



U.S. Department  
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**National Highway  
Traffic Safety  
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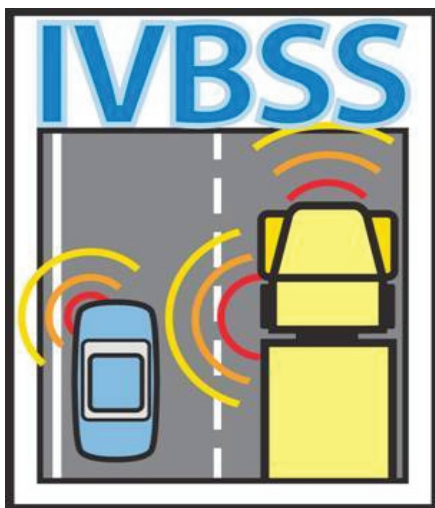


DOT HS 811 482

June 2011

# Integrated Vehicle-Based Safety Systems

## Field Operational Test Final Program Report



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**Technical Report Documentation Page**

1. Report No. <b>DOT HS 811 482</b>		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle <b>Integrated Vehicle-Based Safety Systems Field Operational Test Final Program Report</b>				5. Report Date <b>June 2011</b>	
				6. Performing Organization Code <b>052004</b>	
7. Author(s) <b>Sayer, J., LeBlanc, D., Bogard, S., Funkhouser, D., Bao, S., Buonarosa, M. L., Blankespoor, A.</b>				8. Performing Organization Report No. <b>UMTRI-2010-36</b>	
9. Performing Organization Name and Address <b>The University of Michigan Transportation Research Institute (UMTRI) 2901 Baxter Road Ann Arbor, Michigan 48109-2150</b>				10. Work Unit no. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address <b>U.S. Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office</b>				13. Type of Report and Period Covered	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract  <p>This document presents results from the light-vehicle and heavy-truck field operational tests performed as part of the Integrated Vehicle-Based Safety Systems (IVBSS) program. The findings are the result of analyses performed by the University of Michigan Transportation Research Institute to examine the effect of a prototype integrated crash warning system on driver behavior and driver acceptance. Both platforms included three integrated crash-warning subsystems: forward crash; lateral drift; and lane-change/merge crash warnings. The light-vehicle platform also included curve-speed warning.</p> <p>The integrated systems were introduced into two vehicle fleets: 16 light vehicles and 10 Class 8 tractors. The light vehicles were operated by 108 volunteer drivers for 6 weeks, and the heavy trucks were driven by 18 commercial-truck drivers for a 10-month period. Each vehicle was instrumented to capture detailed data on the driving environment, driver behavior, warning system activity, and vehicle kinematics. Data on driver acceptance was collected through post-drive surveys and debriefings.</p> <p>Key findings indicate that use of the integrated crash warning system resulted in improvements in lane-keeping, fewer lane departures, and increased turn-signal use. Both the passenger car and commercial drivers accepted the integrated crash warning system and benefited from improved awareness of vehicles around them. No negative behavioral-adaptation effects of using the integrated system were observed in either driver group.</p>					
17. Key Words <b>Collision warning, intelligent vehicles</b>			18. Distribution Statement <b>This document is available to the public through the National Technical Information Service <a href="http://www.ntis.gov">www.ntis.gov</a></b>		
19. Security Classification (of this report) <b>None</b>		20. Security Classification (of this page) <b>None</b>		21. No. of Pages <b>40</b>	22. Price



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## List of Acronyms

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BSD	blind-spot detection
DVI	driver-vehicle interface
FCW	forward collision warning
FOT	field operational test
GPS	global positioning system
HT	heavy truck
ISO	International Standards Organization
IVBSS	Integrated Vehicle-Based Safety Systems
LCD	liquid-crystal display
LCM	lane change-merge warning
LDW	lateral drift warning
LED	Light-emitting diode
LV	light vehicle
U.S. DOT	United States Department of Transportation
UMTRI	University of Michigan Transportation Research Institute

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## **Executive Summary**

### **Introduction and Background**

In November 2005, the U.S. Department of Transportation entered into a multi-year cooperative research agreement with an industry team led by the University of Michigan Transportation Research Institute (UMTRI) to develop and test an integrated, vehicle-based crash warning system that addressed rear-end, lane-change and roadway departure crashes for light vehicles and heavy commercial trucks. The work carried out under this agreement was known as the Integrated Vehicle-Based Safety Systems (IVBSS) program. The 5-year effort was divided into two consecutive, non-overlapping phases; the UMTRI-led team was responsible for the design, build, and field-testing of the prototype integrated crash-warning systems.

The light-vehicle team was led by UMTRI and included Visteon Corporation, Honda R&D Americas, Inc., and Takata Corporation. The heavy-truck platform partners were Eaton Corporation, Navistar, Takata Corporation, Con-way Freight, and Battelle. Involvement of industrial partners in the IVBSS program was critical, given their technical knowledge and ultimate ability to deploy such systems into the U. S. vehicle fleet.

The IVBSS program team also included senior technical staff from the National Highway Traffic Safety Administration, the Federal Motor Carrier Safety Administration, the Research and Innovative Technology Administration (RITA), the National Institute for Standards and Technology, and the Volpe National Transportation Systems Center. RITA's Intelligent Transportation Systems Joint Program Office was the program sponsor, providing funding, oversight, and coordination with other U.S. DOT programs. The cooperative agreement was managed and administered by NHTSA, and the Volpe Center acted as the program independent evaluator.

The scope of the systems integration effort conducted during the program included sharing data between sensor subsystems, warning arbitration based on threat severity, and development of an effective driver-vehicle interface (DVI). Integrated crash warning systems offer the potential to provide comprehensive, coordinated information, from which the individual crash warning subsystems can determine the existence of a threat and provide an appropriate warning to drivers.

This report summarizes research findings from the two field tests that were completed in the final year of the program. A detailed description of other program accomplishments is provided in the IVBSS Phase I Interim Report ([UMTRI, 2008](#)) and Third Annual Report ([Sayer et al., 2009](#)).

### **Phase I**

During Phase I (November 2005 to May 2008), several key milestones were achieved. The system architecture was developed, the sensor suite was identified, human factors testing in

support of the driver-vehicle interface development was conducted ([Green et al., 2008](#)), and prototype DVI hardware was constructed to support system evaluation.

Phase I also included the development of functional requirements ([LeBlanc et al., 2008](#)) and system performance guidelines ([LeBlanc et al., 2008](#)), which were shared with industry stakeholders for comment. A verification test plan was developed in collaboration with the U.S. DOT ([Husain et al., 2008](#)) and the verification tests were conducted on test tracks and public roads ([Harrington et al., 2008](#)). Several prototype vehicles were also built and tested.

Preparation for the field operational test began during the second year of Phase I, and included the design and development of a prototype data acquisition system. FOT vehicles were then ordered and a field operational test plan was prepared ([Sayer et al., 2008](#)). Program outreach activities included two public meetings, numerous presentations, demonstrations, and displays at industry venues. Additional details on Phase I accomplishments can be found in the IVBSS Phase I Interim Report ([UMTRI, 2008](#)).

## **Phase II**

Phase II (June 2008 to November 2010) consisted of continued system refinement, construction of vehicles equipped with the integrated system, extended pilot testing, conduct of the two field tests, and analysis of field data. Refinements to the system hardware and software continued, with the majority of changes aimed at improving system performance and reliability. In the process of installing the integrated crash warning system, each vehicle underwent major modifications. All of the sensors necessary for the operation of the integrated system, as well as those needed to obtain data for conducting analyses, were installed so that they would survive continuous, daily use. UMTRI designed, fabricated, and installed data acquisition systems to support objective data collection during the field tests. The data acquisition system served both as a data-processing device and as a permanent recorder of the objective and video data collected.

Two extended pilot tests were conducted ([LeBlanc et al., 2009](#); [Bogard et al., 2009](#)) and results were used to improve system performance prior to the conduct of the field operational tests. Pilot testing also provided evidence of sufficient system performance and driver acceptance to warrant moving forward to conduct the field tests; in addition, it created an opportunity to dry-run test questionnaires, driver instructional materials, and driver recruitment procedures.

## **Accomplishments in Phase II**

### ***Field Operational Testing***

The purpose of field operational testing is to assess the potential safety benefits and driver acceptance associated with the integrated crash warning system that was developed. The light-vehicle and heavy-truck field operational tests were performed separately. The heavy-truck field operational test began in February 2009, with 20 participants that represented a sample of commercial drivers operating within a freight carrier's fleet. This field test was completed in

December 2009, after approximately 10 months of continuous data collection on 10 commercial trucks. Two drivers did not complete the heavy-truck field test, so the final data set includes only 18 commercial drivers.

The light-vehicle field operational test began in April 2009 and was completed in May 2010. The field test collected naturalistic data from 108 licensed drivers over 12 contiguous months and used 15 instrumented passenger cars. Details on the conduct of the field operational tests can be found in the Heavy-Truck and Light-Vehicle Methodology and Results Reports ([Sayer et al., 2010](#); [Sayer et al., 2010](#))

Each vehicle was instrumented to capture information on the driving environment, driver behavior, integrated warning system activity, and vehicle kinematics. Subjective data on driver acceptance was collected using post-drive surveys and driver debriefings.

A field operational test differs from designed experiments by the extent of its naturalism, or lack of direct manipulation of most test conditions and independent variables. Thus, experimental control lies in the commonality of the test vehicles driven for a specific platform and the ability to sample driving data from the dataset on a within-subjects basis. The within-subjects experimental design approach, in which drivers each serve as their own control, allows direct comparisons to be made by individual driver on how the vehicles were used and how drivers behaved with and without the integrated crash warning system.

### ***Data Analyses***

Separate data analysis plans were developed for each vehicle platform. The plans described data analyses that were performed on warning system activity, vehicle exposures, effects on driver behavior, and driver acceptance of the integrated systems. Twenty-nine research questions, hypotheses, and analytical approaches were developed for the heavy-truck platform, while 34 research questions were developed for the light-vehicle platform. The analyses were conducted as planned, and results from the analyses serve as the basis for this final report.

It is important to note that while UMTRI performed a variety of descriptive and statistical analyses using the light-vehicle and heavy-truck FOT data, all collected data were also provided to the Volpe National Transportation Systems Center for use in carrying out the FOT independent evaluation. The data analysis roles that UMTRI and the Volpe Center performed were viewed as being separate but complementary.

### ***FOT Reports***

This report is a summary of results documented in four previous reports. For each vehicle platform, there are two reports: a shorter report summarizing key findings only; and a longer, more comprehensive document detailing the analytical approach and results from all studies conducted. Reports from the heavy-truck platform were completed first. The IVBSS FOT Heavy-Truck Key Findings Report ([Sayer et al., 2010](#)) summarizes research findings on improvements in driver performance and acceptance of the integrated system. Because this

report focuses on key findings only, it does not include results from all analyses that were performed; a more comprehensive report is also available in the form of the IVBSS Heavy-Truck Field Operational Test Methodology and Results Report ([Sayer et al, 2010](#)). An identical set of reports is also available for the light-vehicle platform (IVBSS FOT Light-Vehicle Key Findings Report [[Sayer et al, 2010](#)] and IVBSS Light-Vehicle Field Operational Test Methodology and Results Report [[Sayer et al, 2010](#)]).

## **Key FOT Results**

The following are brief descriptions of the field operational tests, and selected findings for both platforms.

### ***Light-Vehicle Platform***

The system tested on the light-vehicle platform was developed and implemented by Visteon and Takata Corporations, with assistance from UMTRI and Honda R&D Americas, Inc. The light-vehicle platform integrated crash warning system incorporated four subsystems: FCW), lateral drift warning (LDW), lane-change/merge warning (LCM), and curve-speed warning (CSW) subsystems.

### ***Light-Vehicle FOT Data Collected***

A random sample of 108 licensed drivers from southeastern Michigan was recruited to participate in the study. Participants were in one of three age groups of 36 drivers each (equally balanced for gender). The age groups were 20 to 30 (younger), 40 to 50 (middle-aged), and 60 to 70 years old (older). Each participant drove a vehicle (either a 2006 or 2007 Honda Accord) that was equipped with the integrated safety system and data acquisition system for approximately 6 weeks. The first 12 days of vehicle use was the baseline period, during which no warnings were presented to the driver, but all subsystems and equipment operated in the background and on-board data was recorded. On the 13th day of their participation, the system was enabled. This treatment period lasted for 28 days, during which warnings were provided to the drivers and more detailed data was collected. The data set collected and used in the results reported here represents 213,309 miles, 22,657 trips, and 6,164 hours of driving.

A complete description of the vehicle instrumentation and experimental design can be found in the IVBSS Field Operational Test Plan ([Sayer et al., 2008](#)).

### ***Light-Vehicle Platform Key Findings***

The analyses performed were based upon research questions that emphasized the effect the integrated warning system had on driver behavior and driver acceptance (also see IVBSS Light-Vehicle Platform Field Operational Test Data Analysis Plan [[Sayer et al., 2009](#)]). Below is a summary of key research findings:

- The light-vehicle field test provided valuable data and experience that can be used for developing or evaluating strategies to address multiple, simultaneous or near-

simultaneous threats. Multiple-threat scenarios are very rare, and when they occurred during the field test, drivers responded appropriately to the first warning they received. However, there remains a need to arbitrate warnings to prevent confusion associated with the presentation of multiple warnings.

- Drivers reported that they did not rely on the integrated system and the results from examining their involvement in secondary behaviors (eating, drinking, and talking on a cell phone) support this claim. The lack of finding evidence for any signs of increased risk compensation or behavioral adaptation seems to suggest that if there were negative behavioral consequences associated with use of the integrated system, they were relatively minor.
- The integrated system had a statistically significant effect on the frequency of lane departures, decreasing the rate from 14.6 departures per 100 miles during baseline driving to 7.6 departures per 100 miles during the treatment condition.
- There was no effect of the integrated system on forward conflict levels when approaching preceding vehicles. Nor was there any effect on the frequency of hard-braking maneuvers.
- The integrated crash warning system had no effect on drivers' curve-taking behavior, or behaviors when approaching curves.
- A majority of drivers reported that their driving behavior changed as a result of using the integrated system. The most frequently mentioned change was an increase in turn-signal use, which was the result of receiving lane departure warnings triggered when drivers made unsignaled lane changes.
- Drivers accepted the integrated system and rated it well in terms of both usefulness and satisfaction. Drivers reported that the integrated system's warnings were helpful and believed it would increase their driving safety.
- The majority of drivers reported that they would be willing to purchase the integrated system; however, most drivers were willing to spend no more than \$750 for this advanced safety feature.
- A potential approach for reducing invalid warnings, particularly for fixed objects outside the vehicle's path, would be the development of location-based filtering that could modify threat assessments in response to repeated warnings to which drivers do not respond.

### ***Heavy-Truck Platform***

The system tested on the heavy-truck platform was developed and implemented by Eaton and Takata corporations, with assistance from UMTRI, Navistar, and Battelle. The heavy-truck platform integrated system incorporated FCW, LDW, and LCM subsystems.

### ***Heavy-Truck FOT Data Collected***

Twenty commercial drivers from Con-way's Detroit terminal were recruited to participate in the field test. Ultimately, only 18 of these drivers completed the study. Each participant drove one of the 10 specially equipped Class 8 tractors for approximately 10 months. For the first 2 months, the trucks operated in the baseline condition, during which no warnings were provided to the drivers, but all sensors and equipment operated in the background and on-board data was recorded. At the beginning of the third month, the system was enabled and warnings were provided to the drivers, and on-board data collection continued. The data collected represented 601,844 miles, 22,724 trips, and 13,678 hours of driving.

Complete information on the vehicle instrumentation and experimental design can be found in the IVBSS – Field Operational Test Plan ([Sayer et al., 2008](#)).

### ***Heavy-Truck Platform Key Findings***

The analyses performed were based upon research questions that emphasized the effect the integrated warning system had on driver behavior and driver acceptance (also see [Sayer et al., 2009](#)). Key research findings are given below:

- The heavy-truck field test provided valuable data and experience that can be used for developing or evaluating strategies to address multiple, simultaneous or near-simultaneous threats. Multiple-threat scenarios are very rare, and when they occurred during the field test, drivers responded appropriately to the first warning they received. However, there remains a need to arbitrate warnings to prevent confusion associated with the presentation of multiple warnings.
- Drivers reported that they did not rely on the integrated system and the results from examining their involvement in secondary behaviors (eating, drinking, and talking on a cell phone) support this claim. The lack of finding evidence for any signs of increased risk compensation or behavioral adaptation seems to suggest that if there were negative behavioral consequences associated with use of the integrated system, they were relatively minor.
- Drivers stated that the integrated system were made them more aware of the traffic environment around their vehicles and their position in the lane, and that integrated crash warning systems would increase their driving safety.
- Drivers responded that they would prefer driving a truck equipped with the integrated warning system to an unequipped, conventional truck (15 of 18 drivers), and would recommend the purchase of such systems (15 of 18 drivers).
- The integrated crash warning system had no effect on lane departure frequency, but a trend toward a decrease in lane departures was observed for 13 of the 18 drivers.
- Drivers rated the LDW subsystem the highest in terms of satisfaction, and second highest in terms of perceived usefulness. Drivers liked the LCM subsystem the least. This is likely explained by the high rate of invalid warnings that drivers received.

- The integrated crash warning system had a positive effect on driver reaction times and brake reaction times to forward conflicts. Drivers responded more quickly to closing-conflict events in the treatment condition than during baseline driving.
- A potential approach for reducing invalid warnings, particularly for fixed objects outside the vehicle's path, would be the development of location-based filtering that could modify threat assessments in response to repeated warnings to which drivers do not respond.

### **IVBSS Program Summary**

Overall, the IVBSS program was successful in that the integrated crash warning systems were developed, tested, and fielded as planned. In addition, the data necessary for UMTRI and the Volpe Center to perform their analyses were collected and analyzed. While the findings of the independent evaluation are not yet complete, there are several findings relevant to both light vehicle and heavy-truck platforms:

- Multiple-threat scenarios are quite rare, and when they occurred during the field test, drivers responded appropriately to the first warning they received. However, despite the rare occurrence of multiple threats, there is still a need to arbitrate warnings to prevent confusion associated the presentation of multiple warnings in critical situations.
- Results from examining the frequency of driver involvement in secondary behaviors (e.g., eating, drinking, or talking on a cell telephone) suggest that drivers did not rely on the system. This is further supported by what drivers reported qualitatively. The lack of evidence for signs of increased risk compensation, or behavioral adaptation, seems to suggest that if there were negative behavioral consequences associated with use of the integrated system, they were relatively minor.
- The majority of both light-vehicle and heavy-truck drivers stated that the integrated system made them more aware of the traffic environment around their vehicles, and that integrated crash warning systems would increase their driving safety.
- The majority of both light-vehicle and heavy-truck drivers stated that they would purchase, or recommend the purchase of an integrated crash warning system.
- One approach for reducing invalid warnings, particularly for fixed objects outside a vehicle's path, would be the development of location-based filtering that could modify threat assessments to repeated warnings that drivers do not respond to.

# **1 Introduction**

## **1.1 Program Approach**

The goal of the IVBSS program was to assess the safety benefits and driver acceptance associated with a prototype integrated crash warning system. Preliminary analyses conducted by the U.S. DOT indicated that a significant number of crashes could be reduced by the widespread deployment of integrated crash warning systems that address rear-end, lateral drift, and lane change/merge crashes.

### ***1.1.1 IVBSS Team Makeup***

The IVBSS program team included senior technical staff from NHTSA, the Federal Motor Carrier Safety Administration, RITA, the National Institute for Standards and Technology, and the Volpe National Transportation Systems Center. RITA's Intelligent Transportation Systems Joint Program Office was the program sponsor, providing funding, oversight, and coordination with other U.S. DOT programs. The cooperative agreement was managed and administered by NHTSA, and the Volpe Center acted as the program independent evaluator.

The light-vehicle integrated system was developed by a team from UMTRI, Visteon Corporation, Takata Corporation, and Honda R&D Americas, Inc. The LDW subsystem was designed by Takata, and the remaining subsystems were designed and integrated by Visteon. UMTRI provided expertise and direction for the DVI design. Honda provided expertise and assistance implementing the DVI and completing system integration.

The heavy-truck platform was developed by a team from UMTRI, Eaton Corporation, Takata Corporation, Navistar, and Battelle. Con-way Freight served as the fleet, providing the vehicles which were outfitted with the integrated system and a group of drivers who volunteered to participate in the field test and operate the specially-equipped vehicles as part of their normal duties. The LDW subsystem was designed by Takata, the FCW subsystem was developed by Eaton, and the LCM subsystem was developed jointly. Battelle provided expertise and direction for the DVI design. Navistar provided technical assistance in implementing the system.

Last, UMTRI developed the data acquisition systems, deployed and managed the field operational tests, conducted data analyses, and served as the prime contractor on the program.

### ***1.1.2 Structure of the Program***

The IVBSS program was a 5-year effort divided into two consecutive, non-overlapping phases; the UMTRI-led team was responsible for the design, build, field-testing, and analysis of prototype integrated crash warning systems on both light-vehicle and heavy-truck platforms.



### ***1.1.3 Phase I***

During Phase I (November 2005-May 2008) several key program milestones were achieved and are discussed in the following section. This includes the development of system architectures, sensor suites, human factors testing in support of the driver-vehicle interface (DVI) development, and prototype DVI hardware to support system evaluation.

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 in jury drives and accompanied pilot testing. Verification test plans were also developed in collaboration with the U.S. DOT, and verification tests were conducted on test tracks and public roads.

Preparation for the field operational test began in the second year of Phase I, and included the design and development of a prototype data acquisition system. Vehicles that would be used to conduct the field operational test were secured, and a field operational test plan was prepared. A detailed description of Phase I accomplishments is provided in the IVBSS Phase I Interim Report ([UMTRI, 2008](#)).

**Systems Development.** Systems architecture development was completed for both the light-vehicle and heavy-truck platforms during the first year of the program. The systems architecture included partitioning the crash warning functions into subsystems, specifying the sensors and software needed for each subsystem, and identifying hardware interfaces and subsystem communication protocols. Sensor identification included specifying sensor type (vision, radar, inertial, and vehicle parameters), developing requirements, and completing sensor specifications. Most sensors used were commercially available and intended for automotive and heavy-truck safety applications.

**DVI and Human Factors Testing.** The options available in the development of DVIs for use in the IVBSS program were identified, and a series of human factors tests, including initial pilot testing to examine design alternatives, were conducted. This included identifying visual and auditory display requirements and characterization of the warnings. The final DVIs for both platforms were the result of options available for use in a post-production vehicle, engineering judgment, simulator and laboratory studies, and jury drives and pilot testing conducted in representative vehicles.

**Functional Requirements and Performance Guidelines.** Functional requirements and system performance guidelines describe what functions the integrated system must provide and the level of performance expected. Both the functional requirements and system performance guidelines incorporated, or referenced, existing requirements and standards where available. Draft documents were shared with industry stakeholders for comment.

Functional requirements for both platforms described scenarios in which the crash warning system should warn drivers, as well as when warnings should not occur. Functional requirements were developed for each warning subsystem and for multiple-threat scenarios.

System requirements were described in terms of general sensor requirements to provide the functions needed, as well as practical approaches to present warnings to drivers.

The system performance guidelines identified performance metrics for evaluating the integrated crash warning system. The guidelines built upon previous specification efforts for standalone crash warning systems, especially prior U.S. DOT crash warning projects and relevant ISO standards.

**Prototype Vehicle Development.** Prototype vehicles were developed for both platforms in the second half of Phase I. Each prototype represented a fully functioning, street-worthy vehicle. On the light-vehicle platform, six 2007 Honda Accords were equipped with the four crash warning subsystems and warning arbitration packages. On the heavy-truck platform, one International tractor was initially equipped, followed by a second tractor at the end of Phase I. These vehicles were not only used for system development and refinement, but were also used in the conduct of jury drives, initial pilot testing, and the verification tests.

**Verification Testing.** Verification tests were used to demonstrate that the prototype system provided all required system functions in a consistent manner, as well as to ensure general system readiness for field testing. The test procedures were developed in order to verify that the prototype system satisfied all performance requirements. The test plans included detailed test scenarios and test parameters such as speed, closing rate and road geometry. Pass/fail criteria for evaluating system repeatability were also included.

**Field Operational Test Planning.** Preparation for the field operational test that would be conducted in Phase II included the design and development of prototype data acquisition systems for both platforms, and selection of additional sensors such as in-cabin video cameras, microphones, etc. needed to support data analysis requirements. Test vehicles were also secured and a work agreement with the trucking fleet that would participate in the field test was finalized.

A draft field operational test plan was completed at the end of Phase I. This document provided initial plans on how extended pilot testing and the field tests would be conducted. Issues addressed include sampling strategies for drivers, descriptions of how drivers would be recruited and trained, and the types of information that would be collected from drivers upon completing their participation in the tests.

#### ***1.1.4 Phase II***

During Phase II (June 2008 - November 2010), tasks such as continued system refinement, building a fleet of equipped vehicles, extended pilot testing, field operational testing, data analyses, final reporting, and program outreach were all completed.

The majority of system refinements and changes were made to improve system performance and reliability. System changes were also implemented to reduce instances of false alerts, improve consistency of system performance, and add system diagnostics needed to support pilot testing and conduct of the field operational tests. Installation of the integrated crash warning system in

26 research vehicles (16 passenger cars and 10 commercial trucks) was also completed. Each vehicle underwent significant modifications in order to accommodate installation of the integrated crash warning system. Twenty-eight data acquisition systems were fabricated and installed, and a database needed to store and access the data collected was developed. Verification tests, performed on closed-course test tracks and public roads, were conducted on first-article research vehicles for both platforms to ensure system readiness to proceed into extended pilot testing and the field operational tests.

**Extended Pilot Testing.** Extended pilot tests were conducted for each vehicle platform, providing evidence of sufficient system performance and driver acceptance to warrant moving forward to the field operational tests. The results from extended pilot tests were used to improve system performance and functionality prior to conducting the field operational tests. In addition, the extended pilot tests also served as an opportunity to dry-run test questionnaires, driver instructional materials, and driver recruitment procedures. Published results from the extended pilot testing are available for both the light-vehicle ([LeBlanc et al., 2009](#)) and heavy-truck ([Bogard et al., 2009](#)) platforms.

**Field Operational Testing.** The purpose of field operational testing is to collect data needed to assess the potential safety benefits and driver acceptance from integrated system use. The heavy-truck field test began in February 2009, with 20 participants that represented a sample of commercial drivers from the participating freight carrier's fleet. The heavy-truck field test was completed in December 2009, after approximately 10 months of continuous data collection. The light-vehicle field test began in April 2009, and was completed in May 2010. The field test collected naturalistic data from 108 licensed drivers, over 12 contiguous months, using 15 instrumented passenger cars. With the exception of having slightly fewer drivers than expected in the heavy-truck field test, both field tests followed test plans that had originally been developed at the beginning of the program. The field operational test plans are described in the IVBSS Field Operational Test Plan ([Sayer et al., 2008](#))

**Program Outreach.** A number of activities were carried out to share information on program status and current research findings with the public and industry stakeholders. Three day-long public meetings were held; in addition, presentations on the program's status were made at industry meetings and technical symposia. In addition, team members also met with and briefed key stakeholders, and provided several opportunities for industry representatives to experience the prototype systems through demonstration drives.

**Program Reports.** Most of the program documentation has been made publicly available. Appendix A contains an annotated bibliography of 28 program reports containing over 3,000 pages; Web links are also included for most documents. Two Web sites were created to provide public access to program documentation: one maintained by NHTSA ([www.nhtsa.gov](http://www.nhtsa.gov)); and the other located on UMTRI's Web site ([www.umtri.umich.edu/divisionPage.php?pageID=249](http://www.umtri.umich.edu/divisionPage.php?pageID=249)).

## **1.2 Final Report Structure**

The remainder of this report is organized into three sections. Section 2 provides an overview of the light-vehicle field operational test and its key findings. The heavy-truck field operational test and key findings are detailed in Section 3. Program accomplishments and major findings are summarized in Section 4.

## 2 Light-Vehicle Platform

### 2.1 Light-Vehicle Field Operational Test

Key findings for the light-vehicle field operational test are presented in this section of the report. The light-vehicle platform integrated system contained the following warning functions:

- FCW: Warns drivers of the potential for a rear-end crash with another vehicle;
- LDW: Warns drivers that they may be drifting inadvertently from their lane or departing the roadway;
- LCM: Warns drivers of possible unsafe lateral maneuvers based on adjacent vehicles, or vehicles approaching in adjacent lanes, and includes full-time side-object-presence indicators; and
- CSW: Warns drivers they are going too fast to safely negotiate an upcoming curve.

Warning arbitration was also performed for cases when more than one subsystem issued a warning at or very near the same time. The arbitration process was based on when the warning was issued and a prioritization scheme for the detected threat. A driver-vehicle interface was developed, consisting of auditory and haptic cues, as well as visual feedback. The DVI relied primarily on auditory warnings for threats and situations requiring immediate driver action. The visual elements of the DVI conveyed situational information, such as the presence of a vehicle in an adjacent lane, more so than actual warnings.

The system tested was developed by a team from UMTRI, Visteon Corporation, Takata Corporation (TK Holdings), and Honda R&D Americas, Inc. The LDW subsystem was designed by Takata, while the remaining subsystems were designed and integrated by Visteon. UMTRI provided expertise and direction for the DVI design. Honda provided expertise and assistance in implementing the DVI and completing system integration.

Lay people with valid driver licenses were recruited to drive passenger cars equipped with the integrated system and data collection hardware installed on-board. The cars were instrumented to capture information on the driving environment, driver behavior, integrated warning system activity, and vehicle kinematics. Subjective data on driver acceptance was collected using post-drive surveys, driver debriefings and a series of focus groups.

Field operational tests differ from designed experiments to the extent that they are naturalistic and lack direct manipulation of most test conditions and independent variables. Thus, experimental control lies in the commonality of the test vehicles driven and the ability to sample driving data from the data set on a “within-subjects” basis. The within-subjects experimental design approach, in which drivers serve as their own controls, allows direct comparisons to be made by individual drivers on how the vehicles were used and how drivers behaved with and without the integrated crash warning system.

## 2.2 Light-Vehicle FOT Data Collection

Drivers were recruited with the assistance of the Office of the Secretary of State, the driver licensing authority in Michigan. One hundred and eight randomly sampled, passenger car drivers took part in the FOT, with the sample being stratified by age and gender. The age groups examined were 20 to 30 (younger), 40 to 50 (middle-aged), and 60 to 70 years old (older). Sixteen late-model Honda Accords were used as research vehicles, and loaned to participants. Consenting drivers used the test vehicles in an unsupervised manner, pursuing their normal trip-taking behavior over a 40-day period using the test vehicles as their own personal vehicles.

The first 12 days of vehicle use was the baseline period, during which no warnings were presented to the drivers, but all on-board data was collected. On the 13th day of the test, the treatment period began. During this time, the system was enabled, warnings were presented to the drivers, and on-board data collection continued. This treatment period lasted for 28 days, at which point the participant returned the research vehicle to UMTRI. Use of the test vehicles by anyone other than designated participants was prohibited, unless it was considered an emergency. More detailed information on the vehicle instrumentation and experimental design can be found in the Integrated Vehicle-Based Safety Systems (IVBSS) Field Operational Test Plan ([Sayer et al., 2008](#)).

Overall, the data set collected represents 213,309 miles, 22,657 trips, and 6,164 hours of driving. The warning rates during the treatment period were 0.4 per 100 miles for FCW, 7.0 per 100 miles for LDW, 0.63 per 100 miles for LCM, and 0.42 per 100 miles for CSW. The rate of invalid warnings across all drivers was 0.22 per 100 miles for FCW, 0.43 per 100 miles for LDW, 0.02 for LCM, and 0.17 per 100 miles for CSW.

## 2.3 Light-Vehicle FOT Data Analysis

The analyses performed on the light-vehicle dataset were based upon research questions that emphasized the effect that the integrated warning system had on driver behavior and driver acceptance (see Integrated Vehicle-Based Safety Systems (IVBSS) Light-Vehicle Platform Field Operational Test Data Analysis Plan ([Sayer et al., 2009](#))). Along with each research question there was an associated hypothesis and a summary of analysis methods and techniques. A comparison within each driver's data set was made between the baseline and treatment periods to understand how the integrated system affected driver behavior (a "within-subjects" experimental design). Analyses were conducted not only to examine the potential for safety benefits attributable to the integrated crash warning system, but also to determine whether there were any potential negative consequences associated with system use. Descriptive analyses were performed to understand warning system activity (the circumstances in which warnings were presented to drivers) and environmental conditions in which the vehicles were driven (weather, time of day, roadway type, etc.). Subjective information was gathered through a post-drive survey and debriefings held with each of the drivers. The subjective information was used to

determine driver acceptance, as well as providing insights into improving future integrated crash warning systems.

## **2.4 Light-Vehicle Key Findings**

### ***2.4.1 Warnings Arbitration and Comprehensive System Results***

#### **Driver Behavior Results:**

- The integrated system had no effect on the frequency of secondary tasks. Drivers were no more likely to be involved in secondary tasks (e.g., eating, drinking, talking on a cell phone) in the treatment condition than had been observed during baseline driving.
- Multiple-threat scenarios are quite rare, and when they occurred during the field test, drivers responded appropriately to the first warning they received. However, there remains the need for arbitration of warnings to prevent the simultaneous presentation of multiple warnings in critical situations.

#### **Driver Acceptance Results:**

- A majority of drivers reported that their driving behavior changed as a result of driving with the integrated system. The most frequently mentioned change was an increase in turn-signal use, which was the result of receiving lane departure warnings issued when drivers made unsignaled lane changes.
- Drivers accepted the integrated system and rated it favorably for usefulness and satisfaction.
- While 25 percent of the younger drivers were not interested, 72 percent of all drivers said they would like to have the integrated system in their personal vehicles.
- Drivers found the integrated system's warnings to be helpful and further believed that the integrated system would increase their driving safety.
- Eight drivers reported that the integrated system prevented them from having a crash.
- The majority of drivers reported that they would be willing to purchase the integrated system; however, most drivers were willing to spend no more than \$750 for this advanced safety feature.
- Drivers were more willing to purchase the lateral warning subsystems (LDW and LCM) than the longitudinal warning subsystems (CSW and FCW).

### ***2.4.2 Lateral Control and Warnings Results***

#### **Driver Behavior Results:**

- The integrated system had a statistically significant effect on the frequency of lane departures, decreasing the rate from 14.6 departures per 100 miles during baseline driving, to 7.6 departures per 100 miles during treatment. When the integrated

system began warning drivers during the third week of exposure, the departure rate dropped by more than half from the previous week.

- The integrated crash warning system had a statistically significant effect on the duration of lane departures. The mean duration of a lane departure dropped from 1.98 seconds in the baseline condition to 1.66 seconds in the treatment condition.
- The results show a statistically significant effect of the integrated system on turn-signal use during lane changes. Drivers were less likely to make unsignaled lane changes in the treatment condition than during baseline driving.
- There was a statistically significant reduction in lateral offset<sup>1</sup> associated with the integrated system, but the magnitude of the difference was quite small from a practical perspective.
- There was a statistically significant increase (12.6%) in lane changes associated with use of the integrated crash warning system.

#### **Driver Acceptance Results:**

- Drivers rated the lateral subsystems (LCM with blind-spot detection [BSD] and LDW) more favorably than the longitudinal subsystems (FCW and CSW).
- Drivers reported getting the most satisfaction out of the BSD component of the LCM subsystem.
- Drivers found the integrated system to be useful, particularly when changing lanes and merging into traffic.

### ***2.4.3 Longitudinal Control and Warnings Results***

#### ***Driver Behavior Results:***

- There was a statistically significant effect of the integrated crash warning system on the time spent at short headways. Slightly more time was spent at time headways of one second or less with the integrated system in the treatment condition (24%) than during baseline driving (21%).
- There was no effect of the integrated system on forward conflict levels when approaching preceding vehicles. Nor was there any effect on the frequency of hard-braking maneuvers.
- The integrated crash warning system had no effect on drivers' curve-taking behavior, or when approaching curves.

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<sup>1</sup> Lateral offset is the distance between the centerline of the vehicle and the centerline of the lane.



### **Driver Acceptance Results:**

- Drivers rated the usefulness and satisfaction of FCW and CSW lowest among the subsystems. Overall, drivers rated them neutral with regard to satisfaction, but recognized that they had some utility.
- The brake pulse accompanying FCWs was the single system attribute that drivers disliked most.

## **2.5 Actionable Outcomes and Implications for Deployment**

The following are actionable outcomes, or implications for the development and deployment of integrated crash warning systems that are supported by the light-vehicle field operational test findings:

- Despite a low invalid warning rate for the longitudinal subsystems (FCW and CSW), driver subjective feedback suggests that some drivers would expect the invalid rate to be even lower—or perhaps that the percentage of warnings that were invalid affected their confidence or understanding of how the systems operated. Achieving a lower invalid warning rate may be challenging for system engineers, as might the elimination of certain warning scenarios.
- Drivers preferred and obtained the most direct benefit from the lateral subsystems (LDW and LCM). Their preferences could be due in part to the more subtle nature of lateral system warnings when a threat is not imminent. Specifically, the presence of LEDs in the side-view mirrors (BSD) and the haptic seat (LDW) are less intrusive than are the auditory warnings used for CSW and FCW in response to imminent threats.
- Multiple-threat scenarios are quite rare; because there were so few multiple warning events, it was not possible to identify patterns as to which threat drivers responded to first. Nevertheless, drivers generally responded to whatever warning was presented, and their responses were appropriate for the indicated threat. However, there remains the need for arbitration to prevent the presentation of multiple warnings in critical situations.
- There was no direct evidence of driver over-reliance on crash warnings as indicated through involvement in secondary tasks. However, there was a statistically significant observation in that drivers were slightly more likely to maintain a shorter headway (less than 1 second) with the integrated system than without it.
- A potential approach for reducing invalid warnings, particularly for fixed objects outside the vehicle's path, would be the development of location-based filtering that could modify threat assessments in response to repeated warnings which drivers did not respond to.

## 3 Heavy-Truck Platform

### 3.1 Heavy-Truck Field Operational Test

This section presents results from the heavy-truck field operational test. The heavy-truck platform included the following crash warning subsystems:

- FCW: Warns drivers of the potential for a rear-end crash with another vehicle;
- LDW: Warns drivers that they may be drifting inadvertently from their lane or departing the roadway; and
- LCM: Warns drivers of possible unsafe lateral maneuvers based on adjacent vehicles, or vehicles approaching in adjacent lanes, and includes full-time side-object-presence indicators.

The integrated system also performed warning arbitration in the event that more than one subsystem issued warnings at or very near the same time. The arbitration process was based on when the warning was issued and the severity of the detected threat. A driver-vehicle interface (DVI) was developed for the integrated system. The DVI used visual and auditory information, but relied on auditory warnings for what the integrated system determined to be imminent threats requiring immediate driver action. The visual elements of the DVI conveyed situational information, such as the presence of a vehicle in an adjacent lane, more so than actual warnings.

The system tested was developed by a team from UMTRI, Eaton Corporation, Takata Corporation (TK Holdings), and Navistar. The LDW subsystem was designed by Takata; LCM subsystem was designed jointly by Takata and Eaton, the FCW subsystem was designed by Eaton, and the system integration was performed by Eaton. Battelle provided expertise and direction for the DVI design. Navistar provided expertise and assistance during system implementation and integration activities. Con-way Freight served as the fleet, providing the vehicles which were outfitted with the integrated system and a group of drivers who volunteered to participate in the field test.

Commercial truck drivers were recruited to drive Class 8 tractors, similar to those that they normally operated as part of their employment, with the integrated crash warning system and data collection hardware installed on-board. The trucks were instrumented to capture information on the driving environment, driver behavior, integrated warning system activity, and vehicle kinematics. Subjective data on driver acceptance was collected using post-drive surveys and driver debriefings.

A field operational test differs from designed experiments by the extent of its naturalism, or lack of direct manipulation of most test conditions and independent variables. Thus, experimental control lies in the commonality of the test vehicles driven and the ability to sample driving data from the dataset on a within-subjects basis. The within-subjects experimental design approach, in which drivers each serve as their own control, allows direct comparisons to be made by

individual driver on how the vehicles were used and how drivers behaved with and without the integrated crash warning system.

### **3.2 Heavy-Truck FOT Data Collection**

Twenty drivers from Con-way Freight's Detroit terminal were recruited to participate in the study, 18 of whom completed the study. Each participant drove one of the specially-equipped Class 8 tractors for 10 months. The first 2 months were the baseline period, during which no warnings were presented to drivers, but on-board data was collected. The subsequent 8 months were the treatment condition, during which warnings were provided to the drivers and detailed data continued to be collected. Detailed information on the vehicle instrumentation and experimental design can be found in the IVBSS – Field Operational Test Plan ([Sayer et al., 2008](#)).

The data set collected from the heavy-truck field test represents 601,844 miles, 22,724 trips, and 13,678 hours of driving. The warning rates in the treatment condition were 3.3 per 100 miles for FCW, 13.0 per 100 miles for LDW, and 2.0 per 100 miles for LCM. The rate of invalid warnings across all drivers was 1.8 per 100 miles for FCW, 0.2 per 100 miles for LDW, and 3.0 for LCM.

### **3.3 Heavy-Truck FOT Data Analysis**

The analyses performed were based upon specific research questions that emphasized the effect that the integrated warning system had on driver behavior and driver acceptance (see IVBSS Heavy-Truck Platform Field Operational Test Data Analysis Plan ([Sayer et al., 2009](#))). The outcome of the analyses describes how the trucks equipped with the integrated crash warning system were used by the Con-way Freight drivers, whether any changes in driver behavior were observed that could be attributed to the integrated crash warning system, and whether the truck drivers accepted the integrated system.

The analyses included 29 research questions, their related hypotheses, independent and dependent variables, and analysis methods. The research questions addressed some of the most relevant topics related to evaluating the integrated system's effect on driver behavior and driver acceptance.

A comparison within each driver's data set was made between the baseline and treatment periods to understand how the integrated system affected driver behavior (a "within-subjects" experimental design). Analyses were conducted not only to examine the potential for safety benefits attributable to the integrated crash warning system, but also to determine whether there were any potential negative consequences associated with using the integrated warning system. In support of addressing the research questions, a series of descriptive analyses were performed to understand warning system activity (the circumstances in which warnings were presented to drivers) and the conditions in which the vehicles were driven (weather, time of day, roadway type, etc.). Subjective information was gathered through a post-drive survey and debriefings

held with each of the drivers. The subjective information served as the basis for determining driver acceptance, as well as providing insights into improving future integrated crash warning systems.

### **3.4 Heavy-Truck Key Findings**

#### ***3.4.1 Warnings Arbitration and Comprehensive System Results***

##### **Driver Behavior Results:**

- There was no effect of the integrated system on the frequency of secondary tasks. Drivers were no more likely to be involved in secondary tasks (eating, drinking, talking on a cell phone) in the treatment condition than had been observed during baseline driving.
- In multiple-threat scenarios, the initial warning was generally enough to get the attention of drivers, and resulted in an appropriate action when necessary. Based on data collected during the FOT, it does not appear that secondary warnings were necessary in multiple-threat scenarios. However, multiple-threat scenarios are rare and other drivers operating different systems could respond differently.

##### **Driver Acceptance Results:**

- Drivers stated that the integrated system made them more aware of the traffic environment around their vehicles and their position in the lane.
- Drivers prefer driving a truck equipped with the integrated warning system than an unequipped, conventional truck (15 of 18 drivers).
- Drivers would recommend the purchase of such systems to increase safety (15 of 18 drivers).
- The invalid warning rate for lane-change merge warnings (1.6 per 100 miles), and forward collision warnings (1.8 per 100 miles), particularly for line-haul drivers, led some drivers to describe the warnings as “distracting” or “annoying.”
- The majority of drivers believed that integrated crash warning systems would increase their driving safety.
- Seven drivers reported that the integrated system potentially prevented them from having a crash.
- Drivers generally found the system convenient to use.

- Reducing the number of invalid warnings<sup>2</sup> will help increase understanding of the integrated warning system, as nearly one-third of the drivers reported that invalid warnings affected their understanding of the integrated system.
- Some drivers who received higher percentages of invalid warnings reported that they began to ignore the system. A reduction in the number of invalid warnings will reduce the likelihood of drivers ignoring the system.
- There was no direct relationship between drivers' subjective ratings of the subsystems (FCW, LDW, and LCM) and the corresponding rates of invalid warnings they experienced. Drivers had varying opinions of the invalid warnings they experienced based on the type of route they drove (pick-up and delivery and line-haul).

### ***3.4.2 Lateral Control and Warnings Results***

#### **Driver Behavior Results:**

- The integrated crash warning system had a statistically significant effect on lateral offset. During the treatment condition, drivers maintained lane positions slightly closer to the center of the lane on limited-access highways.
- The integrated crash warning system did not have a statistically significant effect on lane departure frequency.
- The change in duration and distance of lane incursions was not affected by the presence of the integrated crash warning system. However, there was a statistically significant change toward longer and further excursions with increased hours of service.
- There was no statistically significant effect of the integrated system on turn-signal use during lane changes or frequency of lane changes.

#### **Driver Acceptance Results:**

- Drivers rated the LDW subsystem the highest in terms of satisfaction, and second highest in terms of perceived usefulness.
- Drivers liked the LCM subsystem the least. This is likely explained by the higher percentage of invalid warnings that drivers received (86% for line-haul drivers).
- Drivers reported increased safety and heightened awareness with the lateral warning subsystems overall.

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<sup>2</sup> Invalid warnings are characterized by an incorrect or inaccurate assessment of the driving environment by the warning system. They often appear to be spurious and random without any identifiable reason or model for their cause.

### ***3.4.3 Longitudinal Control and Warnings Results***

#### **Driver Behavior Results:**

- Drivers maintained marginally longer average time headways with the integrated crash warning system, but despite being statistically significant, the difference is of little practical significance (0.05 seconds).
- There was no statistically significant effect of the integrated crash warning system on forward conflict levels when approaching preceding vehicles. The integrated crash warning system did not affect either the frequency of hard-braking events (less than 0.2g [1.96 m/s<sup>2</sup>]), or the maximum deceleration levels achieved during hard braking events.
- Drivers responded more quickly to closing-conflict events in the treatment condition when compared to baseline driving, and the effect was statistically significant.

#### **Driver Acceptance Results:**

- Both line-haul and pick-up and delivery drivers specifically mentioned that valid FCW warnings and the headway-time margin display were helpful.
- Driver acceptance, while favorable, would almost certainly have been higher had invalid warnings due to fixed roadside objects (poles, signs and guardrails) and overhead road structures (overpasses and bridges) that were encountered repeatedly been lower. Crash warning systems that maintained records of the locations of where warnings were generated, thereby reducing the number of repeated invalid warnings, can potentially improve driver acceptance.

## 4 IVBSS Program Summary

Overall, the IVBSS program was successful in that both prototype vehicle fleets were fielded as planned and the data necessary to perform all analyses were collected, analyzed, and forwarded to the independent evaluator for its use. Drivers on both platforms generally accepted the integrated crash warning system, and benefits in terms of driver behavioral changes were observed.

### 4.1 Summary of Key Findings

- Multiple-threat scenarios were very rare in both the light-vehicle and heavy-truck FOTs, and when they occurred, drivers responded appropriately to the first warning they received. However, there remains the need for arbitration to prevent the presentation of multiple warnings that would otherwise lead to driver confusion in critical situations.
- The LDW subsystem improved lane-keeping performance for both the light-vehicle and heavy-truck drivers. For the light-vehicle platform, a reduction in the frequency of lane departures was also observed.
- Drivers reported that they did not rely on the integrated system, and results from examining their involvement in secondary behaviors support this claim. While there was a statistically significant observation that light-vehicle drivers were slightly more likely to maintain a shorter headway (less than 1 second with the integrated system versus without it), the practical difference is rather small (21% versus 24%). In addition, the lack of evidence for signs of increased risk compensation, or behavioral adaptation, seems to suggest that if there were negative behavioral consequences associated integrated system use, they were relatively minor or would develop over longer periods of system exposure.
- Despite low invalid warning rates for the longitudinal subsystems (FCW and CSW), driver subjective feedback suggests that some drivers would expect the invalid rates to be even lower—or perhaps that the percentage of warnings that were invalid affected their confidence or understanding on how the systems operated. Achieving lower invalid warning rates, particularly when including the detection of stopped objects, may be challenging to realize.
- Light-vehicle drivers preferred the LDW and LCM subsystems; this is likely due to the subtle nature of the warnings when a threat is not imminent. The presence of LEDs in the side-view mirrors (BSD) and the haptic seat (LDW) were less intrusive than are the auditory warnings used for CSW and FCW subsystems in response to imminent threats. While light-vehicle drivers preferred the longitudinal subsystems, it is important to note that all subsystems received generally favorable ratings from drivers. Furthermore, there were several instances where rear-end crashes appear to have been prevented as a direct result of the forward crash warning subsystem.

## **4.2 Actionable Outcomes and Implications for Deployment**

The following are a series of actionable outcomes, or implications for the development and deployment of integrated crash warning systems that are supported by the IVBSS field operational test findings:

- A potential approach for reducing invalid warnings, particularly for fixed objects outside the vehicle's path, would be the development of location-based filtering that could modify threat assessments in response to repeated warnings to which drivers do not respond.
- Additional development of radar systems and algorithms to address trailer reflections for heavy-truck applications is needed to reduce invalid LCM warnings.
- Because the number of invalid warnings to repeated stopped objects was so high, development of crash warning systems that maintain records of locations where warnings occurred should be considered. Specifically, systems are needed that adjust warning thresholds to stopped objects at locations where repeated warnings have been recorded.

## **4.3 Suggestions for Expanded Analysis of the IVBSS Data Set**

- Conduct a detailed examination of driver behaviors, particularly secondary tasks, to determine whether there are behavioral changes more subtle than just the frequency of task involvement associated with the treatment condition (e.g., durations of cell phone calls, durations of text messaging, levels of complexity for eating tasks, etc.).
- Conduct follow-up interviews with light-vehicle FOT participants to inquire whether they purchased a car since use of the test vehicle. If so, did they purchase any crash warning systems, or how their experience as a participant in the IVBSS FOT might have influenced their purchasing decision?
- Perform a more detailed investigation as to why a slight increase in close following was observed in the light-vehicle FOT during the treatment condition. Are there factors that influenced this outcome that were not recognized or included in the existing analyses? Are the results for other indicators of headway maintenance different, and how does headway vary across the entire range of following—not just below one second?
- Even though certain conditions did not show statistically significant differences associated with the treatment condition, might individual drivers? It would be beneficial to examine whether the most aggressive or higher-risk drivers received more, or less, benefit from the integrated system compared to drivers with normal behaviors.



- Perform a detailed evaluation of the potential for reducing invalid warnings for fixed objects outside the vehicle's path that could be achieved with the development of location-based filtering. Specifically, examine how threat assessment algorithms could be modified in response to repeated warnings to which drivers do not respond.
- Conduct a detailed analysis of the data set for instances of missed warnings (i.e., when warnings should have been presented to the driver, but were not).
- Closely examine drivers' behavioral responses to valid warnings to determine where they first direct their attention in response to the different warning types, particularly when they were inattentive, and determine their initial control response (i.e., steer, brake, no response).

In summary, the IVBSS FOT produced valuable research findings and data. This report, which only summarizes key findings, is further supported by a detailed evaluation of the data in the Light-Vehicle Field Operational Test: Methodology and Results ([Sayer et al., 2010](#)) and Heavy-Truck Field Operational Test: Methodology and Results ([Sayer et al., 2010](#)) Reports.

Complementary reports covering integrated system performance, potential safety benefits, driver acceptance, and willingness to purchase will be prepared and published by the Volpe National Transportation Systems Center, the IVBSS FOT independent evaluator.

## **Appendix A: Annotated Bibliography of Program Reports**

### **Final Reports**

#### [IVBSS Light-Vehicle Field Operational Test Key Findings Report](#)

Research findings from the light-vehicle field operational test are summarized in this report. This includes results from analyses performed to examine the effect of using a prototype integrated crash warning system on driver behavior and driver acceptance.

#### [IVBSS Light-Vehicle Field Operational Test Methodology and Results Report](#)

This UMTRI report presents a detailed description of the methodology used to conduct the data analysis of the light-vehicle field operational test, as well as results from all analyses performed.

#### [IVBSS Heavy-Truck Field Operational Test Key Findings Report](#)

Research findings from the heavy-truck field operational test are summarized in this report. This includes results from analyses performed to examine the effect of using a prototype integrated crash warning system on driver behavior and driver acceptance.

#### [IVBSS Heavy-Truck Field Operational Test Methodology and Results Report](#)

This UMTRI report presents a detailed description of the methodology used to conduct the data analysis of the heavy-truck field operational test, as well as results from all analyses performed.

### **Progress Reports**

#### [IVBSS First Annual Report](#)

This document describes progress and accomplishments made during the first year of the program (November 2005—December 2006). Activities during the first year focused on system specification and design, and the construction of prototype vehicles.

#### [IVBSS Phase I Interim Report](#)

This report documents all work performed during Phase I of the program (November 2005 — April 2008). Activities during the first phase focused on system specification, design and development, and construction and verification testing of prototype vehicles.

#### [IVBSS Third Annual Report](#)

This document describes accomplishments and progress made during the first year of Phase II (June 2008 — May 2009). This includes making system refinements to the integrated crash warning system, additional verification testing and extended pilot tests, data analysis, and construction of additional research vehicles.

## **Data Analysis Plans**

### [IVBSS Heavy-Truck Platform Field Operational Test Data Analysis Plan](#)

Plans to carry out the analysis of data collected from the heavy-truck platform field operational test are summarized in this report.

### [IVBSS Light-Vehicle Platform Field Operational Test Data Analysis Plan](#)

Plans to carry out the analysis of data collected from the light-vehicle platform field operational test are summarized in this report.

## **Field Tests**

### [IVBSS Field Operational Test Plan](#)

The plan for conducting the light-vehicle and heavy-truck field operational tests is outlined in this report.

### [IVBSS Heavy-Truck Extended Pilot Test Summary Report](#)

This UMTRI report describes the findings and outcomes from the heavy-truck extended pilot test, which was performed to provide evidence of system readiness for field operational testing.

### [IVBSS Light-Vehicle Extended Pilot Test Summary Report](#)

This UMTRI report describes the findings and outcomes from the light-vehicle extended pilot test, which was performed to provide evidence of system readiness for field operational testing.

## **Driver-Vehicle Interface**

### [IVBSS Arbitration of Heavy-Truck Driver-Vehicle Interface \(DVI\) Warnings](#)

This UMTRI report describes the methods and results associated with the integration and arbitration of DVI messages for the heavy-truck platform. The goals of message integration and arbitration were to: support a timely and appropriate response from the driver; avoid contributing to driver error, distraction, confusion, or information overload; and support the development of an accurate and functional mental model of the integrated system by the driver.

### [IVBSS Heavy-Truck Driver Vehicle Interface \(DVI\) Design Notes](#)

During the development of the DVI specification document, the heavy-truck DVI team addressed a number of issues by conducting short reviews or analyses on specific design topics. This UMTRI report collates these “design notes” into a single report for easy reference.

### [IVBSS Heavy-Truck Driver Vehicle Interface \(DVI\) Literature Review](#)

This UMTRI report provides detailed design specifications for the heavy-truck driver-vehicle interface. Basic program strategies for meeting this objective include systematically managing and prioritizing all information presented to the driver, minimizing the number of system false alarms, and restricting auditory alarms to higher urgency collision conditions.

### [IVBSS Heavy-Truck Driver-Vehicle Interface \(DVI\) Specifications \(Final Version\)](#)

This UMTRI report provides detailed specifications (presentation characteristics and functional characteristics) for a DVI design that meets the objectives of the program. Basic program strategies for meeting this objective include systematically managing and prioritizing all information presented to the driver, minimizing the number of system false alarms, and restricting auditory alarms to higher urgency collision conditions.

### [IVBSS Heavy-Truck Driver-Vehicle Interface \(DVI\) Stage 1 Jury Drive Protocol](#)

This UMTRI report describes two jury-drive evaluations conducted as part of the heavy-truck system development process. Stage 1 jury drive activities and materials, system orientation and demonstration instructions, public roadway drive instructions and materials, test-track drive and debriefing materials, system warnings and alerts review, and a self-administered driver questionnaire are all included in this report.

### [IVBSS Heavy-Truck Driver-Vehicle Interface \(DVI\) Stage 1 Jury Drive Summary](#)

This UMTRI report summarizes objectives and results of the stage 1 jury drives, including a discussion of results, and recommendations for the heavy-truck driver interface.

### [IVBSS Human-Factors and Driver-Vehicle Interface \(DVI\) Summary Report](#)

This document describes human factors research and DVI development work conducted during the first two years of the program. It includes a discussion of laboratory and driving simulator studies, and on-road testing to assess driver-interface concepts for an integrated warning system.

## **Functional Requirements and System Performance**

### [Functional Requirements for IVBSS - Heavy-Truck Platform](#)

Functional requirements that were used to guide development of a prototype integrated crash warning system for the heavy-truck platform are documented in this report.

### [Functional Requirements for IVBSS - Light-Vehicle Platform](#)

Functional requirements that were used to guide development of a prototype integrated crash warning system for the light-vehicle platform are documented in this report.

### [System Performance Guidelines for a Prototype IVBSS - Heavy-Truck Platform](#)

This document outlines system performance guidelines that were used in the development of the prototype crash warning system that was tested as part of the program.

### [System Performance Guidelines for a Prototype IVBSS - Light-Vehicle Platform](#)

This document outlines system performance guidelines that were used in the development of the prototype crash warning system that was tested as part of the program.

## Verification Testing

### [IVBSS Objective Test Scenario Warning Strategies: Kinematic Analyses and DVI Outputs](#)

This UMTRI report presents a series of analyses conducted to identify applicable warning algorithms and potential ambiguities or conflicts in defining these detection algorithms. DVI outputs and potential driver response issues were also identified.

### [IVBSS Verification Test Plan for Heavy-Trucks](#)

This UMTRI document outlines the procedures that were used to verify that the heavy-truck platform met its performance requirements. These tests were also used to identify areas for system improvement to ensure system repeatability and robustness.

### [IVBSS Verification Test Plan for Light Vehicles](#)

This UMTRI document outlines the procedures that were used to verify that the light-vehicle platform met its performance requirements. These tests were also used to identify areas for system improvement to ensure system repeatability and robustness.

### [IVBSS Light-Vehicle On-Road Test Report](#)

Results from on-road tests to verify readiness for field testing are summarized in this report. Test results were also used to identify areas that should be improved prior to the start of the planned field test.

### [IVBSS Heavy-Truck On-Road Test Report](#)

Results from on-road tests to verify readiness for field testing are summarized in this report. Test results were also used to identify areas that should be improved prior to the start of the planned field test.





DOT HS 811 482  
June 2011



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