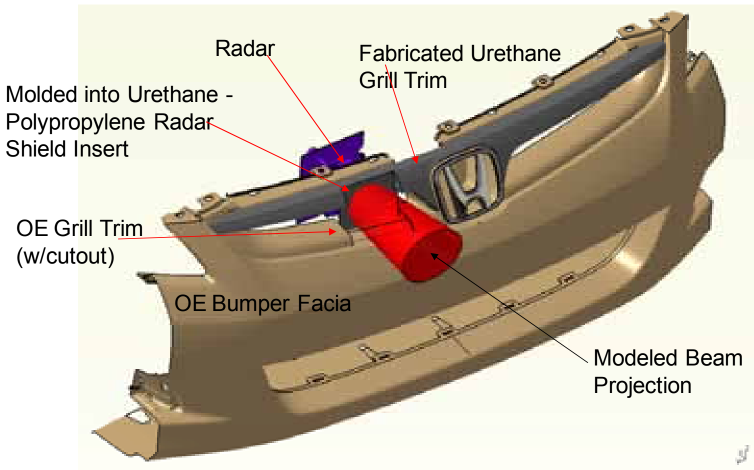


Figure 4. Final front grille with integrated radar shield

3.2.2 Software Modifications

Phase II software releases enhanced system functionality completed at the end of Phase I; including changes to enable the use of new hardware, refinements to the driver-vehicle interface, and system diagnostics. There were two major software releases: a pre-verification test release in August 2008 and an FOT release in April 2009.

The pre-verification test release in August 2008 implemented the following changes:

- Driver-vehicle interface:
  - Provided additional driver display information, including error messages; the driver's ability to adjust alert timing was removed (see Figure 5).
  - Removed the haptic brake pulse cue for CSW and adjusted the FCW brake pulse cue characteristics.
  - Finalized the blind spot detection functionality, including a change from two icons to one icon in the side-view mirror (see Figure 5).
  - Improved logic for dimming the driver display in response to ambient lighting.
- Warning functionality:
  - Upgraded the CSW functionality to reduce false alerts using a database of previous alerts and driver responses.
  - Improved the LCM response to overtaking vehicles.
  - Improved LDW performance in difficult lighting conditions.
  - Adjusted alert timing and behavior for all alert types in selected situations, using calibration parameters.
- Reliability and performance in the field:
  - Implemented diagnostic logic for detection and correction of system issues during development and the FOT.
  - Upgraded the LDW system's image processing robustness and calibration.
  - Provided full continental U.S. coverage for the CSW system.

    - Reduced system latency to provide more timely alerts and reduce nuisance alerts.
- Adapted software for new hardware

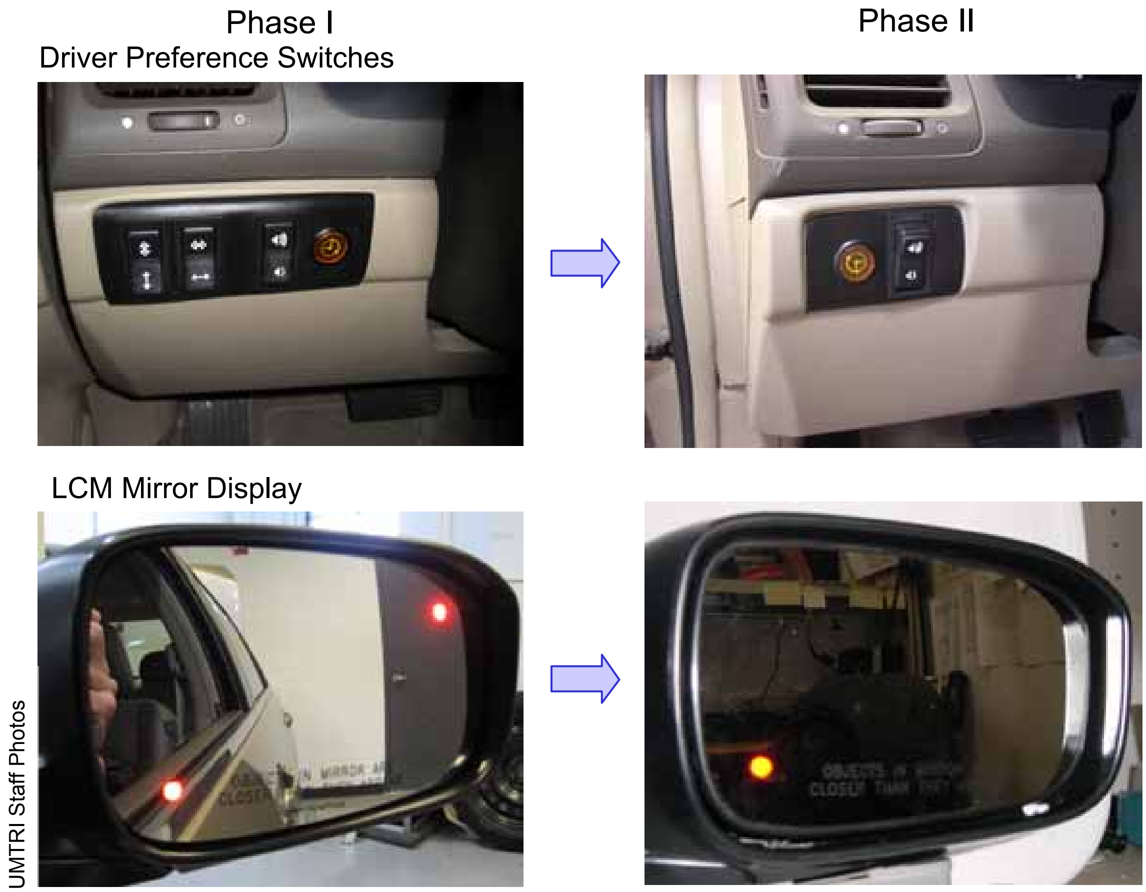


Figure 5. Driver-vehicle interface changes

The second major software release, which followed the extended pilot test, implemented two sets of changes. The first set was localized upgrades based on observations made during the extended pilot testing period. These were:

- Additional diagnostics to determine the cause of system errors; and
- Minor software changes to deliver the intended performance in specific situations, e.g., the LCM alert timing was adjusted when a preceding vehicle in the target lane was detected.

A second set of changes was made in response to observations in the test data, which are described in more detail in the section covering extended pilot test findings (Section 3.4).

3.2.3 Vehicle Builds

The construction of the 16-vehicle FOT fleet was completed during this time period. Much of the design for this integration had been conducted during Phase I, but final adjustments were made during the third year. Most of the tear-down and equipment installation in the FOT vehicles was performed at Roush Engineering under the direction of Visteon Corporation.

A high-level list of systems installed included:

- An electronics rack in the trunk, behind a secure partition, holding modules for the integrated system and the DAS;
- Seven radar sensors;
- Five cameras;
- Two GPS systems;
- A modified set of side-view mirrors, each with a BSD icon and a camera for the DAS;
- Additional sensors and driver display systems; and
- Power electronics.

After the vehicles were built, a series of tests and procedures were performed for quality assurance and calibration. Each vehicle was driven by project staff for approximately 1000 miles to find and correct any issues. Figure 6 shows an approximate timeline of FOT vehicle builds. Next, the DAS was installed and more mileage was accumulated so that infrequent or unexpected issues could be found and studied across multiple vehicles. The system developers and the DAS team signed off on each vehicle when it was believed to be ready for use by the FOT participants. The completed fleet of vehicles is shown in Figure 7.

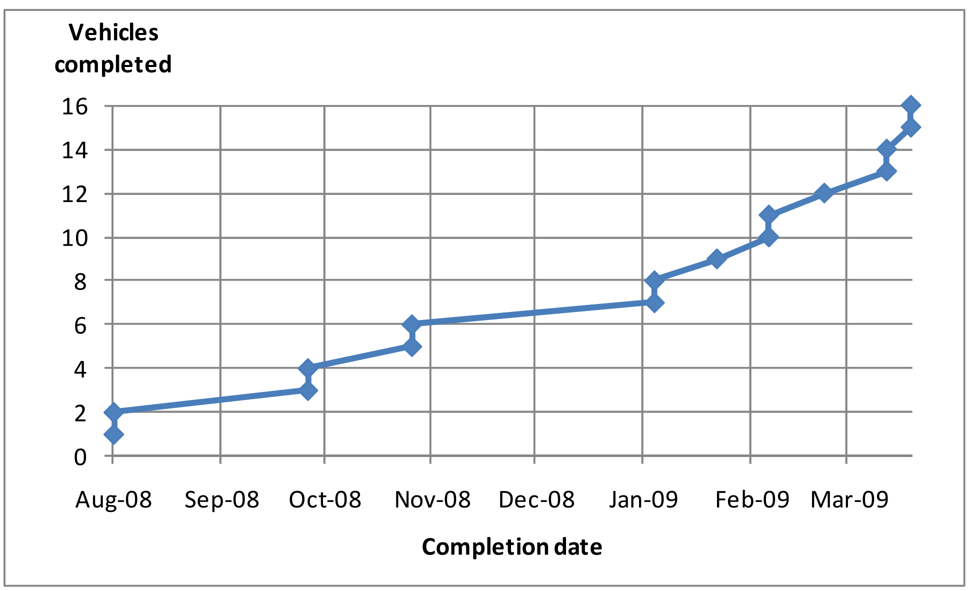


Figure 6. Light-vehicle fleet builds timeline

UMTRI Staff Photo

Figure 7. The light-vehicle fleet

3.2.4 Data Acquisition System and Database Development

Seventeen DAS units were designed and fabricated to support data collection during the light-vehicle FOT. The systems are installed in each vehicle as a complement to the integrated warning system and function as a data-processing device as well as permanent recorder of the numerical and video data collected during the field tests.

The equipment package consists of four subsystems comprising a main computer, video processor, power controller, and cellular communications unit. The main computer consists of an EBX form-factor single-board computer (including display, and Ethernet controllers), two PC104-plus CAN cards, a PC104 analog and digital interface card, and an automotive-grade hard disk. All of these components operate over a –30°C to +85°C temperature range. The video processor consists of an EBX form-factor single-board computer (including display, audio, and Ethernet controllers), two PC104-plus MPEG-4 encoder cards, a digital interface card, and an automotive-grade hard disk. The temperature range of this system also operates from –30°C to +85°C.

To monitor the DAS functionality and integrated crash warning system, UMTRI customized DAS software to compute and report summary statistics that help identify problems and failures while vehicles are in the field. UMTRI downloads and scrutinizes event logs transmitted wirelessly from the DAS to look for unexpected operating system events from the main and video CPU modules, and to ensure the integrated crash warning system is operating properly. This approach provides up-to-date summary and diagnostic information for engineers to remotely monitor the fleet on a continuous basis throughout the FOT.

Data retrieval for the light-vehicle platform occurs when the participants return the vehicles at the conclusion of the six-week testing period. Upon arrival, the DAS is connected to a dedicated intranet, at which point the contents of both the video and main computers on the DAS are uploaded to computer servers for loading into an FOT database and file backup.

3.3 Verification Tests

This section presents the verification test results conducted during Phase II. The tests were conducted to assess the impact of software changes made since the end of Phase I and to ensure the readiness of the system to proceed to the extended pilot and field operational tests.

3.3.1 Track-Based Verification Test

The Phase II track tests were conducted at the Transportation Research Center in East Liberty, Ohio, in October 2008. The test scenarios selected for Phase II were a subset of those conducted during Phase I and were intended to specifically test the software changes made since the end of Phase I, as well as to measure and document the performance of each warning function. A detailed description of verification test procedures can be found in the Integrated Vehicle-Based Safety Systems (IVBSS) Verification Test Plans for Light Vehicles. Table 1 shows the overall results for the Phase II verification tests for the light-vehicle system. The system passed all 16 tests indicating that the system performed within the required performance guidelines.

Table 1. Overall results of track tests for the light-vehicle system

Scenario	Test	Description	Pass/Fail
Rear End (RE)	RE-1	Slower constant Principal Other Vehicle (POV)	Pass
	RE-2	Modestly slowing POV	Pass
	RE-4	Stopped POV	Pass
	RE-8	Slower constant POV on curve	Pass
	RE-10	Cut-in by POV	Pass
Lane Change (LC)	LC-1	POV in blind spot on right	Pass
	LC-4	Adjacent POV on merge - no lane markers	Pass
	LC-5	LC into adjacent POV after passing	Pass
	LC-6	LC into approaching POV	Pass
Road Departure (RD)	RD-2	Clear shoulder with high lateral speed	Pass
	RD-3	Clear shoulder on curve with small radius & low speed	Pass
	RD-5	Shoulder barrier with lane markers	Pass
	RD-6	Approach curve with excessive speed in dry/warm condition	Pass
	RD-8	RD toward adjacent lane with POV forward on left	Pass
Multiple Threats (MT)	MT-2	Avoid LC with POV2 and RE with slowing POV1	Pass
No Warn	NW-2	No FCW when SV on curve passes stopped POV in adjacent lane	Pass

3.3.2 On-Road Verification Tests

The Phase II on-road verification tests were conducted on public roads in southeast Michigan in October 2008. The objectives of the on-road verification tests were to operate the vehicle in an uncontrolled driving environment on public roads in order to:

- Measure the system's susceptibility to issuing nuisance alerts;
- Assess alerts in perceived crash situations when they arise;
- Evaluate system availability over a wide range of driving conditions; and
- Exercise each of the four crash warning functions in order to develop a mental model and a better understanding of warning system logic.

The on-road verification test procedures consisted of a structured route with fixed roadway characteristics, lighting conditions, selected maneuvers by the test vehicle, and exposure to dynamic movements of other vehicles.

Figure 8 shows the alert rate per 100 miles for each function and for the overall system. These alerts include both valid and nuisance alerts.

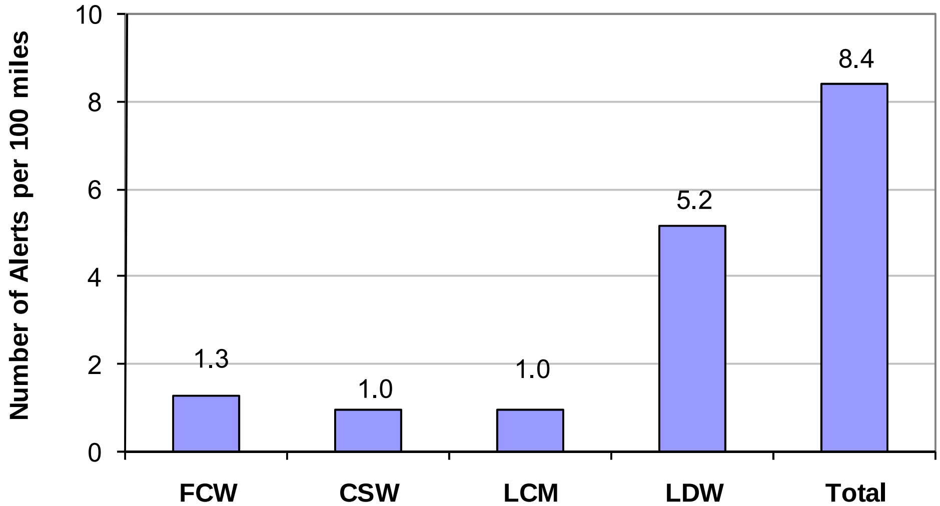


Figure 8. Breakdown of alert rates by system function

Figure 9 shows the LDW warning availability during the on-road verification test. The LDW warning availability refers to the percentage of the time that the system is available to issue a warning. Because the system is disabled when the turn signal or brakes are in use, warning availability includes all instances when the lane tracking is available, and the turn signals and brakes are not in use. It should be noted that warning availability is slightly lower than lane tracking availability, or the proportion of the time that the system can accurately track lane markers. Warning availability exceeded the availability performance guidelines for both freeway and arterial roads. On local roads, LDW availability was below the desired performance level, mostly due to obstructed lane markers in winter driving conditions or slower driving speeds.

The on-road verification test demonstrated the operational capability of the light-vehicle prototype integrated crash warning system. Overall, the system performed within the specifications for alert rates and warning availability. These results, along with the Phase II track test results, indicated that the light-vehicle system was suitable to proceed to the extended pilot test.

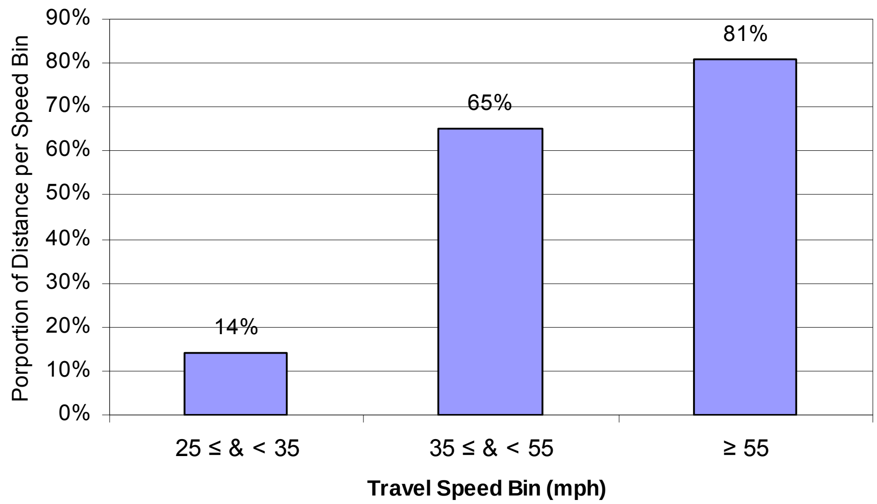


Figure 9. LDW availability by travel speed

3.4 Extended Pilot Test

This section summarizes the light-vehicle extended pilot test and also discusses how the results were used to make changes to the integrated system and FOT experimental procedures. A complete description of this activity is available in the Integrated Vehicle-Based Safety Systems (IVBSS) Light Vehicle Extended Pilot Test Summary Report.[3]

3.4.1 Purpose

The extended pilot test was conducted to demonstrate that the light-vehicle platform was ready to proceed to field operational testing. The specific criteria for readiness were:

- Positive driver acceptance of the integrated crash warning system,
- Integrated crash warning system performance in naturalistic driving that is consistent with expectations and performance guidelines,
- Reliable operation of the hardware and software onboard the test vehicles, and
- Experimental and operational processes that are practical and efficient for conducting the FOT and maintaining quality. Included as part of this activity were the questionnaire designs, test subject instructions, and recruitment processes.

3.4.2 Methodology

The light-vehicle test consisted of 12 participants recruited from the general public, each driving a prototype vehicle equipped with the integrated crash warning system. Each participant drove a vehicle for 26 days with the integrated crash warning system actively providing warnings for the entire duration (i.e., there was no baseline period during which drivers did not receive warnings). Four of the test vehicles were used; the testing period was from November 2008 to March 2009.

The participants were evenly divided into three age groups (20 to 30 years old, 40 to 50 years old, and 60 to 70 years old), and each age group was balanced for gender. The drivers were recruited with the assistance of the Michigan Secretary of State’s database of licensed drivers in southeast Michigan, covering areas that include metropolitan Detroit, the smaller cities of Flint, Ann Arbor, and Monroe, and suburban and rural areas. Recruitment postcards were mailed and the test participants were drawn from respondents to that mailing. Prospective participants were excluded if they had any felony motor convictions in the past three years or if their self-reported mileage was less than 75 percent of the average for that age and gender, using data from the U.S. National Household Travel Survey.

Each driver participated in a two-hour training session. This training session consisted of completing driving style and behavior questionnaires, viewing a video which provided a system overview, an in-car, static demonstration of the warnings, and a 15-minute test drive accompanied by a researcher.

Each vehicle was equipped with a DAS that continuously collected over 500 different data signals, five video streams, and audio from the cabin. The data was continuous, except that audio was triggered by an integrated crash warning system alert.

Upon completion of the 26-day driving period, the test participants returned to UMTRI and completed a post-drive questionnaire. They were also interviewed by an experimenter, during which they responded to a few open-ended questions and provided ratings of specific alerts as they viewed video from selected events that occurred during their own driving.

3.4.3 Results

Travel during the extended pilot test included over 12,600 miles with more than 1,200 crash alerts being issued. One of the 12 participants unexpectedly withdrew from the study after 17 days and could not complete the post-drive instruments. Otherwise, the data set was complete and usable.

The travel distance per driver varied from 433 to 1,934 miles, and the number of alerts varied from 16 to 242. Figure 10 shows locations at the end of each trip for all 12 participants. While driving occurred primarily in southeast Michigan, there were trips by 3 participants to points at least 200 miles from their residence.

Figure 11 shows a breakdown of the alerts by the type of alert. Note that 45 percent of all alerts were cautionary LDW alerts, that is, lane drifts for which the system did not sense a threat beyond the lane edge (e.g., adjacent-lane traffic or a roadside barrier). For these alerts, the alert was a haptic vibration of the seat. Figure 12 shows the alert rate of all alerts combined for each of the 12 drivers, including the haptic cautionary LDW alerts, per 100 miles traveled. There were also imminent LDWs with audible alerts for lane drifts where a threat beyond the road boundary was detected. It should be noted that audible LCM alerts were also issued when the turn signal was on and a threat in the adjacent lane was present. The rate varied from 3.7 to 15.2 alerts per 100 miles.

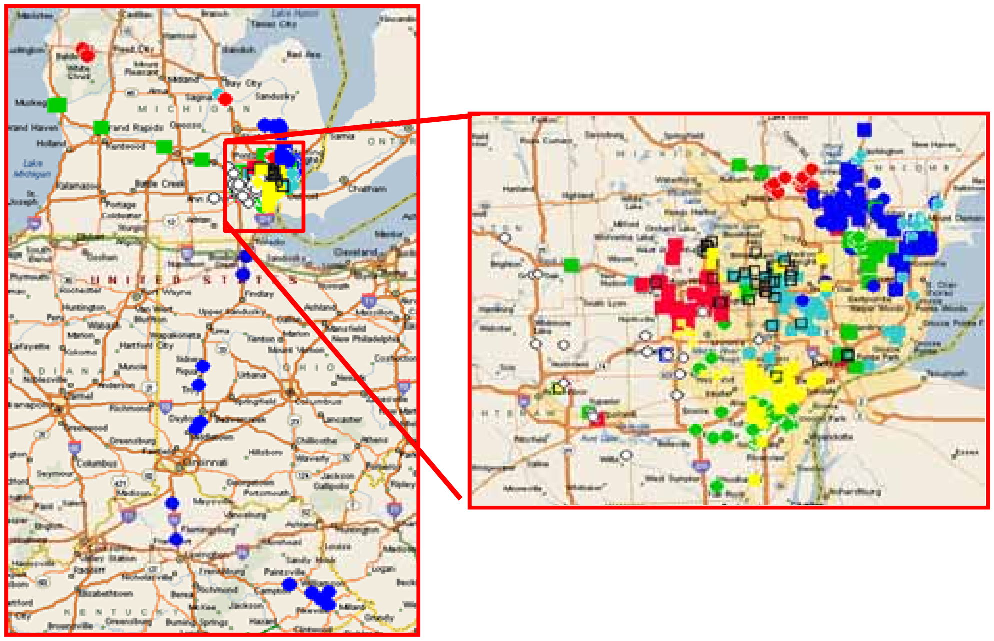


Figure 10. Travel by test participants

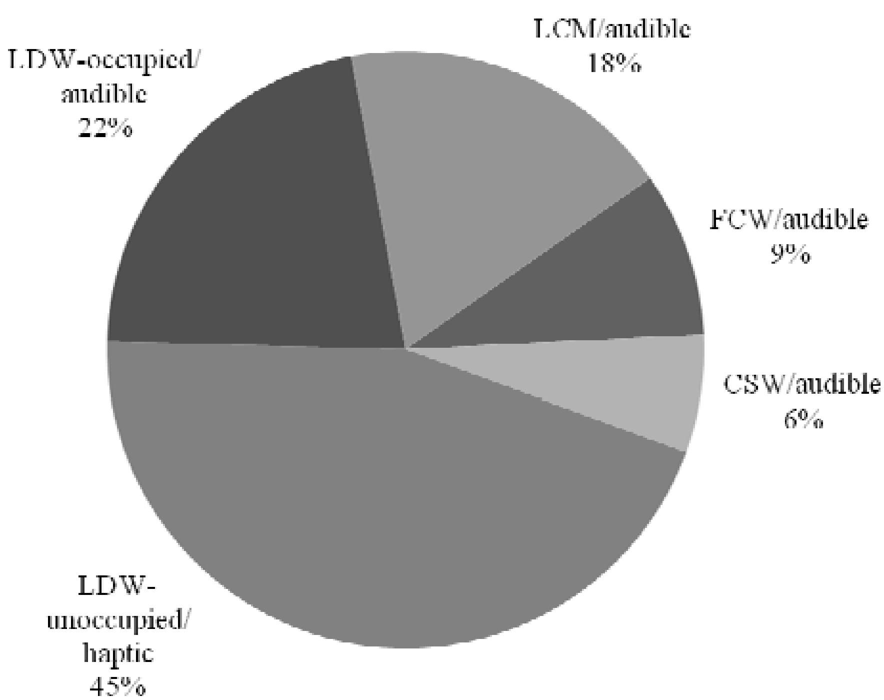


Figure 11. Relative rates of occurrence of each alert type (all drivers)

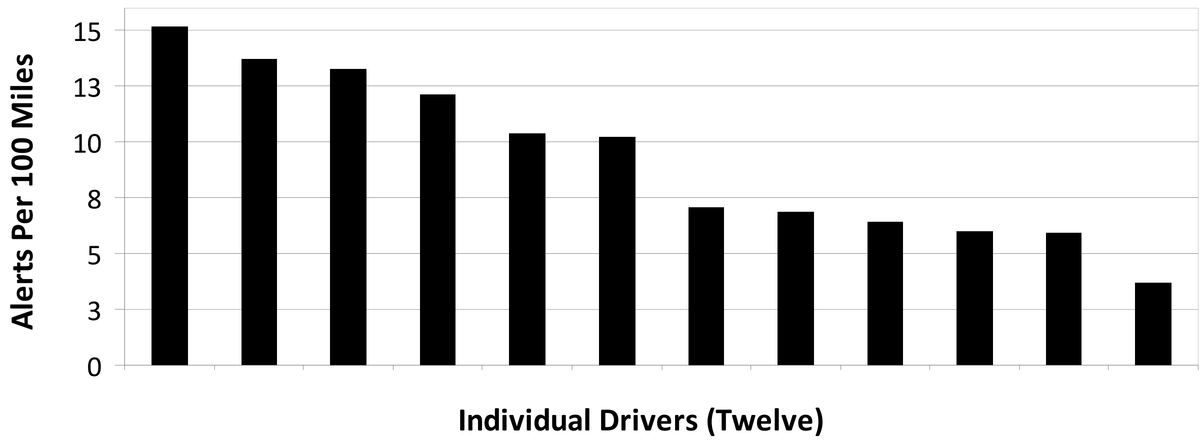


Figure 12. Alert rates per distance traveled for the 12 individual participants

The results of the subjective responses to post-drive questions and interviews showed that drivers had a very positive view of the integrated crash warning system. For example, Table 2 summarizes the participant responses to selected post-drive questions that sought to assess driver acceptance. These questions used a seven-point Likert scale whose anchors are shown in the table. The high means and small standard deviations are evidence of the solid acceptance the system earned in the test.

Table 2. Participant responses to selected post-drive questions (11 participants)

Question	Anchors	Mean	σ, Sigma
How helpful were the integrated system's warnings?	1=Not at all helpful, 7=Very helpful	6.3	0.8
Overall, I felt that the integrated system was predictable and consistent	1=Strongly disagree, 7=Strongly agree	5.5	1.0
Overall, how satisfied were you with the integrated system?	1=Very dissatisfied, 7=Very satisfied	6.4	0.8
Overall, I received warnings . . .	1=Too frequently, 7=Never	4.1	0.8
I always understood why the integrated system provided me with a warning.	1=Strongly disagree, 7=Strongly agree	5.9	1.1
I always knew what to do when the integrated system provided a warning.	1=Strongly disagree, 7=Strongly agree	6.3	0.8
Cost aside, how likely would you be to consider purchasing the integrated system if you were purchasing a new vehicle today?	1=Definitely not, 5=Definitely would	4.5	0.7

3.4.4 Application of the Results

Analyses of onboard data collected during the test and subjective feedback led to integrated warning system improvements. For example, analysis of events within each alert type was conducted jointly with the system developer, leading to suggestions for using system calibration parameters to reduce false and nuisance alerts in specific driving scenarios. These and other changes made are listed in Table 3. The bottom rows in the table address changes to improve operations and data quality, as well as improvements to the post-drive questionnaires. The items in Table 3 were all implemented before the launch of the FOT.

Table 3. List of extended pilot test suggested improvements

Issue in EPT	Improvement for FOT
CSW false alerts	Eliminated a system error that led to spurious and unnecessary alerts
FCW false alerts	Reduced false alerts triggered by roadside objects when the vehicle is approaching a curve
FCW alerts for crossing traffic	Reduced alerts triggered when oncoming vehicles are turning across the path of the IVBSS vehicle
FCW alerts for turning principal other vehicles	Reduced the occurrence of alerts triggered by vehicles ahead that are slowing and turning from the roadway, while still protecting the driver in case those vehicles stop abruptly in their turns
LDW false alerts	Reduced the false alert rate associated with reflections during nighttime driving in rainy weather, as well as false alerts triggered by a false perception of high lateral velocity
LCM false alerts	Reduced the number of alerts that occur when the IVBSS vehicle is changing lanes in front of a slower vehicle that it has just passed
Remotely monitoring the IVBSS fleet	Implemented more diagnostic information and instituted a more complete tool set for monitoring the vehicles in the field
Data collection errors	Corrected errors found in the generation and collection of several data signals
Driver questionnaires	Revised the post-drive questionnaire to reduce the chance that drivers become confused by a question
Driver debriefing	Improved tools used during drivers' debriefs for technical reasons. Also adjusted the manner in which interactive questioning occurs to provide feedback that may be more uniform and objective

3.4.5 Conclusions

The extended pilot test demonstrated the light-vehicle platform's readiness to proceed to the field operational testing, with only minor system changes needed (see Section 3.3.4). Specific findings from the test include the following:

- Positive driver acceptance was received from the eleven drivers whose subjective data were available. Upon questioning, some drivers identified individual alert events that were not useful to them, but on the whole, the ratings of usefulness and satisfaction were quite positive. These findings, although from a small sample, suggest that driver acceptance of the integrated crash warning system in the FOT should be positive.
- The integrated crash warning system performance was generally acceptable; however, several opportunities to reduce the false alert rate and improve system performance were

found. These improvements were made, and did not require substantial changes in the system design.

- No unintended negative safety consequences associated with the integrated crash warning system were observed during the test.
- No evidence was found to suggest major changes in the FOT methodology or experimental design. Improvements were identified and implemented for the collection of objective and subjective data, remote monitoring of the fleet, and fleet operations. These steps were implemented before the launch of the FOT.

3.5 Field Operational Test

3.5.1 Purpose

The primary purpose of the field test is to assess the potential safety benefits and driver acceptance associated with the integrated crash warning system, which will be evaluated under naturalistic driving conditions to determine whether it:

- Is easy to use and to understand by the average driver;
- Will yield measurable safety benefits; and
- Will not pose any additional risk by overwhelming, confusing, or distracting drivers.

To achieve the goals of the FOT, it is necessary to obtain the users' evaluation of the system and to make an objective assessment of how it impacts the driving process. The unstructured character of naturalistic driving requires an investigative approach in making the objective assessment, and the extensive data set will need to be mined through creative inquiry modeled after similar previous efforts. Particular elements of the data that will be closely examined to determine their relationship with system acceptance and benefits; this will include driver age and gender, road class, weather, propensity to engage in secondary tasks such as using a cell phone, and exposure to the system both in terms of miles driven and time, frequency of warnings, and types of warnings received by drivers.

Examination and analyses of these elements and the associated driving performance data will help to better characterize those aspects of the warning system that are either acceptable or unacceptable to drivers, and those circumstances under which it provides safety benefits.

3.5.2 Methodology

The field test will include 108 participants who will each drive an instrumented vehicle for 40 days. The sample will be stratified by age and gender. The age groups to be examined are 20 to 30, 40 to 50, and 60 to 70 years old. Unlike the extended pilot test, the integrated system will be disabled for the first 12 days of the driver's 40-day use of the FOT vehicle. This portion of the test will serve as the baseline period, where drivers will not receive any information or system warnings. Following this period, the integrated system will be enabled for 28 days, during which the integrated system will provide warnings to the drivers. Each participant's driving behavior and performance measures will be monitored for the duration of the test (system disabled and enabled). Other changes made to the methodology based on results from the extended pilot test include revised driver questionnaires and driver debriefing procedures, as mentioned in Table 3.

3.6 FOT Status

The light-vehicle FOT was launched on April 16, 2009, with the first 5 vehicles being released to the first 5 FOT drivers. Figure 13 shows the schedule of vehicle releases for the first 13 drivers of the 108-participant experimental design.

Task Name	Start	EnabledDate	Finish
LV FOT	**Thu 4/16/09**	**NA**	**Tue 7/7/09**
Driver 1	Thu 4/16/09	Tue 4/28/09	Tue 5/26/09
Driver 2	Thu 4/16/09	Tue 4/28/09	Tue 5/26/09
Driver 3	Thu 4/23/09	Tue 5/5/09	Mon 6/1/09
Driver 4	Fri 4/24/09	Wed 5/6/09	Tue 6/2/09
Driver 5	Fri 4/24/09	Wed 5/6/09	Tue 6/2/09
Driver 6	Thu 4/30/09	Tue 5/12/09	Mon 6/8/09
Driver 7	Thu 4/30/09	Tue 5/12/09	Mon 6/8/09
Driver 8	Fri 5/1/09	Wed 5/13/09	Tue 6/9/09
Driver 9	Thu 5/7/09	Tue 5/19/09	Thu 6/18/09
Driver 10	Fri 5/8/09	Wed 5/20/09	Mon 6/15/09
Driver 11	Fri 5/8/09	Wed 5/20/09	Mon 6/15/09
Driver 12	Fri 5/15/09	Wed 5/27/09	Mon 6/22/09
Driver 13	Fri 5/15/09	Wed 5/27/09	Tue 6/16/09
Driver 14	Thu 5/28/09	Tue 6/9/09	Mon 7/6/09
Driver 15	Fri 5/29/09	Wed 6/10/09	Tue 7/7/09
Driver 16	Fri 5/29/09	Wed 6/10/09	Tue 7/7/09

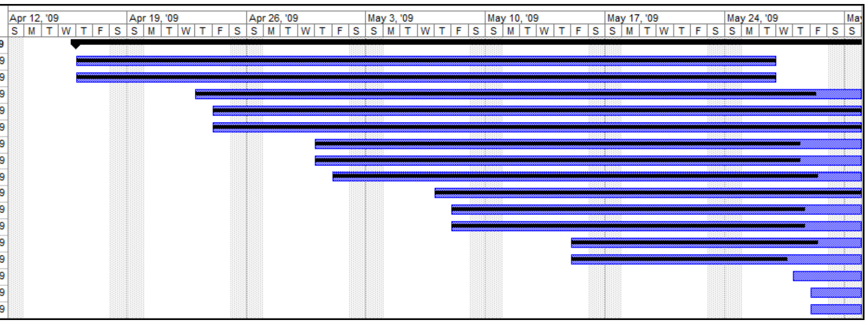


Figure 13. Schedule of light-vehicle releases and returns

4 Heavy-Truck Platform

For the heavy-truck platform, forward collision warning, lane-change/merge warning, and roadway departure warning subsystems were integrated into the safety system and installed on a Class 8 tractor. Key efforts undertaken in the third year of the program include technical refinements, preparation for extended pilot and field operational testing, and launch of the FOT.

4.1 System and Hardware Development

4.1.1 System Development

The team continued to refine both the hardware and software of the integrated crash warning system for the heavy-truck platform. From a hardware perspective, most of the changes were tradeoffs between component size reduction, driver comfort, and improving system robustness. Software refinements focused on performance improvements, false alert mitigation, and providing system diagnostics.

4.1.2 Hardware Integration Design Refinement

The hardware refinement was a joint effort between the system designers from Eaton, UMTRI, and Roush Industries, and drivers from Con-way Freight. The work was carried out first on the prototype platform, the "gold" truck, and then finalized on the first FOT vehicle to be built. Compared to the prototype design, the system architecture and the component sizes have been reduced. The mounting location, sensor brackets, and driver-vehicle interface were modified, and system robustness issues were addressed. Examples of hardware modifications are shown in Figure 14. Hardware modifications implemented include:

- Modifications on the mounting locations and/or the brackets of the following components
  - Central DVI
  - Side display units
  - Side-looking radars
  - Rear-looking radars and cameras
- Additional sensors/brackets for the DAS and its sensors
  - Steering angle sensor
  - Interior cameras
  - DAS cover

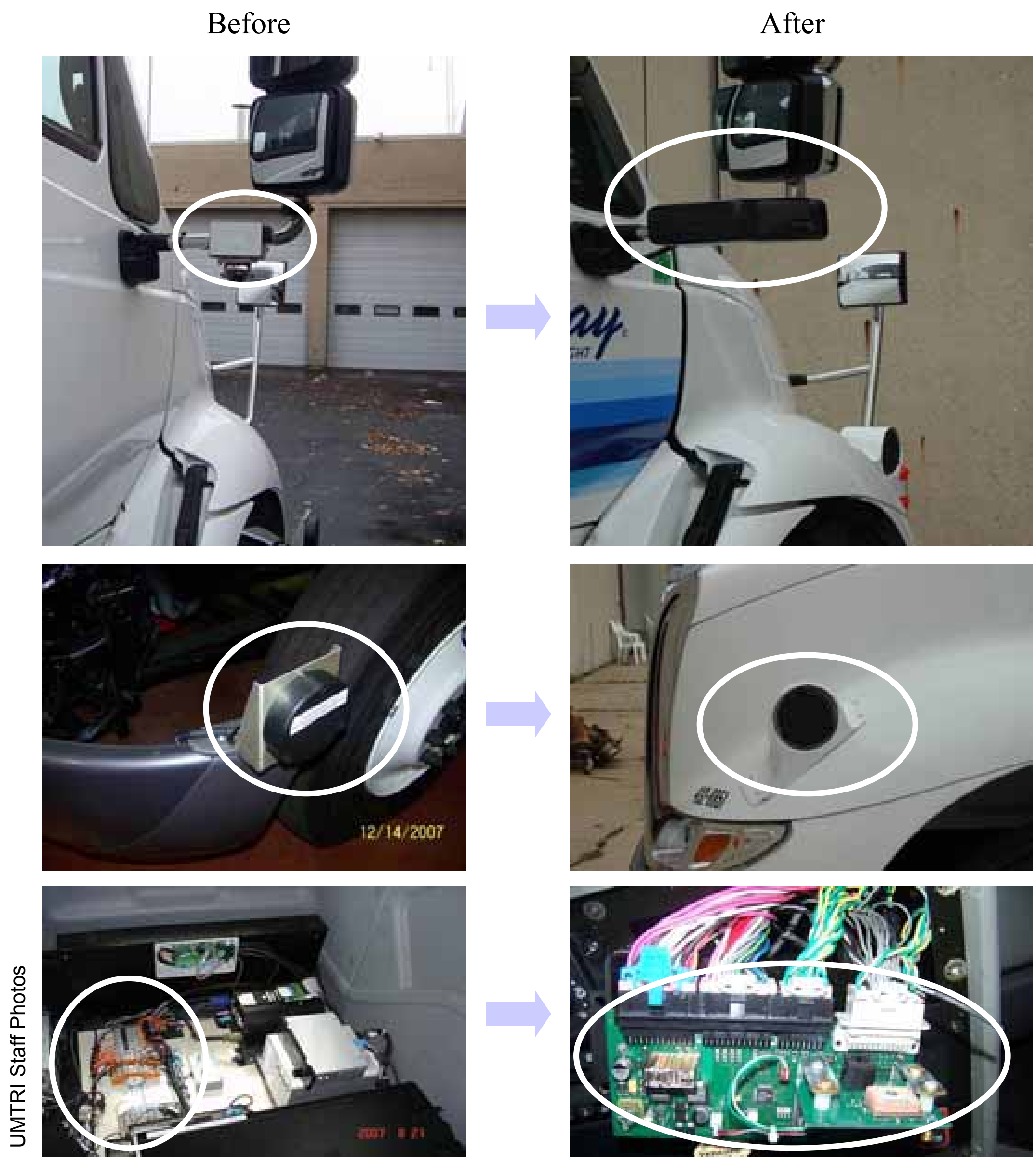


Figure 14. Hardware modifications

4.1.3 *Software Revisions*

Software improvements were also made during this time period based on results from Phase I and feedback from the EPT, including software improvements to address warning performance, software robustness, and the addition of system diagnostics.

All software changes were implemented in one of three major software releases, which took place in October 2008 (prior to the verification test on FOT Vehicle #1), November 2008 (prior to the EPT), and January 2009 (prior to the FOT). All software development for the FOT fleet vehicles was completed in the first quarter of 2009, prior to the launch of the FOT.

Below is a summary of software changes in the order in which they were implemented:

Pre-verification test software release on FOT Vehicle 1 (October 2008)

- Further mitigation of false alerts and system performance consistency
  - Automatic trailer reflection learning
  - Additional false alert mitigation of LCM warnings against fast-overtaking vehicles in the adjacent lane
  - LDW subsystem improvement
    - Improved calibration tool
    - High dynamic mode
    - Curve-widening allowance
    - Eliminate imaging artifacts and glitches
    - Automatic fault alert detection/suppression
- Revised driver vehicle interface
  - Revised LCM sound
  - Simplified scheme for trailer configuration input
  - Side display dimming
- Software re-calibration on FOT vehicles

Pre –EPT software release (November 2008)

- Enhancement of system diagnostics information
  - Comprehensive system status information added to the center display and DAS
- Revised driver-vehicle interface
  - Mute in-cab radio during audible warnings
- Pre-emption logic for simultaneous multiple alerts

Pre –FOT software release (January 2009)

- Further mitigation of false alerts and improvements in system performance consistency
  - Additional false alert mitigation of FCW alerts against stationary objects and slower-moving objects

4.2 Vehicle Builds

The vehicle build process has been a joint effort among Eaton, UMTRI, Roush Industries, International Truck and Engine Corporation, and Con-way Freight, Inc.

As shown in Figure 15, the build process began at International where the base vehicles were original assembled. Then, a series of major vehicle modifications were made to enable installation of the integrated system, including the addition of 10 nodes and more than 100 circuits, and mounting brackets for system sensors, DAS sensors, and DVI unit.

Due to the semi-production nature of system integration, the heavy-truck team went through a detailed process of developing a comprehensive vehicle build procedure, which included a complete list of build materials, a node-by-node wiring diagram, a step-by-step manual for system integration, a sensor alignment procedure, and a system checkout and validation procedure.

The heavy-truck fleet build process was conducted in four waves, starting with the first vehicle in August 2008. FOT vehicles were placed side-by-side with the prototype platform, to identify wiring and configuration differences. Sensor mounting bracket designs and build procedures were further verified and refined in the fabrication of the first FOT vehicle (Figures 15-18). The process was then applied to the rest of the FOT fleet, three vehicles at a time. As shown in Figure 19, the build of the FOT fleet was completed in April 2009.

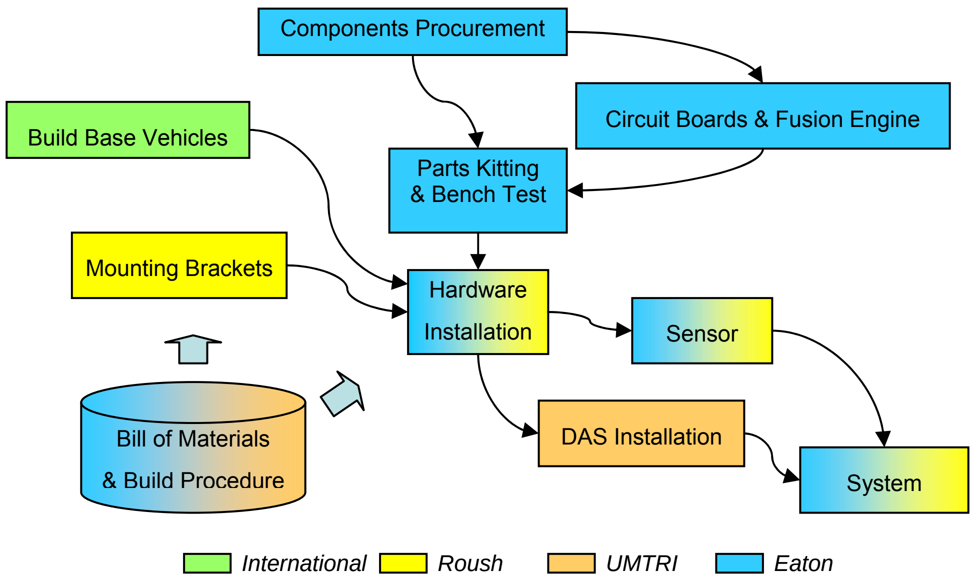


Figure 15. System integration process

Figure 16. FOT vehicle integration site

UMTRI Staff Photos

Figure 17. Exterior view of vehicle sensors

UMTRI Staff Photos

Figure 18. Heavy-truck driver-vehicle interface

Task Name	Start	Finish
Heavy-truck	**Tue 2/19/08**	**Tue 3/31/09**
Prototype DAS build	Tue 3/25/08	Fri 8/15/08
IVBSS software revisions	**Tue 3/25/08**	**Thu 1/22/09**
Gold integration (less DAS)	**Tue 2/19/08**	**Fri 9/26/08**
Gold Truck integration with all sensors & IVBSS	Tue 2/19/08	Fri 5/9/08
First testing with ConWay trailers	Mon 5/12/08	Tue 5/13/08
System design adjustment based on ConWay feedbac	**Thu 5/15/08**	**Fri 8/29/08**
Bill of materials and build procedure for FOT vehicles	**Wed 6/11/08**	**Fri 9/26/08**
FOT vehicle build	**Thu 4/17/08**	**Tue 3/31/09**
Procure components	**Thu 4/17/08**	**Tue 3/31/09**
Node 0 borad programming	**Thu 5/1/08**	**Fri 9/26/08**
Fusion Engine	**Thu 5/1/08**	**Fri 1/23/09**
AC20/DIU programming	**Mon 6/30/08**	**Fri 1/23/09**
Sensor/subsystem inspection/bench testing	**Thu 4/24/08**	**Fri 1/23/09**
FOT build	**Tue 8/5/08**	**Tue 3/31/09**
Fabricate components	Tue 8/5/08	Fri 9/5/08
FOT #1 Build	**Tue 8/5/08**	**Thu 1/22/09**
Hardware Installation	Tue 8/5/08	Fri 9/5/08
Electronic & mechanic check-out	Tue 8/5/08	Fri 9/5/08
Sensor alignment and calibration	Mon 9/8/08	Fri 9/12/08
Software installation and check-out	Mon 9/8/08	Fri 9/12/08
DAS installation and check out	Mon 9/8/08	Fri 9/12/08
Mileage accumulation and software calibration (H7)	Mon 9/15/08	Fri 10/3/08
Trouble shooting&Debug	Tue 8/5/08	Fri 10/3/08
Milestone: FOT 1 ready for the verification test	Fri 10/3/08	Fri 10/3/08
Milestone: FOT 1 ready for EPT	Wed 11/12/08	Wed 11/12/08
Milestone: FOT 1 ready for FOT	Thu 1/22/09	Thu 1/22/09
FOT #2~#4 Build	**Mon 10/13/08**	**Thu 1/22/09**
Roush installation	Mon 10/13/08	Fri 11/14/08
Check-out and debug	Mon 11/3/08	Fri 12/5/08
Mileage accumulation and software calibration (H7)	Mon 11/24/08	Thu 1/8/09
Milestone: FOT 2-4 ready for FOT	Thu 1/22/09	Thu 1/22/09
FOT #6~#8 Build	**Mon 12/1/08**	**Fri 2/13/09**
Roush installation	Mon 12/1/08	Fri 1/16/09
Check-out and debug	Mon 1/5/09	Fri 1/30/09
Mileage accumulation and software calibration (H7)	Mon 1/19/09	Fri 2/13/09
Milestone: FOT 6-8 ready for FOT	Fri 2/13/09	Fri 2/13/09
FOT #5, #9~#10 Build	**Mon 1/26/09**	**Tue 3/31/09**
Roush installation	Mon 1/26/09	Fri 3/6/09
Check-out and debug	Mon 2/9/09	Fri 3/20/09
Mileage accumulation and software calibration (H7)	Mon 2/16/09	Tue 3/31/09
Milestone: FOT5, 9,10 ready for FOT	Tue 3/31/09	Tue 3/31/09

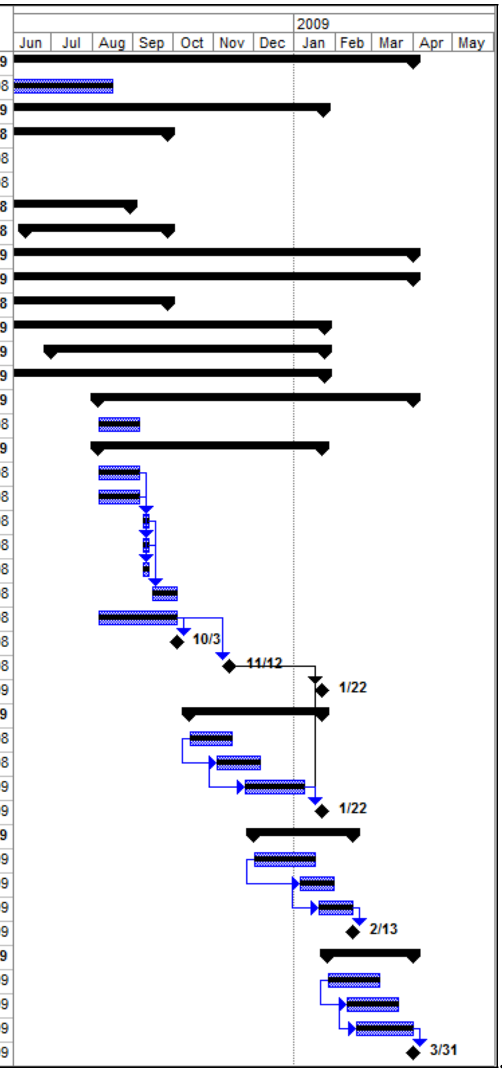


Figure 19. Schedule of heavy-truck builds

4.2.1 Data Acquisition System and Database Development

Eleven DAS units were fabricated for the heavy-truck FOT. The heavy-truck DAS is almost identical to that described in the light-vehicle section of this report (Section 3.2.4). Differences include the arrangement of the external connectors to accommodate the integration of the DAS in the truck, and the method of downloading DAS data. On the heavy-truck platform, data is downloaded from each truck every three weeks by visiting the trucks at the Con-way terminal. Downloading consists of connecting the DAS to the server via a network cable, at which time the downloading of data automatically begins. Once data is on the server, it can be accessed remotely.

4.3 Verification Tests

This section presents test results for the heavy-truck platform conducted during Phase II. The tests were conducted to assess the impact of software changes made since the end of Phase I and to ensure the readiness of the system to proceed to the extended pilot and field operational tests.

4.3.1 Track-Based Verification Testing

The track tests were conducted at the Transportation Research Center in East Liberty, Ohio, in October 2008. The test scenarios selected were a subset of those conducted during Phase I and were intended to specifically test software changes made since the end of Phase I, as well as to measure and document the performance of each warning function. A detailed description of verification test procedures can be found in the Integrated Vehicle-Based Safety Systems Verification Test Plans for Heavy Trucks.

Table 4 shows the overall results for the Phase II verification tests for the heavy-truck system. The system passed all 15 tests, indicating that the system performed within the required design guidelines.

Table 4. Overall results of Phase II track tests for the heavy-truck system

Scenario	Test	Description	Pass/Fail
Rear End	RE-1	Slower constant POV	Pass
	RE-3	Modestly slowing POV at far range	Pass
	RE-4	Stopped POV	Pass
	RE-8	Slower constant POV on curve	Pass
	RE-10	Cut-in by POV	Pass
Lane Change	LC-2	POV in blind spot on left	Pass
	LC-5	LC into adjacent POV after passing	Pass
	LC-6	LC into approaching POV	Pass
Road Departure	RD-2	Clear shoulder with high lateral speed	Pass
	RD-3	Clear shoulder on curve with small radius & low lateral speed	Pass
	RD-5	Shoulder barrier with lane markers	Pass
Multiple Threats	MT-2	Avoid LC with POV2 and RE with slowing POV1	Pass
No Warn	NW-2	No FCW when SV on curve passes stopped POV in adjacent lane	Pass
	NW-6	No LCW when SV changes lanes in front of close POV	Pass
	NW-7	No LCW when SV changes lanes while POV is two lanes over	Pass

4.3.2 On-Road Verification Testing

The on-road verification tests were conducted on public roads in southeast Michigan in October 2008. The objectives of the tests were to operate the heavy truck in an uncontrolled driving environment on public roads in order to:

- Measure the system's susceptibility to issuing nuisance alerts;
- Assess alerts in perceived crash situations when they arise;
- Evaluate system availability over a wide range of driving conditions; and
- Exercise each of the three crash warning functions in order to develop a mental model and a better understanding of warning system logic.

The on-road test procedures consist of a structured route with fixed roadway characteristics, lighting conditions, selected maneuvers by the test vehicle, and exposure to dynamic movements of other vehicles.

Figure 20 shows the alert rate per 100 miles for each warning function and for the overall system. These alerts include both valid and nuisance alerts.

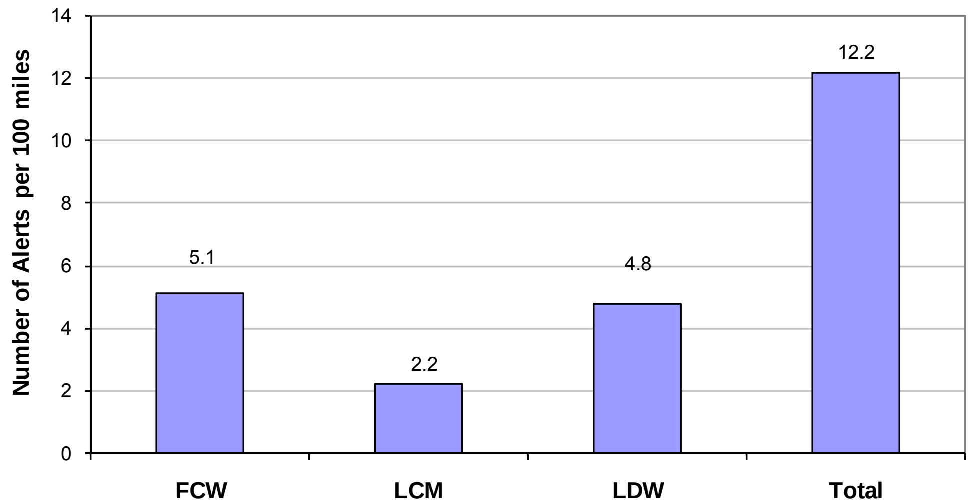


Figure 20. Breakdown of alert rates by system function

Figure 21 shows the LDW warning availability during the on-road verification test. The LDW function exceeded the availability requirement for all three road types.

The on-road verification test demonstrated the operational capability of the heavy-truck prototype safety system. Overall, the system performed within the specifications for alert rates and system availability. These results, along with the Phase II track test results, indicated that the heavy-truck system was suitable to proceed to the extended pilot test.

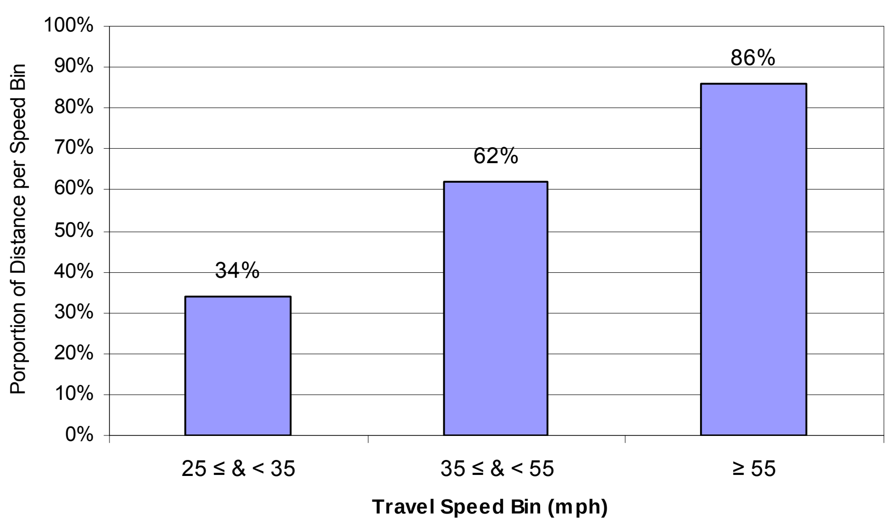


Figure 21. LDW warning availability by travel speed

4.4 Extended Pilot Test

4.4.1 Purpose

The heavy-truck extended pilot test was conducted to provide evidence of proper system performance (alert rate and reliable operation) and driver acceptance prior to conduct of the FOT. The results of this test were to be used to modify the heavy-truck system performance and functionality as required, prior to the start of the FOT. In addition, the extended pilot test served as an opportunity to dry-run questionnaires, driver instructional materials and driver recruitment procedures.

The test entailed use of an IVBSS-equipped heavy-truck by seven Con-way Freight drivers. The drivers used the vehicles for their regular duties for a period of five days each. The test lasted four weeks starting in November 2008 and ending in December 2008, and accumulated data on 5,300 miles of system use. A complete description of the extended pilot test can be found in the Integrated Vehicle-Based Safety System: Heavy Truck Extended Pilot Test Summary Report.[4]

4.4.2 Methodology

The extended pilot test methodology involved selection of an appropriate facility to conduct the study along with recruitment of subjects. It also included the upfit of an FOT-ready vehicle with both the integrated crash warning system and a data acquisition system.

Several Con-way Freight terminals were evaluated for conducting both the extended pilot test and the FOT. One of the primary criteria for selecting a terminal was close proximity to Ann Arbor. This would allow for convenient and easy access for monitoring the trucks and drivers, and performing any system repairs, should they be required. Con-way's Ann Arbor terminal in Whitmore Lake, Michigan, was selected as the best location for the extended pilot test.

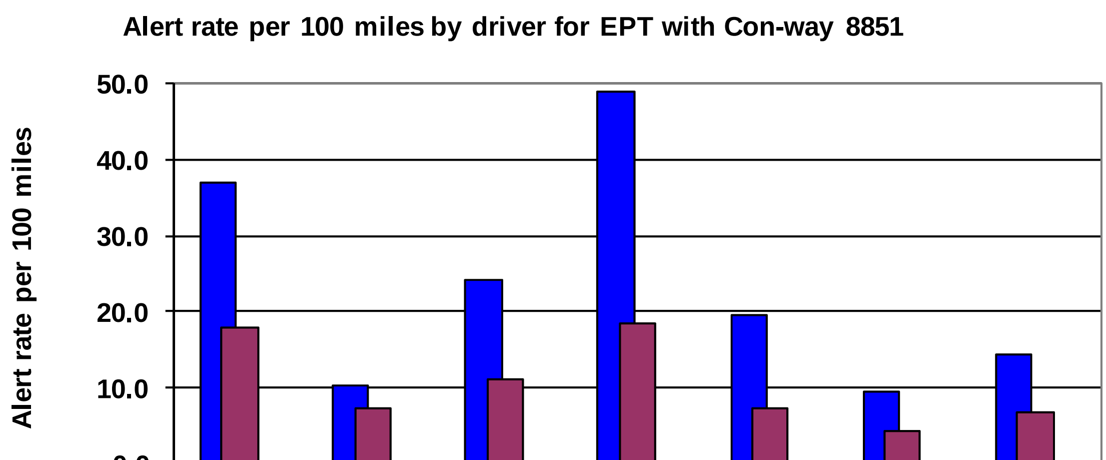
Con-way's Ann Arbor terminal was chosen because it had an adequate pool of drivers from which to recruit test participants, and the truck routes were similar to those slated for use during the FOT. In addition, its location was in close proximity to UMTRI.

Initially, 8 drivers were sought for the EPT. This group was intended to include four pick-up and delivery (P&D) drivers who would drive the tractor during the day and deliver freight to local destinations, and 4 line-haul drivers who would drive the tractor at night between various Con-way terminals. Each driver would operate the tractor for five consecutive workdays, going about their normal driving practices.

To begin the program, drivers at Con-way's Ann Arbor terminal were briefed on the program. This presentation included some background on the integrated crash warning system accompanied by a short video describing its operation. After the presentation, drivers were given the opportunity to ask questions. Only 7 drivers volunteered, but fortunately they represented a broad range of commercial driving experience, with the most experienced driver holding a commercial driver's license for 35 years and the least experienced driver holding a CDL for only 6 years.

4.4.3 Results

Over 5,300 miles of driving were logged during the test. From an exposure perspective, test conditions matched the business practices of Con-way Freight, and therefore were similar to the conditions that would be expected during the FOT. Seven drivers logged 459 trips and experienced 1,162 alerts from the FCW (313), LDW (759), and LCM (90) integrated warning functions. Upon review of each of these alerts using data and video, researchers subjectively classified 551 (47 %) of the alerts as being nuisance alerts. This resulted in an overall nuisance alert rate of 10.3 alerts per 100 miles of travel. For FCW, 249 (79 %) of the alerts were nuisance alerts, while LDW had 255 (34 %) nuisance alerts, and LCM had 47 (52 %) nuisance alerts. Nuisance alert rates were largely independent of route type with overall nuisance alert rates of 11.3 and 9.9 for P&D and line-haul, respectively. These results are presented in Figures 22 and 23.



	1	2	3	4	5	6	7
All alerts	37.1	10.4	24.1	48.9	19.6	9.6	14.5
Invalid	17.8	7.5	11.2	18.4	7.4	4.3	6.9
Distance	499	2182	366	971	393	540	392

Figure 22. Alert rate per 100 miles by EPT driver

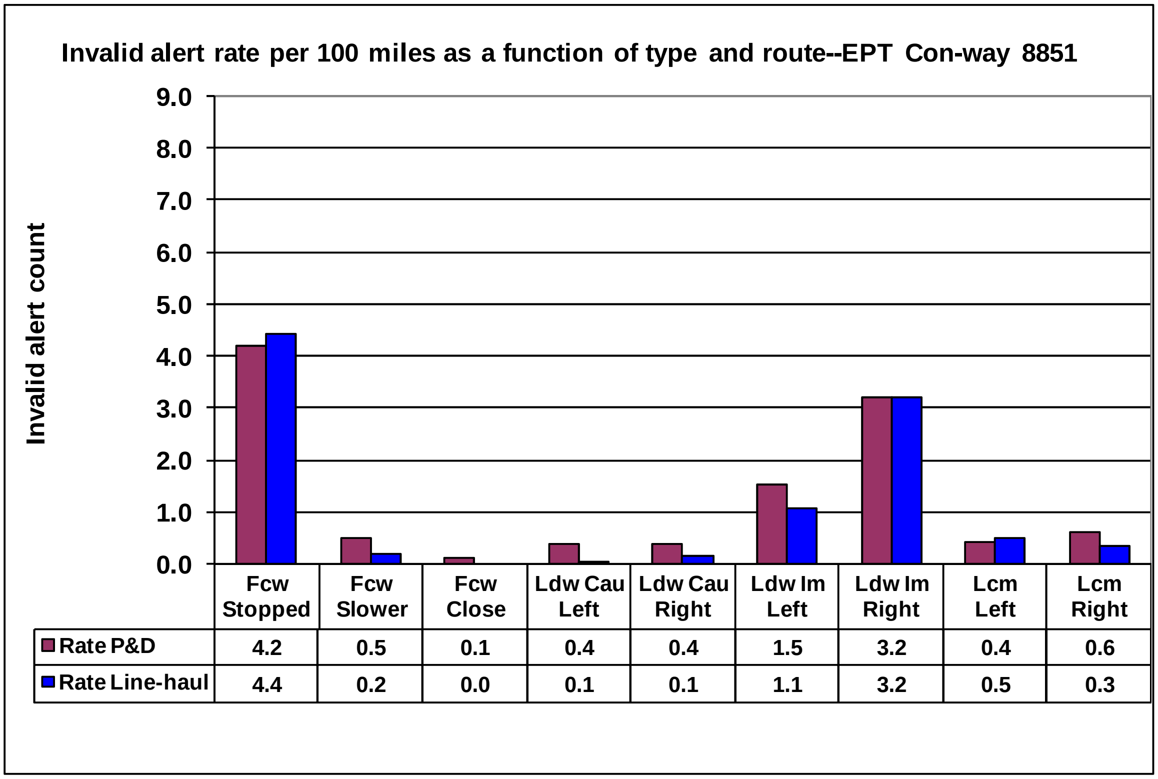


Figure 23. Nuisance alert rate per 100 miles as function of alert and route type

Drivers' subjective impressions indicated that they were somewhat satisfied with the integrated crash warning system as a whole. While 1 of the drivers was clearly unhappy with the inconsistency of the warnings, the remaining 6 drivers responded that they usually understood why warnings occurred. The majority of the drivers felt the system provided the benefit of increased awareness of the traffic situation, and therefore increased their driving safety. Of the three individual subsystems, drivers rated the FCW subsystem lowest, likely a result of the frequency of nuisance alerts. The LDW and LCM subsystems both received higher overall scores, but neither substantially out-performed the other.

Drivers seemed satisfied with the integrated system driver interface. Regarding the intensity of the warnings, drivers felt they were strong enough to gain their attention without being annoying. Only one driver reported using the alert volume control, and none of the drivers reported using the mute function or brightness adjustment. Responses were mixed in terms of the LCM displays. Drivers tended to like the concept, but felt that the location of the displays could be improved to make them more noticeable when checking their mirrors.

4.4.4 Application of the Results

A detailed breakdown of the alert types showed that FCW alerts for stopped objects (234) had a total of 232 (99 %) categorized as nuisance alerts. Based on this finding, the heavy-truck team decided to evaluate, and ultimately implemented, two changes to reduce the occurrence of nuisance FCW alerts associated with stopped objects. These changes were as follows:

- Address stationary objects when following a principal other vehicle: in this scenario a revision to the FCW software would suppress a stopped object alert for a half-second when the following conditions have been met:
    - the subject vehicle has been following an in-path moving POV for at least 3 seconds,
    - the distance to the stationary object is greater than the distance to the POV at 3 seconds prior to the alert request, and
    - the distance to the stationary object is less than the distance to the POV at the time of the alert request. It was anticipated that this change to the FCW threat assessment would reduce nuisance stopped object alerts by 15 to 30 percent.
- Address stopped objects like roadway signs while in a curve: in this scenario, a revision to the FCW software would suppress a stopped object alert for 0.5 seconds if the subject vehicle has been decelerating for the last 5 seconds. It was anticipated that this change would reduce nuisance stopped object alerts by 20 to 40 percent.

4.4.5 Summary

The extended pilot test successfully evaluated system performance and driver acceptance. Driver recruitment and training procedures were tested, as were the driver survey and debriefing methodologies. The integrated crash warning system and DAS hardware operated reliably throughout the test period. However, the integrated crash warning system had an alert rate that was higher than anticipated when compared to previous testing. Nonetheless, drivers were generally still accepting of the system. Valuable data obtained from the test have led to further system performance improvements in the detection of stopped and slower-moving objects by the FCW subsystem in order to reduce the nuisance alert rate. These enhancements were implemented into the heavy-truck fleet for the FOT.

4.5 Field Operational Test

4.5.1 Purpose

The purpose of the FOT is to assess the potential safety benefits and driver acceptance associated with the prototype integrated crash warning system. The integrated system will be evaluated under conditions of naturalistic use to determine whether it:

- Is easy to use and understand by the average driver;
- Will yield measurable safety benefits; and
- Will not pose any additional risk by overwhelming, confusing, or distracting drivers.

Participants in the FOT represent a sample of commercial drivers operating within a freight carrier’s fleet.

To reach these goals, it is necessary to obtain the users’ appraisal of the system and to make an objective assessment of how it impacts the driving process. The unstructured character of naturalistic driving requires an investigative approach in making an objective assessment, and the extensive data set will need to be mined through creative inquiry modeled after similar previous program. Particular elements of the data that will be closely examined to determine their relationship with system acceptance and benefits will include driver age, delivery route types (P&D versus line haul), road class, weather, propensity to engage in secondary tasks such as using a cell phone, exposure to the system both in terms of miles driven and time, the frequency of warnings, and the types of warnings received by drivers.

Examination and analyses of these elements and the associated driving performance data will help to better characterize those aspects of the warning system that are either acceptable or unacceptable to drivers, and those circumstances under which the system provides safety benefits. Feedback from the fleet operator and truck owners will also be important in determining the long-term viability of similar systems in commercial vehicles, as the fleet operators are ultimately the safety system purchasers in the majority of the commercial-truck market.

4.5.2 Methodology

Ten 2008 International ProStar 8600-series tractors are being used as the FOT vehicles. These trucks have been built to specification for, and purchased by, Con-way Freight, the FOT fleet operator. Tractors have been built and equipped with the integrated crash warning system in sets of three or four and introduced into the fleet in a staggered fashion. Twenty Con-way commercial drivers are participating in the field test.

Only drivers with valid CDLs and a minimum of two years experience in driving heavy-duty trucks will be recruited. Every attempt was made to obtain a wide range of driver ages; however, gender cannot be balanced with the population of drivers at the Romulus terminal, as it is exclusively male. Drivers received training on the integrated crash warning system using an instructional video, and a demonstration drive while accompanied by an UMTRI researcher.

FOT participants are operating the trucks and conducting Con-way's normal delivery business over a 10-month period. The first 2 months of vehicle use serve as the baseline period, while the following 8 months are the treatment period. During the baseline period, no system functionalities or warnings are provided to the driver, but all system sensors and equipment are running in the background. At the beginning of the third month of participation, the integrated crash warning system's functionality is made available and warnings are provided where appropriate. Use of the equipped tractors by anyone who is not an FOT participant is limited.

Con-way will operate the tractors with the integrated crash warning system from its Romulus, Michigan, service and distribution center. At this terminal, Con-way operates approximately 80 tractors and 220 trailers in both line-haul and local P&D operations. Preliminary exposure estimates show that 80 percent of the miles traveled by the vehicles will be on limited-access roads, while the remaining 20 percent will be on major surface roads. Each tractor will be assigned to a specific line-haul and P&D route. During the day, the tractor is used on a P&D route, while at night the same tractor will be used for a line-haul route. Tractors will be in operation up to 20 hours per day. The overall total mileage estimate for the fleet is expected to be around 700,000 miles, with 15,000 hours of driving, over the 10-month test period. In general, Con-way uses sets of 28-foot trailers for all line-haul operations. For P&D, Con-way typically uses a 48-foot trailer but can also use 28-, 40-, 45-, and 53-foot trailers. P&D trailer selection is a function of route and time of year, as the freight business varies during the year.

A data acquisition system is installed on each truck, and serves as a permanent recorder of the numerical and video data collected during the field tests. To monitor the functionality of the

DAS and integrated crash warning system, UMTRI uses customized software to compute and report summary statistics that identify system problems and failures. This summary diagnostic information is downloaded using an on-board cell modem to an UMTRI server following each ignition cycle. This approach provides current summary and diagnostic information for engineers to remotely monitor the fleet's health on a continuous basis throughout the test.

Retrieval of heavy-truck data is performed manually. An on-site server and data download mechanism are located on Con-way premises. The research vehicles have designated parking spots located alongside a maintenance facility where data retrieval "umbilical" cords need only to be plugged in to initiate data transfer on a regular basis, approximately every three weeks per vehicle. Data from the fleet is then uploaded into the appropriate database and backed-up for archiving.

4.6 Heavy-truck FOT Status

Figure 24 shows the schedule of vehicle releases for the heavy-truck FOT, which began on February 2, 2009, with the deployment of tractors 1 through 4. On February 23, 2009, tractors 6 through 8 were released. The remaining tractors were released during the weeks of March 10, 2009, and April 10, 2009, respectively.

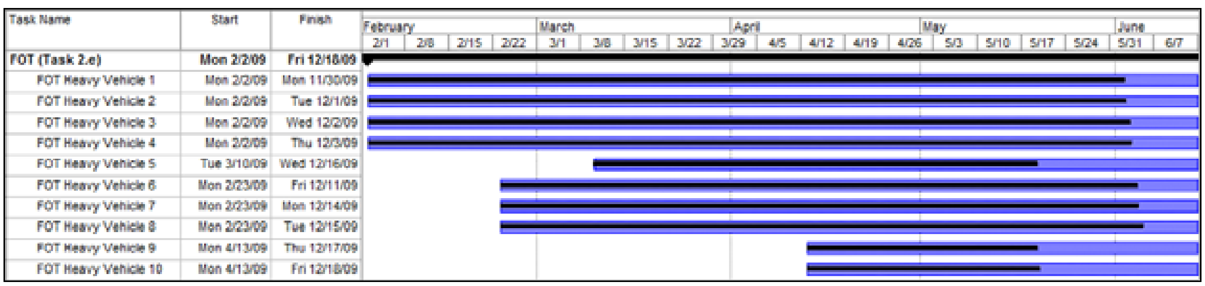


Figure 24. Schedule of heavy-truck vehicle releases including baseline and treatment periods.

As of April 30, 2009 total mileage accumulation for the fleet was 166,228 miles. Of this distance, 42,815 miles were with the integrated crash warning system enabled. Table 5 contains for a summary of distance traveled, including the total accumulated distance with and without the system enabled for each tractor. As of this date, the tractor with the most exposure, FOT2, is averaging approximately 2,380 miles per week or 475 miles per day (based on a five-day work week).

Table 5. Accumulated total and enabled distance as of April 30, 2009, for each tractor

Tractor	**Total Distance, miles**	**Total Distance Enabled, miles**
FOT1	21,137	6,336
FOT2	28,647	10,220
FOT3	22,543	6,140
FOT4	24,622	7,585
FOT5	15,038	0
FOT6	18,494	4,503
FOT7	19,593	4,512
FOT8	12,393	3,519
FOT9	698	0
FOT10	3,063	0
Total	166,228	42,815

5 Independent Evaluation

5.1 Approach

The Volpe Center is responsible for the independent evaluation of the IVBSS program. The goals of the independent evaluation are to:

- Achieve a detailed understanding of system safety benefits;
- Determine driver acceptance of the system; and
- Characterize system performance and capability.

5.1.1 Safety Benefits

Safety benefits are estimated by determining the number of crashes that could be avoided by full deployment of the integrated safety system in the United States. In addition, modifications in driver behavior are examined to determine any unintended consequences that can have negative effects on traffic safety. The driving experience of subjects during the baseline (without the system enabled) and treatment (with the system enabled) periods will be analyzed using field operational test data. Four objectives are as follows:

- Assess whether the integrated system has negative or positive effects on normal driving performance. Measures of vehicle following, lane keeping, lane change, and speeding behavior are analyzed in low-risk driving situations that do not involve driving conflicts.
- Measure the frequency of driver encounters with driving conflicts and examine driver response to resolve these conflicts that represent major pre-crash scenarios of target crashes including rear-end, lane change/merge, and roadway departure crashes.
- Investigate the near-crash experience of drivers when avoiding driving conflicts relative to target crashes.
- Project the number of crashes for each subject in the three target crash types.

Safety is ideally measured from actual crash data. However, crashes are rare events and are therefore unlikely to occur in the limited scope of the field tests. Capturing a significant number of such events would require testing a large fleet of vehicles equipped with the integrated system over a long period of time. As a result, the independent evaluation will estimate safety system benefits using driver-vehicle performance driving conflicts under baseline and treatment conditions. These conflicts refer to driving situations that may lead to a crash if no avoidance maneuver is attempted by the driver. Measures of effectiveness consist of the number of encounters and response types to these conflicts. Safety benefits will be projected using mathematical modeling and computer simulations with field test measurements provided as input data.

5.1.2 Driver Acceptance

The driver acceptance goal consists of five objectives:

- Address issues related to the ease of using the system, principally in terms of the driver interface implementation.

- Examine perceived usefulness of the system based on drivers' subjective assessments of safety while using it, and their perception of how use of the system affects their driving skills and workload.

- Assess the ease of learning including drivers' understanding of the system, how long it takes to learn to use it, and utility of the instructional process.

- Determine drivers' advocacy of the system by their expressed willingness to pay for the system and to endorse its use to others.

- Obtain drivers' assessment of their own driving performance and their judgment of whether system use leads to behavioral adaptation such as changes in their attention to driving tasks, trip making, or vehicle use.

The analysis of driver acceptance will be based on subjective data collected from drivers in the form of post-drive questionnaires, debriefing interviews, and focus groups. The subjective data will be correlated to objective data that describe the intensity and nature of drivers' experiences with the system during the field tests in terms of the number of alerts issued, number of conflicts encountered, alert and conflict rates, and alert validity. This analysis will compare drivers' acceptance of the system to their actual field experience as a method of assessing the impact that different aspects of the system's performance have on drivers' perceptions of the system.

5.1.3 System Capability

The following four objectives are considered to assess the operational performance of the integrated safety system and its components in the driving environment:

- Characterize the performance of the forward-looking, side-looking, lane tracking, and vehicle positioning sensors.

- Examine the performance of the warning logic in alerting the driver to driving conflicts that might lead to rear-end, lane change/merge, or roadway departure crashes.

- Evaluate the capability of the driver-vehicle interface to properly convey visual, audible, or haptic information to the driver.

- Monitor system integrity and reliability throughout the field tests in terms of system availability and records of system failure.

Field test data will be used to characterize the capability of the system. Supplementary tests, including track and on-road tests, will also be conducted to gather additional data for the light-vehicle platform.

Primary activities will be focused on reaching the goals of the independent evaluation. Prior to the start of the field operational tests, the following tasks were completed to ensure the readiness of both vehicle platforms:

- System Verification Tests: Two controlled tests were conducted for each vehicle platform on a test track and on public roads. Track tests involved orchestrated crash-imminent and no-warn driving scenarios. Tests on public roads collected system performance data on a prescribed route that included freeways and arterial roads under different lighting and traffic conditions.
- Extended Pilot Tests: An independent assessment of the data and results was conducted to determine if system operation met performance guidelines and to obtain preliminary information on driver acceptance and their opinion of the systems.

Figure 25 illustrates the flow of the independent evaluation work activities, where the un-shaded blocks refer to the tasks conducted by the Volpe Center and the shaded blocks refer to the field test data supplied by UMTRI. The video processing, data mining, data viewer, and data logger tasks shown in the upper blocks are in progress. In the bottom row, the independent evaluation plan was drafted in December 2007, while the remaining tasks in the lower blocks have not yet been initiated.

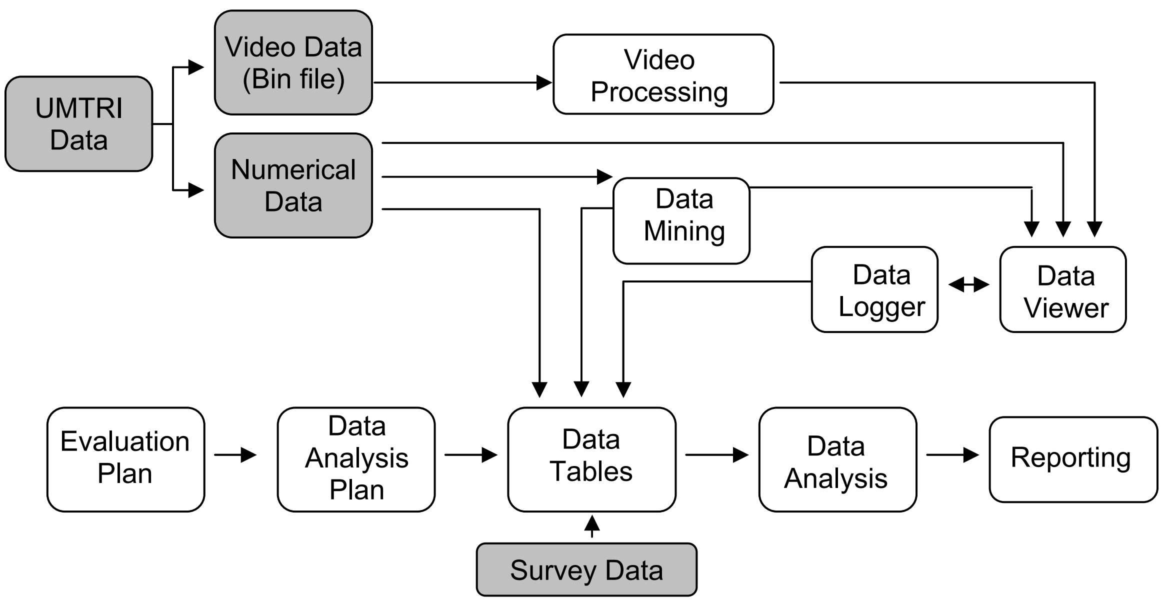


Figure 25. Block diagram of independent evaluation tasks

5.1.4 Video Processing

During the field tests, video data is collected from five cameras to capture the forward, right, and left-lane scenes, as well as the driver’s face and inside the cabin. The video frame size and rate vary by camera and platform. Video frames are compressed using MPEG-4 algorithms and stored in a binary format. A binary video translator is used to convert all video files to standard AVI format. A batch processing application was developed with UMTRI to perform the video conversion and quality assurance. An application was also created to extract video frames as images from AVI files using a third-party video software development kit. An application that will write the images extracted from video files to the corresponding video database on the server will then be finalized. Numerical data are housed in their own databases and video data will be housed in one or more databases. A link between these databases will be established using synchronization mapping tables or equations provided by UMTRI, which will be used by the multi-media data viewer tool as shown in Figure 26.

5.1.5 Data Mining

This task identifies driving conflicts from the numerical data as part of the safety benefit analysis. These conflicts represent vehicle movements, critical events, and driver maneuvers that map to pre-crash scenarios leading to rear-end, lane change/merge, and roadway departure crashes. Algorithms have been developed to mine the data for longitudinal and lateral conflicts. Longitudinal conflicts encompass roadway departure pre-crash scenarios due to excessive speed on curves and rear-end pre-crash scenarios that distinguish between lead vehicle stopped, decelerating, and moving at slower constant speed. Lateral conflicts comprise lane change/merge pre-crash scenarios as well as roadway departure pre-crash scenarios due to lane/road edge departure. Input data consist of information about the forward targets, targets in adjacent lanes, roadway, and in-vehicle sensors as collected by the data acquisition system on each vehicle platform. Development and test of these algorithms for the light-vehicle platform has been completed; however, work is still in progress to revise the algorithms for the heavy-truck platform. Algorithms for both platforms have been thoroughly tested and verified using numerical and video data from the extended pilot tests. Field test data post-processing will be performed using Structured Query Language (SQL) programs.

5.1.6 Data Viewer and Logger

A data viewing tool that displays numerical data and five channels of video data simultaneously was developed. This tool will allow users to analyze events of interest and record their observations. The events include episodes when the system issues an alert and instances of specific driving conflicts. The tool is tied to the field test database, providing easy access to relevant data and storage of user observations through the data logger. This tool is needed to conduct a detailed analysis of timing and appropriateness of the alerts and to understand the context of the driving situations as well as the driver response. The data logger incorporates information about alert validity, driver distraction, eyes off the road, target type, target maneuver, and vehicle path. Figure 26 shows a snapshot of the data viewer with these key characteristics:

- View 20 Hz and 50 Hz data variables at 10 Hz;
- Play at different rates (viewing speed);
- Select data views based on the type of alerts or conflicts;
- Scroll through the data one sample at a time; and
- Display information about alert flags and vehicle controls such as speed, turn signal, and brake activation.

Figure 26. Snapshot of the multi-media data viewer

5.2 Accomplishments and Schedule

The following tasks have been completed during Phase II:

- Assessment of all verification test data;
- Evaluation of all extended pilot test data;
- Development and testing of data mining algorithms for the light-vehicle platform;
- Implementation of a multi-media data viewer, video processing, and synchronization tools; and
- Acquisition and set up of the database hardware and software.

Figure 27 provides a schedule of the major tasks that will be performed during Phase II, including program deliverables. The two program deliverables will include independent evaluation reports for the light vehicle and heavy-truck field operational tests.

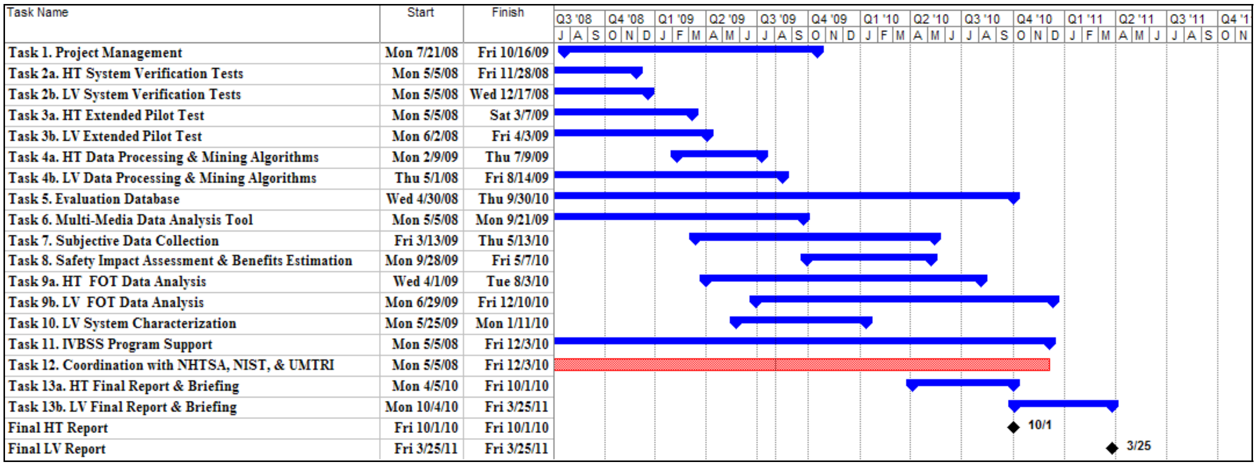


Figure 27. Gantt chart of independent evaluation tasks

5.3 Follow-on Activities

The following activities with be performed by the Volpe Center during the fourth year of the program. Some activities will be completed during this time period, and others will continue into the following year.

Data processing: One of the primary tasks will be processing the FOT data for subsequent analysis. Data will be received from April 2009 through May 2010. This data will be uploaded to a server and processed to make it available for data analysis. Video and numerical data must also be synchronized so it can be used by specialized software tools used to analyze individual crash alerts.

Multi-Media Tool: The software tool that will be used to analyze FOT crash alerts will be completed. The multi-media tool allows synchronized video and numerical data occurring at the time of each alert to be viewed simultaneously. The data viewing tool will be used to analyze each of the alerts that occur during the light-vehicle FOT and a sample of the heavy-truck alerts.

Data mining: This task will be completed. The data mining task applies a series of algorithms to identify driving conflicts that will be used to conduct the safety benefit analysis. Data mining activities will include testing and verification of the algorithms, and applying the data mining techniques to all FOT data to populate driving conflict tables in the FOT database.

Data analysis: Data analysis plans for both platforms will be completed. Analysis tasks will get underway as data becomes available and continue throughout the year and into the final year of the program. Analyses conducted will include queries of numerical data to identify events of interest for further study, examination of individual alerts using the multi-media tool to determine alert validity, identification of driving scenarios and driver distraction behavior, and analysis of the subjective data.

Subjective data collection: Volpe staff will participate in the debriefing interview of each FOT participant at the conclusion on their participation in the test, as well as in the development and conduction of focus groups for the light-vehicle FOT participants.

Characterization testing: Test track and on-road characterization tests of the light-vehicle platform will be completed. Data collected during characterization tests will be used to determine how the system performs in various crash-imminent situations on the test track and on a sample of representative roadway types on public roads under different traffic, lighting, and weather conditions.

6 Projected Fourth Year Activities

The UMTRI-led team will concentrate on completion of the field operational tests, and planning and carrying out data analysis tasks during the fourth year of the IVBSS program. Industry outreach activities will also continue.

6.1 Conduct of Field Operational Tests

At the time this report was published, the light-vehicle and the heavy-truck FOTs were both well underway. However, a significant amount of data remains to be collected from the heavy-truck field test and the majority of the participants for the light-vehicle FOT need to be recruited. The conduct of the light-vehicle FOT will continue into the fourth program year, and is expected to be completed by the end May 2010. Recruitment will continue throughout the field operational test to ensure that data from all 108 participants is collected over the 12-month duration of the test. All 20 drivers have been recruited, and have been participating in, the heavy-truck FOT, which is scheduled to be completed by the end of December 2009.

Sustained efforts on both field tests will emphasize regular monitoring of the vehicle fleet to ensure that the integrated crash warning systems and data acquisition systems are operating normally. Data from the vehicles will continue to be gathered, validated, stored in a relational database, and forwarded to the independent evaluator at regular intervals.

During the field tests, data validation begins with files received via a cellular phone transmission at the end of each ignition cycle. These files include histograms, counts, averages, first and last values, and diagnostic codes that are automatically uploaded to a server when received. Routines are used to automatically scan the server for these files and load them into the database for immediate processing using data validation techniques. These procedures query the data and generate summary reports that are reviewed daily in order to identify any system problems occurring with vehicles in the field.

Related efforts that are being undertaken in the fourth year include: the development of data analysis and visualization tools, development of additional data processing techniques for processing existing data measures taken directly from the vehicles, creation of new data measures from raw signals, and exploration of the data to achieve a more thorough understanding of the data and responses of participants to the integrated crash warning system.

6.2 Data Analysis Plans

Major fourth-year deliverables will include field operational test data analysis plans for each platform. The data analysis plans will detail the research questions that will be addressed. This includes research hypotheses and descriptions of the types of statistical analyses to be performed. For both platforms, the data analysis plans are aimed at questions related to changes in driving performance with, and driver acceptance of the integrated crash warning systems.

Categories of analysis include the following:

- Characterizing exposure data by travel patterns, roadway variables and environmental conditions,
- Reporting on the integrated crash warning system's performance in terms of alert rates, including false alerts,

- Safety-related observations such as drivers' response to warnings and changes in driving performance (such as conflict management) or behaviors (such as engagement in non-driving related tasks), and
- Drivers' subjective perceptions of the system.

Examples of the individual variables to be examined and reported include:

- The rate and circumstances of various types of crash warning alerts, including false alerts;
- The fraction of travel distance or time that system functions are available to the driver;
- Individual driving styles observed (based on measures that portray degrees of conflict tolerance, speeds, and lane change frequencies);
- Distributions of trips, trip distances, and trip times;
- Availability of digital map coverage, including exposure to roadways having the higher-accuracy Advanced Driver Assistance Systems coverage;
- Travel patterns;
- Road class and roadway attributes;
- Weather variables (precipitation, temperature);
- Ambient lighting (time of day);
- Local traffic densities (using surrogate metrics based on onboard data); and
- Driver characteristics and information (age, gender, typical mileage, years of driving experience, driving record, etc.).

6.3 Data Analyses

In-depth data analysis will not begin until data collection from the individual FOTs is completed. Since the heavy-truck field test will be finished before the light-vehicle FOT, analysis will begin with data from the heavy-truck platform. Commonalities in the integrated systems on the two platforms, the manner in which the data are collected, and how data are managed in a relational database will lead to many similarities in not only what research questions are asked, but also how the analyses are performed. Many of the basic routines and statistical tests used in analyzing the heavy-truck field data will be directly applicable to the light-vehicle field test. It is worth noting that there will be a significant difference in volume of the data collected between the two platforms. Data volumes for the heavy-truck field test will be approximately three times larger than that for the light-vehicle test. This is due to the dramatic differences in mileage accumulation achieved by commercial trucks relative to typical passenger vehicles, despite the fact that one-fifth as many drivers are participating and the overall duration of the heavy-truck test is shorter.

The four-month period following completion of each FOT will be used to complete detailed data analyses and preparation of draft reports.

Examples of research questions to be addressed in the analysis include:

- What is the frequency of multiple threats requiring arbitration of warnings by the integrated crash warning system?
- When multiple threats occur, independent of what alert is issued, which threat is the driver most likely to respond to first?
- Is there any evidence of changes in risk compensation associated with the integrated crash warning system as measured through drivers' engagement in non-driving related tasks?
- What are the alert rates for the integrated crash warning system, and how has the process of integration affected the overall alert rates?
- What integrated warning system attributes (i.e., subsystems) do drivers subjectively prefer?
- What integrated crash warning system attributes lead to changes in driving performance (i.e., lane keeping, headway maintenance, turn-signal use)?

7 References

[1] NHTSA. (1996, December). Preliminary Assessment of Crash Avoidance Systems Benefits, Version II, Chapter 3, NHTSA Benefits Working Group. Washington, DC: National Highway Traffic Safety Administration.

[2] UMTRI. (2008, May). Integrated Vehicle-Based Safety Systems (IVBSS) Phase I Interim Report. University of Michigan Transportation Research Institute. DOT HS 810 952. Washington, DC: National Highway Traffic Safety Administration.

[3] LeBlanc, D., Buonarosa, M.L., Blankespoor, A., & Sayer, J. (2009, May). Integrated Vehicle-Based Safety Systems Light Vehicle Extended Pilot Test Summary Report, University of Michigan Transportation Research Institute. UMTRI-2009-13. Washington, DC: Research and Innovative Technology Administration, ITS Joint Program Office.

[4] Bogard, S., Funkhouser, D., & Sayer, J. (2009, May). Integrated Vehicle-Based Safety Systems : Heavy-truck Extended Pilot Test Summary Report, University of Michigan Transportation Research Institute. UMTRI-2009-12. Washington, DC: Research and Innovative Technology Administration, ITS Joint Program Office.

[5] RITA. (2005). IVBSS Program Plan. Washington, DC: Research and Innovative Technology Administration. Retrieved June 18, 2007, from http://www.its.dot.gov/ivbss/ivbss_workplan.htm.

[6] Sayer, J., et al. (2008, December). Integrated Vehicle-Based Safety Systems – Field Operational Test (FOT) Plan, University of Michigan Transportation Research Institute DOT HS 811 058. Washington, DC: National Highway Traffic Safety Administration.

Appendix A: Phase II Project Schedule

Task Name	Start	Finish
FOT Vehicle (Task 2.a)	**Tue 2/19/08**	**Fri 7/31/09**
Heavy-truck	**Tue 2/19/08**	**Tue 3/31/09**
Prototype DAS build	Tue 3/25/08	Fri 8/15/08
IVBSS software revisions	**Tue 3/25/08**	**Thu 1/22/09**
Gold integration (less DAS)	**Tue 2/19/08**	**Fri 9/26/08**
FOT vehicle build	**Thu 4/17/08**	**Tue 3/31/09**
First FOT DAS build (DAS 1)	Mon 7/7/08	Fri 9/12/08
Data definitions of variables	Tue 7/15/08	Wed 12/31/08
DAS builds for FOT	**Fri 9/26/08**	**Wed 2/18/09**
Verification testing	**Fri 9/26/08**	**Fri 10/17/08**
Agreement with DOT on video rates and events	Tue 9/2/08	Tue 9/2/08
Remaining data signals verified	Mon 9/15/08	Tue 2/10/09
Light-vehicle	**Tue 4/1/08**	**Fri 7/31/09**
Procure Fleet Vehicles	Tue 4/1/08	Mon 4/28/08
Prototype DAS build	Tue 4/15/08	Mon 5/5/08
Subsystem Design	Tue 4/1/08	Fri 8/22/08
Calibration	Tue 4/1/08	Fri 8/22/08
Vehicle Integration and Safety Analysis	Tue 4/1/08	Thu 6/19/08
IVBSS software revisions	**Mon 6/2/08**	**Fri 8/22/08**
Extended pilot software and hardware release (Eta)	**Mon 6/2/08**	**Wed 3/18/09**
Data definitions of variables	Fri 6/13/08	Thu 8/28/08
Primary & secondary data signals verified (dictionary)	Wed 6/11/08	Fri 6/26/09
Vehicle builds	**Fri 6/20/08**	**Tue 4/7/09**
ICD Freeze	Fri 8/22/08	Fri 8/22/08
Eta Release	Tue 9/9/08	Tue 9/9/08
Calibration Signoff	Tue 9/9/08	Fri 9/26/08
FOT DAS in vehicle check-out	Wed 9/24/08	Mon 10/6/08
Vehicle Rollout (upfit/check-out/mileage)	**Tue 10/7/08**	**Mon 5/11/09**
Agreement with DOT on video rates and events	Fri 8/1/08	Tue 9/2/08
First FOT DAS build (DAS 2)	Thu 10/2/08	Thu 10/2/08
First FOT DAS builds (DAS 2 and DAS 3)	Mon 9/22/08	Fri 10/10/08
DAS builds for FOT	**Mon 10/13/08**	**Thu 4/30/09**
Remaining data signals verified	Wed 9/24/08	Fri 7/31/09
Verification	**Wed 4/9/08**	**Fri 1/16/09**
FOT Vehicle Prep for Ext. Pilot	Mon 10/27/08	Fri 11/14/08
Subsystem Tuning based on Extended pilot data	Mon 2/16/09	Wed 3/18/09
Populate FADB for CSW for FOT	Fri 3/6/09	Wed 3/25/09
Theta Release	Thu 3/19/09	Tue 4/7/09
Mini-verification (if required)	Fri 4/3/09	Thu 4/9/09
Update Fleet with Theta	Fri 4/10/09	Thu 4/16/09
Milestone: Completed FOT vehicles	Mon 5/11/09	Mon 5/11/09
Milestone: Additional light vehicle for NHTSA	Thu 6/4/09	Thu 6/4/09
Development of Final FOT Design Plan (Task 2.b)	**Tue 7/1/08**	**Mon 11/17/08**
Extended Pilot Test (Task 2.c)	**Fri 7/25/08**	**Wed 5/13/09**
Heavy-truck	**Fri 7/25/08**	**Wed 4/8/09**
Finalize experimental design	Fri 7/25/08	Fri 7/25/08
Submit extended pilot test IRB application	Fri 8/1/08	Fri 8/1/08
Extended pilot test subject recruitment	Fri 8/29/08	Fri 10/31/08
Conduct extended pilot test	**Wed 11/12/08**	**Fri 12/12/08**
Weekly submission of data files	Wed 11/26/08	Tue 12/23/08
Data analysis	Wed 11/19/08	Mon 12/29/08
Deliverable: Extended Pilot Test Results Summary Report	**Fri 1/30/09**	**Wed 4/8/09**
Light-Vehicle	**Fri 7/25/08**	**Wed 5/13/09**
Finalize experimental design	Fri 7/25/08	Fri 7/25/08
Submit extended pilot test IRB application	Fri 8/1/08	Fri 8/1/08
Extended pilot test subject recruitment	Mon 11/10/08	Fri 1/16/09
Conduct extended pilot test	**Tue 11/25/08**	**Tue 3/3/09**
Monthly submission of data files	Mon 2/2/09	Mon 3/16/09
Data analysis	Mon 1/5/09	Fri 3/20/09
Deliverable: Extended Pilot Test Results Summary Report	**Thu 3/26/09**	**Wed 5/13/09**

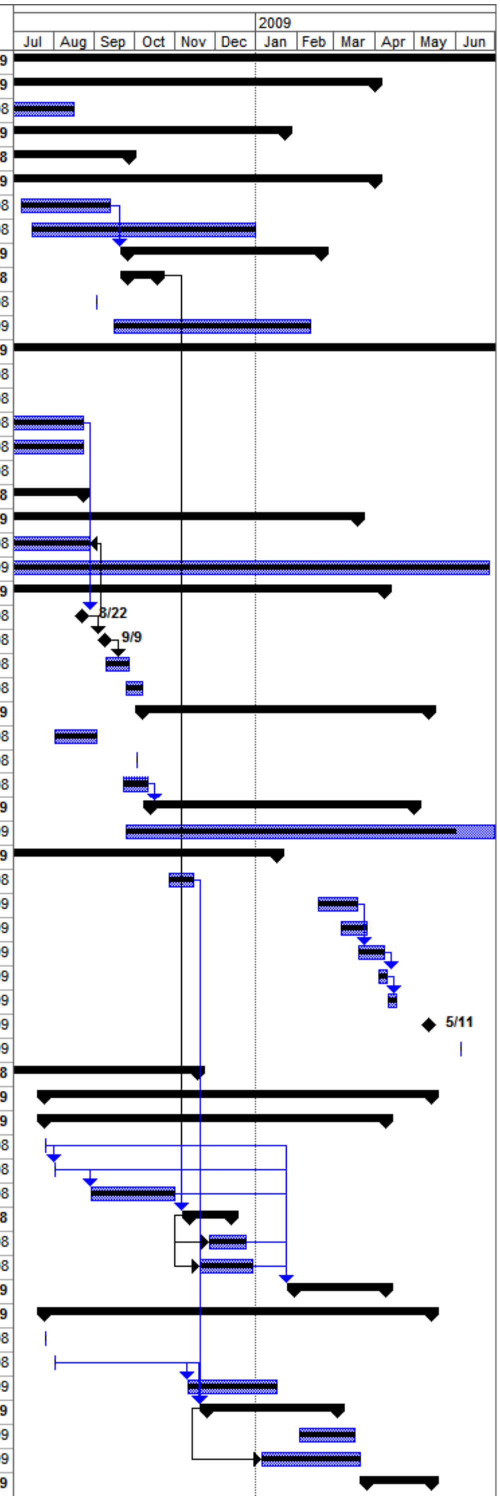


Figure 28. Phase II project schedule (1)

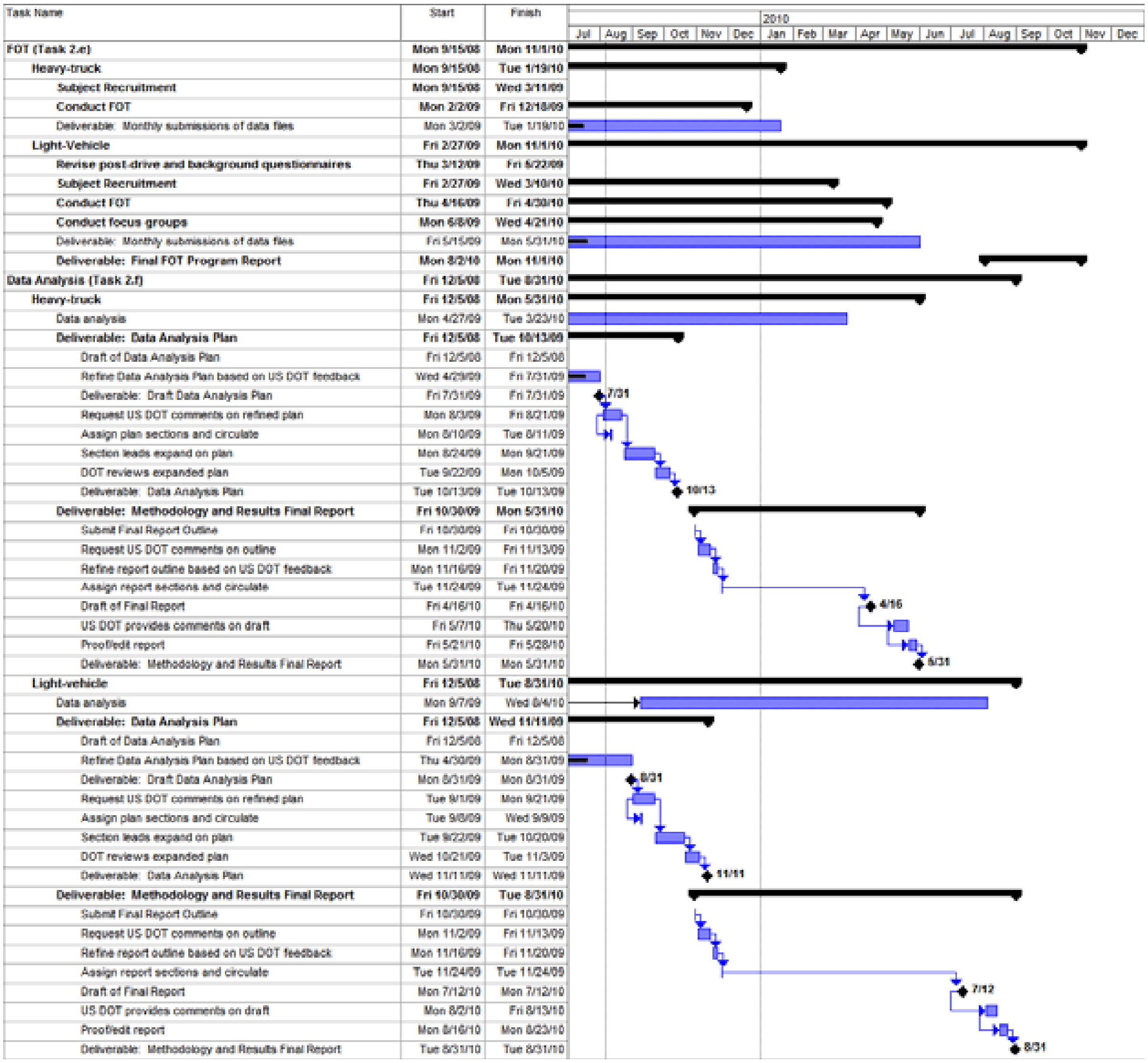


Figure 29. Phase II project schedule (2)

DOT HS 811 221
October 2009

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