Integrated Vehicle-Based Safety Systems (IVBSS) Heavy Truck Platform Field Operational Test Data Analysis Plan

Prepared by

The University of Michigan Transportation Research Institute (UMTRI)

2901 Baxter Road, Ann Arbor, Michigan 48109-2150

for

U.S. Department of Transportation

Cooperative Agreement DTNH22-05-H-01232

November 23, 2009

UMTRI-2009-31 NOVEMBER 2009

INTEGRATED VEHICLE-BASED SAFETY SYSTEMS (IVBSS) HEAVY TRUCK PLATFORM FIELD OPERATIONAL TEST DATA ANALYSIS PLAN:

JAMES R. SAYER
DAVID J. LEBLANC
SCOTT E. BOGARD
ADAM D. BLANKESPOOR

UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Integrated Vehicle-Based Safety Systems (IVBSS) Heavy Truck Platform Field Operational Test Data Analysis Plan		5. Report Date November 2009 6. Performing Organization Code 052004
7. Author(s) Sayer, J., LeBlanc, D. and Bogard, S., and Blankespoor, A.		8. Performing Organization Report No. UMTRI-2009-31
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute (UMTRI) 2901 Baxter Road Ann Arbor, Michigan 48109-2150		10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This document presents the University of Michigan Transportation Research Institute's plan to perform analysis of data collected from the heavy truck platform field operational test of the Integrated Vehicle-Based Safety Systems (IVBSS) program. The purpose of the IVBSS program is to evaluate the effectiveness of, and driver acceptance for, state-of-the-art integrated crash warning systems for both passenger cars and commercial trucks. The heavy truck platform in the IVBSS FOT includes three integrated crash-warning subsystems (forward crash, lateral drift, and lane-change/merge crash warnings) installed into a fleet of ten Class 8 tractors operated by Con-way Freight.

Each truck is instrumented to capture detailed data regarding the driving environment, driver behavior, warning system activity, and vehicle kinematics. Twenty commercial truck drivers from Con-way Freight are operating the Class 8 tractors for ten months in place of the trucks they normally drive. Data on driver acceptance for the integrated system are being collected through a post-drive survey and debriefings.

The plan describes analyses that emphasize a summary of integrated crash warning system activity, examine how the integrated system affects driver behavior, and assess driver acceptance for the integrated system. The analyses are intended to be complementary to analyses being performed by the program's independent evaluator, the Volpe National Transportation Systems Center.

17. Key Words Collision warning, intelligent vehicles		18. Distribution Statement Unlimited	
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 90	22. Price

Table of Contents

List of Figures

List of Acronyms

ACAS	Automotive Collision Avoidance System
AMR	Available Maneuvering Room
CAMP	Crash Avoidance Metrics Partnership
DVI	Driver-Vehicle Interface
FCW	Forward Collision Warning
FOT	Field Operational Test
GPS	Global Positioning System
HT	Heavy Truck
IVBSS	Integrated Vehicle-Based Safety Systems
LCM	Lane Change-Merge warning
LDW	Lateral Drift Warning
LV	Light Vehicle
POV	Primary Other Vehicle
RDCW	Road Departure Crash Warning
SV	Subject Vehicle
U.S. DOT	United States Department of Transportation
UM	University of Michigan
UMTRI	University of Michigan Transportation Research Institute

1 Executive Summary

1.1 Overview

This document presents the University of Michigan Transportation Research Institute's plan to perform analysis of data collected from the heavy truck platform field operational test (FOT) of the Integrated Vehicle-Based Safety Systems (IVBSS) program. The emphasis of UMTRI's analyses is on reporting the range of driving circumstances in which the integrated system was used (exposure), the effect of the integrated system on driver behavior, and driver acceptance of the integrated system.

The purpose of the IVBSS FOT is to evaluate the effectiveness in helping to reduce crashes and to gauge driver acceptance of a state-of-the-art integrated crash warning system for widespread deployment in the U.S. passenger car and commercial-truck fleet. The system being tested was developed and implemented by Eaton and Takata Corporations. A detailed description of the systems examined can be found in the Integrated Vehicle-Based Safety Systems (IVBSS) Phase I Interim Report (UMTRI, 2008). The integrated system includes the following crash warning subsystems:

- Forward crash warning (FCW), which warns drivers of the potential for a rear-end crash with another vehicle;
- Lateral drift warning (LDW), which warns drivers that they may be drifting inadvertently from their lane or departing the roadway; and
- Lane-change/merge warning (LCM), which warns drivers of possible unsafe lateral maneuvers based on adjacent or approaching vehicles in adjacent lanes, and includes full-time side object presence indicators.

1.2 Heavy Truck FOT Data Collection and Analyses

Each of the ten trucks in the IVBSS heavy truck FOT was instrumented to capture information on the driving environment, driver behavior, system activity, and vehicle kinematics. Twenty drivers from the Detroit Terminal of Con-way Freight operated the Class 8 tractors for ten months in place of the trucks they normally drive. The first two months represented the baseline-driving period during which no warnings were presented to drivers, yet all of the data were being collected on-board the vehicle. The subsequent eight months were the treatment condition during which warnings were provided to the drivers, again with detailed data being collected on-board the vehicle. Additional information on the vehicle instrumentation and experimental design can be found in the Integrated Vehicle-Based Safety Systems – Field Operational Test (FOT) Plan (Sayer et al., 2008).

A significant quantity of objective data produced during the FOT is being used to describe the manner in which the vehicles were driven over an estimated 620,000 miles. Furthermore, a comparison within each driver's data set will be made between the baseline and treatment periods to understand how the integrated system affects driver behavior (a "within-subjects" experimental design). These data are critical to assessing not only potential for safety benefits attributable to the integrated crash warning system, but also to determine whether there are any potential negative consequences associated with using the integrated warning system. Subjective information will also be gathered through a post-drive survey and debriefings held with each of the drivers. The subjective information will serve as the basis for determining driver acceptance, as well as providing insights into improving future integrated crash warning systems. A copy of the survey can be found in Appendix A.

The analyses that UMTRI will perform are based upon specific research questions that emphasize the effect that the integrated warning system has on driver behavior and driver acceptance. Sixteen research questions are identified addressing changes in driver behavior related to safety, and another 13 research questions address driver acceptance issues. Each research question, the associated hypothesis, and a summary of the anticipated analysis methods and techniques are outlined in this document, and summarized in Appendix B. However, in order to address the research questions, it is often necessary to perform more basic understanding of warning system activity (the circumstances in which warnings were presented to drivers) and the conditions in which the vehicles were driven. As such, UMTRI will also conduct extensive analyses that detail the circumstances in which the drivers and instrumented vehicles were exposed (warning rates, warning scenarios, weather, time of day, roadway type, etc.).

1.3 Summary

This plan describes data analyses to be performed by UMTRI on system activity and exposure, effects on driver behavior, and driver acceptance for the integrated crash warning system on the heavy truck platform in the IVBSS FOT. The outcome of the UMTRI analyses will be included in a US DOT report to be published in late 2010, and contribute to a broader evaluation of the effectiveness of integrated crash warning systems. Twenty-nine research questions, hypotheses, and methodological approaches are described, and each is linked back to an attempt to understand effects of the integrated warning systems on driver behavior and driver acceptance. Additionally, data will be obtained to aid in identifying specific areas for future integrated system improvements.

It is important to note that while UMTRI will perform various analyses of the heavy truck FOT data, all data are also being transferred to the Volpe National Transportation Systems Center where it will be used to conduct the USDOT's independent evaluation of the IVBSS field operational test. The analysis roles that UMTRI and Volpe are performing are viewed as being complementary to one another.

2 Introduction

This document presents a plan for analyses UMTRI will perform using the data from the heavy truck field operational test (FOT) of the Integrated Vehicle-Based Safety Systems (IVBSS) program. The analysis plan emphasizes the effect of the integrated system on driver behavior and driver acceptance. The outcome of the UMTRI analyses will be a US DOT report that 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 can be attributed to the integrated crash warning system, and whether the truck drivers accepted the integrated system.

The plan includes 29 research questions, their related hypotheses, methodological considerations, independent and dependent variables, and the proposed analysis methods. These 29 questions are thought to address some of the most relevant topics related to evaluating the integrated system's effects on driver behavior and driver acceptance. However, in the process of addressing these research questions, it is likely that there will be findings that provoke additional questions and observations that had not been expected, or conceived, during the process of planning the data analyses. These discoveries may be significant enough to influence additional research questions, or variations on present questions. The potential for exploring additional research questions, or modifications to the existing questions, should they develop, will be explored in consultation with the US DOT.

2.1 Program Overview

The purpose of the IVBSS FOT is to evaluate the effectiveness in helping to reduce crashes and to gauge driver acceptance of a state-of-the-art integrated crash warning system for widespread deployment in the U.S. passenger car and commercial truck fleet. The system being tested on the heavy-truck platform was developed and implemented by Eaton and Takata Corporations. The heavy truck platform integrated system incorporates the following crash warning subsystems:

- Forward crash warning (FCW), which warns drivers of the potential for a rear-end crash with another vehicle;
- Lateral drift warning (LDW), which warns drivers that they may be drifting inadvertently from their lane or departing the roadway; and
- Lane-change/merge warning (LCM), which warns drivers of possible unsafe lateral maneuvers based on adjacent or approaching vehicles in adjacent lanes, and includes full-time side object presence indicators.

For the heavy truck field test, commercial truck drivers working for Con-way Freight, Inc. were recruited to drive Class 8 tractors like those they would normally operate as part of their employment. The trucks were instrumented to capture information on the driving environment, driver behavior, integrated warning system activity, and vehicle kinematics data. Driver information and data on driver acceptance of the integrated warning system were collected using a post-drive survey and driver debriefing.

It is important to note that an FOT differs from most designed experiments by the extent of its naturalism, or lack of direct manipulation, of the majority of test conditions and independent variables. Participants are driving the specially equipped and instrumented vehicles in place of the trucks they would normal drive. However, the driving is largely unmanaged by the research team and derives instead from the company's commercial delivery needs. Thus, experimental control lies in the commonality of the test vehicles driven, the sampling plan through which drivers were selected, and the ability to sample driving data from the data set on a within-subjects basis, in the analysis phase, that provides "control" of the independent variables and test conditions.

The within-subjects experimental design employed means that each driver operates the vehicle in a baseline condition (no warnings are presented to drivers, but all of the data is being collected), and a treatment condition (warnings are being presented to drivers, and all of the data continues to be collected). This experimental approach, in which each driver serves as their own control, is powerful in that it allows direct comparisons to be made by individual driver of how the vehicles were utilized and how drivers behaved with and without the integrated crash warning system. Relative to analyzing the quantitative data produced from the field operational tests, the within-subjects design reduces error variance relative to having different drivers in the baseline and treatment conditions, and means that fewer drivers need to participate in order to achieve a given level of statistical power.

2.2 Main Study Areas to Be Addressed

Data collected will serve as the basis for answering many questions concerning the warning system and its use—so many, in fact, that it is challenging just to identify those research questions that are possible to address within the scope of the IVBSS program. Based in part on the analysis UMTRI has performed in previous field operational tests of driver assistance and crash warning systems (Ervin, et al, 2005 and LeBlanc, et al, 2006), UMTRI is undertaking analysis of the heavy truck FOT data in three broad areas:

- Summarizing vehicle exposure and the integrated warning system activity,
- Examining differences in driving behavior with and without the system, particularly safety-related findings, and
- Evaluating driver acceptance and understanding of the integrated crash warning system.

2.2.1 Vehicle Exposure and Warning System Activity

Characterizing the domain of driving conditions encountered in the HT FOT is necessary to understand the interaction between drivers and the warning systems. It is also necessary in order to develop a more comprehensive understanding of the driving circumstances in which warnings are, or are not, presented, and whether significant differences exist in the driving environments between the baseline and treatment conditions. The heavy truck domain of exposure is simply describing where and how the trucks were driven, and under what types of roadway and environmental conditions.

The general categories of exposure and warning system activity that UMTRI will report include:

- **Travel patterns:** The distribution of trips, trip distances, and trip times, speeds, trailer configurations, and estimated trailer loading;

- **Roadway variables:** Road class and roadway attributes, and availability of lane markings (as determined by the lane departure subsystem);
- **Environmental factors including:** Weather variables, ambient lighting (based on time of day and season), surrogate metrics of traffic density based on radar data; and
- **Driver characteristics and information:** Driver age, years of commercial driving experience, driving record, etc.,

Heavy trucks in the field test are constrained by Con-way Freight's operating models that essentially pair two drivers with a specific truck (tractor). One driver typically operates the truck with one or more trailers for line haul (terminal-to-terminal delivery of freight through Con-way's national network of terminals) during the night shift. When the line-haul driver returns to the terminal in the early morning, a second driver uses the same truck, often with a different set of trailers, for pick-up and delivery of freight (transporting freight to and from the terminal to various shippers and receivers within a fairly well defined region). Each driver is assigned to operate a specific vehicle along the same route (line-haul), or in the same region (pick-up and delivery), over an extended timeframe, nominally 12 months. The assignment of relatively consistent routes presents limitations, as well as opportunities, in how the data are analyzed. Specifically, repetitive driving patterns can result in narrower exposure to a variety of driving conditions. However, the reduction in variability of system exposure can increase the likelihood of being able to make meaningful comparisons between the baseline and treatment conditions. (i.e., it improves the ability to detect changes in driver behavior associated with the integrated system, such as changes in lane keeping and headway maintenance).

2.2.2 Effects on Driver Behavior

The data are being used to study changes in driving behavior, both during safety relevant scenarios (e.g., lane departures or high closing rates) and in longer-term behavioral metrics (e.g., statistics of lane position deviation). The integrated warning system might also influence driver behavior through lower-level driver actions such as turn signal usage or the spectral distribution of steering wheel input.

Behavioral changes may also appear in higher-level activities such as the use of cell phones or other secondary tasks while driving. Once commercial truck drivers begin to experience and accept integrated warning systems, it is important to understand how such systems might influence general driving behavior—and other behaviors that may affect highway safety. The two types of behavioral data to be analyzed include responses to post-drive surveys and review of video data. Surveys attempt to identify and quantify the effect of the warning system on driver behavior, can, or is willing, to self-report. However, changes in behavior are ultimately best assessed through detailed examination of the objective data on how the vehicle was used along with detailed review of driver behavior video.

- Behaviors directly relevant to the integrated crash warning system, in that they could produce system warnings, such as frequency of significant lane exceedance, changes in headway maintenance, and frequency of lane changes.
- Behaviors, or changes in driving patterns, that may be relevant to the potential for warnings, such as the general distribution of lane-keeping performance, speed decrements

and deceleration peaks, turn signal use, other observed lateral-control and forward conflicts, and propensity to engage in secondary tasks (i.e., talk on a cell phone or send text messages).

2.2.3 Driver Acceptance of the Warning System

Driver acceptance of the warning system is being examined using analyses of subjective responses to the post-drive survey. Observed use of, and interaction with, the system may also provide information regarding driver acceptance, but to a lesser degree than the post-drive survey. Acceptance is a fundamental question to be addressed. While integrated crash warning systems may be technically feasible and sound, the general premise that such systems will be widely accepted by commercial truck drivers remains unclear.

Assessing driver acceptance of the warning system will rely predominantly on analyses of subjective responses in conjunction with observed system use. The general categories of acceptance questions being addressed include:

- **Comfort**: Assessment primarily of the integrated system's ability to convey the necessary warnings in a clear, logical, and timely manner;
- **Utility**: The range of driving conditions in which the integrated system is perceived to provide benefit, including perceived safety and desire to drive vehicles with integrated warning systems in the future; and
- **Convenience**: The relative ease of learning and using the system.

While the primary method for assessing HT driver acceptance is through the post-drive survey, additional insights regarding acceptance may also be assessed through direct interaction between researchers and participants in post-drive debriefings. Important secondary sources of data for examining driver acceptance include warning frequency the individual drivers experienced, and data on driver actions that have an increased likelihood to result in warnings (i.e., unsignalized lane changes, frequency of significant lane exceedance, coming into close proximity to other vehicles while performing lane changes or merges, and coming into close proximity to the rear of other, slower moving, vehicles ahead).

3 Heavy-Truck Data Analysis

This section is an expanded description of the three main areas of analysis identified in Section 2.2. The section provides detail regarding the approaches and considerations to be made when analyzing the HT FOT data in the areas of system exposure/activity, driver behavior, and acceptance of the integrated system. Specific research questions are provided in section 4.0.

3.1 Vehicle Exposure and Warning Activity Analyses

Analyses are described below, which are intended to depict the conditions of where, and by whom, the trucks were driven, the frequency of warnings, and the circumstances under which warnings are presented.

3.1.1 Vehicle Exposure

Characterizing the domain of driving circumstances encountered in the FOT is necessary for understanding the interaction between drivers and the warning system. The domain of exposure is simply describing where and how the truck was driven, and under what conditions.

In the field test, exposure is constrained by Con-way Freight operating models and routes. Typically, two drivers operate the same truck (tractor) on different shifts. One driver will typically operate the truck for line-haul deliveries between terminals during the nighttime, whereas the second driver will use the same truck, possibly with a different set of trailers, for pick-up and delivery during the daytime. Each driver and specific vehicle are usually assigned to operate the same route over an extended timeframe, nominally 12 months.

This section describes the major elements of characterizing the exposure data, namely when, where, how, and under what types of circumstances the trucks were operated. Characterizing the exposure involves aggregating occurrences in which certain variables take on certain values. This aggregation is done for many variables, individually and jointly, and results typically include histograms, events, patterns, etc. These results can then be used to depict the conditions to which the driver, truck and the integrated warning system were exposed, and are necessary to better understand the circumstances as to when and why warnings may have been presented. Examples of individual variables and exposure descriptors that will be summarized and presented in this portion of the data analysis include:

Travel patterns:

- Distributions of the number of total trips, trip distances, and trip times;
- Trip objective metrics, where available (e.g., fraction of trips on roads previously traveled by driver for the pick-up and delivery routes);
- Trailer configurations and estimated loading; and
- Route types (pick-up and delivery vs. line-haul)

Roadway variables:

- Road class and roadway attributes;
- Characteristics of curves encountered (speed, radii, and roadway type);
- Maneuvering room statistics; and

- Availability of lane markings (as determined by the lane departure subsystem).

Environmental factors:

- Weather variables (precipitation, temperature);
- Ambient lighting (based on time of day and season by calculating solar zenith angle); and
- Traffic density estimates (using surrogate metrics based on radar returns).

Driver characteristics:

- Age, years of commercial driving experience, driving record, etc.;
- Driving styles observed (based on measures that portray degrees of conflict tolerance such as speed and maintaining close headways).

3.1.2 Integrated Warning System Activity

Analysis of system activity refers to the characterization of the occurrence or non-occurrence of crash warnings and advisories during the field test. This includes simple counts of warning and advisory events, as well as characterizing in several dimensions (individually and jointly), the circumstances in which warnings or advisories occur or do not occur. This serves several purposes, including:

- Characterizes the fraction of travel distance or time that system functions are enabled and available,
- Characterizes the frequency and circumstances of various types of warnings and advisories, including false warnings, and
- Identifies technical successes, as well as remaining challenges that may affect safety and acceptance.

3.1.2.1 Availability of the warning system

Availability refers to the fraction of time or travel during which the system is capable of issuing crash warnings or advisories. Availability will be considered for individual subsystems (FCW, LDW and LCM), as well as for the entire integrated crash warning system. When the integrated system, or a subsystem, is not available, the reason generally falls into one of the following categories:

- Design-specified unavailability, such as the intended suppression of the function when traveling at speeds below the minimum for system function, as well as short-term unavailability designed to improve the system-driver interaction, such as suppression of LDW warnings when the turn signal is applied or suppressions of secondary warnings that occur within a few seconds of a previous warning;
- Absence of one or more measurements needed for a primary system function, such as lack of viable lane markings for visual tracking, loss of radar tracking due to buildup of snow or slush on a fascia, etc.; and
- Temporary or persisting malfunctions of the system, including hardware or software issues such as a failure of a subsystem to boot.

System unavailability will be captured in the analyses, using variables such as the time duration of unavailability, causality, conditions under which unavailability occurred (e.g., vehicle speed, road class, environmental conditions, sensor blockages (video), and absence of lane markings), etc. Unavailability due to system malfunctions is specific to this experimental context and is significant only if its occurrence disrupts drivers' experience sufficiently enough that their subjective responses or driving patterns may be influenced. System failures will be readily apparent using system health or status flags from the subsystems that are stored on-board, as well as being transmitted and monitored remotely. More subtle algorithmic bugs, such as those that result in unintended LDW decisions, are typically encountered early in such tests, where the data are scrutinized regularly. They appear as unexpected displays of warnings or information (or missing displays) that are associated with unusual conditions. Appendix E provides a brief description of the system maintenance and failures that will be reported in more detail as part of the final program report.

3.1.2.2 Crash Warnings and Advisories

This section forms the bulk of the system activity analyses and includes the characterization of situations in which the system issues warnings and, conversely, the study of situations that are otherwise similar, but do not result in warnings. When possible, crash-warning events are classified into driving scenarios. An example of scenario classifications can be found in the automotive crash avoidance system (ACAS) and road departure crash warning (RDCW) FOT reports previously published by UMTRI (Ervin et al., 2005; LeBlanc et al., 2006).

UMTRI will analyze the data to determine the percentage of warnings that are false – those warnings in which there is no threat present, but a warning is issued because of sensor and/or sensor processing limitations. UMTRI does not plan to classify warnings as nuisance warnings *per se*, since this requires assumptions about driver preferences (i.e., a mapping from warning circumstances to the individual driver's subjective judgment) that previous research shows is very difficult or impossible at the level of individual warnings. Instead, the analysis will classify the crash warning events according to the circumstances and driver actions following the warning. Furthermore, drivers will be queried about their reactions to a sample of their own individual warnings during the post-drive debriefing session. This provides a pool of events with associated driver judgments. Previous FOTs have shown that while there are trends in driver ratings as a function of driving circumstances, the variation across drivers and individual events within drivers is very wide. However, together, the objective and subjective analyses have been powerful indicators of the level of acceptability of specific types of warnings and the influence of driving scenario on that acceptance.

As the system is designed to provide the driver with the most useful and intuitive interface, this analysis will be done in the following sections: multiple-threat scenarios, combined LDW and LCM subsystems, and FCW subsystem alone. While the LDW and LCM events will be identified separately in the analysis, they are discussed together in this document – and possibly within the FOT analysis reports – because the system provides these warnings to, and is generally viewed by, the drivers as a unified system.

3.1.2.2.1. Accounting of Warnings and Advisories

All crash warnings and advisories will be counted and analyzed, with separate analyses for the crash warnings and advisories. The analyses will be broken down by the type of conflict: lane change (including aspects of LDW and LCM), road departure, FCW, and multiple-threat scenarios. The number of crash warnings and the frequency of their occurrence by travel mile will be counted as a function of several variables including, but not limited to, travel speed, road type, number of same-direction lanes, relevant lane boundary, presence of adjacent traffic or roadside threats, and so on. Individual and joint distributions of counts and warning rates will be done as functions of metrics such as kinematic conflict levels, closing speeds, level of lead vehicle deceleration, etc.

Classification of crash warning events into scenarios will be done at two levels: a broader classification of events using automatic computations and a classification of a sample of approximately 2,000 crash warnings according to a detailed set of scenario descriptors similar to that employed for FCW in the ACAS FOT (Ervin et al., 2005). An example of a broad scenario classification label for FCW is, "subject vehicle approaching a slowing vehicle with both vehicles remaining in the same lane throughout the episode". A detailed scenario label would append more contextual information that can only be gathered from manual review of video, such as "…the deceleration of the slowing vehicle ahead is not predictable by the subject vehicle driver."

The analysis of any advisories, specifically regarding headway and LCM, would be similar but less extensive than the analyses for crash warnings. Counts, rates, and circumstances would be summarized and reported, as well as any more detailed discussion of particular driving circumstances that result in an unexpectedly high or low number of advisory events.

3.1.2.2.2. Accounting of Driver Visual Attention Measures

Driver visual attention and awareness are recognized as a critical component in successful crash avoidance. The same sample of warning events mentioned in the scenario classification work will be reviewed using in-cabin video and associated data to code driver visual-glance behavior, including the number of directionally specific glances, and duration of glances, away from the forward scene). Driver visual attention will be coded shortly before and after warning events in order to understand the relevance of a driver's visual attention to the incidence of crash warnings. This analysis will contribute broadly toward understanding the effects of the integrated system overall. First, examining visual attention will help in understanding the likely utility of the all types of warnings (i.e., was the driver already looking in the direction of the threat). Second, it will contribute to the evaluation of potential changes in driver behavior associated with the integrated system (i.e., might drivers not look as often when changing lanes, or feel more comfortable looking away for longer periods). Lastly, it will be significant in understanding the role that secondary tasks, and the amount of visual attention they require, play in producing crash warnings from the integrated system. As a result, several research questions, outlined below in section 3.2, will utilize the data on driver visual attention.

3.2 Effects on Driver Behavior

Analysis of driver behavior using the heavy truck FOT data will provide insights into possible safety impacts of the integrated crash warning system. The focus of the UMTRI team's analyses on driver behavior is largely safety oriented, analyzing the interaction of the warning system with safety-related phenomena, including:

- Behaviors in the moments after a warning is issued (or after a warning would have been issued, in the case of baseline driving);
- Behaviors directly relevant to the integrated crash warning system, in that they could produce system warnings;
- Behaviors, or changes in driving patterns, that may be relevant to the potential for warnings; and
- Secondary task behaviors.

This analysis approach is similar in spirit to analyses reported previously reported by UMTRI in Ervin et al. (2005) and LeBlanc et al. (2006). The differences in the analyses for the heavy truck FOT will be in terms of methods and depth of findings, as described below.

3.2.1 Driver Responses to Events

During the baseline period, the integrated system is operating "in the background", even though warnings are not being presented to drivers. Thus, during the baseline driving period, the onboard data provide the timing and circumstances of system decisions to warn, allowing a direct comparison of driver behavior with and without the presentation of warnings. Therefore, this type of analysis looks at driver control and visual attention responses with and without warnings. The research questions to be addressed include whether in the treatment period warnings will cause the driver to respond faster, or more decisively, and with better visual attention than in the baseline period. These analyses, in combination with analyses on the frequency of warnings, can be used to describe potential safety benefits of the integrated warning system, or for specific classes of warning. If aspects of a positive or negative effect are confirmed statistically, those would suggest a potential safety benefit (or hazard), due to event-specific performance change.

The driver responses of interest include not only vehicle control inputs (braking, steering/lane-change behavior, speed control), but also visual attention (eyes forward, eyes on driving task). The analysis will again include two subtasks: a broad analysis that is computed for all events (partitioned into FCW, LDW and LCM, and multiple threats), and a detailed investigation of approximately 2,000 events using scenes from the video camera and human interpretation. Note that visual attention studies are limited because the fleet did not have eye- or head-tracking equipment onboard.

The following are research questions specific to drivers' response to conflicts that will be addressed in the analysis of the data set. Detailed descriptions of the analysis methods to be employed are provided in Section 4:

QC3. When the integrated system arbitrates between multiple threats, which threat does the driver respond to first?

QL3. When vehicles depart the lane, does the vehicle trajectory, including the lane incursion and duration, change between the baseline and treatment conditions?

QF4. Will the integrated system warnings improve drivers' responses to those forward conflicts in which closing-speed warnings occur?

3.2.2 Changes in Conflict Management

This section addresses driver performance in conflict events as well as in pre-conflict driving. The conflict event portion is a variation of the event study described above, with the definition of event tied to more general conflict measures. The intention is to look for any significant changes in how drivers manage the conflicts that the system addresses, both in terms of exposure to relatively high-conflict events and driver responses in those events. The definition of conflicts will draw upon existing studies that directly address that question. UMTRI will also leverage its experience with crash warning field test data to extend the definition to account for indicators of driver intent and anticipation (e.g., the near-crash metric of a same-lane FCW scenario will be different from the metric for a scenario in which the lead vehicle is turning). The primary method of analysis will be a statistical comparison of performance metrics, such as using the speed-indexed time-to-collision model developed by the Crash Avoidance Metrics Partnership (CAMP) for forward conflicts (Kiefer et al., 2003).

The following are research questions specific to the management of conflicts that will be addressed in the analysis of data set. Detailed descriptions of the analysis methods to be employed are provided in Section 4:

QL2. Does lane departure frequency vary between baseline and treatment conditions?

QL6. What is the location of all adjacent vehicles relative to the subject vehicle for valid LCM warnings?

QF2. Will the frequency and/or magnitude of forward conflicts be reduced between the baseline and treatment conditions?

QF3. Does the integrated system affect the frequency of hard-braking maneuvers involving a stopped or slowing POV?

3.2.3 Changes in Pre-Conflict Driving Measures

Pre-conflict driving behavior includes choices of headway times, turn signal use, speed, lane position, gap sizes during lane changes, and initiation of maneuvers such as lane changes. These types of behaviors have been found to be influential in past studies, and may illustrate any major safety benefits that the integrated system can provide. This is presumably because when drivers allow themselves and nearby drivers more time and distance to react, the probability of conflicts building to dangerous levels decreases. Thus, the distributions of the measures noted above will be characterized with and without the warning system.

The following are research questions specific to pre-conflicts driving measures that will be addressed in the analysis of the data set. Detailed descriptions of the analysis methods to be employed are provided in Section 4:

QC4. Do drivers report changes in their driving behavior as a result of the integrated crash warning system?

QL1. Does lateral offset vary between baseline and treatment conditions?

QL4. Does turn signal use during lane changes differ between the baseline and treatment conditions?

QL5. Do drivers change their position within the lane when another vehicle occupies an adjacent lane?

QL7. Will drivers change lanes less frequently in the treatment period, once the integrated system is enabled?

QL8. Is the gap between the subject vehicle (SV) and other leading vehicles influenced by integrated system when the SV changes lanes behind a principal other vehicle (POV) traveling in an adjacent lane?

QF1. Does the presence of integrated system affect the following distances maintained by the heavy truck drivers?

3.2.4 Changes in Secondary Task Behavior

An analysis of video and associated data will be conducted to determine how the integrated system influences drivers' choices to engage in secondary (non-driving) tasks. Previous UMTRI studies have looked at both warning events as well as randomly selected data. Over 5,600 events were coded between the ACAS FOT and RDCW FOT projects (Ervin et al., 2005 and LeBlanc et al, 2006), and such behaviors as cell phone use, eating/drinking, grooming, conversations, and others were coded with subfields for the level of involvement. This resulted in findings that only during the initial period of system availability did drivers engage more frequently in secondary tasks, and that effect disappeared after the initial week of exposure to the system. The same finding is anticipated here, but a careful analysis is important to study whether the system could contribute to additional secondary involvement, and therefore potentially reduce the safety benefits, particularly with the ever-increasing frequency of using personal electronic devices in motor vehicles. Engagement in secondary tasks when warnings are presented by the integrated system will also be coded, and reported as part of the integrated systems warning activity. This will allow analysis on whether engaging in secondary tasks increases the likelihood of warnings.

The following are research questions specific to secondary task behavior that will be addressed in the analysis of the IVBSS heavy truck FOT data set. Detailed descriptions of the analysis methods to be employed are provided in Section 4:

QC1. When driving with the integrated crash warning system (treatment condition), will drivers engage in more secondary tasks than in the baseline condition?

QC2. Does a driver's engaging in secondary tasks increase the frequency of crash warnings from the integrated system?

3.3 Driver Acceptance of the Warning System in Heavy Trucks

Driver acceptance of the integrated crash warning system will be measured primarily through analyses of post-drive surveys and debriefing sessions that include the evaluation of specific warning events drivers themselves received. A copy of the post-drive survey is included in Appendix A of this report. It is unlikely that focus groups will be held with heavy-truck FOT participants due to concerns about confidentiality given that all of the truck drivers know each other. If focus groups are held, that information will also add to the assessment of driver acceptance.

The post-drive survey was prepared in consultation with the IVBSS program Independent Evaluator. Most questions included in the post-drive survey are Likert-type scale questions that are intended to address one of three general areas of the driver's perception of the integrated crash warning system; comfort in using the system, convenience of the system and the utility of the system.

3.3.1 Comfort

Post-drive survey questions related to drivers' comfort with the system are primarily associated with whether the system was easy to understand and whether warnings were effective. These include topics such as whether the warning tones were able to gain the drivers' attention without being annoying or distracting. Also of interest here was whether the system performed as drivers expected, and whether drivers were able to distinguish between the warnings when one was presented for a specific crash threat situation.

The following are research questions specifically assessing driver comfort with the integrated system using post-drive survey data. Detailed descriptions of the analysis methods, and associated survey questions, are provided in Section 4:

QC6. Are the modalities used to convey warnings to drivers salient?

QC11. Do drivers find the integrated system to be easy to understand?

QD1. Did drivers perceive the driver-vehicle interface for the integrated system easy to understand?

3.3.2 Convenience

Post-drive survey questions related to system utility are primarily associated with perceived system benefits and whether drivers want the integrated system, or its subsystems, in their vehicles. The following are research questions specifically assessing system utility from the post-drive survey data. These questions include whether drivers felt the system would increase their awareness of the traffic situation, as well as increase their general driving safety. Also of interest was whether drivers received warnings from the integrated system that they felt they did not need. Detailed descriptions of the analysis methods, and associated survey questions, are provided in Section 4:

QC5. Are drivers accepting the integrated system (i.e., do drivers want the system on their vehicles)?

QC7. Do drivers perceive a safety benefit from the integrated system?

QC9. Do drivers' report a prevalence of false warnings that correspond with the objective false warning rate?

QL9. Are drivers accepting of the LDW subsystem (i.e., do drivers want LDW on their vehicles)?

QL10. Do drivers find the integrated system to be useful, what attributes and in which scenarios was the integrated system most and least helpful?

QL11. Are drivers accepting of the LCM subsystem (i.e., do drivers want LCM on their vehicles)?

QF5. Are drivers accepting of the FCW subsystem (i.e., do drivers want this system on their vehicles)?

3.3.3 Utility

Questions in the post-drive survey intended to address whether the integrated system offered utility to the drivers include questions regarding ease of use, ease of learning, and whether the DVI controls were useful. Particularly of interest was whether the frequency of false warnings affected the drivers' ability to easily learn and correctly understand the system. Detailed descriptions of the analysis methods, and associated survey questions, are provided in Section 4:

QC8. Do drivers find the integrated system convenient to use?

QC10. Do drivers find the integrated system to be easy to use?

QD2. Do drivers find the volume and mute controls useful, and do they use them?

3.3.4 Acceptance Data Methodologies

The following are brief descriptions of, and some background information on, the methodologies being employed to collect data on driver acceptance of the integrated system. All are methodologies that have previously been used for conducting similar evaluations in field operational tests of driver assistance and crash warning systems.

3.3.4.1 Likert-type Scale Questions

Most survey questions will be answered using 7-point Likert-type scales, with higher numbers indicating positive attributes. These data will be used in analyses along with objective data (e.g., the number of warnings) to investigate the effects of warning rates on driver acceptance, in addition to assessing the drivers' perceived utility of the integrated system and its ease of use (including the drivers' impression of the driver-vehicle interface). In addition, a few open-ended questions and questions requesting a yes/no responses are included in the survey.

Summary data, means, medians, and standard deviations will be reported for the questions using Likert-types scales. Where multiple post-drive survey questions contribute toward addressing a broader research question, results will be presented by individual questions with an attempt to draw relationship between the responses as they relate back to the research question. However, no formal analyses, such as factor analysis, that would utilize the responses from multiple post-driver survey questions are planned. Counts of responses to yes/no format questions will be provided, as will written summaries of responses to open-ended survey questions.

3.3.4.2 Van der Laan Scales

The Van Der Laan scale is composed of nine questions, and was developed expressly for evaluating driver assistance systems (Van Der Laan, Heino, and De Waard; 1997). Four versions of the Van der Laan scale are embedded in the heavy truck post-drive survey, one for the integrated system overall and one each for the individual subsystems. The Van der Laan scale represents one way to capture drivers' subjective assessments with the integrated system. The use of the Van der Laan scale will also allow comparisons to be made between the individual subsystems, and results from other evaluations of driver assistance and crash warning technologies (e.g., the ACAS FOT, RDCW FOT, etc.). The scale uses anchors that are adjectives to ascribe positive or negative attributes to the system being evaluated. The results are ultimately collapsed into two composite scores representing the drivers' perceived usefulness and satisfaction with the system, or subsystem.

3.3.4.3 Video-based Review of Warning Events

Lastly, during the driver debriefing sessions, truck drivers will view video from a selected group of the warnings that they received. Researchers will prepare, and show each driver, 12-18 videos representing a sample of warnings from the driver's own experience with the integrated system. Drivers will rate the extent to which the warning they received was useful, evaluate the timing of the warning, and allowed to suggest how the warning could be improved. Analyses of these scenario specific ratings contribute to a more complete understanding of drivers' overall impression for the integrated system, as well as the subsystems under specific driving scenarios. These ratings will be used to identify the scenarios that drivers are most, and least, accepting of receiving warnings. This information can then be used to improve future systems by reducing the frequency of warnings that drivers report had the least utility.

4 Research Questions

This section describes the analysis of heavy-truck FOT data to address the three broad study areas as described in the previous section: system exposure/activity, driver behavior, and acceptance of the integrated system. Specific research questions, including their relative importance, are outlined along with methodological approaches, independent variables, dependent variables, constraints, and amenable analyses techniques are listed. Other than where sample size has been identified as a constraint, UMTRI is confident that adequate data exist to address all of the research questions that have been identified and that the sample sizes are amenable to the analysis techniques listed.

The independent and dependent variables identified with each research question have been carefully considered. Each independent variable listed is thought that it could either influence the performance of the integrated system, acceptance of the integrated system, or driver behavior that could in turn affect system performance and the frequency of warnings.

In addition to the research questions listed, the field test can be expected to provoke questions and observations that were unexpected during the analysis planning stage. These discoveries may be significant enough to influence the tactics used in addressing certain research questions, as well as generate new research questions.

4.1 Warnings Arbitration and Comprehensive System Analyses

This portion of the analyses will summarize the performance of the integrated system and warnings arbitration process. This includes the presentation of descriptive data addressing the frequency of warning arbitration, and a characterization of the scenarios when arbitration was performed. Research questions related to the arbitration of warnings include assessing what threats drivers respond to when multiple threats are present, whether the availability of the integrated system changes overall driver behavior (such as engagement in secondary tasks), and drivers' overall impression of the integrated system.

4.1.1 Vehicle Exposure and Warning Activity Analyses

The frequency that multiple threats were arbitrated will be described for both the baseline and treatment conditions. The descriptive statistics will include the characterization of multi-threat driving scenarios, and descriptions of the circumstances in which warnings are deemed false. Warning frequency and likelihood of false warnings will be presented as a function of road class, route type, driver, exposure (over time), and other conditional variables directly pertinent to warnings arbitration.

4.1.2 Driver Behavior Research Questions

QC1 *Research Question:* When driving with the integrated crash warning system in the treatment condition, will drivers engage in more secondary tasks than in the baseline condition?

Research Hypothesis: When driving with the integrated crash warning system in the treatment condition, drivers will not engage in secondary tasks with any greater frequency, or take on more challenging tasks, than in the baseline condition.

Importance: If, by chance, drivers rely too much on the integrated system, or believe that the system will allow them to engage in secondary tasks where they had previously not done so, it is important to understand whether warning systems could result in unintended safety consequences.

Method: A sample of approximately 2000 video clips that are not associated with warning events, will be systematically reviewed and coded by trained personnel for incidences of when drivers are engaged in secondary tasks in both the baseline and treatment periods. The technique will be very similar to that reported in Sayer, Devonshire, and Flannagan (2005), although using an updated taxonomy of secondary tasks. The results will be coded as categorical data.

Dependent Variables
Engagement in a secondary tasks (multiple categorical tasks representing a wide range of tasks drivers might perform) coded for frequency

Independent Variables
Treatment Condition
Route Type

Data Analysis and Presentation: Summary statistics to be provided in tabular form identifying the frequency with which each secondary task is performed.

QC2 *Research Question:* Does a driver's engaging in secondary tasks increase the frequency of crash warnings from the integrated system?

Research Hypothesis: A driver's engagement in secondary tasks will not increase the frequency of crash warnings from the integrated system.

Importance: It is important to understand the underlying causes of warnings being issued, but also to be able to differentiate between warnings that result from necessary driving-related tasks as opposed to tasks that are not requisite to driving.

Method: A sample of approximately 1800 video clips from the treatment period, half-associated with warning events and half without warnings will be systematically reviewed and coded for incidences of drivers engaging in secondary tasks. The results will be coded as categorical data using taxonomy of secondary tasks, identifying which secondary tasks were most likely to result in warnings from the integrated system.

Dependent Variables
Engagement in a secondary tasks (multiple categorical tasks representing a wide range of tasks drivers might perform) coded for frequency

Independent Variables
Route Type
Warning Type

Data Analysis and Presentation: Perform case-crossover or case-control analyses.

QC3 *Research Question:* When the integrated system arbitrates between multiple threats, which threat does the driver respond to first?

Research Hypothesis: When the integrated system arbitrates between multiple threats, there will be no difference in whether the driver responds to the warned threat and the threat for which the warning was suppressed.

Importance: The outcome of addressing this question will contribute toward a better understanding of how drivers' perceived threats, and how better to arbitrate between multiple threats.

Method: Identify instances of warning arbitration in the heavy truck data set. Review quantitative and video data for an estimated sample of 200 multiple threat scenarios in which the integrated system arbitrated between two or more potential threats. Code the driver's response as an indicator of the most relevant threat perceived by the driver. Determine whether drivers are more likely to respond first to the threat the system identifies, or do drivers respond to the suppressed threat(s). Results will be coded as categorical data.

Dependent Variables
First response by the driver, is it consistent with the warning provided

Independent Variables
Treatment Condition
Route Type

Data Analysis: Categorical data analysis (logistic regression or generalized logit modeling) as sample size permits.

Data Presentation: The data will most likely be presented in a tabular format.

Notes: The frequency of multiple threats, and their arbitration, is expected to be rare, and as such, sample sizes may not support the examination of all independent variables listed.

4.1.3 Driver Acceptance Research Questions

QC4 *Research Question:* Do drivers report changes in their driving behavior because of the integrated crash warning system?

Research Hypothesis: Drivers will not report any changes in their driving behavior.

Importance: Like research question QC1, it is important to understand changes in driver behavior that result from the integrated crash warning system. These changes can either be safety positive, safety neutral, or have a negative safety outcome, and therefore should be identified as part of this analysis of the FOT data.

Method: Calculate the mean, median and standard deviation for the post-drive question on behavioral changes in driving related to the integrated crash warning system (Q7) and summarize responses to the related open-ended question (Q13, Q14).

Dependent Variables
Likert-type scale responses and open-ended questions.

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses; provide histograms of responses to Likert-type scales.

QC5 *Research Question:* Are drivers accepting the integrated system (i.e., do drivers want the system on their vehicles)?

Research Hypothesis: Drivers will be indifferent regarding wanting the integrated crash warning system.

Importance: It is important to understand whether drivers want the integrated system, and if not, how the system needs to be improved in order for drivers to become more accepting. Acceptance by drivers will be key to ensuring that integrated systems reach the market place in order to have any impact on reducing crashes.

Method: Calculate the mean, median and standard deviation for the post-drive question related to the overall acceptance of the integrated crash warning system (Q12), summarize responses to the related open-ended questions (Q39, Q40), and calculate the overall score from the Van der Laan scale (Q30).

Dependent Variables
Likert-type scale responses and Van der Laan score.

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.

QC6 *Research Question:* Are the modalities used to convey warnings to drivers salient?

*Research Hypothesis***:** The modalities used to convey warnings are not salient.

Importance: Warnings are not effective if drivers do not see/hear them, or the warnings are not clear in what they are intended to convey. This analysis will help to understand what attributes of warnings drivers like and dislike for an integrated warning application.

Method: Calculate the mean, median and standard deviation for the post-drive questions related to the warnings overall (Q11,) and specifically the auditory warning tones (Q17, Q18), and the blind spot detection lights (Q19, Q20,Q35, Q36) and calculate the overall scores from the Van der Laan scale (Q44).

Dependent Variables
Likert-type scale responses
Van der Laan score.

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.

QC7 *Research Question:* Do drivers perceive a safety benefit from the integrated system?

Research Hypothesis: Drivers do not perceive having experienced a safety benefit from the integrated system.

Importance: Like research question QC5, it is important to understand whether drivers want the integrated system perceive the system to have a benefit. If not, acceptance will be more difficult to achieve for integrated systems to reach the market place and impact reducing crash rates.

Method: Calculate the mean, median and standard deviation for the post-drive questions related to driver situational awareness (Q7), perceived safety benefit (Q6, Q10) and general helpfulness of warnings (Q4), summarize responses to the related open-ended question (Q5) and calculate the utility score from the Van der Laan scale (Q30).

Dependent Variables
Likert-type scale responses
Van der Laan utility score.

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan utility score.

QC8 *Research Question:* Do drivers find the integrated system convenient to use?

Research Hypothesis: Drivers do not find the integrated system convenient to use (easy to learn, easy to use, and easily understand).

Importance: If drivers do not find the system to be convenient to use, analysis of this research question could point to areas for improvement in future integrated warning systems.

Method: Calculate the mean, median and standard deviation for the post-drive questions related to the ease of learning to drive with the integrated system (Q8, Q21, Q22, Q32

Q37), the ease of understanding what about the driving environment the system was trying to convey through the warnings (Q9, Q15, Q16), and calculate the satisfaction score from the Van der Laan scale (Q30).

Dependent Variables
Likert-type scale responses
Van der Laan satisfaction score

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores

QC9 *Research Question:* Do drivers' report a prevalence of false warnings that correspond with the objective false warning rate?

Research Hypothesis: Drivers' reports of false alarms will not correspond to objective rates of false warnings.

Importance: Addressing this question is important because it gives researchers a sense of how false alarms can "overshadow" a driver's experience with a warning system.

Method: Calculate the mean, median, and standard deviation for the post-drive questions related to the prevalence of false warnings (Q24, Q26, Q27, Q28). Perform exploratory analyses that attempt to determine if any relationship exists between false alarm rate and driver subjective ratings.

Dependent Variables
Likert-type scale responses.

Independent Variables
Proportion/rate of false alarms determined from objective data
Route Type

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and determine the relationship between observed false warnings and subjective impressions (acceptance).

QC10 *Research Question:* Do drivers find the integrated system to be easy to use?

Research Hypothesis: Drivers will not find the system easy to use.

Importance: Like question QC8, if drivers do not find the system to be easy to use, analysis of this research question could point to areas for improvement in future integrated warning systems.

Method: Calculate the mean, median, and standard deviation for the post-drive questions related to the comfort of using the integrated system (Q18, Q20). Also, calculate the utility score from the Van der Laan scale (Q30).

Dependent Variables
Likert-type scale responses
Van der Laan utility score

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.

QC11 *Research Question:* Do drivers find the integrated system to be easy to understand?

Research Hypothesis: Drivers will not find the system easy to understand.

Importance: If drivers do not find the system easy to understand, analysis of this research question could point to areas for improvement in future integrated warning systems and may contribute to a better understanding of drivers' responses to other questions.

Method: Calculate the mean, median, and standard deviation for the post-drive questions related to the ease of understanding the integrated system (Q21, Q22). Also, summarize the results of the question asking whether drivers relied on the system (Q13), and calculate the satisfaction score from the Van der Laan scale (Q30).

Dependent Variables
Likert-type scale responses
Van der Laan utility score

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.

4.2 Lateral Control and Warnings Analyses

This portion of the analyses will summarize the performance of the lateral drift (LDW) and lane change/merge (LCM) crash warning subsystems. This includes presentation of descriptive data addressing the warning rates and availability of the warning functionalities, as well as characterization of the scenarios when warnings were requested. Research questions related to lateral control of the vehicle and drivers' responses to the LDW and LCM warnings are listed. By performing the following analyses, it will be possible to describe any observed changes in driver performance associated with, and subjective responses to, those aspects of the integrated crash warning system that address lateral control and crash warnings.

4.2.1 Vehicle Exposure and Warning Activity Analyses

Lateral drift warning frequency in both the baseline and treatment conditions will be described. The descriptive statistics will include the characterization of LDW warnings based on driving scenario, and descriptions of the circumstances in which warnings are deemed false. Warning frequency and likelihood of false warnings will be presented as a function of road class, route type, driver, exposure (over time), and other conditional variables directly pertinent to the subsystem and lateral control.

Lane change/merge warning frequency in both the baseline and treatment conditions will be described. The descriptive statistics will include the characterization of LCM warnings based on driving scenario, and descriptions of the circumstances in which warnings are deemed false. Warning frequency and likelihood of false warnings will be presented as a function of road class, route type, driver, exposure (over time), and other conditional variables directly pertinent to the subsystem and lateral control.

4.2.2 Driver Behavior Research Questions

QL1 *Research Question:* Does lateral offset vary between baseline and treatment conditions?

Research Hypothesis: There will be no difference in lateral offset between the baseline and treatment conditions.

Importance: It is important to understand the overall effect of the integrated system on driver behavior, not just in the event of a warning. Previous FOTs have reported overall improvements in lane keeping by drivers because of a crash warning system, and it is believed that the same could be true in the IVBSS FOT.

Method: Identify a subset of lane keeping events by removing data with deliberate lane change or obstacle avoidance maneuvers. For the selected lane keeping events, collect the lateral offset distance, which is the distance between the center of the lane and the center of the subject vehicle. This analysis will compare the distribution of the vehicle's lateral offset for the baseline and treatment periods (Figure 1).

This analysis will depend on the set of steady-state lane keeping events that are pulled from the entire dataset. The lane keeping events examined for this analysis will be constrained by the criteria listed in Table QL1.1 to remove unwanted driving maneuvers. Intentional maneuvers such as lane changes, braking events, and large steering corrections will be removed. Additionally, these lane-keeping events will be limited to straight sections of road to limit the analysis to a clearly defined driving activity. The lateral offset will be computed for the independent variables listed in Table QL1.2.

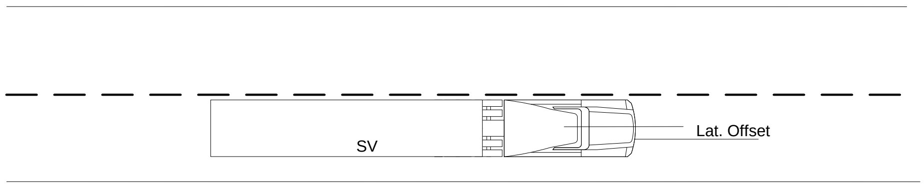

Figure 1. QL1 Concept drawing: Does lateral offset vary between baseline and treatment conditions?

Table QL1.1. Analysis Constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent
2. No intentional lateral or longitudinal maneuvers such as braking, large steering corrections, or lane changes.
3. Buffer time before and after any intentional maneuver removed above
4. Speed > 11.2 m/s (25 mph).

Table QL1.2. Variables

Dependent Variables
Lateral offset within lane

Independent Variables
Route Type
Speed
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Ambient Light (Day/Night)
Hours of Service (time behind the wheel)
Road Type

Data Analysis: Linear Mixed Models using driver as a random effect

Data Presentation: The data will be presented using illustrations similar to that shown in Figure 2. This is an example illustrating the affect of the RDCW system on lateral offset from the RDCW FOT final report (LeBlanc, et al, 2006).

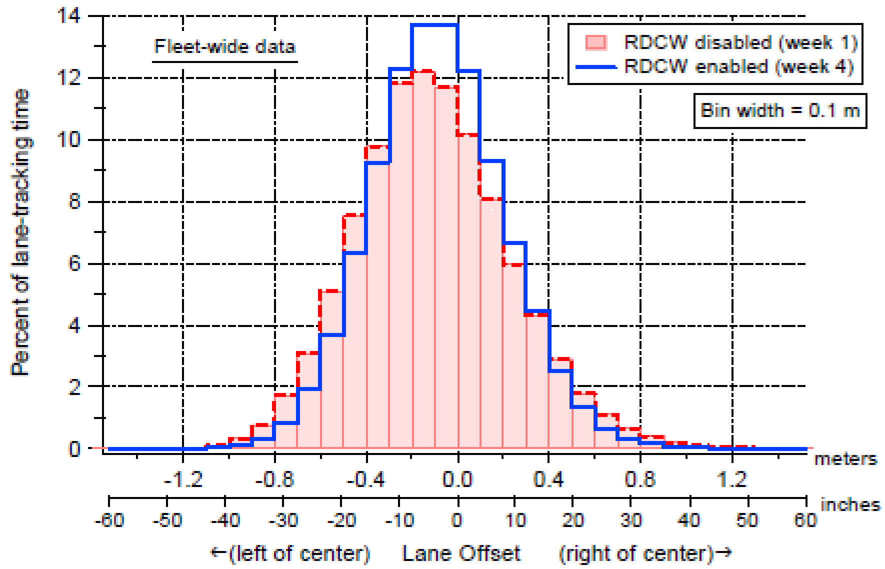

Figure 8.11 Distributions of lane offset during lane tracking, for the fleet during weeks 1 and 4

Figure 2. QL1 sample method of illustrating the affects of the integrated crash warning system on lateral offset.

QL2 *Research Question:* Does lane departure frequency vary between baseline and treatment conditions?

Research Hypothesis: There will be no difference in lane departure frequency between the baseline and treatment conditions.

Importance: One major goal of the FOT is to determine whether an integrated system can reduce the incidence of lane departures that might ultimately lead to a road departure and a crash.

Method: Identify all unintentional lane departure events based on the measurements made by the LDW system (i.e., the LDW subsystem requests a warning be issued). These lane departures will exclude periods of active driving preceding the drift event such as changing lanes, braking, and large steering corrections. The deliberate maneuvers will be excluded based upon review of video associated with the events. The analysis will compare the drift frequency for each of the independent variables listed in Table QL2.2. The drift frequency will be computed by counting the lane departures divided by the distance when the LDW system is available. A General Linear Mixed Models analysis will be conducted to determine if the frequency of lane departure warnings varies with the independent variables.

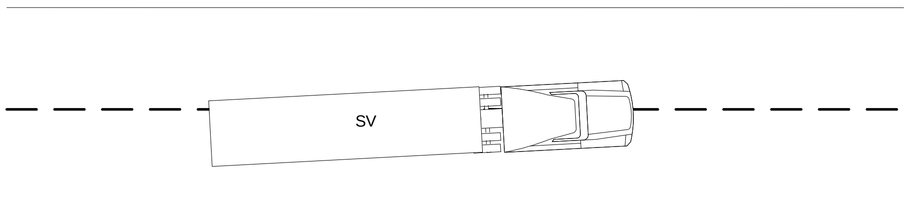

Figure 3. QL2 Concept drawing: Does the frequency of lane departures vary between baseline and treatment conditions?

Table QL2.1. Analysis Constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent 2. No lane changes, with or without turn signal 3. No intentional lateral or longitudinal maneuvers such as braking or large steering corrections 4. Speed > 11.2 m/s (25 mph).

Table QL2.2. Variables

Dependent Variables
Lane departure warning request

Independent Variables
Route Type
Speed
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Presence of POV in closing zone or blind zone
Ambient Light (Day/Night)
Hours of Service (time behind the wheel)
Boundary type
Road curvature
Road type

Data Analysis: General Linear Mixed Models using driver as a random effect and an appropriate distribution function, we will consider binomial, multinomial or Poisson distributions.

Data Presentation: The data will be presented using illustrations similar to that shown in Figure 4. This is an example illustrating the affect of the RDCW system on rates of lane departure warnings from the RDCW FOT final report (LeBlanc, et al, 2006).

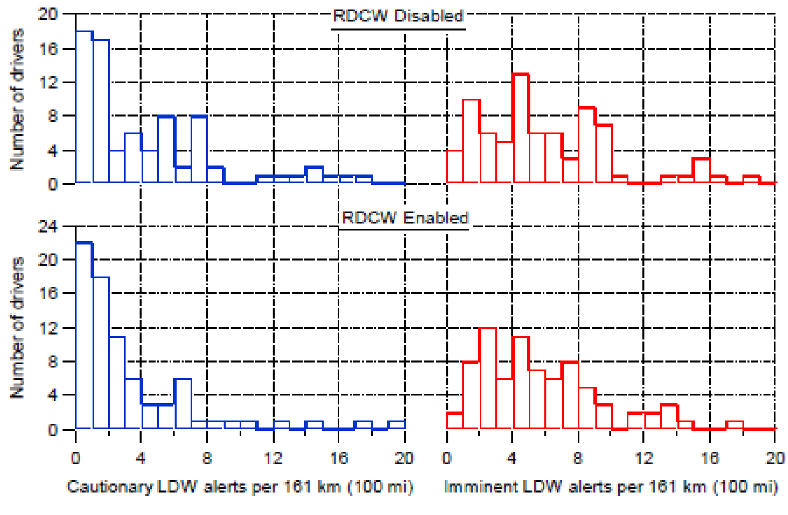

Figure 4. QL2 sample method of illustrating the affects of the integrated crash warning system on lane departure warning rates.

QL3 *Research Question:* When vehicles depart the lane, does the vehicle trajectory, including the lane incursion and duration, change between the baseline and treatment conditions?

Research Hypothesis: There is no difference in the distance or duration of the lane departures between the baseline and treatment conditions.

Importance: It is important to understand not only if the frequency of lane departures is reduced with the integrated system (QC2), but also the magnitude of a departure should it occur. In particular whether warnings from the integrated system prompt drivers to not deviate as fall out of the lane, and return sooner to their lane—whereby potentially reducing crash risk.

Method: Evaluate all lane departure events as identified by the lane tracking system where the edge of the vehicle crosses one of the lane boundaries. These lane departures will exclude periods of active driving such as changing lanes, braking, and large steering corrections preceding the drift event. For each of the selected lane departures, determine the time from when the edge of the vehicle first crosses the lane boundary to when the entire vehicle is again in its own lane. In addition, record the maximum lane incursion distance into the adjacent lane. All of the drift events in this analysis require the subject vehicle to return to its original lane in less than 20 seconds to exclude construction zones, passing maneuvers, or similar scenarios. This return time is intended to be long enough for a slow drifting vehicle (0.2 m/s, or 0.45 mph, lateral velocity) to exceed the lane boundary and return (about 10 seconds for a large excursion – the center line of the vehicle crossing the lane boundary).

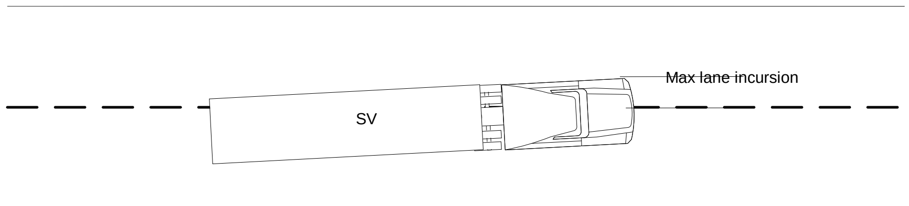

Figure 5. QL3 Concept drawing: When vehicles depart the lane, does the trajectory, including the lane incursion and duration, change between the baseline and treatment conditions?

Table QL3.1. Analysis constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent
2. No lane changes, with or without turn signal
3. No intentional lateral or longitudinal maneuvers such as braking or large steering corrections
4. Subject vehicle returns to original lane in less than 20 seconds
5. Speed > 11.2 m/s (25 mph).

Table QL3.2. Variables

Dependent Variables
Maximum lane incursion distance
Duration of incursion
Independent Variables
Route Type
Speed
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Presence of POV in closing zone or blind zone
Ambient Light (Day/Night)
Hours of Service (time behind the wheel)
Boundary type
Road Type

Data Analysis: Linear Mixed Models using driver as a random effect.

Data Presentation: The data will be presented using illustrations similar to that shown in Figure 6. These are example illustrations showing the affect of the RDCW system on the extent of lane incursion and duration from the RDCW FOT final report (LeBlanc, et al, 2006).

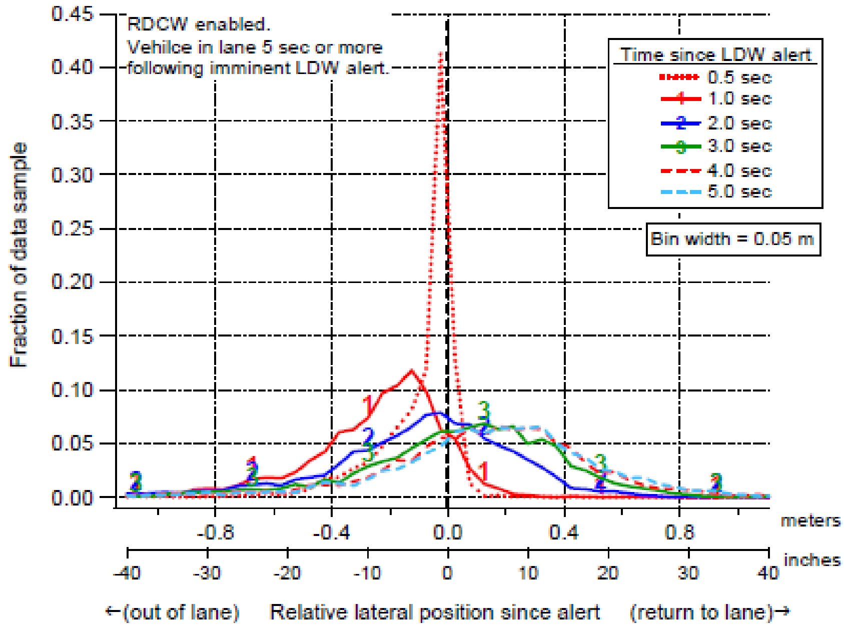

Figure 8.2 Distributions of the change in lateral lane position for vehicles remaining in the lane for 5 seconds following imminent LDW alerts

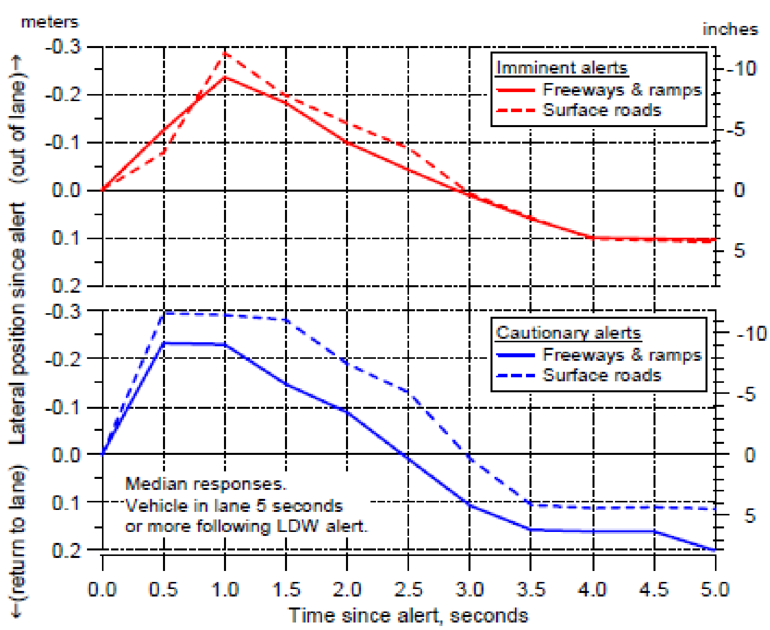

Figure 8.3 Median lateral-position responses for vehicles remaining in the lane for 5 seconds following LDW alerts: by alert level and road type

Figure 6. QL3 sample method of illustrating the affects of the integrated crash warning system on extent and duration of lane departures.

QL4 *Research Question:* Does turn signal usage during lane changes differ between the baseline and treatment conditions?

Research Hypothesis: There will be no difference in the use of the turn signals for lane changes with the integrated system.

Importance: It is important to understand the overall affect of the integrated system on driver behavior, not just in the event of a warning. Previous FOTs have reported overall improvements in turn signal use by drivers because of a crash warning system, and it is believed that the same could be true in the IVBSS FOT.

Method: Identify a set of left and right lane-change events to determine if the corresponding lateral-direction indicator (turn signal) is used differently when the integrated system is enabled as compared to the baseline period as show in Figure 7. Fundamentally, this analysis will address changes in the frequency of turn signal use for lane changes, that is, it will compare lane-changes with and without the use of a turn signal for both baseline and treatment periods. Additional analysis will then address if there is a measureable difference in turn-signal activation as measured by the amount of time between when the turn signal is activated on by the driver and the occurrence of the lane-change for both the baseline and treatment periods.

To perform this analysis a set of constrained and well-defined lane-changes will be identified in the data set. Lane-changes are comparatively complex events that involve both infrastructure information, primarily lane boundary demarcation, as well as lateral performance information from the sensors onboard the vehicle. At one extreme they occur on poorly marked roads but can be identified by patterns in the lateral kinematic variables that when integrated show a lateral translation of approximately 3.6 m (11.8 feet), a typical lane width, within a defined period. At the other extreme, they occur on well-marked roads but without any noticeable difference in the lateral performance, as is the case when the lane-change occurs at the entry or exit to curves (i.e., the road changes laterally relative to the path of the vehicle). To control for the complex nature of defining lane-changes the analysis will be constrained to lane-change events that meet the criteria shown in Table QL4.1. To define the instant in time when a lane-change occurs, the analysis will use the time when the lateral centerline of the vehicle crosses the shared boundary line between the old and new lanes.

Shown in Table QL4.2 are the dependent variables for the analysis and a list of independent variables that will be included in the analysis to investigate the relationship between turn-signal use and other aspects of the vehicle environment and performance criteria.

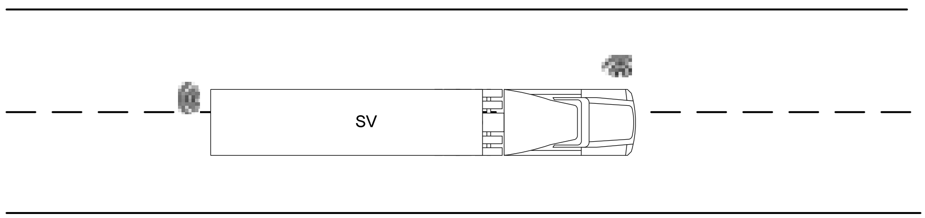

Figure 7. QL4 Concept drawing: Turn signal usage during lane changes.

Table QL4.1. Analysis Constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent
2. Lane change is across a dashed boundary type
3. Lane change is performed on a straight segment of roadway
4. Speed > 17.9 m/s (40 mph).
5. No intentional lateral maneuvers by the SV driver in a five second window prior to the lane change (i.e., the SV is in a steady state condition within its lane).

Table QL4.2. Variables

Dependent Variables
Use of turn signal and duration of turn signal

Independent Variables
Route Type
Side (Left or Right)
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Ambient Light (Day/Night)
Road Type

Data Analysis: Generalized Linear Mixed Models with generalized logit link and driver as a random effect.

Data Presentation: The data will most likely be presented in a tabular format.

QL5 *Research Question:* Do drivers change their position within the lane when another vehicle occupies an adjacent lane?

Research Hypothesis: When adjacent same-direction traffic is present on only one side of the host vehicle, drivers will not alter their lane position to increase the separation between the host and vehicle and the adjacent traffic.

Importance: It is important to understand the overall affect of the integrated system on driver behavior, not just in the event of a warning. If drivers are receiving too many LCM warnings, they may attempt to reduce the frequency of these warnings my maintaining a larger distance from adjacent vehicles. However, in maintaining a larger distance, drivers might also be increasing the risks of a warning, or crash, on the opposite side of the vehicle.

Method: For this analysis, a large set of randomly sampled events of 5 seconds in duration will be identified in the data set. For every event, in this set, a lane-offset position will be calculated that characterizes the lateral position of the vehicle, with respect to the lane boundary markers, within the lane. Additionally, each candidate event will be characterized as being in an environment in which there is no object or vehicle occupying the opposite space adjacent to the vehicle, which may inhibit the driver from changing his lateral position away from a passing vehicle. This opposite space is shown in Figure QL5.1 as a clear should or unoccupied adjacent lane. The qualification of this ‘empty’ space will be determined by the side and rear sensing radar showing the space as unoccupied. To reduce possible lane-position adjustments for other reasons, the constraints shown in

Table will be implemented. These constraints will require the event to occur on straight sections of road with good boundaries in which there was no intentional lateral maneuvers temporally near the each sample (Table QL5.1). Finally, each element in the set will be analyzed to determine if a vehicle (or vehicles) is present in the space adjacent to the subject vehicle as shown by the crosshatched region in Figure 8.

Shown in Table QL5.2 are the dependent variables for the analysis and a list of independent variables that will be included in the analysis to investigate the relationship between turn-signal use and other aspects of the vehicle environment and performance criteria.

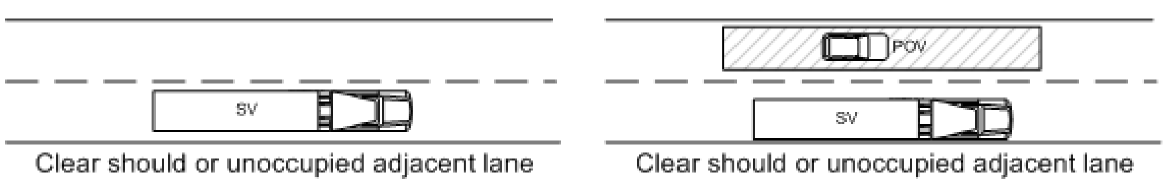

Figure 8. QL5 Concept drawing: Lane offset change away from an occupied space.

Table QL5.1. Analysis Constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent
2. Straight Road
3. Speed > 11.2 m/s (25 mph).
4. No intentional lateral maneuvers by the driver in near temporal proximity to each 5 second event

Table QL5.2. Variables

Dependent Variables
Average distance to the shared lane boundary

Independent Variables
Route Type
Side (Left or Right) of restricted AMR
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Ambient Light (Day/Night)
Road Type

Data Analysis: Linear Mixed Models using driver as a random effect.

Data Presentation: The data will be presented in illustrations similar to that shown in Figure QL3.2. The illustrations will show the degree of lateral offset relative to an occupied or unoccupied adjacent space.

QL6 *Research Question:* What is the location of all adjacent vehicles relative to the subject vehicle for valid LCM warnings?

Research Hypothesis: Valid LCM warnings will be evenly distributed along the side of the tractor and trailer unit.

Importance: It is important to understand where vehicles are located when they result in LCM warnings in order to understand how future systems can be improved and contribute to drivers' perception of the systems utility.

Method: Divide the region adjacent to each side of the heavy truck into three zones for the front and rear backspotter radar and the rear looking (trailer coverage) MACOM radar as shown in Figure 9. Identify a set of not less than 200 LCM warnings for conditions in which the space adjacent to the truck is occupied by a same-direction vehicle only. That is, the conditional statements operating on the objective data must exclude cases in which the space was occupied by a fixed roadside object such as a guardrail or barrier or cases in which the system mistakenly characterized a reflective object from the trailer as an adjacent vehicle. Next, for each LCM event, characterize the zones on the corresponding side of the vehicle as being occupied or not. Next, for those targets in the rear-looking radar zone identify the range and range-rate from the radar to the closest vehicle in that zone. The analysis is to be performed using the constraints shown in Table QL6.1. These rules will help establish a steady-state condition for the subject vehicle and dictate how long the turn signal and targets had to have persisted for the event to be considered a candidate for the analysis. Warning validity will be determined by reviewing video associated with the events.

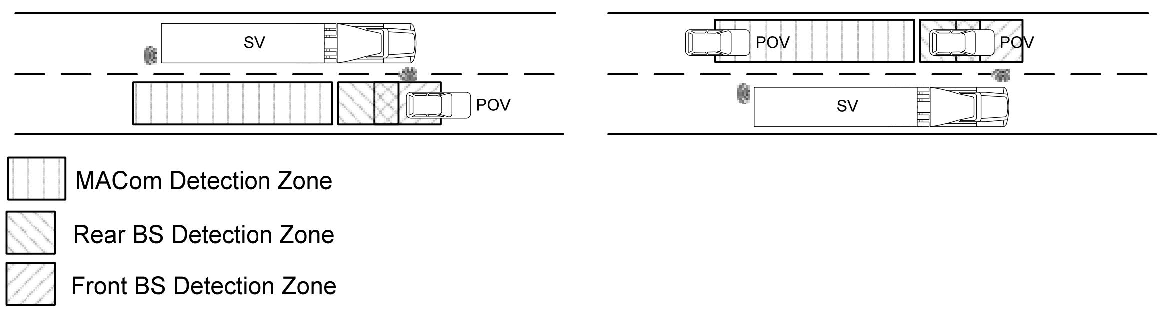

Figure 9. QL6 Concept drawing: Adjacent zone to determine the location of adjacent vehicles relative to the subject vehicle for valid LCM warnings.

Table QL6.1. Analysis Constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent
2. Dashed boundary between the SV and POV(s)
3. Turn signal active for at least 1 s before LCM warning is issued
4. Speed > 11.2 m/s (25 mph).
5. For MACOM radar: target duration > 2 s and a non-zero range rate
6. For backspotter radar: the vehicle is present for at least 2 s at a range between 0 and 10 ft.
7. No intentional lateral maneuvers by the SV driver in a five second window prior to the LCM (i.e., the SV is in a steady state condition within its lane).

Table QL6.2. Variables

Dependent Variables
Count and distribution of valid LCM warnings for the six zones around the vehicle

Independent Variables
Route Type
Side (Left or Right)
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Ambient Light (Day/Night)
Road Type

Data Analysis: Linear Mixed Models using driver as a random effect.

Data Presentation: The data will be presented in illustrations, as well as in tabular format, to show distributions of vehicle location for valid LCM warnings.

QL7 *Research Question:* Will drivers change lanes less frequently in the treatment period, once the integrated system is enabled?

Research Hypothesis: The frequency of lane changes is independent of whether the LCM subsystem is enabled.

Importance: It is important to understand the overall affect of the integrated system on driver behavior, not just in the event of a warning. Previous FOTs have reported reductions in lane changes by drivers because of a crash warning system, and it is believed that the same could be true in the IVBSS FOT.

Method: Identify all instances of valid lane changes with the use of the turn signal.

Table QL7.1. Analysis Constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent
2. Lane change is across a dashed boundary type
3. Lane change is performed on a straight segment of roadway
4. Turn signal active for at least 1 s before the lane change
5. Speed > 11.2 m/s (25 mph).
6. No intentional lateral maneuvers by the SV driver in a five second window prior to the lane change (i.e., the SV is in a steady state condition within its lane).

Table QL7.2. Variables

Dependent Variables
Lane changes performed

Independent Variables
Route Type
Treatment Condition
Wiper State
Trailer Configuration
Hours of service
Ambient Light (Day/Night)
Road Type
Route type
Surrogate measure of traffic density

Data Analysis: General Linear Mixed Models with driver as a random effect. For frequency, evaluate the use of the negative binomial distribution.

Data Presentation: The data will be presented in figures, as well as in tabular format, to show the prevalence of lane changes.

QL8 *Research Question:* Is the gap between the subject vehicle (SV) and other leading vehicles influenced by the integrated system when the SV changes lanes behind a principal other vehicle (POV) traveling in an adjacent lane?

Research Hypothesis: The size of the gap between the SV and POVs that drivers are willing to allow when changing lanes will not be influenced by the integrated system.

Importance: Gap size is important to understand because it is directly related to the time a driver has available to respond should a lead vehicle brake suddenly. Ideally, use of the integrated system would make drivers more aware of unsafe following distances, and therefore they would allow more distance between themselves and lead vehicles.

Method: Identify instances where the SV is closing in on a lead vehicle in the same lane and makes a lane change behind a passing POV1 in an adjacent lane. For each event code the closing rate and range to POV2 at the instant when the SV left front tire crosses the boundary for the last reliable forward measure from the FCW radar as illustrated in Figure 10. Also, upon changing lanes determine the range and range-rate of the SV to POV1. Video data of each event will be reviewed. Quantitative data will be used to determine the position of the SV left front tire when possible, and analysis of video will be used for the other cases when the boundaries are obscured by a lead vehicle. It is assumed that lane changes to the right under similar circumstances are rare, and therefore only lane changes to the left will be considered. The constraints identified in Table QL8.1 will be used to ensure that the candidate set of events is reliable and consistent with the scenario definition.

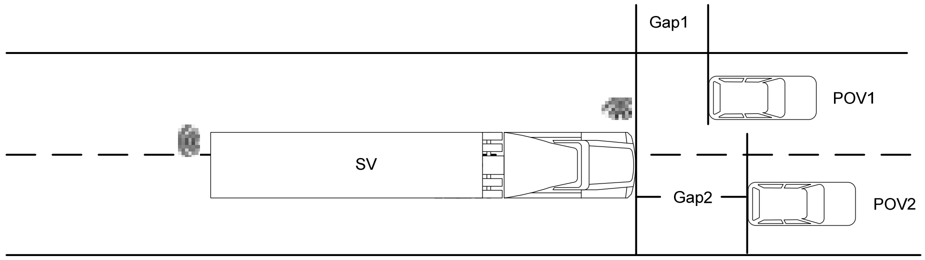

Figure 10. QL8 Concept drawing: Location of adjacent and forward vehicles relative to the subject vehicle during lane-changes.

Table QL8.1. Analysis Constraints

Constraints
1. Boundary types known and lane offset confidence 100 percent
2. Lane change is across a dashed boundary type
3. Lane change is performed on a straight segment of roadway
4. Turn signal active for at least 1 s before the lane change
5. Speed > 11.2 m/s (25 mph).
6. No intentional lateral maneuvers by the SV driver in a five minute window prior to the lane change (i.e., the SV is in a steady state condition within its lane).

Table QL8.2. Variables

Dependent Variables
Range and range-rate between the SV, POV1, and POV2 during lane changes.

Independent Variables
Route Type
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Ambient Light (Day/Night)
Road Type

Data Analysis: Linear Mixed Models using driver as a random effect.

Data Presentation: The data will be presented in illustrations, as well as in tabular format, to describe the location and distance separation of adjacent and forward vehicles (POVs) relative to the SV during lane-changes.

4.2.3 Driver Acceptance Research Questions

QL9 *Research Question:* Are drivers accepting of the LDW subsystem (i.e., do drivers want LDW systems on their vehicles)?

Research Hypothesis: Drivers will be indifferent regarding wanting LDW on their vehicles.

Importance: It is important to understand whether drivers want the LDW as part of an integrated warning system. This analysis will help to identify how the systems need to be improved in order for drivers to become more accepting of them. Acceptance by drivers will be critical to ensuring that integrated systems reach the market place in order to have any impact on reducing crashes.

Method: Calculate the mean, median and standard deviation for the post-drive question related to the overall acceptance of the LDW subsystem (Q27) and calculate the overall score from the LDW and LCM Van der Laan scale questions (Q43).

Dependent Variables
Responses to Likert-type scale responses and Van der Laan score.

Independent Variables
Route Type (Pick-up and Delivery vs. Line Haul)

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.

QL10 *Research Question:* Do drivers find the integrated system to be useful, what attributes and in which scenarios was the integrated system most and least helpful?

Research Hypothesis: Drivers will be indifferent regarding the integrated crash warning system being useful.

Importance: It is important to understand whether drivers find utility in the LDW and LCM subsystems as part of an integrated warning system. If drivers are going to accept these systems, they will need to be perceived as contributing to the reduction of crashes.

Method: Calculate the mean, median and standard deviation for post-drive questions related to the overall utility of the integrated crash warning system (Q4, Q6, Q9), summarize responses to the related open-ended questions (Q1, Q2, Q5), and calculate the perceived usefulness score from the Van der Laan scale (Q30).

Dependent Variables
Responses to Likert-type scale responses and Van der Laan score.

Independent Variables
Route Type (Pick-up and Delivery vs. Line Haul)

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.

QL11 *Research Question:* Are drivers accepting of the LCM subsystem (i.e., do drivers want LCM on their vehicles)?

Research Hypothesis: Drivers will be indifferent regarding wanting LCM on their vehicles.

Importance: It is important to understand whether drivers want LCM subsystems as part of an integrated warning system. This analysis will help to identify how the systems need to be improved in order for drivers to become more accepting of LCM. Acceptance by drivers will be critical to ensuring that integrated systems reach the market place in order to have any impact on reducing crashes.

Method: Calculate the mean, median and standard deviation for the post-drive question related to the overall acceptance of the LCM subsystem (Q26) and calculate the overall score from the LCM Van der Laan scale question (Q43).

Dependent Variables
Responses to Likert-type scale responses and Van der Laan score.

Independent Variables
Route Type (Pick-up and Delivery vs. Line Haul)

Data Analysis and Presentation: Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.

4.3 Longitudinal Control and Warnings

This portion of the analyses will summarize the performance of the forward crash warning subsystem. This includes presentation of descriptive data addressing FCW warning rates and characterization of the scenarios when warnings were requested. Research questions related to longitudinal control of the vehicle and drivers' responses to the FCW warnings are listed. The following analyses are intended describe any observed changes in driver performance associated with, and subjective responses to, the FCW component of the integrated crash warning system.

4.3.1 Vehicle Exposure and Warning Activity Analyses

Forward crash warning frequency in both the baseline and treatment conditions will be described. The descriptive statistics will include the characterization of FCW warnings based on driving scenario, and descriptions of the circumstances in which warnings are deemed false. Warning frequency will be presented as a function of road class, route type, driver, exposure (over time), and other conditional variables directly pertinent to the FCW subsystem and longitudinal control of the vehicle. A characterization of the circumstances in which false warnings occur will also be done.

4.3.2 Driver Behavior Research Questions

QF1 *Research Question:* Does the use of the integrated system affect the following distances maintained by the heavy truck drivers?

Research Hypothesis: Measures of following distance do not vary between baseline and treatment conditions.

Importance: Following distance is important to understand because it is directly related to the time a driver has available to respond should a lead vehicle brake suddenly. Ideally, use of the integrated system would make drivers more aware of unsafe following distances, and therefore they would allow more distance between themselves and lead vehicles.

Method: Compute and compare various statistics of following distance when the integrated system is enabled and disabled. This will be done for those periods of time when the heavy truck is in a quasi-steady state "following" mode.

The definition of "following" mode was established in past projects for light vehicle (Ervin et al., 2005), and the specific thresholds will be updated for heavy trucks by using IVBSS FOT data. This definition is intended to consider only extended periods of following behavior, which exclude significant forward conflict (i.e., sizable closing speeds), lane changes, turns, or other maneuvers by either the preceding or the following vehicle that introduce confounding influences on the heavy truck driver's intentions or ability to maintain his or her preferred following distance. The following distance measure will be the time headway (distance to the preceding vehicle divided by the following vehicle's speed). Detecting changes in the distribution of time headway will be done following previous approaches developed in Ervin et al., 2005. Detecting changes in time headway will be done after identifying the factors that influence drivers' choice of that measure; candidates for this list of factors are listed in Table QF1.2 as independent variables.

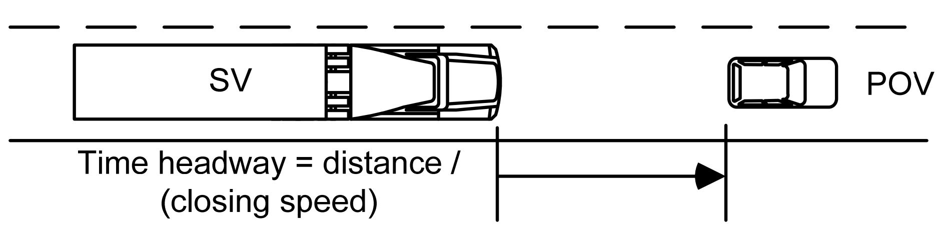

Figure 11. QF1 Concept drawing: Time headway margin.

Table QF1.1 Analysis Constraints

Constraints
1. Speed > 11.2 m/s (25 mph).
2. Neither the subject vehicle nor the principal other vehicle is undertaking a maneuver; the drivers of both vehicles are only seeking to maintain a fixed speed and a fixed lane. The speed and lane choice remain fixed for a period of many seconds.
3. The time headway is less than a specific value. This value may be approximately 3 to 8 seconds, and will be determined by using IVBSS FOT data to determine the headway at which truck drivers alter their speed because of a preceding vehicle.

Table QF1.2. Variables

Dependent Variables
Statistic representing the distribution of time headway

Independent Variables
Route Type
Speed
Treatment Condition
Wiper State
Average Axle Load
Ambient Light (Day/Night)
Trailer Configuration
Hours of Service (time behind the wheel)
Road Type
Surrogate measure of traffic density

Data Analysis: Linear Mixed Models with driver as random effect

Data Presentation: The data will be presented using illustrations similar to that shown in Figure 12. This is an example illustration showing the affect of a forward collision warning system on headway maintenance from the ACAS FOT final report (Ervin, et al, 2005).

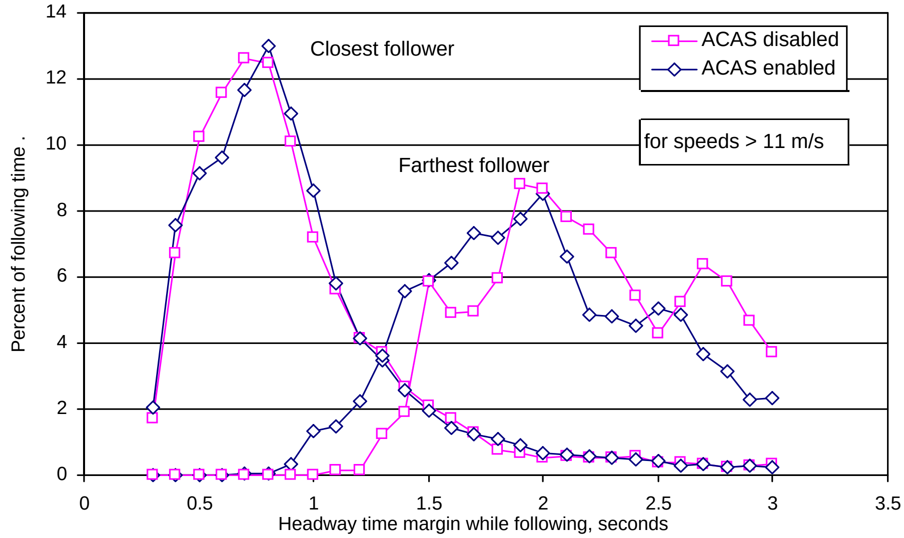

Figure 12. QF1 sample method of illustrating the affects of the integrated crash warning system on headway maintenance.

QF2 *Research Question:* Will the frequency and/or magnitude of forward conflicts be reduced between the baseline and treatment conditions?

Research Hypothesis: The integrated system will not change the frequency or severity of forward conflict events.

Importance: One major goal of the FOT is to determine whether an integrated system can reduce the incidence of forward conflicts that might ultimately lead to rear-end crashes.

Method: The dependent measure will be the actual deceleration required to maintain a minimal headway margin. Unlike typical uses of required deceleration measures, this analysis will use the actual motion of the POV during the entire maneuver in this calculation. This new metric has the advantage that it computes a small deceleration value if little slowing of the SV is required to avoid impact, and yet computes a large deceleration value if indeed significant braking is required. Furthermore, the metric assumes that drivers not only wish to avoid impact, but also seek to maintain some minimal margin in near crashes. The value for the parameter that represents the minimal headway that drivers wish to maintain will be determined by using IVBSS FOT data in the baseline mode.

Tables QF2.1 and QF2.2 show the analysis constraints and the dependent and independent variables, respectively.

Driving scenarios will include two classes of scenarios, each with at least the following specific scenarios

- Shared-lane scenarios (in which the SV and POV remain in the same lane for several seconds before and after the peak conflict):
  - POV decelerating to a stop or near stop (both near and far from intersections with traffic signals or stop signs)
  - POV decelerating, but not approaching a near stop
  - POV at constant speed
  - POV stopped for several seconds before peak conflict occurs
- Multiple-lane scenarios:
  - POV decelerating and leaving the SV's lane (includes lane changes and turns)
  - SV passing POV
  - POV merges or cuts in front of POV

These scenarios will be identified automatically using many variables including, but not limited to, radar data, vehicle speed, yaw rate, SV accelerations, driver brake and throttle actions, and roadway attribute data. These automatic determinations involve substantial filtering of data and the algorithms will be built upon those used previously for light vehicles (Ervin et al., 2005). The algorithms will need to be expanded for this analysis since the plan is to distinguish between more scenarios, but the basic pieces of identifying SV and POV maneuvers have been done previously. Completing the algorithms will involve a moderate effort whereby SQL code is written to identify elements of the maneuvers. The algorithms are then validated through use of video. The final algorithms and validation efforts will be documented in the analysis report.

Another independent variable will be the average axle load for the trailers, which affects the braking and stability characteristics of the truck in heavy braking. Using the average axle load is a way to address variation in different trailer configurations and loading levels while minimizing how much the data is subsetted (and thus preserving as much statistical power as possible).

The surrogate measure of traffic density will be similar to that used in the ACAS FOT program (Ervin et al., 2005) and is based upon observations of same-direction traffic in the SV's lane and, where appropriate, in adjacent lanes. Algorithms used to estimate independent and dependent variables, such as average axle load, traffic density, and required deceleration to maintain a minimum headway will all be documented in the analysis report. For example, the minimum headway to be used may have a default value of 0.25 sec based on a preliminary engineering judgment that drivers may consider this the smallest headway time margin to be maintained in near-crash conditions. IVBSS baseline data for the driver population will be used to determine whether this preliminary estimate seems reasonable.

Table QF2 shows that statistics of the dependent variable will be used to test the hypothesis for this research question. The following statistics will be considered and reported (these are similar to those used for FCW analyses in Ervin et al., 2005):

- The rates of significant conflict per hundred potential conflicts, for each driver, with and without IVBSS,
- The mean value for the required deceleration to maintain a minimum headway, for each driver, with and without IVBSS,
- The 90th percentile value for the required deceleration to maintain a minimum headway, for each driver, with and without IVBSS, where 90th percentile corresponds to rather high-required decelerations.

In the case of Ervin et al., 2005, which was for passenger vehicles, each of these statistics was seen as a meaningful metric that together could suggest whether drivers were changing their forward conflict characteristics.

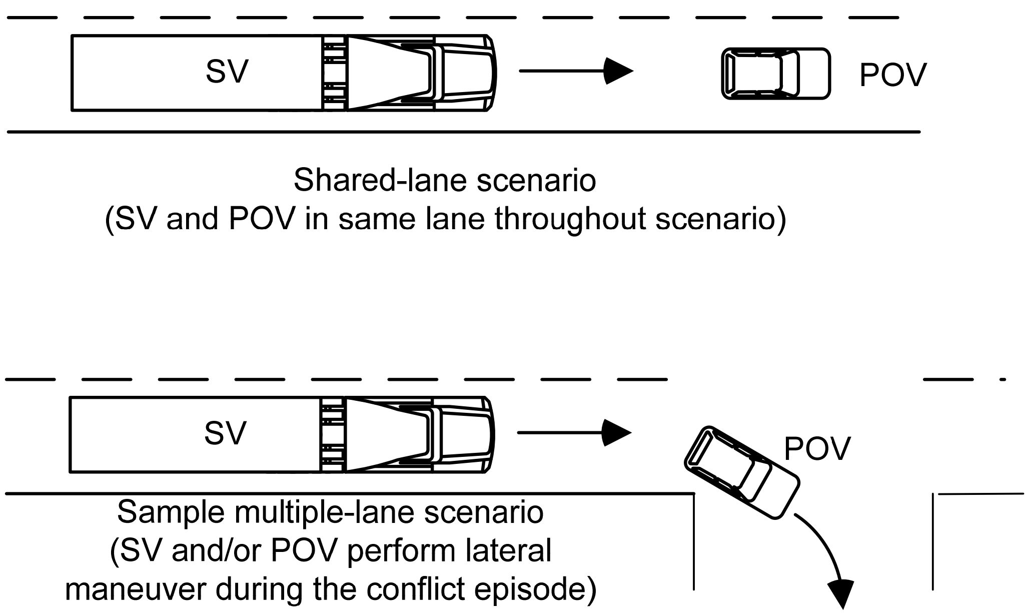

Figure 13. QF2 Concept drawing: Actual deceleration required to maintain a headway buffer

Table QF2.1 Analysis Constraints

Constraints
1. Speed > 11.2 m/s (25 mph).
2. The data allows a confident automatic identification of the driving scenario.

Table QF2.2. Variables

Dependent Variable
Statistics of the actual deceleration required to maintain a minimal headway
Independent Variables
Route Type
Speed
Treatment Condition
Wiper State
Average Axle Load
Ambient Light (Day/Night)
Trailer Configuration
Hours of Service (time behind the wheel)
Road Type
Driving scenario as listed above (only those with sufficient data will be treated statistically)
Surrogate measure of traffic density

Data Analysis: General Linear Mixed Models with driver as random effect and consideration of alternative distributions and corresponding link functions (e.g., negative binomial for count data)

Data Presentation: The data will be presented in illustrations, as well as in tabular format.

QF3 *Research Question:* Does the integrated system affect the frequency of hard-braking maneuvers involving a stopped or slowing POV?

Research Hypothesis: The integrated system will have no effect on either the frequency of hard braking maneuvers involving a slower or slowing POV.

Importance: One major goal of the FOT is to determine whether an integrated system can reduce the incidence of forward conflicts that might ultimately lead to rear-end crashes. If the FCW subsystem is affective, then one might expect fewer hard-braking maneuvers with the integrated system as a result if increased driver awareness.

Method: Looking at actual braking level is a complement to the investigation described in QF2, in which the actual required deceleration is studied. The consideration here of actual braking levels recognizes that hard braking – whether required or not – may contribute to crash risk for heavy trucks because of their unique dynamics. Only those events in which a POV may contribute to the driver's use of braking are considered. For instance, the analysis will not address cases in which the SV is stopping without a POV. The constraints and independent variables are the same as those in QF2, including the use of the driving scenarios listed under question QF2.

The dependent variable is the deceleration used. This will be the peak-sustained deceleration (sustained over one second) during any braking event. Two statistics will be used:

- The frequency per mile of braking events where the sustained peak braking level is greater than 0.3 g.
- The 90th percentile value of braking levels for situations that require at least 0.15 g braking, as computed using the required deceleration metric described under question QF2.

The first item addresses whether hard braking occurs more or less often with IVBSS. The second item examines whether the use of IVBSS results in fewer extreme braking situations.

Table QF3.1. Analysis Constraints

Constraints
1. Speed > 11.2 m/s (25 mph).
2. The data allows a confident automatic identification of the driving scenario.

Table QF3.2. Variables

Dependent Variable
Statistics of the decelerations employed by the driver.

Independent Variables
Route Type
Treatment Condition
Speed
Wiper State
Average Axle Load
Ambient Light (Day/Night)
Trailer Configuration
Hours of Service (time behind the wheel)
Road Type
Driving scenario (only those with sufficient data will be treated statistically)
Surrogate measure of traffic density

Data Analysis: Linear Mixed Models with driver as random effect.

Data Presentation: The data will be presented in illustrations, as well as in tabular format.

QF4 *Research Question:* Will the integrated system warnings improve drivers' responses to those forward conflicts in which closing-speed warnings occur? (Closing-speed warnings are those that are triggered by the SV closing on the POV, and not those warnings associated with following distance alone.)

Research Hypothesis: The integrated system will not affect drivers' responses in closing-speed FCW events.

Importance: One major goal of the FOT is to determine whether an integrated system can reduce the incidence of forward conflicts in part by increasing drivers' awareness of lead vehicles and closing rates. If the FCW subsystem is affective then one might expect fewer conflicts with lead vehicles, and conflicts that do occur should be less severe.

Method: Two dependent measures will be used. One is the time lag between the warning and the time at which the conflict is resolved, and the other is the peak conflict metric that develops after the warning is issued. The conflict is considered resolved at the latest moment that the deceleration of the SV matches the actual deceleration required (as defined in the discussion of QF2). The peak conflict metric is the maximum difference between the actual deceleration required at any moment and the associated deceleration of the SV.

Tables QF4.1 and QF4.2 show the analysis constraints and the dependent and independent variables, respectively. These were discussed in previous forward-conflict research question discussions. Driving scenarios addressed will consider the set of shared-lane scenarios, as defined in the discussion of QF2.

Table QF4.1 Analysis Constraints

Constraints
1. Speed > 11.2 m/s (25 mph).
2. The data allows a confident automatic identification of the driving scenario.
3. Shared-lane scenarios.

Table QF4.2. Variables

Dependent Variables
Time lag between the warning and the time at which the conflict is resolved.
Peak value of the difference between the actual deceleration required and the driver's deceleration (after the warning is issued).

Independent Variables
Route Type
Speed
Treatment Condition
Wiper State
Average Axle Load
Trailer Configuration
Hours of Service (time behind the wheel)
Road Type
Driving scenario (only scenarios those with sufficient data will be treated statistically

Data Analysis: General Linear Mixed Models with driver as random effect and consideration of alternative distributions and corresponding link functions (e.g., negative binomial for count data).

Data Presentation: The data will be presented in illustrations, as well as in tabular format.

4.3.3 Driver Acceptance Research Questions

QF5 *Research Question:* Are drivers accepting of the FCW subsystem (i.e., do drivers want this system on their vehicles)?

Research Hypothesis: Drivers will be indifferent regarding wanting FCW on their vehicles.

Importance: It is important to understand whether drivers want the FCW subsystem as part of an integrated system, and if not, how the FCW subsystem needs to be improved in order for drivers to become more accepting. Acceptance by drivers will be critical to ensuring that integrated systems reach the market place in order to have any impact on reducing crashes.

Method: Calculate the mean, median, and standard deviation for post-drive questions regarding how easy the DVI was to understand (Post-drive survey questions Q28 and Q36).

Dependent Variables
Responses to Likert-type scale responses

Independent Variables
Route Type (Pick-up and Delivery vs. Line Haul)

Data Analysis and Presentation: Summarize open-ended responses and provide histograms of responses to Likert-type scales.

4.4 Driver-Vehicle Interface

This portion of the analyses will summarize drivers' perceptions of the driver-vehicle interface for the integrated crash warning system. This analysis builds off descriptive data for the collective system as well as the FCW, LDW and LCM subsystems by attempting to find a relationship between the frequency drivers experience warnings and their acceptance and understanding of the integrated crash warning system.

4.4.1 Driver Acceptance Research Questions

QD1 *Research Question:* Did drivers perceive the driver-vehicle interface for the integrated system easy to understand?

Research Hypothesis: Drivers will not find the driver-vehicle interface easy to understand.

Importance: If drivers do not find the driver-vehicle interface of the integrated system easy to understand, analysis of this research question could point to areas for improvement in future integrated warning systems and may contribute to a better understanding of drivers' responses to other questions.

Method: Calculate the mean, median, and standard deviation for post-drive questions regarding how easy the DVI was to understand (Post-drive survey questions Q15, Q16, Q31).

Dependent Variables
Responses to Likert-type scale responses

Independent Variables
Route Type (Pick-up and Delivery vs. Line Haul)

Data Analysis and Presentation: Summarize open-ended responses and provide histograms of responses to Likert-type scales.

QD2 *Research Question:* Do drivers find the volume and mute controls useful, and do they use them?

Research Hypothesis: Drivers do not find the volume and mute controls useful, and do not use them.

Importance: This question is important because it will contribute to an understanding of how drivers may have coped with a high frequency of warnings, and will help to suggest whether similar controls need to be included in future integrated warning systems.

Method: Calculate the mean, median, and standard deviation for post-drive questions regarding how useful the volume and mute controls were (Post-drive survey questions Q33, Q34.) Also, calculate the mean, median, and standard deviation for the post-drive question regarding drivers' acceptance of new technology in their truck (Q38).

Dependent Variables
Responses to Likert-type scale responses

Independent Variables
Route Type

Data Analysis and Presentation: Summarize open-ended responses and provide histograms of responses to Likert-type scales.

5 Conclusions

This document presented a data analysis plan for the heavy truck platform of the Integrated Vehicle-Based Safety Systems Field Operational Test (IVBSS FOT), providing an overview of the analyses that UMTRI expects to perform using data collected from the heavy truck field operational test. A significant quantity of objective data will be produced during the FOT that can be used to describe the manner in which the vehicles were driven over an estimated 620,000 miles. This data is critical to assessing not only potential for safety benefits attributable to the integrated crash warning system, but also to determine whether there are any potential negative consequences associated with the integrated warning system.

The analyses that UMTRI expects to perform are based upon 29 specific research questions that emphasize the effect that the integrated warning system has on driver behavior and driver acceptance of the integrated system. Each research question, hypothesis, relative importance, and a summary of the anticipated analysis methods and techniques were provided. The product of these analyses should be guidance for the development of future integrated systems, highlighting characteristics that worked well as well as those that did not.

UMTRI views the analysis plan, and any further development, as a collaborative and iterative processes that will engage the independent evaluators and the U.S. DOT in order to ensure that the analyses conducted by UMTRI and the independent evaluator are complementary.

The final outcome of the UMTRI analyses of the heavy truck data will be included in a US DOT report in late 2010 that describes in detail 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 can be attributed to the integrated crash warning system, and whether the truck drivers were accepting of the integrated system. Finally, recommendations for the design of future integrated systems will be offered.

6 References

Ervin, R., Sayer, J., LeBlanc, D., Bogard, S., Mefford, M. L., Hagan, M., Bareket, Z., & Winkler, C. (2005). Automotive Collision Avoidance System (ACAS) Field Operational Test – Methodology and Results. DOT HS 809 901. Washington, DC: National Highway Traffic Safety Administration.

Kiefer, R., LeBlanc, D., and Flannagan, C. (2005). "Developing an inverse time-to-collision crash alert timing approach based on driver's last-second braking and steering judgments," *Accident Analysis & Prevention, 37*, 295–303.

LeBlanc, D., Sayer, J., Winkler, C., Bogard, S., Devonshire, J. Mefford, M., Hagan, M. L., Bareket, Z., Goodsell, R., & Gordon, T. (2006). Road Departure Crash Warning System (RDCW) Field Operational Test – Final Report. NHTSA. Washington, DC: National Highway Traffic Safety Administration.

LeBlanc, D., Sayer, J., Winkler, C., Bogard, S., Devonshire, J. Mefford, M., Hagan, M. L., Bareket, Z., Goodsell, R., & Gordon, T. (2006). Road Departure Crash Warning System Field Operational Test – Methodology and Results. Report No. UMTRI-2006-9-1. Ann Arbor, MI: University of Michigan Transportation Research Institute.

Sayer, J., LeBlanc, D., Bogard, S., Hagan, M., Sardar, H., Buonarosa, M, and Barnes, M. (2008) Integrated Vehicle-Based Safety Systems – Field Operational Test (FOT) Plan. DOT HS 811 010. Washington, DC: National Highway Traffic Safety Administration.

Sayer, J.R., Devonshire, J.M., & Flannagan, C.A. (2005). The Effects of Secondary Tasks on Naturalistic Driving Performance. Report No. UMTRI-2005-29. Ann Arbor, MI: University of Michigan Transportation Research Institute.

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

Van Der Laan, J. D., Heino, A., De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research, 5(1), 1-10.

Appendix A: Heavy Truck Post-Drive Survey

Subject #___________

Date _____________

IVBSS Heavy Truck Field Operational Test - Questionnaire and Evaluation

Please answer the following questions about the Integrated Vehicle Based Safety System (IVBSS). If you like, you may include comments alongside the questions to clarify your responses.

Example:

A.) Strawberry ice cream is better than chocolate.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

If you prefer chocolate ice cream over strawberry, you would circle the "1", "2" or "3" according to how strongly you like chocolate ice cream, and therefore disagree with the statement.

However, if you prefer strawberry ice cream, you would circle "5", "6" or "7" according to how strongly you like strawberry ice cream, and therefore agree with the statement.

If a question does not apply:

Write "NA," for "not applicable," next to any question which does not apply to your driving experience with the system. For example, you might not experience every type of warning the questionnaire addresses.

The integrated system consists of three functions. Please refer to the descriptions below as you answer the questionnaire.

Forward Collision Warning (FCW) – The forward collision warning function provided an auditory warning whenever you were approaching the rear of the vehicle in front of you and there was potential for a collision. When you received this type of warning, the display read "Collision Alert". Additionally, this system provided you with headway information in the display as you approached the rear of a vehicle (e.g., object detected, 3 seconds)

Lane Departure Warning (LDW) – The lane departure warning function provided an auditory warning whenever your turn signal was not on AND you were changing lanes or drifting from your lane. When you received this type of warning, the display read "Lane Drift" and a truck in the display appeared to be crossing a lane line.

Lane Change / Merge Warning (LCM) – The lane change / merge warning function provided an auditory warning whenever there was a vehicle in the truck's blind spot, your turn signal was on, and the system detected sideways motion indicating your intention to make a lane change. A red LED illuminated in the side display on whichever side your turn signal was on. Additionally, if your turn signal was off, and there was no indication that you were intending to make a lane change, but there was a vehicle in the truck's blind spot, a yellow LED was illuminated in the side display.

General Impression of the Integrated System

1. **What did you like most about the integrated system?**

2. **What did you like least about the integrated system?**

3. **Is there anything about the integrated system that you would change?**

4. **How helpful were the integrated system's warnings?**

1	2	3	4	5	6	7
Not all Helpful						Very Helpful

5. **In which situations were the warnings from the integrated system helpful?**

____

____

____

6. **Overall, I think that the integrated system is going to increase my driving safety.**

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

7. **Driving with the integrated system made me more aware of traffic around me and the position of my truck in my lane.**

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

8. **How long after it became enabled did it take you to become familiar with the operation of the integrated system (a day, a week, etc.)?**

____

9. **The integrated system made doing my job easier.**

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

10. Did the integrated system prevent you from getting into a crash or a near crash?
Yes________ No_________

If Yes, please explain ____

____

11. I was not distracted by the warnings.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

12. Overall, how satisfied were you with the integrated system?

1	2	3	4	5	6	7
Very Dissatisfied						Very Satisfied

13. Did you rely on the integrated system? Yes____ No____

a. If yes, please explain?

____

____

14. As a result of driving with the integrated system did you notice any changes in your driving behavior? Yes____ No____

a. If yes, please explain.

____

____

15. I always knew what to do when the integrated system provided a warning.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

16. I could easily distinguish among the auditory warnings (i.e., as being a Lane Drift, Forward Collision or Lane Change /Merge warning).

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

17. The auditory warnings' tones got my attention.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

18. The auditory warnings' tones were not annoying.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

19. The yellow lights mounted near the exterior mirrors got my attention.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

20. The yellow lights mounted near the exterior mirrors were not annoying.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

21. Did the integrated system perform as you expected it to?

Yes________ No_________

If no, please explain

____

____

22. The number of false warnings affected my ability to correctly understand and become familiar with the system

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

23. The number of false warnings caused me to begin to ignore the integrated system's warnings.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

24. The integrated system gave me warnings when I did not need them.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

25. The false warnings were not annoying.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

26. The integrated system gave me left/right hazard warnings when I did not need them.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

27. The integrated system gave me left/right drift warnings when I did not need them.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

28. The integrated system gave me hazard ahead warnings when I did not need them.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

29. **How did the false warnings affect your perception of the integrated system?**

____

____

____

Overall Acceptance of the Integrated System

30. Please indicate your overall acceptance rating of the integrated system *warnings*
For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The integrated system **warnings** were:

useful						useless
pleasant						unpleasant
bad						good
nice						annoying
effective						superfluous
irritating						likeable
assisting						worthless
undesirable						desirable
raising alertness						sleep-inducing

Displays and Controls

31. The integrated system display was useful.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

32. Did you look at the display less as your experience with the integrated system increased?

Yes________ No_________

33. The mute button was useful.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

34. The volume adjustment control was useful.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

35. The two lane change/merge warning displays mounted near the exterior mirrors were useful.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

36. The lane change /merge warnings displays are in a convenient location.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

37. The half circle icons on the center display helped me to understand and to use the integrated system.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

38. In general, I like the idea of having new technology in my truck.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

39. Do you prefer to drive a truck equipped with the integrated system over a conventional truck?

Yes__________ No____________

Why?

____

____

____

40. Would you recommend that the company buy trucks equipped with the integrated system?

Yes_____________ No____________

Why?

____

____

____

__Forward Collision Warning (FCW) acceptance__

41. Please indicate your overall acceptance rating of the forward collision warnings.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

Forward collision warnings were:

useful						useless
pleasant						unpleasant
bad						good
nice						annoying
effective						superfluous
irritating						likeable
assisting						worthless
undesirable						desirable
raising alertness						sleep-inducing

Lane Departure Warning (LDW) acceptance

42. Please indicate your overall acceptance rating of the lane departure warnings.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

Lane departure warnings were:

useful	☐	☐	☐	☐	☐	useless
pleasant	☐	☐	☐	☐	☐	unpleasant
bad	☐	☐	☐	☐	☐	good
nice	☐	☐	☐	☐	☐	annoying
effective	☐	☐	☐	☐	☐	superfluous
irritating	☐	☐	☐	☐	☐	likeable
assisting	☐	☐	☐	☐	☐	worthless
undesirable	☐	☐	☐	☐	☐	desirable
raising alertness	☐	☐	☐	☐	☐	sleep-inducing

Lane Change/Merge (LCM) acceptance

43. Please indicate your overall acceptance rating of the lane change/merge warnings.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The lane change / merge warnings were:

useful	☐	☐	☐	☐	☐	useless
pleasant	☐	☐	☐	☐	☐	unpleasant
bad	☐	☐	☐	☐	☐	good
nice	☐	☐	☐	☐	☐	annoying
effective	☐	☐	☐	☐	☐	superfluous
irritating	☐	☐	☐	☐	☐	likeable
assisting	☐	☐	☐	☐	☐	worthless
undesirable	☐	☐	☐	☐	☐	desirable
raising alertness	☐	☐	☐	☐	☐	sleep-inducing

Acceptance of yellow lights mounted near the mirrors

When a vehicle was approaching or was in the research vehicle's blind spots, a yellow light near the exterior mirror was illuminated.

44. Please indicate your overall acceptance rating of the yellow light in the mirrors.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The **yellow lights in the mirror** mounted near the exterior mirrors were:

useful						useless
pleasant						unpleasant
bad						good
nice						annoying
effective						superfluous
irritating						likeable
assisting						worthless
undesirable						desirable
raising alertness						sleep-inducing

Appendix B: Research Question Summary Table

Question Number	Research Question	Method	Dependent Variables	Independent Variables	Analysis
QC1	When driving with the integrated crash warning system in the treatment condition, will drivers engage in more secondary tasks than in the baseline condition?	A sample of 2000 video clips not associated with warning events from the integrated system, will be systematically reviewed and coded for incidences of engaging in secondary tasks for both the baseline and treatment periods	Engagement in a secondary tasks (multiple categorical tasks representing a wide range of tasks drivers might perform) coded for frequency	Treatment Condition Route Type	Summary statistics to be provided in tabular form identifying the frequency with which various secondary tasks are performed
QC2	Does a driver's engaging in secondary tasks increase the frequency of crash warnings from the integrated system?	A sample of 1800 video clips from the treatment period, will be reviewed and coded for incidences of secondary tasks	Engagement in a secondary tasks (multiple categorical tasks representing a wide range of tasks drivers might perform) coded for frequency	Route Type Warning Type	Summary statistics provided in tabular form identifying the frequency with which various secondary tasks are performed, and are associated warnings
QC3	When the integrated system arbitrates between multiple threats, which threat does the driver respond to first?	Identify instances of warning arbitration. Review data for a representative sample of approximately 200 of multiple threat scenarios with arbitration. Code the driver's response as an indicator of the most relevant threat perceived	First response by the driver, is it consistent with the warning provide	Treatment Condition Route Type	Categorical data analysis (logistic regression or generalized logit modeling) as sample size permits
QC4	Do drivers report changes in their driving behavior as a result of the integrated crash warning system?	Calculate summary statistics for the post-drive question on behavioral changes in driving related to the integrated crash warning system and summarize responses to the related open-ended question	Likert-type scale data and open-ended responses	Route Type	Summarize open-ended responses and provide histograms of responses to Likert-type scales

Question Number	Research Question	Method	Dependent Variables	Independent Variables	Analysis
QC5	Are drivers accepting the integrated system (i.e., do drivers want the system on their vehicles)?	Calculate summary statistics for the post-drive questions on overall acceptance of the integrated crash warning system, summarize responses to the related open-ended questions, calculate overall Van der Laan score	Likert-type scale data, open-ended responses and Van der Laan scores	Route type	Summarize open-ended responses, provide histograms of responses to Likert-type scale and provide Van der Laan scores
QC6	Are the modalities used to convey warnings to drivers salient?	Calculate the mean, median and standard deviation for the post-drive questions on warnings overall and calculate Van der Laan scores	Likert-type scale data, open-ended responses and Van der Laan scores	Route type	Summarize open-ended responses, provide histograms of responses to Likert-type scale and provide Van der Laan scores
QC7	Do drivers perceive a safety benefit from the integrated system?	Calculate the mean, median and standard deviation for the post-drive questions on driver situational awareness, perceived safety benefit, general helpfulness of warnings, summarize open-ended responses and calculate Van der Laan utility score	Likert-type scale data, open-ended responses and Van der Laan utility score	Route type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan utility score
QC8	Do drivers find the integrated system convenient to use?	Calculate the mean, median and standard deviation for the post-drive questions on ease of learning to drive with the integrated system, the ease of understanding and calculate Van der Laan satisfaction score	Likert-type scale data, open-ended responses and Van der Laan satisfaction score	Route type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan satisfaction scores

Question Number	Research Question	Method	Dependent Variables	Independent Variables	Analysis
QC9	Do drivers' report a prevalence of false warnings that correspond with the objective false warning rate?	Calculate the mean, median, and standard deviation for the post-drive questions related to the prevalence of false warnings. Perform exploratory analyses that attempt to determine if any relationship exists between false alarm rate and driver subjective ratings.	Likert-type scale data	Proportion/rate of false alarms determined from objective data, Route Type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and determine the relationship between observed false warnings and subjective impressions (acceptance).
QC10	Do drivers find the integrated system to be easy to use?	Calculate the mean, median, and standard deviation for post-drive questions related to comfort using the integrated system. Also, calculate the utility score from the Van der Laan scale.	Likert-type scale responses, Van der Laan utility score	Route Type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.
QC11	Do drivers find the integrated system to be easy to understand?	Calculate the mean, median, and standard deviation for the post-drive questions related to the ease of understanding the integrated system. Also, summarize the results of the question asking whether drivers relied on the system, and calculate the satisfaction score from the Van der Laan scale.	Likert-type scale responses, Van der Laan utility score	Route Type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide utility Van der Laan scores.

Question Number	Research Question	Method	Dependent Variables	Independent Variables	Analysis
QL1	Does lateral offset vary between baseline and treatment conditions?	Identify a set of lane keeping events and determine the lateral offset distance.	Lateral offset within lane	Route Type, Speed, Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Ambient Light, Hours of Service, Road Type	Linear Mixed Models using driver as a random effect
QL2	Does the lane departure warning frequency vary between baseline and treatment conditions?	Identify a set of unintentional lane departures from warning requests, excluding lane changes, and attempt to remove deliberate maneuvers to avoid obstacles.	Lane departure warning request	Route Type, Speed, Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Ambient Light, Hours of Service, Road Type, POV in closing zone or blind zone, Boundary type, Road curvature	General Linear Mixed Models using driver as a random effect and an appropriate distribution function (consider binomial, multinomial or Poisson distributions).
QL3	When vehicles depart the lane, does the vehicle trajectory, including the lane incursion and duration, change between the baseline and treatment conditions?	Evaluate all lane departure events as identified by the lane tracking system, excluding lane changes and deliberate maneuvers. Determine the duration and maximum distance of the incursion.	Maximum lane incursion distance and Duration of incursion	Route Type, Speed, Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Ambient Light, Hours of Service, Road Type, POV in closing zone or blind zone, Boundary type	Linear Mixed Models using driver as a random effect
QL4	Does turn signal use during lane changes differ between the baseline and treatment conditions?	Identify a set of left and right lane-change events to determine if the corresponding lateral-direction indicator (turn signal) is used differently when the integrated system is enabled.	Use of turn signal and duration of turn signal	Route Type, Side (Left or Right), Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Ambient Light, Road Type	Generalized Linear Mixed Models with generalized logit link and driver as a random effect

Question Number	Research Question	Method	Dependent Variables	Independent Variables	Analysis
QL5	Do drivers change their position within the lane when another vehicle occupies an adjacent lane?	Identify 5-second events with a vehicle in the adjacent lane and compare host lane position to lane position in events in which there is no vehicle in the adjacent lane.	Average distance to the shared lane boundary	Route Type, Side (Left or Right), Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Ambient Light, Road Type	Linear Mixed Models using driver as a random effect
QL6	What is the location of all adjacent vehicles relative to the subject vehicle for valid LCM warnings?	The space adjacent to the heavy truck will be divided into 3 zones longitudinally. For each valid LCM warning, the zones will be characterized as occupied or not.	Count and distribution of valid LCM warnings for the six zones around the vehicle	Route Type, Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Ambient Light, Road Type	Linear Mixed Models using driver as a random effect
QL7	Will drivers change lanes less frequently in the treatment period, once the integrated system is enabled?	Identify all instances of valid lane changes with the use of the turn signal. Compare baseline with exposure period.	Lane changes performed	Route Type, Treatment Condition, Wiper State, Trailer Config., Hours of Service, Ambient Light, Road Type, Route Type, Surrogate of traffic density	General Linear Mixed Models with driver as a random effect. For frequency, evaluate the use of the negative binomial distribution
QL8	Is the gap between the subject vehicle (SV) and other leading vehicles influenced by integrated system when the SV changes lanes behind a principal other vehicle (POV) traveling in an adjacent lane?	Identify instances where the SV is closing in on a lead vehicle in the same lane and makes a lane change behind a passing POV1 in an adjacent lane. For each event code the closing to POV2	Range and range-rate between the SV and POV1 and POV2 during lane changes.	Route Type, Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Hours of Service, Ambient Light, Road Type	Linear Mixed Models using driver as a random effect
QL9	Are drivers accepting of the LDW subsystem (i.e., do drivers want LDW on their vehicles)?	Calculate the mean, median and standard deviation for the post-drive question related to the overall acceptance of the LDW subsystem	Responses to Likert-type scale responses and Van der Laan score.	Route Type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan score.

Question Number	Research Question	Method	Dependent Variables	Independent Variables	Analysis
QL10	Do drivers find the integrated system to be useful, what attributes and in which scenarios was the integrated system most and least helpful?	Calculate the mean, median and standard deviation for post-drive questions related to the overall utility of the integrated crash warning system	Responses to Likert-type scale responses and Van der Laan score.	Route Type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan scores.
QL11	Are drivers accepting of the LCM subsystem (i.e., do drivers want LCM on their vehicles)?	Calculate the mean, median and standard deviation for the post-drive question related to the overall acceptance of the LCM subsystem	Responses to Likert-type scale responses and Van der Laan score.	Route Type	Summarize open-ended responses, provide histograms of responses to Likert-type scales, and provide Van der Laan score.
QF1	Does the presence of integrated system affect the following distances maintained by the heavy truck drivers?	Compute and compare various statistics of following distance when the integrated system is enabled and disabled.	Statistic representing the distribution of time headway	Route Type, Speed, Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Hours of Service, Ambient Light, Road Type, Surrogate measure of traffic density	Linear Mixed Models with driver as random effect
QF2	Will the frequency and/or magnitude of forward conflicts be reduced between the baseline and treatment conditions?	The dependent measure will be the actual deceleration required to maintain a minimal headway margin. The severity of these events will be compared when the integrated system is disabled and enabled.	Statistics of the actual deceleration required to maintain a minimal	Route Type, Speed, Treatment Condition, Wiper State, Average Axle Load, Trailer Configuration, Hours of Service, Ambient Light, Road Type, Driving Scenario, Surrogate measure of traffic density	General Linear Mixed Models with driver as random effect and consideration of alternative distributions and corresponding link functions (e.g., negative binomial for count data)

Question Number	Research Question	Method	Dependent Variables	Independent Variables	Analysis
QF3	Does the integrated system affect the frequency of hard-braking maneuvers involving a stopped or slowing POV?	The frequency of hard-braking events will be compared when the integrated system is disabled and enabled	Statistics of the decelerations employed by the driver.	Route Type, Treatment Condition, Speed, Wiper State, Average Axel Load, Ambient Light, Trailer Configuration, Hours of Service, Road Type, Driving Scenario, Surrogate of traffic density	Linear Mixed Models with driver as random effect.
QF4	Will the integrated system warnings improve drivers' responses to those forward conflicts in which closing-speed warnings occur?	The integrated system will not affect drivers' responses in closing-speed FCW events.	Time lag between the warning and the time at which the conflict is resolved. Peak value of difference between deceleration required and driver's deceleration	Route Type, Speed, Treatment Condition, Wiper State, Average Axel Load, Trailer Configuration, Hours of Service, Road Type, Driving Scenario	Linear Mixed Models using driver as a random effect
QF5	Are drivers accepting of the FCW subsystem (i.e., do drivers want this system on their vehicles)?	Drivers will be indifferent regarding wanting FCW on their vehicles.	Responses to Likert-type scale responses	Route Type	Summarize open-ended responses and provide histograms of responses to Likert-type scales.
QD1	Did drivers perceive the driver-vehicle interface for the integrated system easy to understand?	Calculate the mean, median and standard deviation for post-drive questions regarding how easy the DVI was to understand	Responses to Likert-type scale responses	Route Type	Summarize open-ended responses and provide histograms of responses to Likert-type scales.
QD2	Do drivers find the volume and mute controls useful, and do they use them?	Calculate the mean, median and standard deviation for questions regarding how useful volume and mute controls were technology	Responses to Likert-type scale responses	Route Type	Summarize open-ended responses and provide histograms of responses to Likert-type scales.

Appendix C: Descriptions of Data Analysis Techniques

A. Linear Mixed Models

Linear Mixed Models (LMM) is a maximum-likelihood modeling approach that accommodates estimation of the effect of virtually any combination of random and fixed effects on a continuous dependent measure. Random effects are those in which the tested examples are considered a sample from a wider population. For example, in this study, tested drivers are a sample from the broad population of all drivers. Random effects are generally modeled as covariances. Fixed effects are those in which the specific levels tests are all that are of interest. In the present study, the state of a warning system (on or off) is of specific interest and means are estimated and compared.

Unlike General Linear Models (GLM), which is the more traditional way to model continuous dependent measures, LMM does not require case-wise deletion of missing data. In the present study, this is an important feature, as many analyses will make use of events that may occur once for some drivers and many times for others. All such data points can be used with LMM and the covariance between observations from the same driver can be accounted for using random effects.

B. General Linear Mixed Models

General Linear Mixed Models (GLMM) is an extension of LMM in which additional link functions may be used to expand estimation to dependent measures that do not fit the standard LMM format. For example, mixed logistic models can be estimated using GLMM for binary dependent measures by using a logit link and a logistic distribution. Similarly, categorical dependent measures can be analyzed using a generalized logit link and a multinomial distribution.

In the present study, GLMM is important because many drivers will provide more than one data point per analysis. Most notably, comparisons of baseline to system-enabled performance will be done within drivers by comparison their performance in the two phases. When the dependent measure is categorical or involves count data, a link function is required to transform the dependent measure to one that is linear in the estimated parameters. The inclusion of random effects in GLMM, as contrasted with traditional logistic regression, for example, allows us to account for covariance between observations from the same driver.

C. Logistic Regression

When the dependent measure is binary and each driver provides one data point, logistic regression can be used to predict the probability of an event (one of the two states of the binary variable). The logit link is used to transform the dependent measure to one that is linear in the parameters. The logit link is given in Equation 1:

$$\log it(p) = \log\left(\frac{p}{1-p}\right) = \log(p) - \log(1-p) \qquad (1)$$

where p is the probability of the event.

Logistic regression models the relationship between various predictors (e.g., driver age, road type, time of day) and the binary outcome (e.g., responded to second warning vs. did not respond).

D. Generalized Logit Models

When the dependent measure has more than two categories and they are not ordinal (e.g., three levels of injury), generalized logit models can be used to predict the probability of each outcome category as a function of predictor variables. In this case, one category is chosen as the reference, and the generalized logit is the log of the ratio of the probability of the category of interest to the reference, as in Equation 2:

$$\log it(p_i) = \log\left(\frac{p_i}{p_k}\right) = \log(p_i) - \log(p_k) \qquad (2)$$

where i is the category of interest and k is the reference category.

E. Case Cross-Over and Case-Control

In a case-crossover study, individual drivers are used as their own control. A random set of events of interest are identified (i.e., warnings) and identified as event windows. In addition, a nominally "matched" set of control windows for each driver is also drawn from the data set and referred to as control windows. If an individual driver is chosen for multiple warning events, his/her control window will be sampled relative to the specific warning event and treated as independent. The control windows will be defined based on a fixed period prior to the event of interest (i.e., the warning).

The events and the matched control windows are then reviewed for behaviors that might contribute to warning events, namely secondary behaviors. The basic table from a case-crossover study is shown in Table C.1 below. Equation 3 shows the computation of the estimate of the odds of a warning given secondary behaviors compared to no secondary behaviors (odds ratio).

Table C.1. Case Cross-Over Design Table

		Event Window (Warning)	
		Secondary behavior	No secondary behavior
Control Window	Secondary behavior	a	b
	No secondary behavior	c	d

$$\frac{c}{b}=\frac{p(s\mid w)p(s'\mid w')}{p(s'\mid w)p(s\mid w')}=\frac{p(w\mid s)p(s)p(w'\mid s')p(s')p(w)p(w')}{p(w)p(w')p(w\mid s')p(s')p(w'\mid s)p(s)}$$
$$=\frac{p(w\mid s)p(w'\mid s')}{p(w\mid s')p(w'\mid s)}=\frac{odds(w\mid s)}{odds(w\mid s')} \tag{3}$$

Case-crossover design is a powerful tool, particularly because it uses individual drivers as their own control. However, it relies on selection based on a warning event, thereby tending to overrepresent drivers who receive more warnings. An alternative approach is the case-control study, in which a set of cases (warning events) and a set of controls (non-warning events) are selected at random. These video clips are then inspected for the presence of secondary behaviors. The ratio of the resulting conditional probabilities is an estimate of the odds ratio of warning for secondary behavior vs. no secondary behavior.

Appendix D: Variable Descriptions and Sources

The following table attempts to link the variables used in the proposed analyses back to their original sources. In certain instances, the sources are very explicit while others have yet to be specified in detail (such as variables that are to be derived).

Variable	*Units*	*Description and Source*
Ambient Light	deg	Determined by calculating the angle of the sun relative to the horizon (Solar Zenith Angle: an angle < 90 = daytime; between 90 and 96 civil twilight; > 96 nighttime). Time of day is determined via global positioning satellite signal
Average Axle Load	Kg	GVW divided by number of axles. Although GVW has a strong influence on vehicle performance both laterally and longitudinally, average axle load is a more precise measure of a vehicle's stopping capability since braking force is directly related to number of braked wheels (i.e., tire/road surface area and friction material surface area).
Baseline Period	-	Period of testing in which all quantitative data is being collected, and the integrated system is operating in the background, but warnings are not presented to drivers. Synonymous with *Disabled*.
Boundary Type	-	Classification of the pavement marking as being a solid line, dashed line, of no marking present
Deceleration Required	m/s^2	An estimate of the actual deceleration required to maintain a minimal headway, derived from the forward radars and vehicle state variables
Disabled	-	The integrated system is operating in the background, but warnings are not presented to drivers. Synonymous with *Baseline Period*.
Distance Past Lane Edge	m	A derived measure of how far the front tire of the vehicle has drifted past the lane boundary (calculated for either left or right front wheel)
Driver	-	Unique identification number that links each tractor and trip with a subject via manual coding of the face video
Driving Scenario	-	A categorical grouping, supported by specific quantitative bounding values, that identifies the circumstances in which a vehicle is being operated. Frequently used in describing the circumstances when crash warnings are presented
Driver Video	-	Video of the driver's face and over-the-shoulder view that illustrates behavior in the vehicle cabin
Enabled	-	The integrated system is operating and warnings are presented to drivers. Synonymous with *Treatment Period*.

Variable	*Units*	*Description and Source*
Gross Vehicle Weight	Kg	Estimated total vehicle weight using engine and state variables while the vehicle is accelerating
Hours of Service	hrs	Elapsed time since the start of a drivers tour, measured in hours
Lane Boundaries	-	Lane boundary combinations for each side of the vehicle from the LDW subsystem (0=missing; 1 = dashed; 2=solid; 3=virtual)
Lane Change	-	Specifics details to be finalized, but representing a quantitative value(s) that indicates the transition from one lane of travel to another
Lane Offset	m/s	Vehicle offset from lane center from the LDW subsystem
Lane Offset Confidence	%	Confidence in the vehicle offset from lane center and lateral speed from the LDW subsystem
Lateral Speed	m/s	Vehicle speed lateral to lane direction from the LDW subsystem
Likert-Type Scale Value	-	A number between 1 and 7 indicating general agreement of a driver with a question included in the post-drive survey. Anchor terms are provided at the two ends of the extreme
Post-Drive Survey	-	A series of Likert-type scaled or open-ended questions completed by drivers upon completion of their study participation
POV Type	-	A video analysis based classification of the vehicle type (passenger or commercial) for vehicles treated as a Principal Other Vehicle (POV)
Road Type	-	A number between 1 and 6 indicating the type of road, derived from HPMS and previous UMTRI FOTs
Route Type	-	Daytime delivery and pick-up (local roads) and Nighttime line-haul delivery between distribution terminals (Each *Driver* is exclusively associated with one of the two route types)
Side	-	Left and right side of the vehicle (generally coded as 1 = left and 2 = right)
Speed	m/s	Estimate of forward speed from the vehicle control message (VSC1) on the J1939 CAN bus of the subject vehicle

Variable	*Units*	*Description and Source*
Surrogate Traffic Density	-	Specifics details to be finalized, most likely based upon radar tracks, representing a qualitative value that indicates the prevalence of other vehicles sharing the roadway going in the same direction of travel
Time-to-collision	s	An instantaneous estimate of the number of seconds until a crash based on range and range-rate from the forward looking radar (TTC = - Range/Range-rate for Range-rate < 0.0)
Traffic Density	-	A count of the number of same-direction vehicles that is smoothed and weighted by the number of thru lanes.
Trailer Configuration	-	Input from the driver via the DVI and defines the number and length of the trailers attached to the tractor/power unit
Treatment Condition	-	Baseline and Treatment periods (generally coded as 0 = baseline and 1 = treatment), were baseline represents that no warnings are being presented to drivers
Treatment Period	-	Period of testing in which all quantitative data is being collected, and warnings are being presented to the drivers. Synonymous with *Enabled*.
Van der Laan Score	-	One of two possible scores relating driver perceive usefulness or satisfaction with the system being evaluated acquired in the post-drive survey
Warning Type		One of the three possible warnings from the integrated system on the heavy truck platform (FCW, LDW, LCM)
Wiper State	-	Wiper switch state from the J1939 CAN bus and relates to the wiper speed and is used as a surrogate for active precipitation

Appendix E: IVBSS FOT Maintenance and Failure Detection

This appendix identifies issues related to the maintenance and failure of system components and sensors as experienced during the FOT, and will be included as part of the final program report – but technically is not part of the data analysis process. This section of the final report will also cover how the failures and maintenance issues are detected in a typical fleet operation, and discuss how a production application of this technology would likely differ from those used in the FOT (i.e., 1-AC20; location of Blind Spot sensors; diagnostic messages via the Driver Vehicle Interface or thru conventional diagnostic handling protocols, self alignment by the ranging sensors and alignment error codes when out-of-range, frequency of sensor alignment).

Each incident that results in work by Eaton or UMTRI to keep the system performing as designed will include the following descriptors:

- Incident Date—the day of first detection either by a driver or using diagnostic information delivered to UMTRI via the end-of-trip summary data transfer protocol
- Unit Id—Unique number used by the fleet and UMTRI to identify equipment
- System—Acronym describing the system affected by the incident
- Incident Description—A brief note explaining how the incident manifests itself
- Action Taken—Description of action necessary to restore the system performance
- Hours—Time needed to perform the action
- Action Date—Date of correction