U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

NHTSA
www.nhtsa.gov

DOT HS 810 829 **August 2007**

Final Report:
Objective Test Procedures for Road Departure Crash Warning Systems

This publication is distributed by the U.S. Department of Transportation, National Highway Traffic Safety Administration, in the interest of information exchange. The opinions, findings and conclusions expressed in this publication are those of the author(s) and not necessarily those of the Department of Transportation or the National Highway Traffic Safety Administration. The United States Government assumes no liability for its content or use thereof. If trade or manufacturer's names or products are mentioned, it is because they are considered essential to the object of the publication and should not be construed as an endorsement. The United States Government does not endorse products or manufacturers.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 2007	Final Report, 2003-2006

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Final Report: Objective Test Procedures for Road Departure Crash Warning Systems (RDCWS)	DTFH61-00-Y-30132
6. AUTHOR(S)	
Sandor Szabo and Richard Norcross	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. Department of Commerce National Institute of Standards and Technology 100 Bureau Drive, Mail Stop 8230 Gaithersburg, MD 20899-8230	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
U.S. Department of Transportation National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590	DOT HS 810 829
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	

13. ABSTRACT (Maximum 200 words)

This is the final report describing work performed by the National Institute of Standards and Technology (NIST) to develop the objective test procedures and the supporting measurement methodologies for evaluating Objective Test Procedures for Road Departure Crash Warning Systems (RDCWS). Included with the final report are three separate documents. The first document, titled "Final Report: Objective Test Procedures for Road Departure Crash Warning Systems (RDCWS)" is an overview of the project and results. The second report, "Recommendations for Objective Test Procedures for Road Departure Crash Warning Systems," contains test procedures recommended for a warning system that meets the requirements of the RDCWS FOT. The third document, entitled "An Independent Measurement System for Performance Evaluation of Road Departure Crash Warning Systems," provides a detailed description of a measurement system developed by NIST for use in evaluating the performance of the FOT RDCWS during track-based and on-road tests.

14. SUBJECT TERMS	15. NUMBER OF PAGES
	212
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

Table of Contents

PART I: Final Report: Objective Test Procedures for Road Departure Crash Warning Systems

Section	Title	Page
	Executive Summary	2
I-1	Introduction	3
I-2	NIST/USDOT RDCWS Testbed	6
I-3	RDCWS Objective Test Procedures	10
I-4	Independent Measurement System	13
I-5	Validation of Field Operational Test RDCWS	20
I-6	RDCWS On-Road Objective Test Procedures	27
I-7	RDCWS On-Road Tests	30
I-8	Conclusions	34

PART II: Recommendations for Objective Test Procedures for Road Departure Crash Warning Systems

Section	Title	Page
	History	36
II-1	Introduction	37
II-2	Definitions	40
II-3	Basic Test Organization	54
II-4	Independent Measurement System	56
II-5	Warning System Evaluations	59
II-6	Tests for Departures on Roads With Default Minimum AMR	66
II-7	Tests for Departures on Roads With Default Maximum AMR	84
II-8	Tests for Departures Toward an Obstacle	97
II-9	Tests for Departures at Excessive Speed	121
Appendix II-A	Methods for Determining Road Dimensions and Geometry	131
Appendix II-B	Methods for determining Lane Marker Characteristics	132

PART III: An Independent Measurement System for Performance Evaluation of Road Departure Crash Warning Systems

Section	Title	Page
III-1	Introduction	138
III-2	Data Collection System	140
III-3	Camera Calibration Setup	142
III-4	Camera Calibration	145
III-5	Data Processing	156
III-6	Analyze Data Main Control Panel	165
III-7	Locating Video Based on GPS Time	169
III-8	Lateral Drift Analysis	171
III-9	Lane Marker Contrast	183
III-10	Map Point Map Display	185
Appendix III-A	Adobe Premier Notes	188
Appendix III-B	Creating a DVD Using DVDit!	189
Appendix III-C	Extracting GPS Data From Video Using VMS and Media Mapper	193
Appendix III-D	Non-Linear Camera Calibration	199
Appendix III-E	UTM Conversions	201

Part I:
Final Report: Objective Test Procedures for Road Departure Crash Warning Systems

Prepared by
Sandor Szabo and Richard Norcross
National Institute of Standards and Technology
100 Bureau Drive, Mail Stop 8230
Gaithersburg, MD 20899-8230

This document was prepared for the U.S. Department of Transportation under interagency agreement DTFH61-00-Y-30132. Send comments and/or questions to sandor.szabo@nist.gov.

Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

Executive Summary

An analysis of the 1998 Fatality Analysis Reporting System (FARS) crash database estimated that 992,000 crashes involved vehicles leaving the roadway [1]. In response to the large number of crashes and the public's interest in safer automobiles, the automotive industry is developing advanced Road-Departure Crash Warning Systems (RDCWS) to address this type of crash (as well as others, such as rear-end and lane-change collisions).

The National Highway Traffic Safety Administration is interested in determining the benefits and effectiveness of the RDCWS. NHTSA initiated a Field Operation Test (FOT) to evaluate a near-production RDCWS in real-world conditions with normal drivers [2]. In support of the FOT, NHTSA sponsored the National Institute of Standards and Technology (NIST) to develop objective tests and measurement methods for evaluating RDCWS. The tests foster a rigorous assessment of warning-system performance based on quantitative measurements. The tests replicate typical crash scenarios based on crash statistical studies. Performance metrics based on equations of motion provide an objective means of quantifying warning-system performance. Independent measurements performed during the tests provide the data needed by the metrics without influence from or on the warning system or its sensors. The test results provide insight into the accuracy of the system (e.g., does the system recognize the crash scenario?) and the benefit of the system (e.g., how much time does the system provide the driver to take corrective action?).

This is the final report describing work performed by NIST under interagency agreement DTFH61-00-Y-30132 to develop the objective test procedures and the supporting measurement methodologies for evaluating RDCWS. This report contains three parts; Part I titled Final Report: Objective Test Procedures for Road Departure Crash Warning Systems, Part II titled "Recommendations for Objective Test Procedures for Road Departure Crash Warning Systems," and Part III titled "An Independent Measurement System for Performance Evaluation of Road Departure Crash Warning Systems, " which provides a detailed description of a measurement system developed by NIST for use in evaluating the performance of the FOT RDCWS during track-based and on-road tests.

I-1 Introduction

An analysis of the 1998 Fatality Analysis Reporting System (FARS) crash database estimated that 992,000 crashes involved vehicles leaving the roadway [1]. In response to the large number of crashes and the public's interest in safer automobiles, the automotive industry is developing advanced Road-Departure Crash Warning Systems to address this type of crash (as well as others such as rear-end and lane-change collisions).

The National Highway Traffic Safety Administration is interested in determining the benefits and effectiveness of RDCWS. To that end, NHTSA initiated a Field Operation Test to evaluate a near-production RDCWS in real-world conditions with normal drivers [2]. In support of the FOT, NHTSA asked the National Institute of Standards and Technology to develop objective tests and measurement methods for evaluating RDCWS. The tests foster a rigorous assessment of warning-system performance based on quantitative measurements. The tests replicate typical crash scenarios based on crash statistical studies. Performance metrics based on equations of motion provide an objective means of quantifying warning-system performance. Independent measurements performed during the tests provide the data needed by the metrics without influence from, or on, the warning system or its sensors. The test results provide insight into the accuracy of the system (e.g., does the system recognize the crash scenario?) and the benefits of the system (e.g., how much time does the system provide the driver to take corrective action?).

This is the final report describing work performed by the NIST under interagency agreement DTFH61-00-Y-30132 to develop the objective test procedures and the supporting measurement methodologies for evaluating RDCWS. Figure 1 illustrates the process NIST followed to accomplish the work.

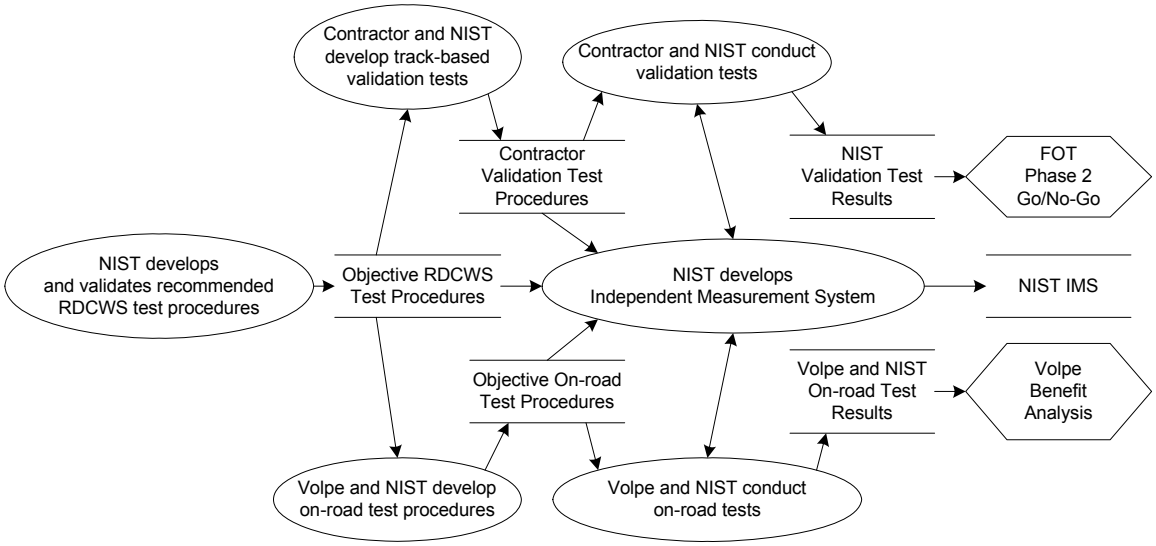


Figure 1. Overview of work performed by NIST. Ovals represent major activities, open-sided boxes represent deliverables, and hexagons represent major milestones.

A summary of NIST's accomplishments include:

1. <u>Developed an RDCWS testbed vehicle</u>
   NIST equipped a U.S. DOT-provided Chrysler Concord with a commercial lane-departure warning system in order to gain an understanding of such issues as sensing, departure scenarios and test procedures. NIST also instrumented the vehicle with a differential global positioning system receiver (DGPS), inertial sensors, and cameras to record and analyze system performance. The testbed supported development and validation of the objective test procedures and of an independent performance-measurement system. A description of the testbed appears in Section I-2 of this report.

2. <u>Developed objective test procedures for RDCWS</u>
   From earlier research and experience gained with the testbed vehicle, NIST developed a recommended set of RDCWS objective test procedures. The tests included procedures, evaluation metrics and proposed measurement methods. From these procedures, NIST worked jointly with the FOT RDCWS contractor to develop a validation test to determine whether the FOT warning system was ready to proceed with Phase 2 of the FOT. Section I-3 of this report contains an overview of the test procedures that appear in [7].

3. <u>Developed an independent measurement system for evaluation of RDCWS</u>
   NIST developed an independent measurement system (IMS) to evaluate the RDCWS performance on the validation tests. The IMS uses sensors separate from the warning system sensors to eliminate bias and improve accuracy. NIST developed an extensive software package for calibrating sensors, processing data, making measurements, and generating results. Section I-4 of this report contains an overview of the IMS. Complete documentation of the IMS appears in [8].

4. Conducted validation tests of RDCWS
   NIST assisted the contractor in developing a RDCWS validation test procedure based on the NIST objective test procedures. NIST also assisted in conducting all the validation tests at the Transportation Research Center in East Liberty, Ohio. NIST completed the final report in May 2004 indicating that the warning system had passed all tests. Results from the tests supported NHTSA's decision to allow the contractor to proceed with Phase 2. Section I-5 of this report contains an overview of the validation test procedures that appear in [9].

5. Developed on-road objective test procedures
   Validation tests are track-based tests, but re-creating all conditions and scenarios on a test track is not practical. NIST and the Volpe Transportation Systems Center (Volpe) developed an objective procedure for evaluating warning-system performance in on-road conditions. The procedures quantify true positive, false positive and false negative warnings under a wide range of conditions. This final report contains an overview of the on-road objective test procedures in Section I-6. Volpe will submit the final version of the test plan with its final report.

6. Conducted on-road tests of RDCWS
   NIST and Volpe carried out the on-road tests and used the IMS to collect data and analyze warning-system performance. This final report contains an overview of the on-road test effort in Section I-7. The results from the tests will appear in Volpe's final report, which will provide a benefit analysis of the RDCWS.

I-2 The RDCWS Testbed

NIST developed an RDCWS testbed early in the project to support:

- Evaluations of commercial warning systems;
- Design and validation of test procedures; and
- Design and development of an independent measurement system.

Figure 1 depicts the components of the NIST/USDOT testbed. The vehicle is a Chrysler Concorde from the Intelligent Cruise Control FOT on loan from USDOT. NIST equipped the vehicle with a laptop, cameras, recording system, DGPS/inertial system, and a commercial lane-departure warning system, the Assistware SafeTRAK system.

Figure 1. The RDCWS testbed vehicle with installed equipment

As illustrated in Figure 2, NIST expanded the autonomous vehicle laboratory for the test-bed vehicle.

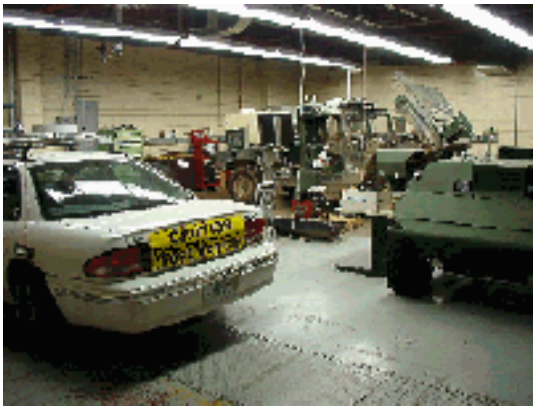


Figure 2. NIST testbed vehicle in newly expanded mobility laboratory

The testbed serves the following purposes:

- Experiment with warning systems to determine scenarios and conditions critical to performance;
- Experiment and validate test procedures (e.g., how to depart road at a constant rate);
- Gather output from warning systems in order to gain an understanding of the type and frequency of data (needed to gauge data collection and analysis requirements);
- Generate ground truth to compare with warning-system data; and
- Test and evaluate measurement equipment.

The vehicle contains a DGPS with inertial measurement unit (IMU; the Applanix POS/LV 220). The POS/LV uses a dual antenna and receiver GPS (see top of roof in Figure 1) to provide carrier-phase position and instantaneous heading. The system is capable of real-time or post-processing differential corrections. The IMU consists of three fiber-optic gyros and three linear accelerometers. An encoder-based distance measurement indicator attached to a rear wheel provides precise odometry. The POS/LV uses a Kalman filter to combine the readings from all the sensors and to provide solutions during GPS dropout. Some relevant specifications from Applanix include:

- 5 ms latency in data;
- 1 Hz GPS output;
- 200 Hz inertial sensor output (with Kalman filtered GPS);
- GPS accuracy (post processing) Position 2 cm, Pitch/roll < 0.005°, heading < 0.02°; and
- IMU accuracy (1 min GPS outage): X, Y Position 1.5 m, Z Vertical Position 2.0 m, Roll/pitch/heading 0.07°.

NIST developed a general-purpose evaluation procedure for the dynamic accuracy of the position measurement system [3]. Most position measurement systems specify static (i.e., stationary) accuracy. Computational latency in the position solution reduces the accuracy of a moving vehicle. In the NIST procedure, a downward-looking photo sensor

produces the trigger that latches the solution when the vehicle drives over a retro-reflective disk (see Figure 3). The driver can maneuver the vehicle over the disk from a variety of directions and speeds. Figure 4 shows the position (small circles) and velocity (vectors emanating from each circle) of the vehicle during a test where the retro-reflector rests on a National Geodetic Survey marker. The marker is in a grassy area, which limited the top speed to 10.6 m/s (shown highlighted on the left side of circle: northing – 0.03, easting – 0.081), or approximately 38 km/h (24 mph). A circle-fitting process produces the radius and origin of the circle. Subsequent calculations generate the mean and standard deviation of the radii. The radius error, the difference between the measured mean and the known mean (hand measured), for the data in the figure was 0.2 cm ± 1.3 cm (95% level of confidence). The difference between the origin of the fitted circle and the NGS survey marker location was 0.3 cm. The tests illustrated the system was capable of cm-level accuracy while moving. The test procedure was presented at the "Performance Metrics for Intelligent Systems (PerMIS) Workshop" held at NIST in August 2002.

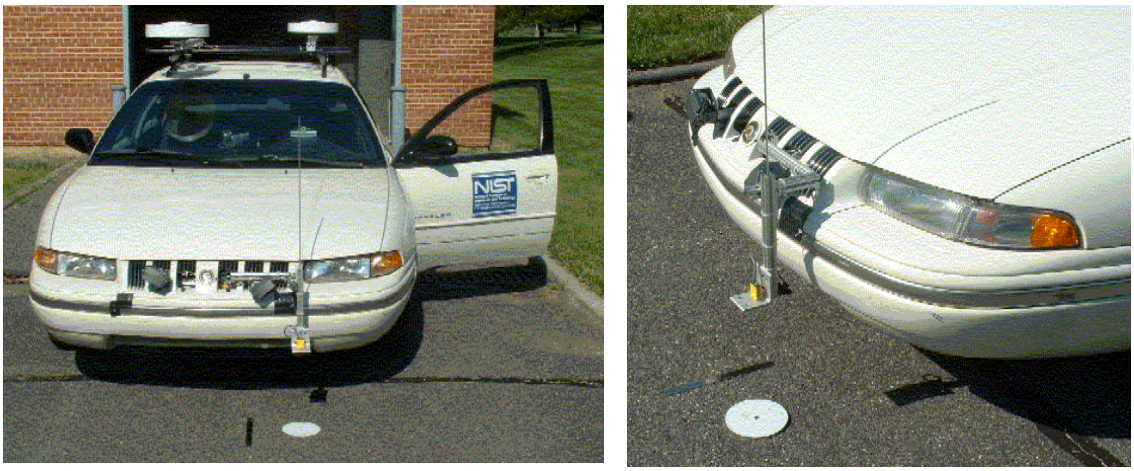


Figure 3. Downward-looking photo sensor triggers a position measurement when vehicle drives over a retro-reflective disk. Vertical rod is guide for the driver.

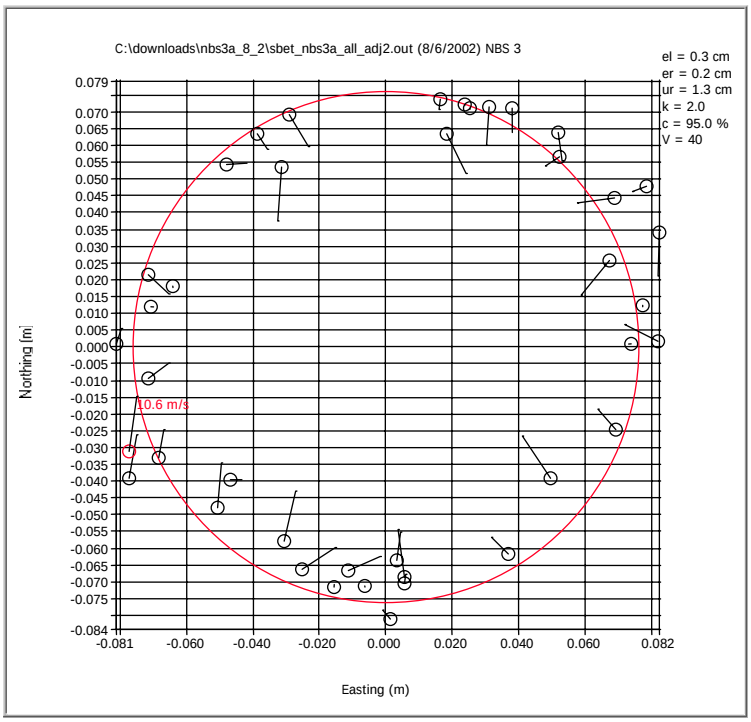


Figure 4. Plot of pose measurement points (shown as small circles) triggered when vehicle driven over the edge of a circular target with a radius of 7.62 cm. Vectors emanating from each circle give velocity at point (magnitude and direction). The largest velocity vector, 10.6 m/s (left side of target), provides a reference for the scale of the vector magnitudes.

I-3 RDCWS Objective Test Procedures

NIST developed objective test procedures in parallel with reviewing previous and ongoing research. The test procedures incorporated results from the following efforts:

1. Research conducted on RDCWS that outlined test procedures appears in a final report titled "Run-Off-Road Collision Avoidance Using IVHS Countermeasures" [4].
2. The Road Departure Crash Warning System FOT Request for Applicants issued by NHTSA [2] contains the performance capabilities expected of a warning system.
3. A NHTSA and Volpe National Transportation Systems Center report on an analysis of crash data identifies high-risk crash scenarios [1].
4. An International Standards Organization test procedure for lane-departure warning systems [5].
5. A study conducted by the Applied Physics Laboratory to develop a public algorithm for RDCWS [6]. The algorithm supports evaluation of performance data collected during tests.

NIST delivered the first draft of the recommended RDCWS objective test procedures to NHTSA on September 20, 2002, containing track-based and on-road test procedures. Track-based tests determine whether the warning system meets a minimum level of functionality. However, the set-up and execution of a large number of track tests is time consuming and costly, and it is impractical to evaluate a warning system under all conditions (e.g., weather, lighting, road surfaces, lane marker quality, etc.) and in all potential scenarios (e.g., traffic, speeds, departure rates, road geometry). The on-road tests permit evaluation of the system under a broader range of conditions and without the need for elaborate track setups. However, on-road tests consisting only of ideal conditions and scenarios can bias warning-system performance. In an effort to remove such bias, NIST and Volpe embarked on a research effort to develop and validate a comprehensive set of objective, on-road test procedures. This work is described in Section I-6.

NIST and NHTSA then worked together to refine the RDCWS test procedures. Bruce Wilson of Volpe also reviewed the procedures and provided comments. NIST delivered to NHTSA a second draft on February 11, 2003, and it was subsequently sent to the FOT contractor (Visteon) at the end of February 2003. The contractors developed a "validation" test from the procedures. The validation test did not include all the RDCWS objective tests, since the FOT warning system did not perform certain functions. Details of the test plan and execution of the tests are discussed in Section I-5.

NIST observed the validation tests and incorporated experiences into the current draft of the objective test procedures [7]. NIST submitted this version to NHTSA along with this final report. The remainder of this section provides a brief overview of the type of tests recommended for RDCWS.

An RDCWS consists of the sensor, the alert logic (correctness and timing), and the driver interface. The objective tests address sensor and alert logic performance. A complete

evaluation of the driver interface considers how a driver responds to the warning. This is a complex area where significant human factor research is ongoing. These NIST tests evaluate only the driver interface from the standpoint of whether the interface presented the warning or not.

The evaluation of the warning system focuses on two areas: correctness and timing. The correctness of each warning issued by the system is either true positive, false positive, false negative or true negative (Table 1). Statistical evaluations, such as efficacy rate (the percentage of warnings that produce the desired effects) and false alarm rate summarize the results of the ratings.

Table 1. Rating of warning system signals.

System Response	Situations Requiring a Signal	Situations in Which a Signal Is Not Required
Signal	True Positive (TP) Correctly warns of road departure	False Positive (FP) False alarm
No Signal	False Negative (FN) Misses road departure	True Negative (TN) Correctly does not warn of road departure.

The second evaluation area examines the timing, since a warning is of little benefit if it does not provide the driver with sufficient time to avoid an accident. Equations of motion determine the time afforded to a driver and are the basis for the performance metrics. Time limits determine whether a warning is useful. Since using the warning-system sensors and processing algorithms may bias the system evaluation, the metrics require independent, real-time measurements to assess timing.

The ability to detect the road edge is critical to the success of a RDCWS. For basic warning systems, the road edge is the lane markers in the vehicle's current travel lane and the system issues a warning before the vehicle enters the adjacent lane. However, driver behavior can produce slight lane excursions, and warnings for these instances might become a nuisance, thereby reducing driver acceptance of such a system. The intent of a RDCWS is to detect true crash conditions, such as driving off-road or drifting into obstacles outside the current lane. The objective to limit nuisance alarms and to focus on real crashes led to the concept of available maneuvering room (AMR), which is the region outside the lane marker that is drivable (e.g., paved shoulder) and is clear of obstacles. The AMR added to the outer lane boundary defines the road boundary.

The objective tests evaluate warning-system performance for different types of road-edges. The first test set examines the system's ability to detect a road edge defined by the outer lane marker under the assumption that there is a minimal amount of AMR. These tests are appropriate for a basic lane-departure system.

The next test set examines the system's ability to detect a road edge defined by the transition from pavement to off-road. These tests are appropriate for systems with advanced imaging sensors and processing algorithms that traditional lane-departure systems may lack.

The third test set examines the system's ability to detect a road edge defined by an obstacle on the shoulder. The tests consider two types of crash scenarios that stem from a lateral drift. In one scenario, the obstacle is adjacent to the vehicle (e.g., a Jersey barrier or guardrail). In the other case, the vehicle drifts into an obstacle ahead, such as a car parked on the shoulder. In either case, the road edge is an imaginary line at the base of the obstacle and parallel to the lane marker. These scenarios require range sensors and processing algorithms that traditional lane-departure systems may lack.

The final set of tests evaluates system performance when the vehicle is traveling too fast for an approaching curve, which is called the "curve-speed scenario."

I-4 Independent Measurement System

The independent measurement system collects and analyzes warning-system data and evaluates system performance. The warning-system evaluation uses sensors and equipment separate from the warning system under test. For example, the evaluated distance to a lane marker at the time of warning should not come from the warning system itself. Errors in the warning-system camera and image-processing algorithm could lead to incorrect assessment of warning-system performance. A complete manual describing the system and the procedures for collecting and analyzing data appears in [8].

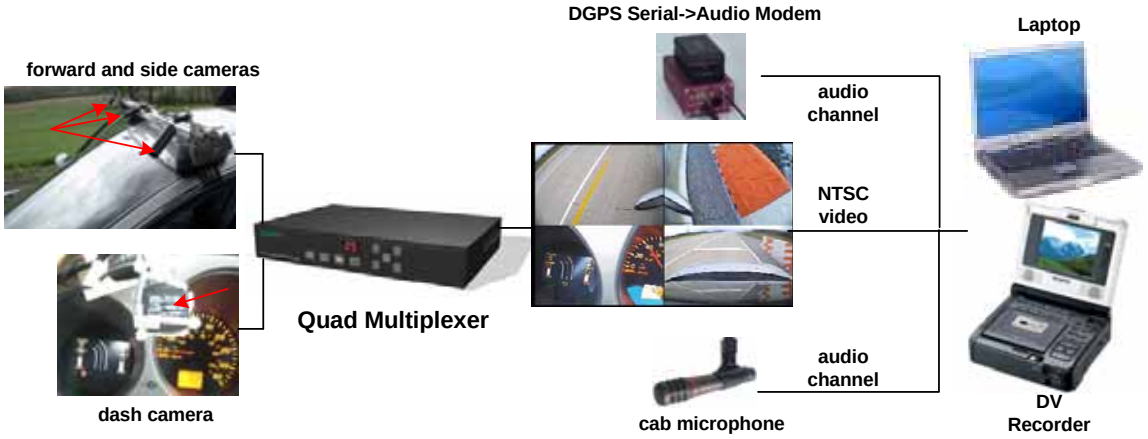


Figure 5. Independent Measurement System

Figure 5 illustrates the components of the IMS data collection system. Three cameras on a roof rack provide views ahead and to the sides of the vehicle. A fourth camera is mounted on the dashboard and captures the warning-system display. A quad multiplexer combines the four video signals into a single video stream. The output of the multiplexer appears in Figure 6. Other components of the IMS include a GPS receiver to sense vehicle position and velocity, and a cab microphone to pick up audible alerts and comments from the driver. To simplify data collection, a modem-like device converts the GPS data into an audio signal. A digital VCR simultaneously records the output of the quad video, the microphone (the first audio channel) and the GPS (the second audio channel), synchronizing the data streams. The enclosure and camera rack take approximately one hour to install on a vehicle. Ease of installation and reliability led the contractors to use the IMS to measure performance instead of their in-house system.

Figure 6. Four camera views combined into one. Top left and right are view of calibration sticks aligned with front wheels. Bottom right shows calibration sticks in front of vehicle. Bottom left is view of warning system display.

The calibrated cameras perform the following functions:

1. The left and right downward-facing cameras measure the lateral distances relative to the front wheels. The top left and right quadrants in Figure 6 show the calibration sticks for the side-looking cameras. The black and white stripes on the calibration sticks have known positions. The user identifies the pixel locations of the stripes (see red circles in top left of Figure 7) to define a transformation between pixel coordinates in the image and ground coordinates relative to the front wheels. The overlaid red circles indicate the calibrated portion of the video data (see top right quadrant in Figure 7). The software overlays the red circles on all subsequent video. When the evaluator clicks on a pixel along the line segments connecting the red circles, the software returns the lateral distance from the front wheel as well as the GPS coordinates of the pixel. The software uses linear interpolation for measurements between the circles.
2. The forward-facing camera provides lateral measurements in front of the vehicle and uses similar calibration sticks. It provides a view of the surrounding environment, as well as providing an alternative means for lateral measurements (e.g., distance to lane marker cannot be measured with the side camera when the vehicle is straddling the marker).
3. A dash-view camera shows the system status, as well as the system health, the sensitivity setting, and the alerts. For an alert (an example is shown in Figure 13), the display shows the alert direction (either right or left), severity (either caution or imminent), and type (either lane departure or curve speed). The appearance of the alert on the display correlates with the audible warning to the driver.

Figure 7. Results from pixel to ground calibration is shown using red circles. Circles in top left quadrant indicate transitions from black to white marking on calibration stick. Once the calibration stick is removed (e.g., top right view), the circles provide a reference for calibrated measurements (i.e., pixel to ground coordinate transformations).

The IMS includes a nonlinear calibration routine for measurements over areas larger than those covered by the calibration sticks. The routine removes nonlinear perspective and radial distortions, and requires placement of many targets over the area, requiring substantial time for setup and takedown. Consequently, the IMS currently uses the calibration stick method; an example of a calibration grid with identified grid points appears in Figure 8. The same image with the distortions removed appears in Figure 9.

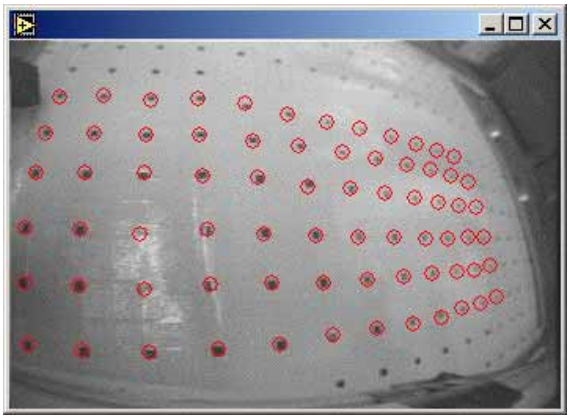


Figure 8. Nonlinear calibration grid with identified grid points (red circles)

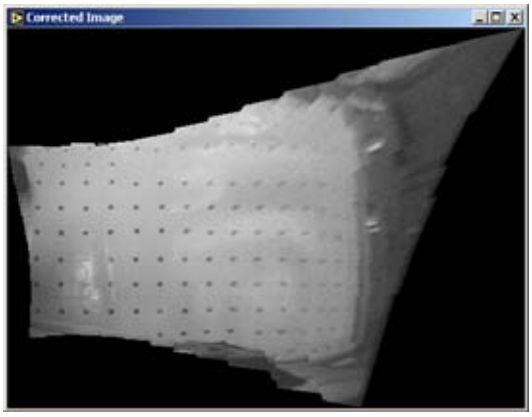


Figure 9. Nonlinear distortions removed after calibration.

Figure 10. The Analyze Data control panel.

NIST developed an extensive software program to analyze collected data. Figure 10 shows the program's main graphics interface, called "Analyze Data." The program performs the following functions:

1. Opens video files and provides VCR type controls to step through video data.
2. Opens DGPS data files and correlates the GPS data with AVI video.
3. Converts latitude and longitude (in degrees) into northing and easting (in meters).
4. Displays vehicle trajectory (interpolated and non-interpolated) on local map.
5. Interpolates GPS position (at 1 Hz) for each video frame (at 30 Hz).
6. Supports video-based distance measurements to the side and in front of the vehicle along the calibration stick line. Can measure:
    a. GPS coordinates of pixel (along calibration stick);
    b. Lateral distance (in meters) to pixel;
    c. Offset of vehicle within lane;
    d. Lane width; and
    e. Lateral velocity of vehicle with respect to road edge or obstacle.
7. Longitudinal distance measurements using GPS distance traveled.
8. Locates event in video file (e.g., warnings, operator comment button) based on GPS time. Event times can come from RDCWS data acquisition system.
9. Calculates curve radius based on GPS coordinates of road edge pixels.
10. Analyzes curve speed warnings using crash prevention equations.
11. Analyzes lateral drift warnings using crash prevention equations.
12. Generates scene lighting data (amount of video where overcast or sunny conditions exists).
13. Generates lane-marker contrast measurements (helpful to determine lane marker quality).
14. Displays data (e.g., GPS position, warning position) on MapPoint street map.

NIST also developed a prototype lane-tracking system for measuring lane position and lateral velocity automatically. The figures below show some of the challenges with lane tracking. An adaptive template algorithm was successful in tracking continuous, good-quality lane markers. The software requires improvements to handle poor quality markers, double markers and dashed markers. The tracker operates in each camera view (see Figure 13) to provide lane data in situations where the markers fade or are obscured.

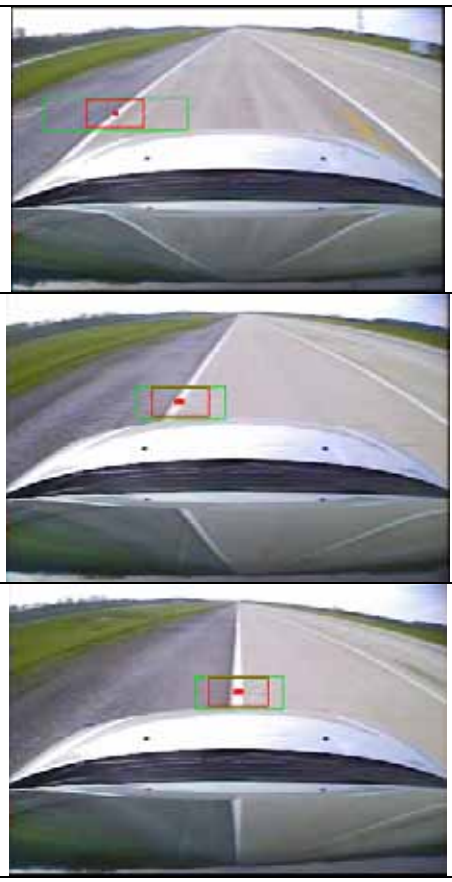


Figure 11. Sequence of image frames (widely spaced apart) illustrating how lane marker appearance varies. The green box is the search window whose location and size come from tracking results in the previous image. The red box is the location of the best match with a match template. The red bar is the refined location of the lane marker.

Figure 12. These are the two-dimensional templates used in the search. The tracker updates the template when a successful match occurs. As the scene slowly changes, the template will adapt to variations in the lane marker's appearance.

Figure 13. Tracking lane marker in multiple windows

Volpe used a copy of the IMS software to analyze on-road test data and commented positively on the wide variety of functions and their ease of use. The software will support future projects, such as the Integrated Vehicle-Based Safety Systems (IVBSS) program currently starting up.

I-5 Validation of Field Operation Test RDCWS

Visteon, the lead contractor for the FOT warning system, developed a set of validation test procedures based on the NIST objective test procedures [9]. They used the term "validation" in the sense that the tests validate that the system meets the intended functionality. The validation tests did not include objective tests evaluating the system's ability to determine the width of the shoulder, because of the difficulty in creating a robust image-processing system. In addition, the validation tests were constrained to the geometry of the test track and to fit within the FOT budget. NIST worked closely with Visteon to develop the validation tests and to ensure the tests met NHTSA requirements. NHTSA used the results of the validation tests to determine whether the RDCWS was ready for Phase 2 of the FOT. The validation test procedure consisted of the following tests:

1. Curve speed warning system tests
   a. Over speed tests (vehicle traveling too fast for curve)
   b. Most-likely path tests (system able to distinguish between branches in the road)
2. Lateral drift warning system tests
   a. Basic departure test
   b. Discrete obstacle test
   c. Continuous obstacle test
   d. Curved road departure test
   e. Adjacent vehicle drift tests

NIST and the FOT contractor conducted a series of validation tests between May 19, 2003, and April 27, 2004. These tests took place at the Transportation Research Center (TRC) in East Liberty, Ohio. Figure 14 shows the set-up for one of the tests (departure towards a continuous Jersey barrier).

Figure 14. Example test set-up at TRC for departure toward a Jersey barrier.

NIST mounted the IMS on the vehicle, collected data during each test, analyzed the results, and sent reports to NHTSA. The following section describes the tests.

May 19-30, 2003 – Transportation Research Center

The purposes of this effort were to validate the test procedures, to test the contractor's measurement system, to test NIST's IMS, and to conduct the first evaluations of the warning system. NIST observed the following during the tests:

1. The curve-speed warning system appeared to function properly.
2. The lateral-drift warning system (with and without barriers on the shoulder) worked largely as expected. Sometimes a warning occurred where a lane marker was crossed when there were no barriers nearby, as opposed to delaying the warning, since there was available maneuvering room on the shoulder.
3. Several warnings appeared to be late. Part of the lateness may be due to a delay (around 1 second) between warnings issued from the SafeTRAK/SAM component (in the trunk) and the Driver Interface (DVI). This implied that the SafeTRAK detected the warning condition in time, but that the DVI did not issue the warning until after a delay. The contractor needs to address this delay before the system is ready to deploy.
4. The warning system appeared to miss road departures over yellow lane markers on white concrete. This may be due to the low contrast of yellow on white and may be difficult to detect using a monochrome camera. The warning system should be able to handle this scenario. NIST recommended that this type of scenario be included in future performance tests. NIST also decided to switch from using black-and-white cameras to a color camera with the IMS
5. The contractor's measurement system did not function properly. The system required a large hand-held VHS camera attached to the passenger side door. Only departures on one side could be measured, so cameras had to be switched. A single meter stick was used for calibration and the system could only support measurements out to 1 meter from the wheel.
6. The NIST IMS functioned properly during the entire test.

October 1-23, 2003 – Transportation Research Center

The purpose of this effort was to conduct the first official round of testing of the warning system. NIST submitted an interim report to NHTSA on November 18, 2003. NIST observed the following during the tests:

1. All lateral drift tests passed, except for test 3.2.4.1, Discrete Obstacle Without Look-Aside Data Base (LADB), which is a lateral departure toward a car parked on the shoulder. Visteon and Assistware were made aware of this failure, and worked on modifications to bring the system into compliance.
2. In tests 3.2.4.1 and 3.2.4.2, Discrete Obstacle With and Without LADB, the procedure should include a specification to start the departure trajectory from an offset of 0.6 m inside the lane, so that the trajectory leads toward a collision within the prescribed 4-second departure trajectory. Note that the driver can still avoid a collision at this point.

3. In test 3.3.4.2 (Continuous Obstacle No Warning Test, designed to test for false alarms during normal weaving within a lane), the procedure should include a specification that a weave exceed a minimum value. Currently, the weave (the lateral drift) should not exceed a maximum value of ± 0.5 m. During the tests, the maximum weave was 0.17 m and the average was 0.11 m as measured using the IMS. This weave is very small and may not be indicative of normal driving behavior. The procedure should state a weave must exceed a minimum lateral drift (e.g., 0.3 m).
4. In test 3.5.4.1, Adjacent Vehicle Drift Test, there were instances where the front of the test vehicle may not have been even with the rear wheel of the adjacent vehicle. This may have caused some failed runs, since the side radar was not able to see this adjacent vehicle. This also precluded the use of the side-view camera to measure the distance between the vehicles (an optional measurement), since the adjacent vehicle was not located in the coverage area of the 2-meter calibration stick. The procedure should state that the test-vehicle front wheel should align with the rear wheel of the adjacent vehicle at the start of the departure to ensure that the adjacent vehicle is within the field- of-view of both the side radar and the calibration stick.
5. In some of the tests, the driver aborts before occurrence of a warning. The only way to detect this is to examine the lateral velocity in the cameras. A better approach would be to monitor the steering wheel to see when the driver decides to abort. The procedure should require that the dash camera be in a position where the dash and steering wheel are visible, possibly along the pillar next to the driver's left ear.
6. Test 2.1.4.3, Cold/Wet Within-Speed Test (looks for false alarms), was not completed due to time limitations. It is recommended that this test be deleted, since susceptibility to within-speed false alarms is examined in test 2.1.4.4, Warm/Dry Within-Speed, which the system had passed previously.
7. Tests 2.2.4.1 and 2.2.4.2, Most Likely Path (MLP) Path A and Path B, are too long. Both tests look for false alarms at two branches, called step 1 and step 2. This resulted in 40 MLP branches, 10 runs for each test times 2 branches per run. It is recommended that each test consist of 3 runs with 2 MLP branches each, for a total of 12 MLP steps.
8. The 2-meter calibration stick does not provide enough coverage area. Two meter sticks end-to-end should be added to provide four meters of coverage, which allows using the opposite lane marker to make measurements when the vehicle is on top of the lane marker during a departure. In addition, Visteon may want to use the calibration disks (1 meter spacing) available in the forward camera.
9. NIST and Visteon conducted analyses of the data. The results (i.e., whether a system passed or not) are consistent for both analyses. The actual measurements vary to some degree; these variances may be due to the following:
    a. NIST measurements coincide with the audible warning. The audible warning occurs after the visual warning; however, Visteon's measurements occur at the time of the visual alert.
    b. NIST uses a linear interpolation between stripes on the 2-meter stick.
    c. NIST uses a forward-view camera to measure lateral distances when the side-view cameras are not useful (i.e., the lane boundaries are covered by the vehicle). Visteon estimates lateral position by integrating lateral velocity measurements in the side-view cameras.

February 17-19, 2004 – Transportation Research Center

The purpose of this effort was to collect test data to determine whether modifications to the warning system improved performance. Visteon used the NIST Independent Measurement System to collect data. The warning system continued to have difficulties with the tests.

April 26-27, 2004 – Transportation Research Center

This was the final round of testing. Overall, the warning system performed well, passing all the tests based on the evaluation criteria determined by the system developers. However, the results of two tests (tests 3.2.4.1 and 3.2.4.2) were inconclusive. In these tests, the test vehicle drifts toward a car parked on the shoulder. To pass the test, the system must issue a warning when the vehicle reaches a region called the "expected lateral distance at warning," which is measured with respect to the lane boundary. A warning at this distance provides time during a real-world road departure for a driver to steer away from a parked car. However, in many runs, the vehicle was alongside the parked car when the warning occurred, yet still within an acceptable lateral distance for a warning. This was possible because of subtle driver steering corrections that reduced the departure rate just before reaching the parked car. A crash would have occurred if the vehicle had remained on a true collision course.

NIST recommends further research to improve the execution of this test (ensure the vehicle is on the desired trajectory) and to strengthen the criteria for detecting late warnings (possibly include a longitudinal distance at time of warning criteria). NIST discussed these issues with the RDCWS contractors and the contractors are investigating to determine the cause of the late warnings. NIST has also discussed these issues with Bruce Wilson at Volpe, who will conduct characterization tests of the warning system later in the year.

NIST delivered a final-results report to NHTSA on May 24, 2004 [9]. NHTSA used results to determine that the system was ready for Phase 2 of the FOT. This was a critical decision point since Phase 2 involved instrumentation of twenty vehicles, selection of drivers from the public and collecting many months of data.

NIST processed video and DGPS data for each test run. The table and figures below are an example of the results obtained by NIST for the "Adjacent Vehicle Drift" test (appears in [9], page 34). This test is a lateral departure on a straight road into a lane occupied by an adjacent vehicle.

Table 2. Data from Adjacent Vehicle Drift Test, April 27, 2004

Run #	Local Time of Alarm	Depart Side	Warn Type	Lateral Velocity (m/s)	Lateral Distance (m)	Distance to Adj. Vehicle (m)	Time to Collision	Pass/Fail
1	10:38:04.64 am	left	I	0.39	-0.10	1.23	3.15	Pass
2	10:38:13.41 am	left	I	0.37	-0.19	1.46	3.94	Pass
3	10:38:21.39 am	left	I	0.35	-0.18	1.63	4.70	Pass
4	10:38:27.69 am	left	I	0.25	-0.41	1.59	6.48	Pass
5	10:38:40.21 am	left	I	0.47	-0.10	1.05	2.22	Pass
6	10:42:58.03 am	left	I	0.38	-0.21	1.12	2.95	Pass
7	10:43:03.57 am	left	I	0.19	-0.25	1.40	7.47	Pass
8	10:43:10.24 am	left	N	0.37	0.00	1.40	3.74	Fail
9	10:43:19.92 am	left	I	0.30	-0.28	1.32	4.40	Pass
10	10:43:26.39 am	left	I	0.47	-0.21	1.44	3.03	Pass
11	10:43:32.23 am	left	I	0.19	-0.37	1.78	9.14	Pass
12	10:43:39.00 am	left	I	0.35	-0.20	1.45	4.11	Pass
13	10:43:45.01 am	left	I	0.35	-0.11	1.39	4.00	Pass
14	10:43:49.21 am	left	N	0.35	0.00	1.47	4.17	Fail
15	10:44:26.45 am	left	I	0.36	-0.12	1.43	3.92	Pass
16	10:45:31.82 am	left	I	0.44	-0.15	1.63	3.70	Pass
17	10:49:09.44 am	left	I	0.44	-0.05	1.27	2.91	Pass
18	10:49:15.91 am	left	I	0.43	-0.11	1.44	3.31	Pass
19	10:49:22.41 am	left	I	0.21	-0.20	1.48	6.91	Pass
20	10:49:30.56 am	left	I	0.30	-0.30	1.61	5.37	Pass
21	10:49:36.63 am	left	I	0.20	-0.31	1.47	7.46	Pass
22	10:49:42.17 am	left	I	0.18	-0.32	1.66	9.00	Pass
23	10:49:47.91 am	left	I	0.50	-0.20	1.40	2.80	Pass
			Mean	0.34	-0.19	1.44	4.73	
			Std Dev	0.10	0.11	0.17	2.02	
			Median	0.35	-0.20	1.44	4.00	
			Min	0.18	-0.41	1.05	2.22	
			Max	0.50	0.00	1.78	9.14	

In Table 2, the column labeled "Lateral Distance" is the distance to the lane marker (negative means inside the lane) and the column labeled "Distance to Adj. Vehicle" is the distance at the time of warning (or line crossing, when no warning is issued). The "Time to Collision" is a function of the lateral velocity and the distance to the adjacent vehicle at the time of warning and provides an indication of how much time the driver has to respond. The median time-to-collision (TTC) is 4 seconds and the minimum TTC is 2.22 seconds. Figure 15 and Figure 16 are from the failed test runs and show no warning when the vehicle departed with a vehicle in the adjacent lane (Warn Type is either "I" [imminent] or "N" [none given]).

Figure 15. Failed run # 8 (warning icon should appear at arrow)

Figure 16. Failed run # 14

NIST and Volpe collaborated on a paper describing the performance methods [11], and it was presented at the Performance Metrics for Intelligent Systems (PerMIS) Workshop held at NIST in August 2004.

Figure 17 illustrates the results of a drift-toward-barrier test presented at the PerMIS workshop. The plot shows distance to the barrier at warning, versus the lateral velocity toward the barrier for each test run (shown as small circles). The curve between the "On-time" and "Late" labels is the crash prevention boundary (CPB) equation, generated using equation (1):

$$y_w = (v\theta)t_r + \frac{(v\theta)^2}{2a_{lat}} \qquad \textbf{(1)}$$

Where

y_w = the lateral distance between the vehicle front tire and the barrier (perpendicular to the wheel)
v = vehicle forward speed
t_r = delay between warning and start of steering (driver reaction time)
θ = the departure angle. (Note the graph below converts angle to lateral velocity)
a_{lat} = the limit on lateral acceleration the driver will experience when steering to avoid the barrier (acts as a sensitivity setting)

If the location of a warning (i.e., the circle) is below the CPB, then the warning is late. All the warnings in Figure 17 appear in the "on time" region of the graph.

Figure 17 shows examples of performance evaluation issues, where the warnings appear to be early. The warning system may have based the alert on distance to the road edge, not to the barrier. The FOT warning system uses the lane marker plus an AMR value to determine the road edge. The system caps the AMR at a maximum value to prevent large variations in AMR (e.g., at large shoulders) from causing large variations in warning lo-

cation. The graph also shows relatively constant warning distances, as opposed to distances varying with lateral velocity (a line fit through the warning distances should have a slope similar to the CPB line). The system should warn earlier for higher lateral velocities since, the driver needs more room to avoid the departure. These issues demonstrate the importance of having all parties agree on system behavior and methods when evaluating system responses.

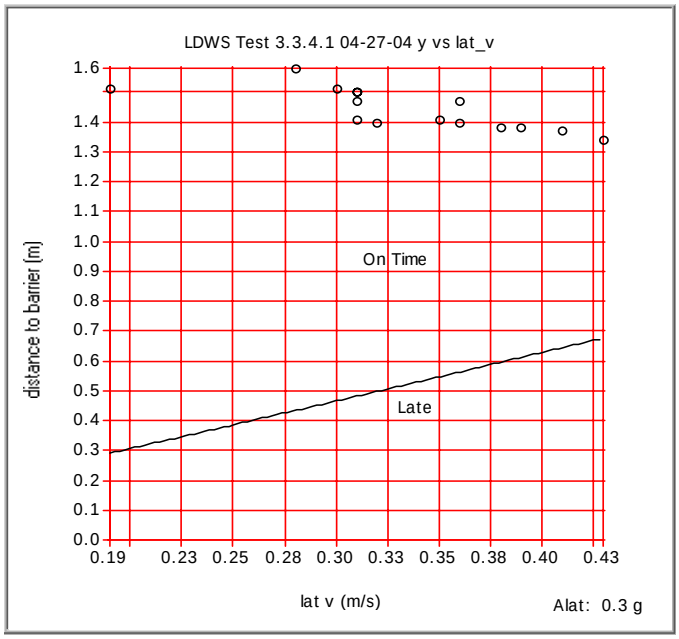


Figure 17. Graph of distance-to-barrier at time of warning versus lateral velocity toward barrier.

I-6 RDCWS On-Road Objective Test Procedures

Engineers conduct on-road tests in naturalistic environments to evaluate the warning system under a wider range of conditions and in scenarios that are more complex than encountered during track-based tests. The engineers either invoke true positive warnings using maneuvers similar to track-based tests (e.g., drift toward a Jersey barrier), or invoke false positive warnings via encounters with likely sources (e.g., roadside signs on curves). These tests generate statistically significant numbers of warning events, as opposed to the fewer warning events generated by public drivers performing daily routines during the Phase 2 FOT data collection effort.

NIST submitted a first draft of a set of on-road test procedures to Volpe in August 2004. The goal of the test procedures is to quantify the following warning system characteristics:

1. Availability: Availability is the percent of time the system is tracking the road edge correctly. Even though the system reports availability, nothing exists to determine the accuracy of the report (i.e., can evaluators rely on the reported availability?). Availability has a direct impact on estimating system benefit. For example, a system that is unavailable during rain will not be able to achieve a reduction in accidents that occur in rain.
2. False Positive Rate: The false positive rate describes the number of false alarms over a specified duration (e.g., per miles driven or per number of encounters). A high level of false positives tends to reduce the effectiveness of the warning system. It is also desirable to identify the causes of false alarms in order to improve performance in future systems.
3. False Negative Rate: The frequency at which the system misses warning conditions is the false negative rate. A high level of missed alarms indicates serious problems and that further work is required before deploying the system.

The NIST on-road test procedures included the following attributes designed to increase the degree of objectivity:

1. The tests take place on a variety of road types and require a minimum number of miles driven on each road type. This ensures that tests do not occur only on ideal roads.
2. The tests occur at different hours of days and lighting conditions. This allows evaluation of the effects of sun angle, nighttime lighting, and clear versus overcast conditions on warning-system performance.
3. The tests include encounters with a range of roadside obstacles. This includes side-on (e.g., Jersey barriers, adjacent lane vehicles) and side-forward encounters (e.g., traffic barrels, mailboxes).
4. Each near-crash encounter or false alarm is recorded and pertinent measurements made. The IMS provides independent measurement and full-frame video for precise measurements.

5. Each evaluation of a warning uses metrics defined in objective test procedures. This provides insight into the amount of time provided by a warning and the variability of alert timing.

Volpe expounded upon the initial draft of the on-road test procedures and NIST participated in developing a formal test procedure [12]. The test procedures expose the warning system to a variety of conditions expressed in vehicle mileage (see Table 3). In addition, the tests include encounters with a range of scenarios (see Table 4). The conditions and mileage come from analyses of crash statistics and from analyses of warning system characteristics. The on-road test procedures evaluate warning correctness and timing using metrics and measurement procedures identical to the NIST track-based objective test procedures. NIST submitted the latest version of the on-road test procedures with this final report.

Table 3. Conditions for on-road tests and the amount of exposure.

Conditions	Quantity
Road Type	
Freeway (NavTech Class 1 or 2)	> 50 miles
Non-freeway (NavTech Class 3 or 4)	> 200 miles
Lighting and atmosphere	
Low angle sunlight (split between dawn to one hour after dawn and one hour before dusk to dusk) and clear atmosphere	> 30 miles
Other sunlight (9 a.m. to 4 p.m.), no cloud cover, and clear atmosphere	> 60 miles
Daylight and cloudy	> 30 miles
Daylight, cloudy, and rainy	> 30 miles
Night lighting and clear atmosphere	> 30 miles
Night lighting and rainy atmosphere	> 30 miles

Table 4. Scenarios for on-road tests and the number of encounters.

Scenarios	Quantity
Lateral drift alert encounters	
Departure on rural roads with narrow shoulder ≤ 1 m	≥ 10
Departure on roads with medium shoulder 1 m – 2 m	≥ 10
Departure on highway with wide shoulder ≥ 2 m	≥ 10
Drift left towards solid lane boundary	≥ 10
Drift left towards striped lane boundary	≥ 10
Side obstacle encounters	
Drift left towards vehicle traveling in adjacent lane	≥ 10
Drift right towards vehicle traveling in adjacent lane	≥ 10
Drift towards guard rails in close proximity (≤ 1 m) to lane edge	≥ 10

Drift towards Jersey barriers in close proximity (≤ 1 m) to lane edge	≥ 10
Drift towards traffic barrels in close proximity (≤ 1 m) to lane edge	≥ 10
Side-forward obstacle encounters	
Drift towards vehicle parked on shoulder	≥ 10
Drift towards bridge abutment	≥ 10
Drift towards telephone pole	≥ 10
Drift towards obstacle in curve	≥ 10
CSW curvature encounters (all at alert inducing speeds)	
Tight radius curve (radius ≤ 100 m) to the right wipers on	≥ 10
Tight radius curve (radius ≤ 100 m) to the right wipers off	≥ 10
Tight radius curve (radius ≤ 100 m) to the left wipers on	≥ 10
Tight radius curve (radius ≤ 100 m) to the left wipers off	≥ 10
Medium radius curve (radius > 100 m) to the right	≥ 10
Medium radius curve to the left	≥ 10
CSW ramp encounters (all at alert inducing speeds)	
Pass tight right ramp while in right lane without signal	≥ 10
Pass tight left ramp while in left lane without signal	≥ 3
Pass tight right ramp while in right lane with signal	≥ 10
Pass tight left ramp while in left lane with signal	≥ 3
Turn on tight right ramp while in right lane without signal	≥ 10
Turn on tight left ramp while in left lane without signal	≥ 3
Turn on tight right ramp while in right lane with signal	≥ 10
Turn on tight left ramp while in left lane with signal	≥ 3
CSW overpass encounters (all at alert inducing speeds)	
Pass beneath random overpasses	≥ 20
Pass beneath one or more overpasses known to issue false positive alerts	≥ 10

I-7 RDCWS On-Road Tests

NIST and Volpe conducted the on-road test procedures described in the preceding section using the FOT RDCWS. The University of Michigan Transportation Research Institute (UMTRI) provided the vehicle and collected warning-system data using their Data Acquisition System (DAS). The tests required two periods of driving to obtain the encounters and exposure specified in the test procedures. The tests took place in the fall of 2004 and spring of 2005.

A large fraction of the tests took place along the FOT pilot route shown in Figure 18. This route contains the various required road types, and there is a wide range of lane marker quality that presented significant challenges to the warning system.

Figure 18. FOT pilot route used for large portion of on-road tests. The dots are the vehicle position (15 s intervals) and the pins are the location of warnings. This run took place on March 14, 2003 (trip 403).

October 26-27, 2004 - Ann Arbor, MI

The tests consisted of three 90-minute drives along the pilot-test route in Ann Arbor, Michigan. NIST and Volpe personnel drove the vehicle during morning, afternoon, and nighttime conditions. The test included a fourth 90-minute drive to help determine if the pilot-test route was missing any events or scenarios.

The exercise discovered the following deficiencies in testing and data collection:

1. Nighttime video data was difficult to analyze. Before the next round of tests, NIST evaluated several infrared (IR) illuminated cameras and selected a pair of side-looking IR cameras that provided acceptable video (note flashlight-like beam in upper quadrant windows shown in Figure 19).

2. It was difficult to locate missed alerts during all the hours of driving. For the next round, the driver flagged missed alerts using the comment button.

NIST processed the IMS video and GPS data to produce 30 Hz calibrated video with DGPS available for each video frame. NIST then analyzed each lateral drift warning and produced a summary of the alert that included:

1. Identification of warning scenario type (from on-road test procedures)
2. Lateral offset at time of warning (all measurements are at time of warning)
3. Available maneuver room
4. Lateral velocity
5. Lateral and longitudinal distance to road side obstacle
6. Curve data (class, vehicle position in curve, vehicle distance to curve)
7. Lane marker data (color, type, subjective quality)
8. Road type
9. Environment data (wet/dry, day/night)
10. Lateral drift alert rating (true positive, etc.).

NIST sent the processed data, the measurement and evaluations, and a copy of the IMS analysis software to Volpe. Volpe analyzed the data to determine what additional conditions (i.e., mileage) and scenario encounters remained. The results guided the next round of tests conducted the following spring.

March 14-17, 2005 – Ann Arbor, MI

NIST, Volpe, and NHTSA personnel participated in the next round of tests. Again, UMTRI provided excellent support. A radar unit malfunctioned and UMTRI replaced the unit immediately. After each day's run, UMTRI downloaded data and checked the data's integrity.

NIST processed the second round of on-road test data collected. NIST analyzed the data twice by separate engineers to ensure quality control. NIST sent the results to Volpe for inclusion in a final report. The final data includes:

1. Complete video of all trips – Over 15 hours of compressed video and audio.
2. Correlated DGPS – Each video frame is correlated to DGPS time and position
3. Calibration data – Each video pixel is registered with DGPS position
4. Lateral Drift alerts – 362 alerts analyzed:
   a. Lateral position and lateral velocity at time of alert
   b. Type of scenario – e.g., departure on country road with no shoulder
   c. Road and atmospheric conditions
   d. True/False positive rating
5. Lateral Drift missed alerts (false negatives) – 79 missed alerts were analyzed and classified.

The final report for the on-road tests (to be submitted by Volpe) will summarize warning-system performance in a quantitative fashion, and will include:

1. Total mileage under various road types and conditions (day/night, clear/overcast, etc.).
2. Total number of true-positives, false-positives, and false-negatives.

3. Histograms summarizing the distribution of warning times (e.g., number of warnings where time to crash was between 1 s and 1.5 s).
4. Documented cases of interest.

Documenting cases of interest is an important tool for evaluating system performance. In one instance, headlight glare off of road salt during nighttime driving caused the warning system to miss several departures. Figure 19 shows four images at about one-second intervals documenting a missed departure (trip 427, March 16, 2005, 10:03:28 p.m.). The forward camera view (lower right quadrant) in frame # 47510 shows the road just before encountering a stretch of heavily applied salt. This is a two-way road with double yellow lines indicating no passing allowed. The lane markers are in good repair and the contrast between the markers and the asphalt is good. The forward view one second later (frame # 47540) shows the start of heavy glare coming from road salt. Frame # 47660 shows the start of a random lateral drift left. Frame # 47750 shows the vehicle well into the opposite lane without the system issuing a warning (no visible warning icon in dash shown in lower left quadrant). Note that this glare appears in the IMS camera and not the warning-system camera. However, both cameras employ similar CCD technology and reside closely to one another on the vehicle. Even though the glare saturates the lane markers, the system is still tracking (i.e., the system reports that it is available), but this may be a case of false availability. The system classifies the peaks in intensity caused by the headlights as lane markers. As the vehicle drifts, the two intensity peaks also drift, creating the appearance that the vehicle remains centered in the lane.

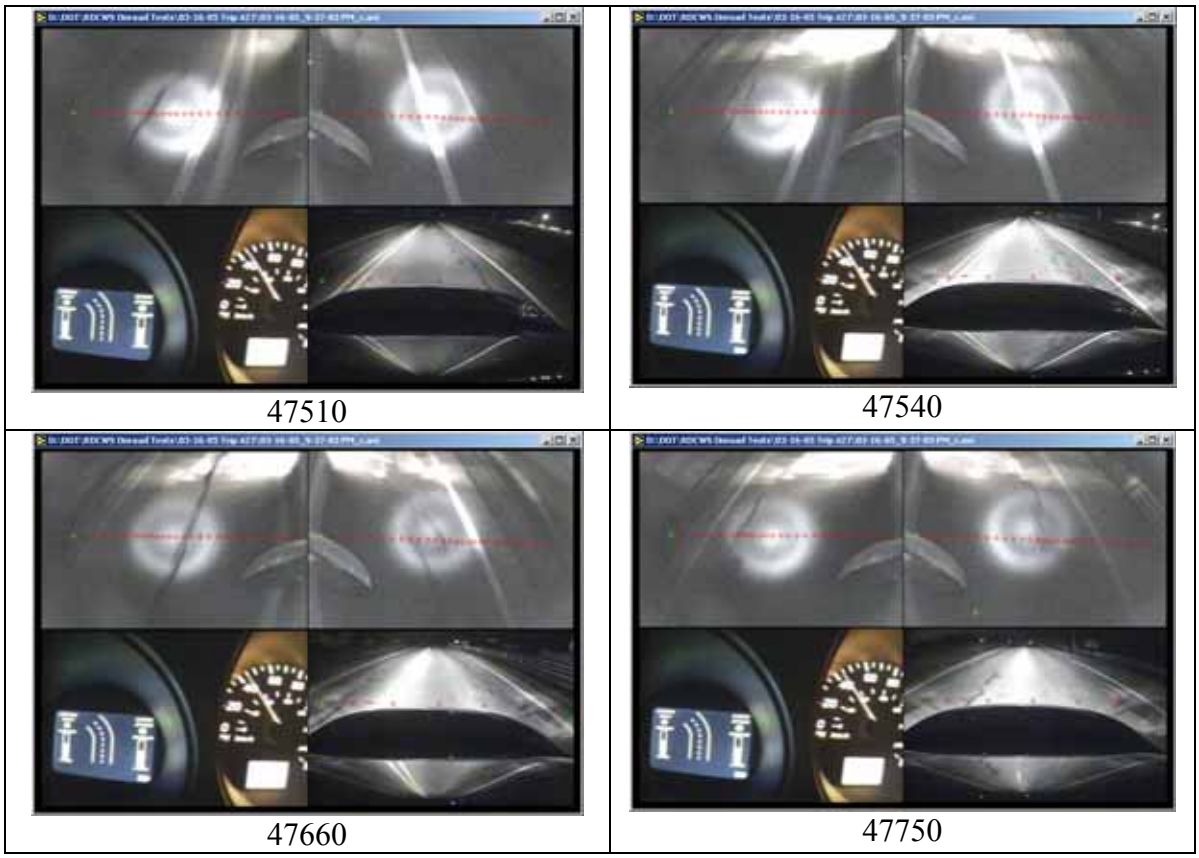


Figure 19. Headlights reflecting off road salt caused excessive glare in IMS camera (lower right quadrant in each image).

I-8 Conclusions

The goal of the cooperative agreement between NIST and USDOT was to develop objective test procedures and measurement methods for Road Departure Crash Warning Systems. NIST developed a suite of test procedures to evaluate basic warning-system performance. The procedures identified the performance metrics and methods used to evaluate performance. NIST developed an independent measurement system (IMS) to collect data and make analyses required to evaluate the system according to the performance metric. In essence, the IMS provides a ground truth to support the evaluation of warning-system performance.

The test procedures, performance metrics, and measurement methods were essential to the success of the RDCWS FOT. NIST assisted and observed the contractors during the validation testing of the FOT RDCWS. Data collected during the test helped identify several problems and led to significant improvements in warning-system performance. Results from the testing supported the decision by USDOT to proceed with Phase 2 of the FOT.

NIST then worked with Volpe to develop on-road test procedures. These tests provided data for Volpe's warning-system characterization task. NIST and Volpe took care to ensure the objectivity of the tests. The on-road test is a logical extension of the objective tests, employing similar scenarios, procedures, metrics, and measurement methods.

In all, the various tests and measurement methods serve as a framework for future evaluations of vehicle-based warning systems. The work has shown the importance of objective testing in evaluating system performance, in guiding research and development, and in decision-making policy. When the time comes to deploy these warning systems, manufacturers will have ways to demonstrate to the public the effectiveness of their safety systems. Demonstrable effectiveness should lead to wider public acceptance and to a decrease in vehicle-based crashes and fatalities.

Part II:
Recommendations for Objective Test Procedures for Road Departure Crash Warning Systems

History

June 26, 2002 – First draft of procedures for lateral drift warning system submitted to NHTSA.

September 13, 2002 – Updated previous draft based on information obtained from the contractor's second quarterly review (July 24, 2002). Procedures added for curve speed warning system.

December 18, 2002 – Updated based upon comments from Dave Smith and Lloyd Emery of NHTSA during meetings on December 10, 12, and 18, 2002.

January 31, 2003 – This draft represents latest detailed design of tests at time of February 5 FOT Quarterly Review.

February 18, 2003 – This draft represents latest detailed design at time of trip to visit RDCWS contractor on February 18. The version includes curve speed warning test and the on-road nuisance tests.

November 15, 2005 – This draft represents results from validation tests conducted by the RDCWS contractors and NIST. The on-road tests now exist separately in a Volpe/NIST document. This draft submitted to NHTSA as part of NIST's RDCWS final report.

II-1 Introduction

Under the auspices of the U.S. Department of Transportation Intelligent Vehicle Initiative, the National Highway Traffic Safety Administration is evaluating the safety benefits of Road Departure Crash Warning Systems. These systems warn inattentive drivers when their vehicle is about to depart the road or collide with a roadside obstacle. To further understand the capabilities and benefits of these warning systems, NHTSA, with the assistance of the National Institute of Standards and Technology, is devising test procedures that provide performance data in an objective and quantitative manner. These tests will evolve to provide new insight into performance measurement and to maintain pace with the capabilities of the warning systems. In the long term, these tests may become part of a standard procedure developers follow to achieve a safety rating similar to the "5-star" ratings used in the automotive industry today.

The RDCWS Field Operation Test program [13] validated many of the tests included in this report. The developers of the FOT RDCWS used an early version of these procedures to validate system performance. The developers adapted the procedures to meet the time, funding and available track geometry of the FOT. The RDCWS FOT contractor and NIST conducted the tests (called validation tests) at the Transportation Research Center from October 1, 2003, through April 28, 2004. The successful performance of the system during the tests allowed the FOT to proceed to Phase 2.

These tests use considerable research from the international community, NHTSA, the Volpe National Transportation Systems Center, and NIST, including the following:

1. An outline of the NIST RDCWS research results appears in a final report titled "Run-Off-Road Collision Avoidance Using IVHS Countermeasures" [16] (referred to as the ROR report in this document).
2. The Road Departure Crash Warning System FOT Request for Applicants issued by NHTSA [13] contains the performance capabilities expected of a warning system.
3. A NHTSA and Volpe report on an analysis of crash data identifies high-risk crash scenarios [13].
4. Reference [17] is the International Standards Organization test procedure for lane-departure warning systems.

A RDCWS consists of the sensor, the alert logic (correctness and timing) and the driver interface. The tests in this document address sensor and alert logic performance only. A complete evaluation of the driver interface would consider how a driver responds to the warning. These tests only evaluate the driver interface from the standpoint of whether the interface presented the warning or not.

The methods for evaluation of the warning system focus on two areas: correctness and timing. The correctness of each warning issued by the system is either true-positive, false-positive, false-negative or true-negative (Table 5). Statistical evaluations, such as

efficacy rate (the percentage of warnings that produce the desired effects) and false-alarm rate, summarize the results of the ratings.

Table 5. Rating of warning system signals.

System Response	Situations Requiring a Warning	Situations in Which a Warning is not Required
Warning	True Positive (TP) Correctly warns of road departure	False Positive (FP) False alarm
No Warning	False Negative (FN) Misses road departure	True Negative (TN) Correctly does not warn of road departure.

The second area of evaluation examines timing. A warning is of little benefit if it does not provide the driver with sufficient time to avoid the departure. Equations of motion are the basis of the performance metrics and determine the time afforded to a driver. Time limits determine whether a warning is useful or not.

The methods quantify performance, but do not specify the passing grade (e.g., the system must pass 90% of the tests). The organization interested in the test results should select the pass/fail criteria (some examples are provided in Section II-5).

Evaluation of the metrics requires real-time measurements, preferably from an independent measurement system. Using the warning system sensors and processing algorithms may bias the system evaluation. For illustrative purposes, the test procedures include instructions for taking measurements using an IMS developed by NIST.

The ability to detect the road edge is critical to the success of a warning system. For basic warning systems, the road edges are the lane markers in the vehicle's current travel lane and the system issues a warning before the vehicle enters the adjacent lane. However, driver behavior can produce slight lane excursions and warnings for these instances might become a nuisance. The intent of a road departure crash warning system is to detect true crash conditions, such as driving off-road or drifting into obstacles outside the current lane. The objective to limit nuisance alarms and to focus on real crashes led to the concept of an available maneuver room (AMR), which is the region outside the lane marker that is drivable (e.g., paved shoulder) and clear of obstacles. The AMR added to the outer lane boundary, which defines the road boundary.

Tests evaluate warning system performance for different types of road edges. The first set of tests examines the system's ability to detect a road edge defined by the outer lane marker under the assumption that there is a minimal amount of AMR. These tests are appropriate for a basic lane departure system.

The next test set examines the system's ability to detect a road edge defined by the transition from pavement to off-road. The size of the shoulder may vary considerably, which would lead to a wide range of warning locations. Previous work [16] suggests a need for

consistent warning location. Therefore, the AMR has a default maximum value regardless of the shoulder width.

Another test set examines the system's ability to detect a road edge defined by an obstacle on the shoulder. In one case, the vehicle drifts into an obstacle adjacent to the vehicle, such as a Jersey barrier or guardrail. In the other case, the vehicle drifts into an obstacle ahead, such as a car parked on the shoulder. In either case, the road edge is an imaginary line at the base of the obstacle and parallel to the lane marker.

The tests above address lateral drift scenarios. The final set of tests evaluates system performance when the vehicle is traveling too fast for an approaching curve (the curve-speed scenario).

This document has nine sections. The first section is this introduction. Section II-2 contains definitions of the terminology used throughout the document. Section II-3 contains an overview of the general test structure common to each test. Section II-4 describes a measurement system to independently collect data for analyzing warning system performance. Section II-5 describes evaluation procedures that are commonly used in lateral drift and curve speed tests. Section II-6 contains tests to evaluate departures on roads with no available maneuver room. Section II-7 contains tests to evaluate departures on roads with available maneuver room. Section II-8 contains tests to evaluate departures towards barriers and obstacles. Section II-9 contains tests to evaluate departures on curves due to excessive speed.

II-2 Definitions

This section contains definitions of terms used in the tests. The definitions fall into one of the following categories: road, vehicle, crash and environmental.

2.1.1 Road Definitions

2.1.1 Road

The road consists of all travel lanes in the same direction of travel. This includes paved shoulders clear of obstacles. Roads may be divided or undivided.

2.1.2 Undivided Road

An undivided road is a road with two-way traffic (see Figure 20). Either double lane markers or a single dashed lane marker separates the directions of travel. A single dashed lane marker indicates passing in either direction. Double lane markers consist of combinations of solid and dashed stripes. Dashed indicates passing is permitted and solid prohibits passing.

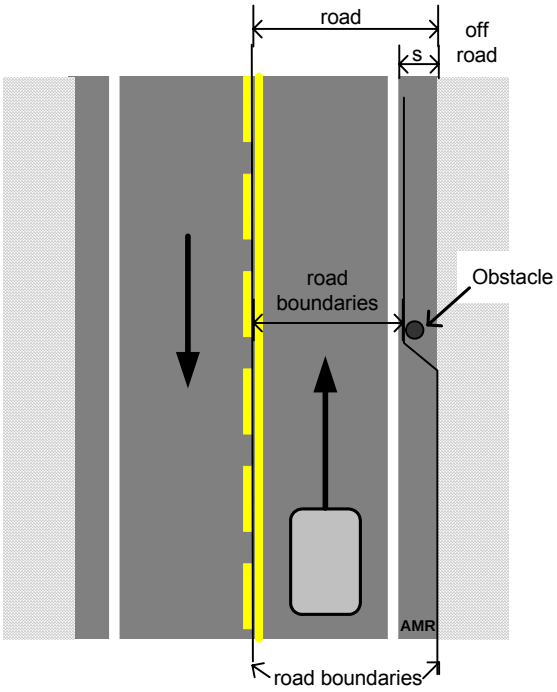


Figure 20. Undivided road includes all travel lanes and the shoulder (s)

2.1.3 Divided Road

A divided road is a road with one-way traffic (see Figure 21). Dashed white lane markers separate lanes of traffic.

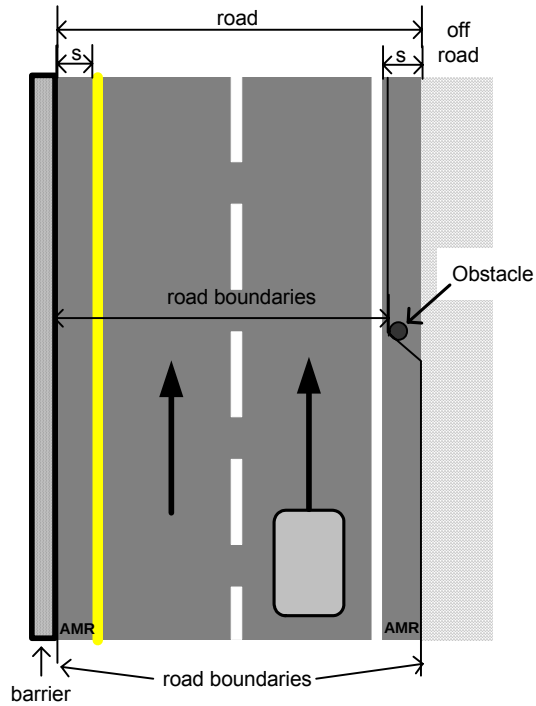


Figure 21. Divided road includes all travel lanes and the shoulder (s)

2.1.4 Lane

The lane is the area of paved surface between two parallel lane markings. The distance between the inside edges of the lane markings should be 3.7 m (12 ft.). The lane must have markings on the left side. If the lane has no markings on the right side (worn or missing), then the lane is 3.7 m measured from the inside edge of the left side lane marker.

2.1.5 Shoulder

The shoulder is the portion of drivable surface to the right of an undivided road and on either side of a divided road. Refer to "s" in Figure 20 and Figure 21.

2.1.6 Available Maneuver Room

The available maneuver room is the region of the road outside the outer lane marker that is safe to drive (see "AMR" in Figure 20 and Figure 21). Obstacles on the shoulder or absences of shoulders limit the AMR. By design, the AMR does not exceed a default maximum value (1 m), regardless of the size of the shoulder. The default minimum value is 15 cm (6 in.).

2.1.7 Road Boundary

The road boundary (also referred to as road edge) is the real or imaginary boundary line on the pavement and defines the edge of the road (see Figure 20 and Figure 21). The road boundary is parallel to the outer lane marker and extends beyond the outer lane marker by the available maneuver room distance. A warning system senses the available maneuver room (e.g., obstacles on the shoulder) and adjusts the road boundary accord-

ingly. The warning system also uses the distance to the road boundary to calculate when to issue a warning.

2.1.8 Curved Road

A curved road is a section of road with a radius less than 1,000 m.

2.1.9 Straight Road

A straight road is a section of road with a radius greater than 1,000 m.

2.1.10 Lane Markings

The definitions for lane markings come from part three of the Manual on Uniform Traffic Control Devices (http://mutcd.fhwa.dot.gov/). Lane marker dimensions for the test are:

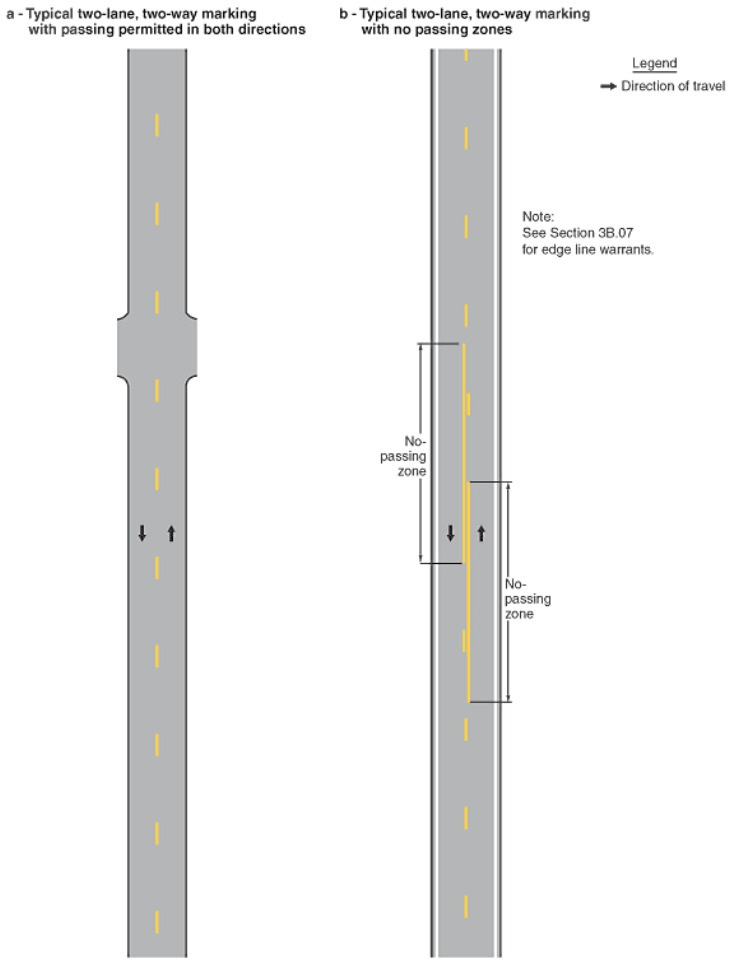
Lane marker value	Dimensions
Maker width	10 cm to 15 cm (4 in to 6 in.)
Dashed marker length	3 m (10 ft) ± 5 %
Dash marker gap length (distance between dashed markers)	9 m (30 ft) ± 5 %

Appendix A, Methods for Determining Road Dimensions and Geometry, contains the recommended method to verify the lane marker dimensions.

The manual states:

> Centerline pavement markings, when used, shall be the pavement markings used to delineate the separation of traffic lanes that have opposite directions of travel on a roadway and shall be yellow.
>
> The centerline markings on two-lane, two-way roadways shall be one of the following as shown in Figure 3B-1:
>
> A. Two-direction passing zone markings consisting of a normal broken yellow line where crossing the centerline markings for passing with care is permitted for traffic traveling in either direction;
>
> B. One-direction no-passing zone markings consisting of a normal broken yellow line and a normal solid yellow line where crossing the centerline markings for passing with care is permitted for the traffic traveling adjacent to the broken line, but is prohibited for traffic traveling adjacent to the solid line; and
>
> C. Two-direction no-passing zone markings consisting of two normal solid yellow lines where crossing the centerline markings for passing is prohibited for traffic traveling in either direction.

Figure 3B-1. Examples of Two-Lane, Two-Way Marking Applications



When used, lane line pavement markings delineating the separation of traffic lanes that have the same direction of travel shall be white.

Where crossing the lane line markings with care is permitted, the lane line markings shall consist of a normal broken white line.

Where crossing the lane line markings is discouraged, the lane line markings shall consist of a normal solid white line.

Where crossing the lane line markings is prohibited, the lane line markings shall consist of two normal solid white lines.

If used, the right edge line pavement markings shall consist of a normal solid white line to delineate the right edge of the roadway.

2.1.11 Lane Marker Reflectivity

The lane marker reflectivity (or brightness) is the ratio between the luminance of the marker (light coming from the marker) and the luminance on the marker (the light reaching the marker).

In daylight conditions, the measure of reflectivity is the coefficient of luminance under diffuse illumination (Q_d).

In nighttime conditions, the brightness is a function of the headlights and the retro-reflectivity of the lane marker. The measure of retro-reflectivity is the coefficient of retro-reflected luminance (R_L).

Both of these coefficients are in units of millicandelas per square meter per lux ($mcd \bullet m^{-2} \bullet lx^{-1}$). The geometry regarding the orientation of the light source, the orientation the viewer and the distance to the lane marker is part of the measurement process 0.

The values below come from Table 1 in reference (II-14).

Lane Marker Color	Minimum coefficient under diffuse illumination, Q_d (mcd m^{-2}/lx)
White	< 130 (for Asphalt) < 160 (for Concrete)
Yellow	< 100

Appendix II-B contains the recommended method to verify the lane marker reflectivity.

2.1.12 Lane Marker Color

The daytime color of the lane marker is defined by its chromaticity and luminance (x,y,Y). The CIE (Commission International d'Eclairage, or International Commission on Illumination, http://www.cie.co.at/cie/) chromaticity chart shows the coordinates (x,y) of visible colors. The luminance (Y) defines the brightness of the color.

The four points listed in the table below bound the region of allowable colors for both white and yellow lane markers. Each color includes the luminance factor (Y). The values come from Table 1 and Table 3 of reference (II-12). One can use a commercial measurement device to measure color properties.

Lane Marker Color	Daytime Chromaticity Coordinates (x,y)	Luminance factor Y (%)
White	0.355, 0.355 0.305, 0.305 0.285, 0.325, 0.335, 0.375	Minimum of 45
Yellow	0.560, 0.440 0.490, 0.510 0.420, 0.440, 0.460, 0.400	Minimum of 30

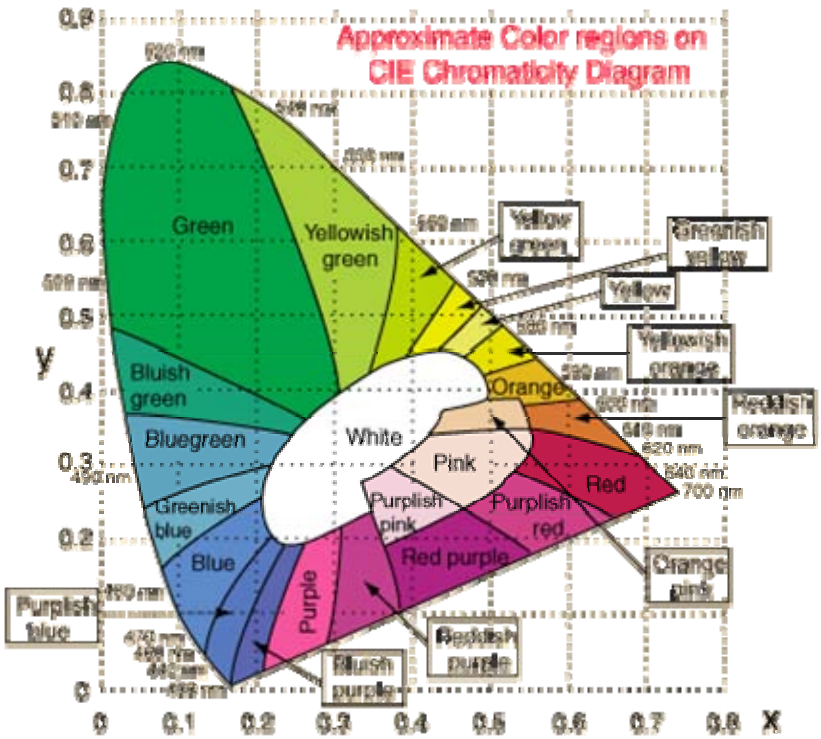


Figure 22. CIE Chromaticity Chart

2.2 Vehicle Definitions

Several definitions follow the terminology in reference [18].

2.2.1 Vehicle Coordinate Systems

Figure 23 shows the vehicle coordinate system. The origin of this system lies on the road directly under the vehicle's center of gravity. The z-axis points down into the road.

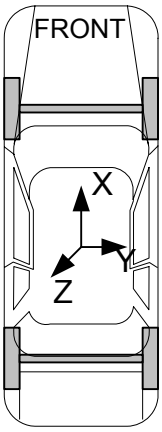


Figure 23. Vehicle coordinate system (z-axis is down)

2.2.2 Longitudinal Speed

The longitudinal speed is the vehicle's speed along the x-axis. The ROR report recommends that the warning system should determine vehicle velocity to an accuracy of 3 mph (L-20 page 24 in [14]). Use the time to travel a known distance to verify the speedometer's accuracy.

The vehicle's speedometer provides vehicle speed during tests. An independent measurement system verifies the vehicle's speed during a test using a dash camera aimed at the speedometer.

2.2.3 Lateral Position

The lateral position is the position of the vehicle's origin relative to the center of the lane. The lateral position measurement is along the vehicle y-axis. Most measurements in this test use a similar lateral measurement called Distance to Road Edge (see section 2.2.7 below).

2.2.4 Lateral Velocity

The lateral velocity is the rate of change of lateral position.

2.2.5 Yaw Rate

Yaw rate is the rate of rotation about the vehicle z-axis.

2.2.6 Road Departure

The vehicle departs the road when the outside edge of any of the vehicle tires crosses the outside edge of the road.

2.2.7 Distance to Road Edge

The distance to the road edge is the distance from the vehicle's outside front tire to the road edge measured along the vehicle's y-axis.

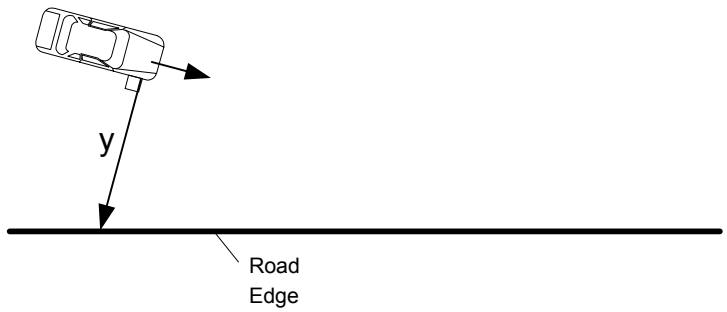


Figure 24. Distance to road edge is perpendicular to vehicle

The tests measure the lateral position using the IMS (see section II-4) video. A calibration procedure transforms pixels in the image into distance to road-edge measurements. The analyst selects the pixel on the road edge and the IMS returns the distance.

2.2.8 Road Departure Rate

The road departure rate is the rate of change in distance to the road edge.

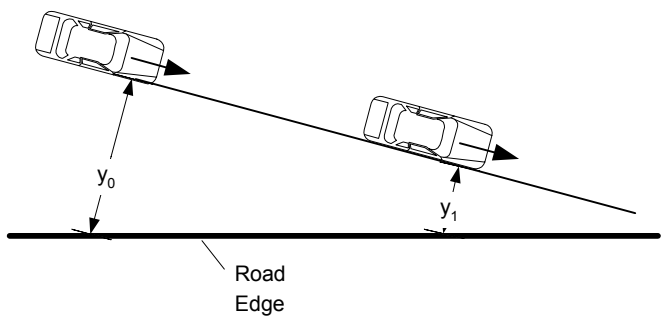


Figure 25. Computing lateral velocity

Use the following equation to compute road departure rate:

$$v_{lat} = \frac{y_1 - y_0}{t_1 - t_0}$$ **Road Departure Rate**

Where:

y_1, y_0 - are the lateral positions at time t_1 and t_0 respectively (see figure above).

Many tests require the driver to depart the road at a given rate, for example, above 0.75 m/s. The driver achieves the desired departure rate by traversing a known distance in a known time interval. For example, the driver starts the departure at 0.75 m from the lane marker and crosses the lane marker in one second. Afterward, the analyst uses the IMS calibrated video to measure the exact departure rate.

2.2.9 Road Departure Angle

The road departure angle is the angle between the forward x-axis of the vehicle and the road edge.

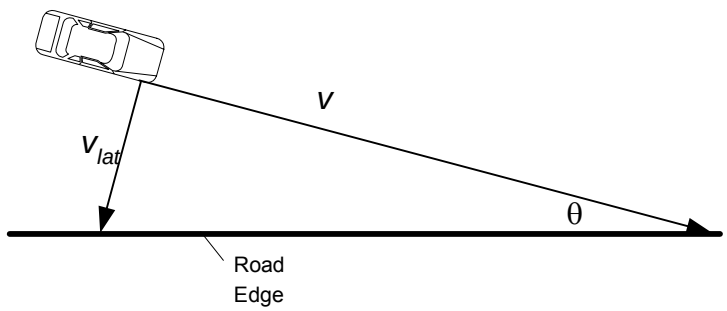


Figure 26. Departure angle on straight road. *V* is the forward velocity and V_{lat} is the lateral velocity.

The following formula estimates the departure angle from the departure rate and the forward velocity:

$$\theta^{\circ} = \tan^{-1}\left(\frac{v_{lat}}{v}\right)\left(\frac{180}{\pi}\right)$$

Departure Angle (in degrees) from forward and lateral velocities.

Where:
v_{lat} = is the road departure rate (m/s) (see section 2.2.8)
v = vehicle forward speed (m/s)

2.2.10 Distance to Curve Entry Point

The curve entry point marks the transition between a straight road segment and a curved road segment (see Figure 27). The distance to the curve entry point is measured using the IMS in the following manner:

Determine the start location of the measurement, for example, the time of a warning. Note the lateral distance to the departure-side road edge. Record the initial (n_2, e_2) location of the vehicle.

Advance the video until the lateral distance visibly decreases. This marks the curve entry point. Record the location of the vehicle at the curve entry point (n_2, e_2).

Determine the distance to the curve entry point using the following formula:

$$x_m = \sqrt{(n_1 - n_2)^2 + (e_1 - e_2)^2}$$

Measured distance to Curve Entry Point

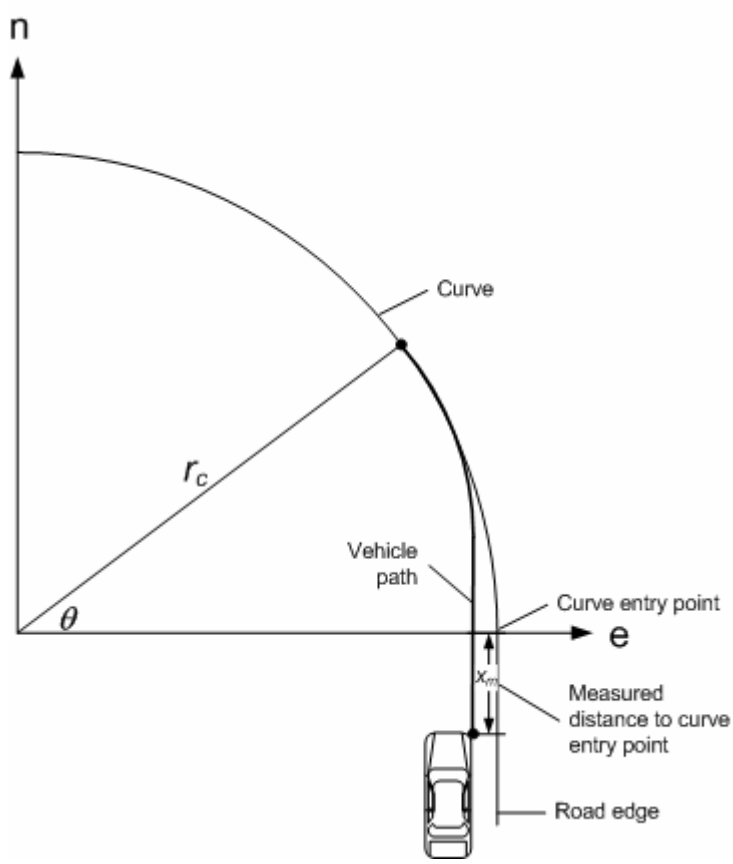


Figure 27. Measured distance to curve entry point at time of warning (x_m)

2.3 Warning System Definitions

2.3.1 System Response Rating

The rating of a system's response to a warning situation falls into one of the following categories [18]:

Table 6. Rating of warning system signals.

System Response	Situations Requiring a Warning	Situations in Which a Warning is not Required
Warning	True Positive (TP) Correctly warns of road departure	False Positive (FP) False alarm
No Warning	False Negative (FN) Misses road departure	True Negative (TN) Correctly does not warn of road departure.

2.3.2 Imminent Crash Condition

An imminent crash condition exists when there is a high probability of a lateral collision, a loss of steering control, or a rollover. A RDCWS considers leaving the paved portion

of the road at a high speed as an imminent crash condition because of the high probability of loss of steering control and rollover.

2.3.3 Crash Warning

A crash warning is a signal to the driver indicating an imminent crash condition exists and that the driver should take immediate action to prevent the crash.

2.3.4 Advisory Warning

An advisory warning is a signal to the driver that the vehicle is about to drift outside the current lane or that the current speed is too great for an upcoming curve.

2.3.5 Warning Sensitivity

Warning sensitivity is a user-controlled variable that determines the timing of a warning. High sensitivity produces earlier warnings and low sensitivities produce later warnings. The sensitivities affect evaluation of a warning system by setting a maximum value for lateral acceleration (due to driver steering correction) on a lateral drift departure and required longitudinal deceleration (due to driver braking to slow the vehicle) on a curve over-speed departure. A summary of the warning system sensitivities appears in the following table. Unless stated otherwise, the sensitivity is at the mid-range value (3).

Table 7. Warning system sensitivity values for lateral acceleration (alat) and longitudinal deceleration (dreq), where g equals gravity (9.8 m/s2).

Sensitivity	a_{lat} m/s^2	d_{req} m/s^2
1	4.12 (0.42 g)	6.86 (0.70 g)
2	3.53 (0.36 g)	5.88 (0.60 g)
3	2.94 (0.30 g)	4.90 (0.50 g)
4	2.35 (0.24 g)	3.92 (0.40 g)
5	1.76 (0.18 g)	2.94 (0.30 g)

2.3.6 Reaction Time

The reaction time defines the amount of delay between onset of a warning and onset of a steering maneuver by the driver. An average reaction time for these tests is $t_r = 1.5$ s. A lower bound (t_l) and an upper (t_h) define the range of acceptable reaction times. The evaluation equations use these values to determine the earliest and latest location of a warning. Table 8 gives suggested values for the reaction times.

Table 8. Reaction time with low and high limits.

Name	Time	Description
t_l	0.75 s	Lower bound used to define latest possible warning location.
t_r	1.5 s	Ideal reaction time
t_h	2.0 s	Upper bound used to define earliest possible warning location.

2.3.7 Obstacle

An obstacle is an object of sufficient mass to cause damage to a vehicle upon collision.

2.3.8 Radar Corner Cube Reflector

Radar cross section (RCS) is the measure of a target's ability to reflect radar signals in the direction of the radar receiver. The corner reflector has an RCS almost as high as a flat plate but over a wider reflectance angle (over ±60º).

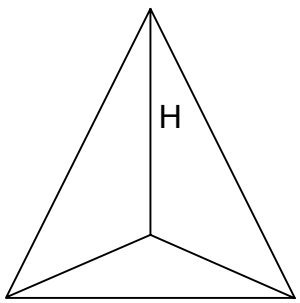


Figure 28. Corner Cube Reflector

Use the following equation to determine the height of a corner cube for a desired RCS.

$$H = \left(\frac{3\lambda^2 \sigma}{4\pi} \right)^{1/4}$$ **Height of corner cube**

Where:

H = height of corner cube (m)

σ = desired radar cross section (RCS) (m^2)

λ = radar wavelength (m)

2.3.9 Time of Warning

The time of warning is the time when the warning system issues an alert. Determining whether a warning is late, early or on time requires the time of the warning relative to the road departure.

The IMS (see section II-4) captures the time of the warning from the visual icon on the warning system display or from the audible alert (using a microphone). The analyst searches through the video to locate the warning and uses the GPS clock and the video frame clock (the frames are 29.9 ms apart) to measure the time of the warning.

2.3.10 Time to Line Crossing

The time to line crossing is the calculated time until the vehicle's lead tire crosses an in-path lane marker given the vehicle continues on its current trajectory.

2.3.11 Time to Road Departure

The time to departure is the time until the vehicle's lead tire crosses a line parallel to the outer lane marker offset by the available maneuver room.

2.3.12 Nuisance Alarm

Nuisance alarms are warnings deemed unwarranted by a driver. They include false alarms due to incorrectly predicting the time or position of a crash (i.e., early warning) and false positives due to incorrect sensor readings (from noisy or cluttered environments).

2.4 Environmental Definitions

2.4.1 Daylight Time

Daylight is the times of day starting at sunrise and ending at sunset. The times are available from the U.S. Naval Observatory (http://aa.usno.navy.mil/data/).

2.4.2 Night Time

Night is the times of day after civil twilight at sunset and ending at twilight before sunrise. Civil twilight is when the sun is 6 degrees below the horizon. According to definitions used by the U.S. Naval Observatory:

> In the morning before the beginning of civil twilight and in the evening after the end of civil twilight, artificial illumination is normally required to carry on ordinary outdoor activities. Complete darkness, however, ends sometime before the beginning of morning civil twilight and begins sometime after the end of evening civil twilight.

The times of civil twilight are available from the U.S. Naval Observatory (http://aa.usno.navy.mil/data/).

2.4.3 Rain

Rain is precipitation in the form of water drops larger than 0.5 mm (0.02 in.). The following table shows how rainfall intensity is determined:

Table 9. Rain rate of fall.

Rainfall Intensity	Rate-of-fall in 6 min	Visual Estimation
Light	≤ 0.25 mm (0.01 in.)	From scattered drops that, regardless of duration, do not completely wet an exposed surface up to a condition where individual drops are easily seen
Moderate	0.25 mm to 0.762 mm (0.03 in.)	From scattered drops that, regardless of duration, do not completely wet an exposed surface up to a condition where individual drops are easily seen.
Heavy	> 0.762 mm	Rain seemingly falls in sheets; individual drops are not identifiable; heavy spray to the height of several centimeters over hard surfaces.

2.4.4 Fog

Fog is as a visible aggregate of minute water particles (droplets), which is close to the earth's surface and reduces horizontal visibility to less than 1 km (5/8 mi), and unlike drizzle, it does not fall to the ground.

Names given to fog types identify their methods of formation. The principle types are radiational fog, ice fog, advection fog, upslope fog, rain-induced fog, and steam fog. These types of fog are called "dense" when the surface visibility is equal to or less than 400 m (1/4 mi). A Dense Fog Advisory occurs when the dense fog becomes widespread.

2.4.5 Snow

Snow precipitation consists of water crystals, mostly branched in the form of six-pointed stars. It usually falls steadily for several hours or more. Qualifiers, such as occasional or intermittent, indicate a steady, prolonged (for several hours or more) fall is not expected. Like rain, visibility determines snow intensity. The following table shows snow intensity versus visibility:

Snow Intensity	Visibility
Light	> 1 km (5/8 mi)
Moderate	400 m (1/4 mi) to 1 km
Heavy	< 400 m

II-3 Basic Test Organization

Each test procedure in this document consists of the following subsections.

Test Title

Each test in this document starts with a short description of the purpose of the test and a figure (see Figure 29) showing the trajectory of the vehicle, the road geometry, pertinent test props and key events of the test.

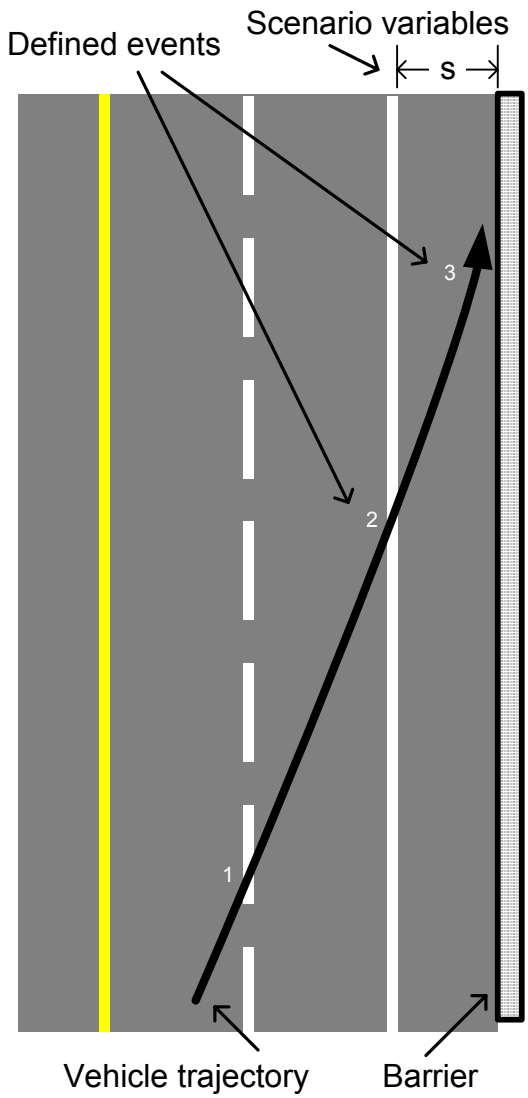


Figure 29. Each test procedure includes a figure that illustrates pertinent aspects of the test.

Events and System Response

This section describes the events during the test and the response of the warning system to the event. Typically, the response is a specific warning signal.

Conditions
This section describes the conditions for the test. Some conditions remain fixed throughout the test, for example, road geometry and lane marker quality. Other conditions may vary between a set of tests, for example, speed and departure rate.

Measurements
This section lists all the measurements that are required for the tests. Also presented are methods and procedures for processing the measurements.

Procedure
This section lists the steps of the test, which have the following format:
1. Setup and verify scenario conditions;
2. Drive system/vehicle along desired trajectory;
3. Record trajectory and warning system responses;
4. Process data to determine performance variables; and
5. Evaluate the system response to determine whether system passed.

Evaluation Methods
This section contains the methods for judging whether the system passes the test. The methods used for most tests are:
1. Is the correct warning system response given (e.g., did the system miss the event)?
2. Is the timing of the warning acceptable?

II-4 Independent Measurement System

This section describes an independent measurement system used to collect warning-system performance data required for system evaluation. Evaluation of the warning system should use sensors and equipment separate from the warning system under test. For example, the distance to a lane marker at the time of warning should not come from the warning system itself. Errors in the warning system camera and image-processing algorithm could lead to incorrect assessment of warning system performance. Details of the IMS appear in [17]. This section provides enough details to understand one approach for collecting data and measurements to analyze warning system performance.

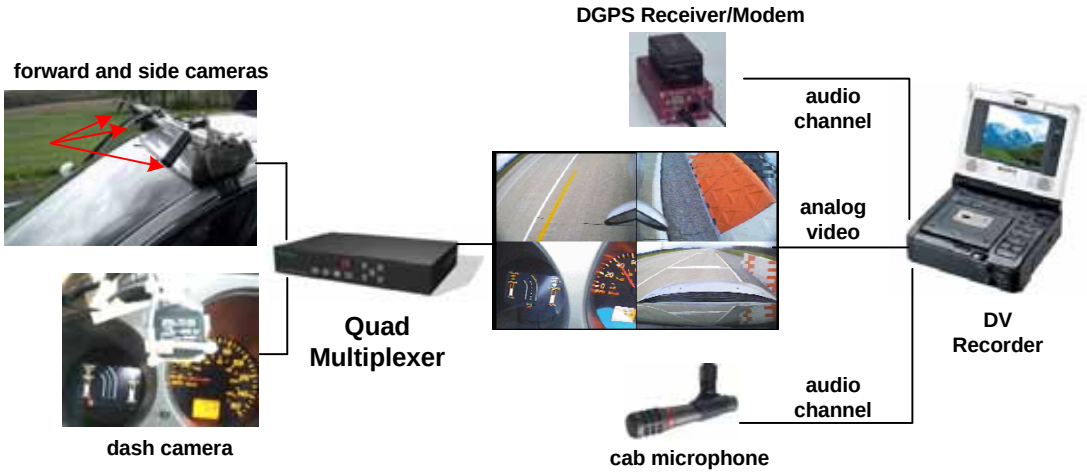


Figure 30. Independent Measurement System

Figure 31 illustrates the components of the IMS described [17]. Three cameras situated on a roof rack provide forward and side-looking video. A fourth camera mounted on the dash captures the warning system display. A quad multiplexer combines the four video signals into a single video stream. The output of the quad appears in Figure 32.

Figure 31. Four camera views combined into one. Top left and right are view of calibration sticks aligned with front wheels. Bottom right shows calibration sticks on the road in front of vehicle. Bottom left is view of warning system display.

The cameras perform the following functions:

1. The left and right downward-facing cameras measure lateral distances relative to the front wheels. The top left and right quadrant in Figure 32 show calibration sticks for calibrating the side-looking cameras. The black and white stripes on the calibration sticks have known dimensions. The user identifies the pixel locations of the stripes (see red circles in top left of Figure 33, which defines a transformation between pixel coordinates in the image and ground coordinates relative to the front wheels). After camera calibration, the sticks are no longer required. The overlaid red circles indicate the calibrated portion of the video data (see top right quadrant in Figure 33). Clicking on a pixel centered with the red circle returns the lateral distance as if the calibrated sticks existed. Linear interpolation gives distance measurements between the circles.
2. A forward-facing camera provides lateral measurements ahead of the vehicle. The camera calibration uses calibration sticks as well. This provides a better view of the surrounding environment then the side-looking cameras only.
3. A dash view camera shows vehicle speed and when an alert is given.

Figure 32. Result of pixel to ground calibration is shown using red circles. Circles in top left view identify transitions from black to white marking on calibration stick. After removal of the calibration stick (e.g., top right view), the circles provide a reference for the operator when measuring lateral distances from the front wheel.

Other components of the IMS include a Differential Global Positioning Satellite receiver to sense vehicle position and velocity, and a cab microphone to pick up the audible alerts and comments from the driver. To simplify data collection, a modem-like device converts the GPS data into an audible signal. A digital videocassette recorder simultaneously records the output of the video, microphone (one audio channel), and GPS (the second audio channel), ensuring synchronization of the data streams.

II-5 Warning System Evaluations

This section describes various methods for rating warning system performance that are common among tests. The methods describe how to score the system, but the methods do not specify what score is acceptable. Some example criteria for establishing an acceptable score include:

1. The system must pass 95 percent of the runs for a given test (good when there is large number of test runs)
2. The system may only fail 1 time for a given set of test runs (good when there is a small number of test runs)

The organization interested in the test results should specify the acceptable pass/fail criterion.

5.1 Lateral Drift Evaluation

A warning must provide a driver with time to react and time to avoid (i.e., steer away from) a departure. The reaction phase starts at the time of warning and continues until the driver initiates the steering correction. The steer phase consists of the trajectory the vehicle follows during the steering correction. The magnitude of the steer should not exceed a_{lat} limits defined in **Table 7** of section 2.3.5 (Warning Sensitivity). The lateral drift analysis uses separate equations for straight or curved roads.

5.1.1 Straight Road

A lateral drift on a straight road occurs when the vehicle departs a straight road at a fixed angle to the direction of the roadway.

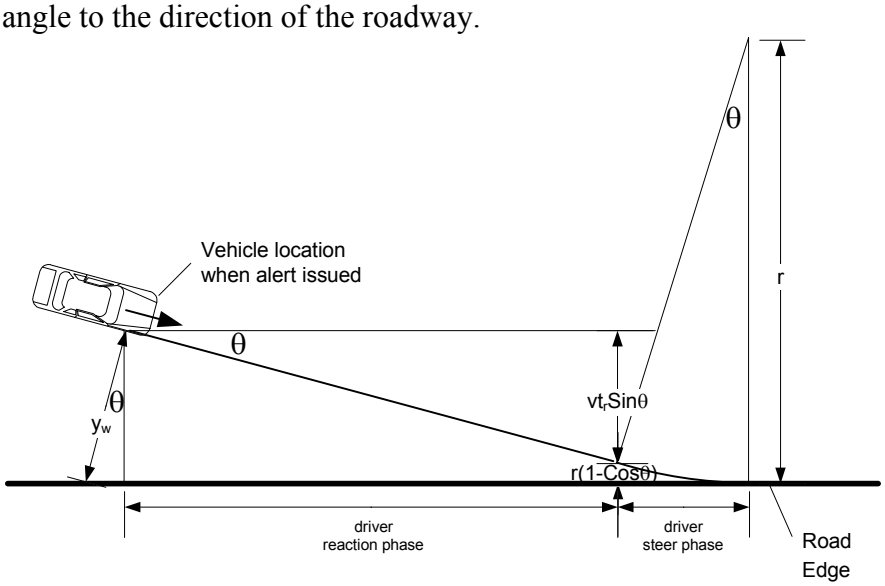


Figure 33. Geometry for a lateral drift scenario on a straight road

Given the geometry of the lateral departure of a straight road shown in Figure 33, one determines the desired lateral distance to issue an alert using the following equation:

$$y_w = \frac{vt_r \sin\theta + r(1-\cos\theta)}{\cos\theta},$$

Where:

v = vehicle forward speed (m/s)

t_r = delay between warning and start of steering (see section 2.3.6) (s).

θ = the departure angle (radians). If measuring departure rate, convert to angle using equation in section 2.2.9).

r = the radius of the curve the vehicle must travel to avoid the departure (m)

The equation simplifies to:

$$y_w = vt_r \tan\theta + r(1/\cos\theta - 1).$$

Use the measured lateral velocity (v_{lat}) to calculate the departure angle (see section 2.2.9):

$$\theta = \tan^{-1}\left(\frac{v_{lat}}{v}\right)$$

The radius should not cause the vehicle to exceed a maximum lateral acceleration (a_{lat}, see section 2.3.5), therefore:

$$r = \frac{v^2}{a_{lat}}$$

To determine the desired location of a warning (the lateral distance to road boundary) for comparison with the measured time of a warning:

1. Measure v and v_{lat} at the time of warning.
2. Obtain t_r from section 2.3.6 and a_{lat} from section 2.3.5 sensitivity setting 3.
3. Calculate desired location using the following equation:

$$y_w = v_{lat}t_r + \frac{v^2}{a_{lat}}(1/\cos\theta - 1) \qquad \textbf{(2)}$$

Use the following procedure to determine whether the actual measured warning location during a test is *early*, late, or *on time*.

1. Use the desired location warning equation to determine the latest warning location (*LWL*) (warning occurs closer to road boundary) using sensitivity setting 1 (highest a_{lat} from section 2.3.5) and reaction time t_l (shortest reaction time from section 2.3.6).
2. Use the desired location warning equation to determine the earliest warning location (*EWL*) (warning occurs farther from road boundary) using sensitivity setting 5 (lowest a_{lat} from section 2.3.5) and reaction time t_h (longest reaction time from section 2.3.6). Use the following relationships to compare the measured location of the warning (y_m) with *LWL* and *EWL* to determine whether the warning is *early*, *late,* or *on time* (refer to Figure 35):

   If $y_m > EWL$, then the warning is *early*

   If $y_m < LWL$, then the warning is *late*

   If $EWL \geq y_m \leq LWL$, then the warning is *on time*

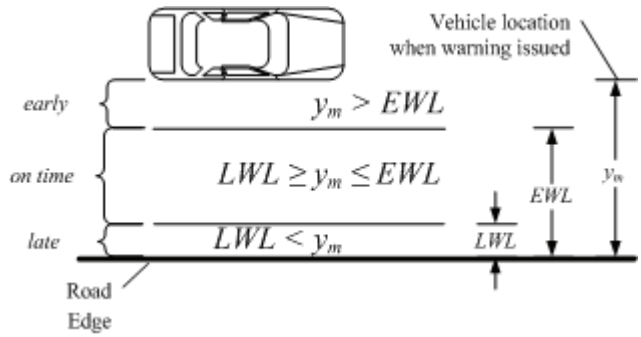


Figure 34 Relationship to determine timeliness of warning on lateral-distance based warning.

5.1.2 Curved Road

A lateral drift on a curved road occurs when the vehicle is traveling straight and departs a curved road.

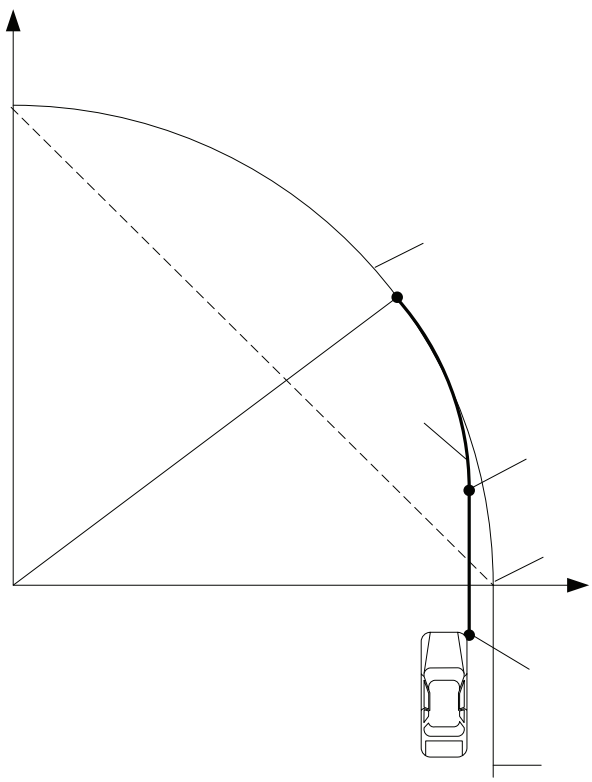


Figure 35. Geometry for a lateral drift scenario on a curved road

Reference [22] describes the derivation of the lateral acceleration required to avoid a lateral departure on a curved road (see Figure 35 - note the change in x and y axes to remain consistent with y measurements being lateral from the vehicle):

$$a_{lat} = \frac{v^2}{r_c - \dfrac{x_w + vt_r}{\sin\left(2\tan^{-1}\left(\dfrac{r - y_w}{x_w + vt_r}\right)\right)}} \qquad \textbf{(3)}$$

Where:

v = vehicle forward speed (m/s)
r_c = the radius of the curve (m)
t_r = delay required by driver to initiate the steering correction
y_w = the lateral distance to the center of the curve (m).
x_w = the longitudinal distance to the curve entry point (m) (See section 2.2.10.)

Subject to:

$$vt_r < \sqrt{r_c^2 - y_w^2} - x_w \qquad \textbf{(4)}$$

(The onset of steering must occur prior to the road boundary).

Note that in this scenario, the vehicle must travel straight during the departure (i.e., remain parallel to the road edge until entering the curve). The initial lateral position (y_w) dictates the ideal location for a warning (x_w,), which is relative to the curve entry point. The curve entry point is the point where the lateral distance to the road edge starts to decrease. Using the IMS, the distance is derived from speed and time.

To determine the desired location of a warning (longitudinal distance to curve entry) for comparison with the measured time of a warning:

1. Measure v, the lateral distance to the road edge y_m, and r_c during a test.
2. Determine y_w from $y_w = r_c - y_m$.
3. Obtain t_r from section 2.3.6 and a_{lat} from section 2.3.5 sensitivity setting 3.
4. Calculate desired location using the following equation:

$$x_w = \sqrt{(r_c - y_w)\left(r_c - \frac{2v^2}{a_{lat}} + y_w\right)} - vt_r \qquad \textbf{(5)}$$

Use the following procedure to determine whether the actual measured warning location during a test is *early*, *late,* or *on time*.

1. Measure v, the lateral distance to the road edge y_m, the longitudinal distance to the curve entry x_m (note: x_m is negative if vehicle hasn't entered the curve) and r_c at the time of a warning.
2. Determine y_w and x_w from $y_w = r_c - y_m$ and $x_w = x_m$.
3. If $vt_r \geq \sqrt{r_c^2 - y_w^2} - x_w$ then turn begins after vehicle leaves the lane (can't use equation (3)). Classify warning as *late*.
4. Use equation (3) to determine the lateral acceleration required to stay on the road.
5. If a_{lat} > sensitivity setting 1 (highest a_{lat} from section 2.3.5) then classify warning as *late*.
6. If a_{lat} < sensitivity setting 5 (lowest a_{lat} from section 2.3.5) then classify warning as *early*.

7. Else a_{lat} falls within the acceptable limits and classify the warning as *on time*.

5.2 Curve Speed Evaluation

A curve-speed warning must provide a driver with time to react (reaction phase) and to slow (brake phase) to a safe speed. The braking action should not exceed a limit on deceleration.

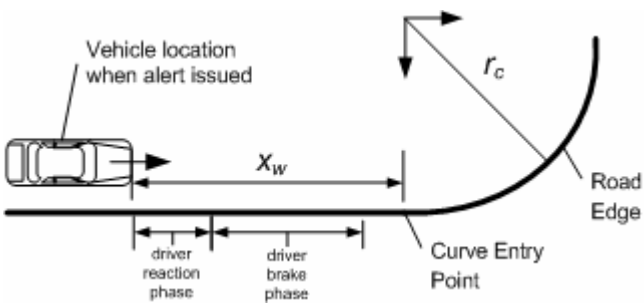


Figure 36. Geometry for a curve speed warning scenario.

Use the following equation to calculate the amount of deceleration required to reach the safe speed:

$$d_{req} = \frac{v^2 - v_s^2}{2(x_w - t_r v)} \qquad \textbf{(6)}$$

Where:

d_{req} = required deceleration (m/s^2)
v = vehicle initial forward speed (m/s)
v_s = safe speed for the curve (m/s)
t_r = driver reaction time (s)
x_w = the distance between the warning location and the start of the curve (m) (See section 2.2.10.)

The safe speed for a curve of radius r does not exceed a maximum lateral acceleration (a_{lat}, see section 2.3.5). Use the following equation to calculate the safe speed:

$$v_s = \sqrt{a_{lat} r} \qquad \textbf{(7)}$$

To determine the desired location of a warning (distance to curve entry) for comparison with the measured time of a warning:

1. Measure v, y_a, and r_c during a test.
2. Obtain t_r from section 2.3.6, and a_{lat} and d_{req} from section 2.3.5 sensitivity setting 3.
3. Calculate desired location using the following equation:

$$x_w = \frac{v^2 - v_s^2}{2d_{req}} + t_r v \qquad \textbf{(8)}$$

Use the following procedure to determine whether the actual measured warning location during a test is *early*, *late,* or *on time*.

1. Use the desired location warning equation to determine the latest warning location (*LWL*) (warning occurs closer to road boundary) using sensitivity setting 1 (highest a_{lat} from section 2.3.5) and reaction time t_l (shortest reaction time from section 2.3.6).
2. Use the desired location warning equation to determine the earliest warning location (*EWL*) (warning occurs farther from road boundary) using sensitivity setting 5 (lowest a_{lat} from section 2.3.5) and reaction time t_h (longest reaction time from section 2.3.6).
3. Use the following relationships to compare the measured location of the warning (x_m) with *LWL* and *EWL* to determine whether the warning is *early*, *late,* or *on time* (refer to Figure 37):

   If $x_m > EWL$, then the warning is early
   If $x_m < LWL$, then the warning is late
   If $EWL \geq x_m \leq LWL$, then the warning is on time

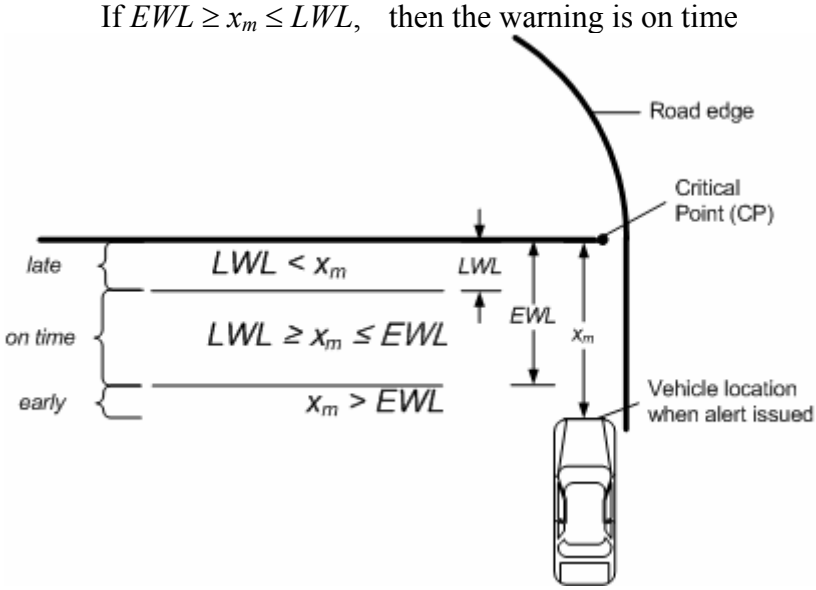


Figure 37. Relationship to determine timeliness of warning on lateral-distance based warning.

5.3 Timeliness of Warning

Once warnings are evaluated as *early*, *late,* or *on time* for the given scenario (departure on straight road, departure on curved road, curve speed departure), the results are accumulated as follows:

$$\left(\frac{\#Early}{\#TP}\right)\cdot 100$$ **Percent of Warnings Early**

$$\left(\frac{\#OnTime}{\#TP}\right)\cdot 100$$ **Percent of Warnings on Time**

$$\left(\frac{\#Late}{\#TP}\right)\cdot 100$$ **Percent of Warnings Late**

Where *#Early, #OnTime, #Late, and #TP* are the total number of early warnings, on time warnings, late warnings, and the true positive warnings. Each test procedure describes how to determine if a warning is a true positive (also referred to as the correct response (CR)). The results of several test runs are summarized in the following table.

Test Run Summary Results

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

5.4 Efficacy Rate

Reference [18] defines the efficacy rate as the rate that a desired effect occurs.

$$efficacy\ rate = \left(\frac{\#TP}{\#TP + \#FN} \right) \cdot 100$$

5.5 False Alarm Rate

Reference [18] defines the false alarm rate.

$$false\ alarm\ rate = \left(\frac{\#FP}{\#TP + \#FP} \right) \cdot 100$$

II-6 Tests for Departures on Roads with Default Minimum AMR

The tests in this section evaluate warning system response to road departures where the available maneuver room is at a default minimum. This situation arises when the sensor processing has unacceptable uncertainty, when maps of the road network are unavailable, or when the warning system lacks the sensing capability to detect the drivable surface on the side of the road.

The tests evaluate the system's ability to:

1. Detect lane markers,
2. Determine lane marker type,
3. Determine departure velocities, and
4. Determine driver lane change intent.

The test scenarios include departures on a divided straight road, on an undivided straight road, and on a divided curved road.

6.1 One-Way Straight Road (Default Minimum AMR)

This test assesses the performance of the lateral drift warning function for road departures on divided straight roads. This scenario falls under the "going straight on freeway with two lanes at non-junction" scenario identified in the NHTSA test scenario report as one of the major settings for road departure crashes [15]. The test also examines warning system response during lane changes (i.e., when vehicle crosses dashed lane markers) with and without turn signals.

The figure below illustrates the test scenario. Both a left and a right departure are tested.

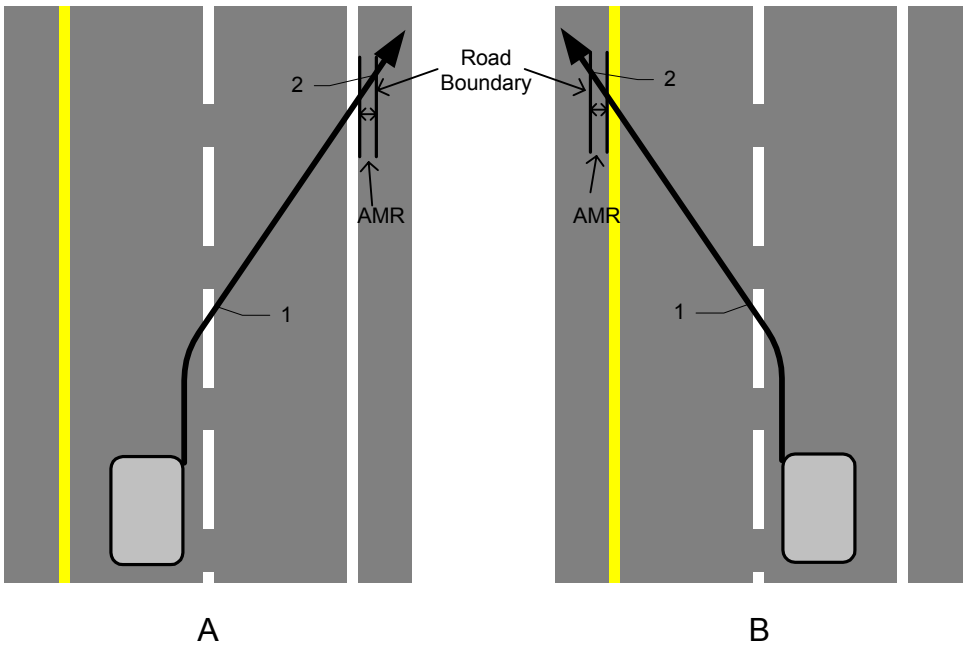


Figure 38. Scenario for road departure on divided road

6.1.1 Events and System Response

The following table defines the events for this test and the correct warning signal the system shall provide. See the figure above to locate the event (e.g., ID A1 is label 1 in figure A).

ID	Event	Correct Response
A1	Crossed dashed line	1. Issue no warning if correct turn signal active. 2. Issue an advisory warning if no turn signal active or incorrect turn signal active.
A2	Road departure	1. Issue road departure warning
B1	Same as A1	1. Same as A1
B2	Same as A2	1. Same as A2

6.1.2 Test Conditions

The conditions for this test include the following.

6.1.2.1 Road Geometry

The road geometry for the test is the following:

Road Geometry	Dimension
Straight (defined using radius of curvature)	> 1,000 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry, contains the recommended method to verify the road geometry.

6.1.2.2 Available Maneuver Room

In this test, the warning system recognizes the road edge but cannot determine if there is additional AMR. Therefore, the system should assume a default minimum AMR.

Available Maneuver Room	Comment
15 cm (6 in.)	Default minimum AMR

6.1.2.3 Speed

The vehicle speeds during the tests cover warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

6.1.2.4 Departure Rate

The vehicle departure rates are either high or low. These rates are comparable to the rates suggested in the ROR report and in the ISO standard for testing lateral drift warning systems.

Low Departure Rate	High Departure Rate
≤ 0.75 m/s	> 0.75 m/s

6.1.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given;

2. Determine the desired location of a warning given the conditions; and
3. Determine the amount of time the warning gives driver.

6.1.3.1 Time of Warning

See section 2.3.9.

6.1.3.2 Longitudinal Speed

See section 2.2.2.

6.1.3.3 Distance to Road Edge

See section 2.2.7.

6.1.3.4 Lateral Velocity

See section 2.2.4.

6.1.4 Test Procedure

The general procedure for the test repeats a series of road departure trajectories depicted in Figure 38.

6.1.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. Measure the geometry if it is unknown (see Appendix II-A, Methods for Determining Road Dimensions and Geometry).
2. Ensure lane marker characteristics meet the test conditions (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure GPS has sufficient satellite signals.
8. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.

6.1.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed and sets the cruise control at the speed.
2. Set turn signal. The driver runs the first departure with turn signal active. Since this departure will be a True Negative, the operator documents the departure time. The operator runs the remaining departures without activating the turn signal.

3. Execute departure. The driver steers toward the road boundary at the prescribed departure rate (high or low) until the road boundary is crossed. See section 2.2.8 for a method to achieve the prescribed departure rate.
4. Record departure rate. The assistant records the estimated departure rate as either low or high.
5. Go to start of next departure trajectory. The driver steers the vehicle back onto the road for the next departure.
6. The driver repeats the departure trajectories to fulfill the following conditions:
   a. Five left departures at the low departure rate;
   b. Five right departures at the low departure rate;
   c. Five left departures at the high departure rate;
   d. Five right departures at the high departure rate;
   e. One right departure at the high departure rate with the right turn signal on; and
   f. One left departure at the high departure rate with the left turn signal on.
7. Repeat steps 1 – 6 for the middle prescribed speed.
8. Repeat steps 1 – 6 for the high-prescribed speed.

6.1.4.3 Post-Test Procedures

The procedures after the test consist of the following steps:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

6.1.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

6.1.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

For the road departure events:

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

For the cross dashed-line events:

- The rating is a true positive if the system responds with a warning before the road boundary is crossed and the turn signal is inactive.
- The rating is a false positive if the system responds with a warning before the road boundary is crossed and the turn signal is active.

6.1.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location for the warning. The desired location depends on the measured departure rate and the forward speed.

1. Locate the time of warning in the video data (e.g., locate first video frame alert).
2. Measure lateral position and lateral velocity to the road edge at time of warning.
3. Use equation (2) in section 5.1.1 to determine the desired location for a warning on a straight road.

6.1.5.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.1.1. The results of the timeliness evaluations are accumulated according to section 5.3.

6.1.6 Reporting

The evaluator compiles the test reports in accordance with the following tables.

Name of Test	Departure on One-Way Straight Road With Fixed Available Maneuver Room
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors					Response						
Speed mph	**Departure Rate m/s**	**Direction**	**Signal**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**v_l m/s**	**y_m m**	**y_w m**	**T OT/E/L**
40	≤ 0.75	Left	No	5	1						
"	"	"	"		2…						
40	≤ 0.75	Right	No	5							
40	> 0.75	Left	No	5							
40	> 0.75	Right	No	5							
40	> 0.75	Left	On	1							
55	≤ 0.75	Left	No	5							
55	≤ 0.75	Right	No	5							
55	> 0.75	Left	No	5							
55	> 0.75	Right	No	5							
55	> 0.75	Left	On	1							
55	> 0.75	Right	On	1							
70	≤ 0.75	Left	No	5							
70	≤ 0.75	Right	No	5							
70	> 0.75	Left	No	5							
70	> 0.75	Right	No	5							
70	> 0.75	Left	On	1							
70	> 0.75	Right	On	1							

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.

v_f = measured vehicle forward speed

v_l = measured vehicle lateral speed (departure rate)

y_m = measured lateral distance between the vehicle front tire and the road boundary at the time of warning

y_w = the desired lateral distance at the time of warning using equation (2)

T = Timeliness of warning OnTime, Early or Late

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	**Probable Cause**
1	Example: shadows on road misinterpreted as road edge
…	…

Lane Change with Turn Signal Event Evaluation

Number of Lane Change Tests	**Number of Incorrect Responses**	**Number of Correct Responses**
#	#	#

6.2 Two-Way Straight Road (Default minimum AMR)

The Two-Way Straight Road (with default minimum AMR) test assesses the performance of the lateral drift warning function for road departures on undivided straight roads. This scenario falls under the "going straight on undivided non-freeway with two lanes at non-junction" scenario identified in the NHTSA test scenario report as one of the major settings for road departure crashes [15].

The figure below illustrates the test. The road boundary depends on the type of marker the vehicle first encounters during the departure trajectory. A solid marker prohibits passing. The road boundary is the left edge of the solid marker and the available maneuver room is zero. A dashed marker allows passing and indicates a wider lane but no AMR. The warning system issues a departure alert only if the turn signal is not active. This test has no available maneuver room because the adjacent lane may have undetected on-coming traffic. The double solid lane case is similar to the solid/dashed marker in figure A.

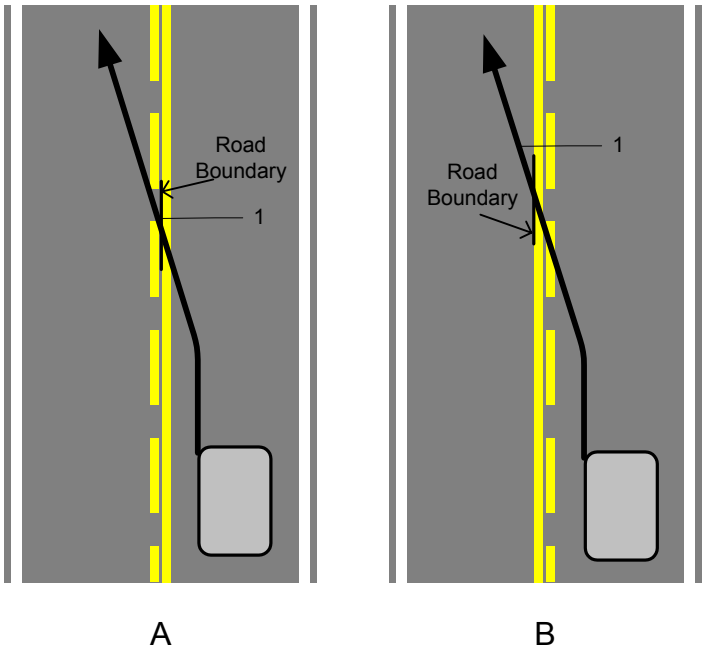


Figure 39. Vehicle trajectory during test

6.2.1 Events and System Response

The following table defines the events for this test and the correct warning signal the system shall provide. See the figure above to locate the event (e.g., Id A1 is label 1 in Figure A).

ID	Event	Correct Response
A1	Road Departure with passing not permitted	1. Issue road departure warning
B1	Road Departure with passing permitted	1. Issue no warning if the correct turn signal active. 2. Issue a road departure warning if no turn signal active or incorrect turn signal active.

6.2.2 Test Conditions

The conditions for this test include the following.

6.2.2.1 Road Geometry

The road geometry for the test is the following:

Road Geometry	Dimension
Straight (defined using radius of curvature)	> 1,000 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the geometry.

6.2.2.2 Available Maneuver Room

In this test, the warning system recognizes the road edge but cannot determine if there is on-coming traffic. Therefore, the AMR equals zero.

Available Maneuver Room	Comment
0 cm	Not allowed to cross over the lane marker

6.2.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

6.2.2.4 Departure Rate

The vehicle departure rates during the tests fall within two ranges. These rates are comparable to the rates suggested in the ROR report and in the ISO standard for testing lateral drift warning systems.

Low Departure Rate	High Departure Rate
≤ 0.75 m/s	> 0.75 m/s

6.2.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions

3. Determine the amount of time the warning gives driver

6.2.3.1 Time of Warning

See section 2.3.9.

6.2.3.2 Longitudinal Speed

See section 2.2.2.

6.2.3.3 Distance to Road Edge

See section 2.2.7.

6.2.3.4 Lateral Velocity

See section 2.2.4.

6.2.4 Test Procedure

The general procedure for the test is to repeat a series of road departure trajectories depicted in Figure 39.

6.2.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. Measure the geometry if it is unknown (see Appendix II-A, Methods for Determining Road Dimensions and Geometry).
2. Ensure lane marker characteristics meet the test conditions (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure GPS has sufficient satellite signals.
8. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.

6.2.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed and sets the cruise control at the speed.
2. Set turn signal. The driver runs one departure with turn signal active and documents the departure time. The driver runs the remaining departures with the turn signal inactive.
3. Execute departure. The driver steers toward the road boundary at the prescribed departure rate (high or low) until the road boundary is crossed. See section 2.2.8 for a method to achieve the prescribed departure rate.

4. Record departure rate. The assistant records the estimated departure rate as either low or high.
5. Go to start of next departure trajectory. The driver steers the vehicle back onto the road for the next departure
6. Repeat steps 1-5 for:
   a. Five left departures in no passing zone at the low departure rate
   b. Five left departures in no passing zone at the high departure rate
   c. Five left departures in passing zone at the low departure rate
   d. Five left departures in passing zone at the high departure rate
   e. One left departure in passing zone at the high departure rate with turn signal on.
7. Repeat steps 1 - 6 for the middle prescribed speed.
8. Repeat steps 1 - 6 for the high prescribed speed.

6.2.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

6.2.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

6.2.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

For the no passing permitted road departure event:

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

For the passing permitted road departure event:

- The rating is a true positive if the system responds with a warning before the road boundary is crossed and the turn signal is inactive.
- The rating is a false positive if the system responds with a warning before the road boundary is crossed and the turn signal is active.

6.2.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. The desired warning location varies with the departure rate and the forward speed.

1. Locate the time of warning in the video data (e.g., the first video frame with the alert).
2. Measure lateral position and lateral velocity to the road edge at the time of the warning.

3. With equation (2) in section 5.1.1, determine the desired location for a warning on a straight road.

6.2.5.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.1.1. The results of the timeliness evaluations are accumulated according to section 5.3.

6.2.6 Reporting

The evaluator completes the following tables with information from each test.

Name of Test	Departure on Undivided (Two-Way) Straight Road with No AMR
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors						Response						
Speed mph	**Departure Rate m/s**	**Direction**	**Pass Zone**	**Signal**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**v_l m/s**	**y_m m**	**y_w m**	**T OT/E/L**
40	≤ 0.75	Left	NP	None	5	1						
"	"	"	"	"	"	2…						
40	> 0.75	Left	NP	None	5							
40	≤ 0.75	Left	P	None	5							
40	> 0.75	Left	P	None	5							
40	> 0.75	Left	P	ON	1							
55	≤ 0.75	Left	NP	None	5							
55	> 0.75	Left	NP	None	5							
55	≤ 0.75	Left	P	None	5							
55	> 0.75	Left	P	None	5							
55	> 0.75	Left	P	ON	1							
70	≤ 0.75	Left	NP	None	5							
70	> 0.75	Left	NP	None	5							
70	≤ 0.75	Left	P	None	5							
70	> 0.75	Left	P	None	5							
70	> 0.75	Left	P	ON	1							

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.

v_f = vehicle forward speed

v_l = vehicle lateral speed (departure rate)

y_m = the measured lateral distance between the vehicle front tire and the road boundary at the time of warning

y_w = the desired lateral distance at the time of warning using equation (2)

T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	# of runs	# CR	# OT	# E	# L	% OT	% E	% L
Date/time of test runs								

False Alarm Incident Report

Run #	Probable Cause
1	Example: shadows on road misinterpreted as road edge
…	…

Lane Change with Turn Signal Event Evaluation

Number of Lane Change Tests	Number of Incorrect Responses	Number of Correct Responses
#	#	#

6.3 Curved Road (Default Minimum AMR)

The Curved Road (default minimum AMR) test examines the performance of the lateral drift warning function for road departures on a curved road. This scenario is not part of the curve speed warning function. During the Curved Road test, the vehicle travels within the established speed limit for the roadway. The test uses three curves of different radii: a slow-speed curve, a medium-speed curve and a high-speed curve.

In this scenario, the vehicle travels straight until a road departure occurs (Figure 40). The driver uses a guide target to maintain the straight road trajectory during the departure. The test area must have sufficient room for safe recovery after the road departure.

Run the tests in the opposite direction to test a left-side departure (e.g. for a divided highway).

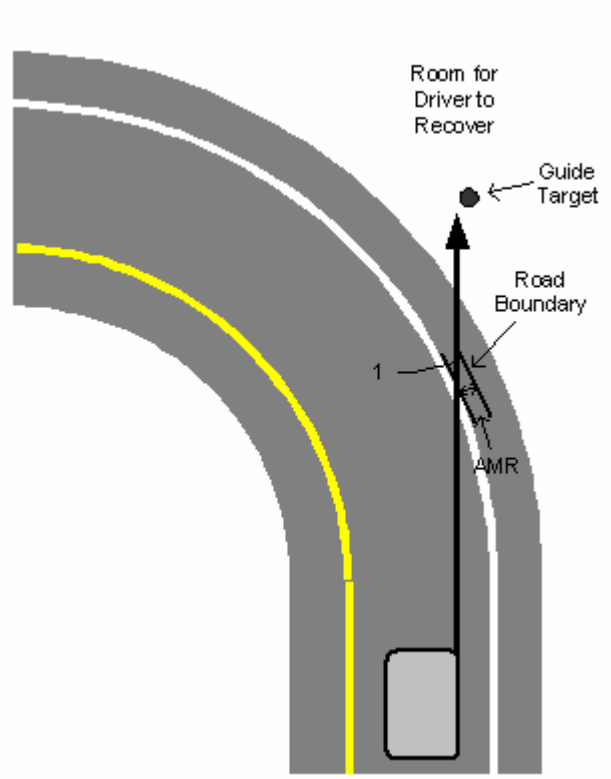


Figure 40. Vehicle trajectory during test

6.3.1 Events and System Response

The following table defines the event for this test and the correct warning signal response. The numeral in Figure 40 above displays the proper trajectory for the event.

ID	Event	Correct Response
1	Crossed solid line	Issue crossed solid line warning

6.3.2 Test Conditions

The conditions for this test include the following.

6.3.2.1 Road Geometry

The curve radius for this test should be appropriate for the low-speed, medium-speed, and high-speed conditions. The following equation calculates the curve radius for each speed condition using lateral acceleration limits (a_{lat}) from section 2.3.5.

$$r = \frac{v^2}{a_{lat}}$$

To simplify setting up the test, a curve radius may fall within a range of radii by using the lateral acceleration limits for sensitivities 2 and 4.

Road Geometry	Dimension
Low-speed curve, 64 km/h (40 mph)	91 m - 136 m
Medium-speed curve, 89 km/h (55 mph)	172 m - 257 m
High-speed curve, 113 km/h (70 mph)	278 m - 417 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the geometry.

6.3.2.2 Available Maneuver Room

In this test, the warning system recognizes the road edge but cannot determine if there is additional AMR. Therefore, the system should assume a default minimum AMR.

Available Maneuver Room	Comment
15 cm (6 in.)	Default minimum AMR

6.3.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range. The operator uses appropriate curve radii as the trajectory speed changes.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

6.3.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions
3. Determine the amount of time the warning gives driver

6.3.3.1 Time of Warning

See section 2.3.9.

6.3.3.2 Longitudinal Speed

See section 2.2.2.

6.3.3.3 Distance to Road Edge

See section 2.2.7.

6.3.3.4 Distance to Curve Entry Point

See section 2.2.10.

6.3.4 Test Procedure

In this test, the driver repeats a series of road departure trajectories as depicted in Figure 40 above.

6.3.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. Measure the geometry if it is unknown (see Appendix II-A, Methods for Determining Road Dimensions and Geometry).
2. Ensure lane marker characteristics meet the test conditions (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in [20]. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure GPS has sufficient satellite signals.
8. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.

6.3.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed (low-speed curve is 64 km/h [40 mph]). The driver uses the cruise control if available.
2. Straighten vehicle before curve entry. Before entering the curve, the driver centers the vehicle in the lane using the lane markers as a visual guide. The vehicle remains centered into the curve.
3. Maintain straight trajectory into the curve. As the vehicle enters the curve, the driver uses a guide target to maintain a straight trajectory through the departure.
4. Depart road. The driver crosses over the lane marker and then recovers from the departure.
5. Repeat the departure trajectories for:
   a. Five right departures
   b. Five left departures
6. Repeat steps 1 - 5 for the middle-speed curve.
7. Repeat steps 1 - 5 for the high-speed curve.

6.3.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

6.3.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

6.3.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

6.3.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. This will vary depending on the measured departure rate and forward speed.

1. Locate the time of warning in the video data (for example, by locating video frame where alert is first displayed).
2. Measure lateral position to the road edge at time of warning.
3. Use equation (5) in section 5.1.2 to determine the desired location for a warning on a curve.

6.3.5.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.1.1. The results of the timeliness evaluations are accumulated according to section 5.3.

6.3.6 Reporting

The evaluator completes the following tables from the data from each test.

Name of Test	Departure on Divided Curved Road With Fixed Available Maneuver Room
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors				Results					
Curve	**Speed mph**	**Direction**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**y_m m**	**x_w m**	**T OT/E/L**
LS	40	Left	5	1					
"	"	"		2…					
LS	40	Right	5						
MS	55	Left	5						
MS	55	Right	5						
HS	70	Left	5						
HS	70	Right	5						

Curve = Low-speed curve, medium-speed curve or high-speed curve

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.

v_f = vehicle forward speed

y_m = the measured lateral distance between the vehicle front tire and the road boundary at the time of warning

x_w = the desired distance to curve entry point at the time of warning using equation (5)

T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	# of runs	# CR	# OT	# E	# L	% OT	% E	% L
Date/time of test runs								

False Alarm Incident Report

Run #	Probable Cause
1	Example: shadows on road misinterpreted as road edge
…	…

II-7 Tests for Departures on Roads With Maximum AMR

The Departure on Roads with Maximum AMR tests evaluate warning system response to road departures where a shoulder provides increased available maneuver room. These tests do not assess the ability of the system to detect obstacles on the shoulder. Therefore, these tests do not provide a complete assessment of a fully functional warning system. A warning system must also pass the "Tests for Departures Toward an Obstacle" that appear in Section II-8.

These tests assess the capability of a warning system to detect the shoulder and measure its width. The transition between on-road and off-road must have some discriminating visual property, such as color or texture. The tests employ two off-road materials: dirt and artificial grass. The off-road material lies upon a paved surface so that the vehicle may depart from the road with minimal risk.

The tests employ two shoulder widths. The large shoulder width is twice the maximum AMR. The system should detect the large shoulder but limit the AMR to the maximum in order to provide consistent warnings. The small shoulder is half the maximum AMR. The system should detect the small shoulder and issue the warning earlier than for a large shoulder. An earlier warning indicates the system successfully detected the decreased shoulder width.

The test scenarios include departures on a straight road and on a curved road.

7.1 Straight Road With Shoulder (Maximum AMR)

The Straight Road With Shoulder test assesses the warning system's ability to detect the shoulder width and to adjust the warning location on a straight road departure.

The figure below illustrates the test scenario. The left-side departure is similar.

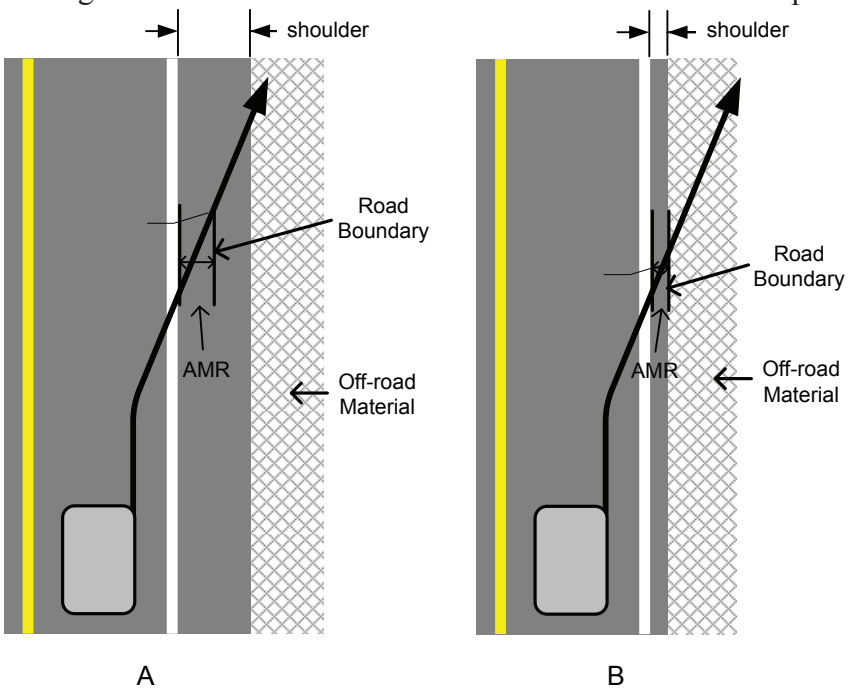


Figure 41. Straight Road With Shoulder Test Trajectory

7.1.1 Events and System Response

The following table defines the events for this test and the correct warning response. See the figure above to locate the event (e.g., ID A1 is label 1 in figure A).

ID	Event	Correct Response
A1	Road departure	1. Issue road departure warning
B1	Same as A1	1. Same as A1, except earlier

7.1.2 Test Conditions

The conditions for this test include the following.

7.1.2.1 Road Geometry

The road geometry for the test is:

Road Geometry	Dimension
Straight (defined using radius of curvature)	> 1,000 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the road geometry.

7.1.2.2 Available Maneuver Room

In this test, shoulder width affects the AMR. However, the test limits the AMR to a default maximum value to prevent large variations in warning location due to large variations in shoulder width.

Available Maneuver Room	Comment
1 m (39 in.)	Default maximum AMR

7.1.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

7.1.2.4 Departure Rate

The vehicle departure rates during the tests fall within two ranges. These rates are comparable to the rates suggested in the ROR report and in the ISO standard for testing lateral drift warning systems.

Low Departure Rate	High Departure Rate
≤ 0.75 m/s	> 0.75 m/s

7.1.2.5 Shoulder Width

This test uses two shoulder widths. The small shoulder is one half the default maximum AMR and the large shoulder is twice the AMR. Update these values if the default minimum or maximum AMR changes.

Shoulder Width Name	Dimension
Small Shoulder	0.5 m (19.5 in.)
Large Shoulder	2 m

7.1.2.6 Off-Road Material

These tests use two types of material to simulate off-road surfaces. The operator places the material on a wide shoulder to reduce the visual width of the shoulder to the widths specified above.

Off-road	Characteristics
Dirt	Brown or variations
Grass	Green artificial grass material

7.1.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions
3. Determine the amount of time the warning gives driver

7.1.3.1 Time of Warning

See section 2.3.9.

7.1.3.2 Longitudinal Speed

See section 2.2.2.

7.1.3.3 Distance to Road Edge

See section 2.2.7.

7.1.3.4 Lateral Velocity

See section 2.2.4.

7.1.3.5 Test Procedure

The test repeats a series of road departure trajectories as depicted in Figure 41.

7.1.3.6 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. Measure the geometry if it is unknown (see Appendix II-A, Methods for Determining Road Dimensions and Geometry).
2. Ensure lane marker characteristics meet the test conditions (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure GPS has sufficient satellite signals.
8. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.
9. Set AMR width with dirt off-road material.

7.1.3.7 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed. The driver may use cruise control if the vehicle is properly equipped.
2. Execute departure. The driver steers toward the road boundary at the prescribed departure rate (high or low) until the road boundary (dirt or grass) is crossed. See section 2.2.8 for a method to achieve the prescribed departure rate.

3. Record departure rate. The assistant records the estimated departure rate as either low or high.
4. Go to start of next departure trajectory. The driver steers the vehicle back onto the road for the next departure.
5. Repeat steps 1-4 for:
   a. Five right departures at the low departure rate
   b. Five right departures at the high departure rate
6. Repeat steps 1 - 5 for the prescribed middle speed.
7. Repeat steps 1 - 5 for the prescribed high-speed.
8. Repeat steps 1 – 7 with the small shoulder width.
9. Repeat steps 1 – 8 for grass off-road material.

7.1.3.8 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

7.1.4 Evaluation Methods

Use the following methods to evaluate warning system performance.

7.1.4.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

7.1.4.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. The desired location varies with the lane curvature and the forward speed.

1. Locate the time of warning in the video data (e.g., first video frame with an alert).
2. Measure lateral position and lateral velocity to the road edge at time of warning.
3. Use equation (2) in section 5.1.1 to determine the desired location for a warning on a straight road.

7.1.4.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.1.1. The results of the timeliness evaluations are accumulated according to section 5.3.

7.1.5 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Departure on Straight Road With Shoulder
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors						Results						
Off-road Mat.	**Speed mph**	**Departure Rate m/s**	**Direc-tion**	**Signal**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**v_l m/s**	**y_m m**	**y_w m**	**T OT/E/L**
Dirt	40	≤ 0.75	Left	No	5	1						
"	"	"	"	"		2…						
Dirt	40	≤ 0.75	Right	No	5							
Dirt	40	> 0.75	Left	No	5							
Dirt	40	> 0.75	Right	No	5							
Dirt	40	> 0.75	Left	On	1							
Dirt	55	≤ 0.75	Left	No	5							
Dirt	55	≤ 0.75	Right	No	5							
Dirt	55	> 0.75	Left	No	5							
Dirt	55	> 0.75	Right	No	5							
Dirt	55	> 0.75	Left	On	1							
Dirt	55	> 0.75	Right	On	1							
Dirt	70	≤ 0.75	Left	No	5							
Dirt	70	≤ 0.75	Right	No	5							
Dirt	70	> 0.75	Left	No	5							
Dirt	70	> 0.75	Right	No	5							
Dirt	70	> 0.75	Left	On	1							
Dirt	70	> 0.75	Right	On	1							
Grass	40	≤ 0.75	Left	No	5							
Grass	40	≤ 0.75	Right	No	5							
Grass	40	> 0.75	Left	No	5							
Grass	40	> 0.75	Right	No	5							
Grass	40	> 0.75	Left	On	1							
Grass	55	≤ 0.75	Left	No	5							
Grass	55	≤ 0.75	Right	No	5							
Grass	55	> 0.75	Left	No	5							
Grass	55	> 0.75	Right	No	5							
Grass	55	> 0.75	Left	On	1							
Grass	55	> 0.75	Right	On	1							
Grass	70	≤ 0.75	Left	No	5							
Grass	70	≤ 0.75	Right	No	5							
Grass	70	> 0.75	Left	No	5							
Grass	70	> 0.75	Right	No	5							
Grass	70	> 0.75	Left	On	1							
Grass	70	> 0.75	Right	On	1							

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.

v_f = measured vehicle forward speed

v_l = measured vehicle lateral speed (departure rate)

y_m = measured lateral distance between the vehicle front tire and the road boundary at the time of warning

y_w = the desired lateral distance at the time of warning using equation (2)

T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	**Probable Cause**
1	Example: shadows on road misinterpreted as road edge
…	…

7.2 Curved Road With Shoulder (Maximum AMR)

The Curved Road With Shoulder test assesses the warning system's ability to detect the shoulder width and to adjust the warning location on a curved road departure. This test is similar to the test in section 7.1.

The figure below illustrates the test scenario. The left-side departure test uses a right turn curve.

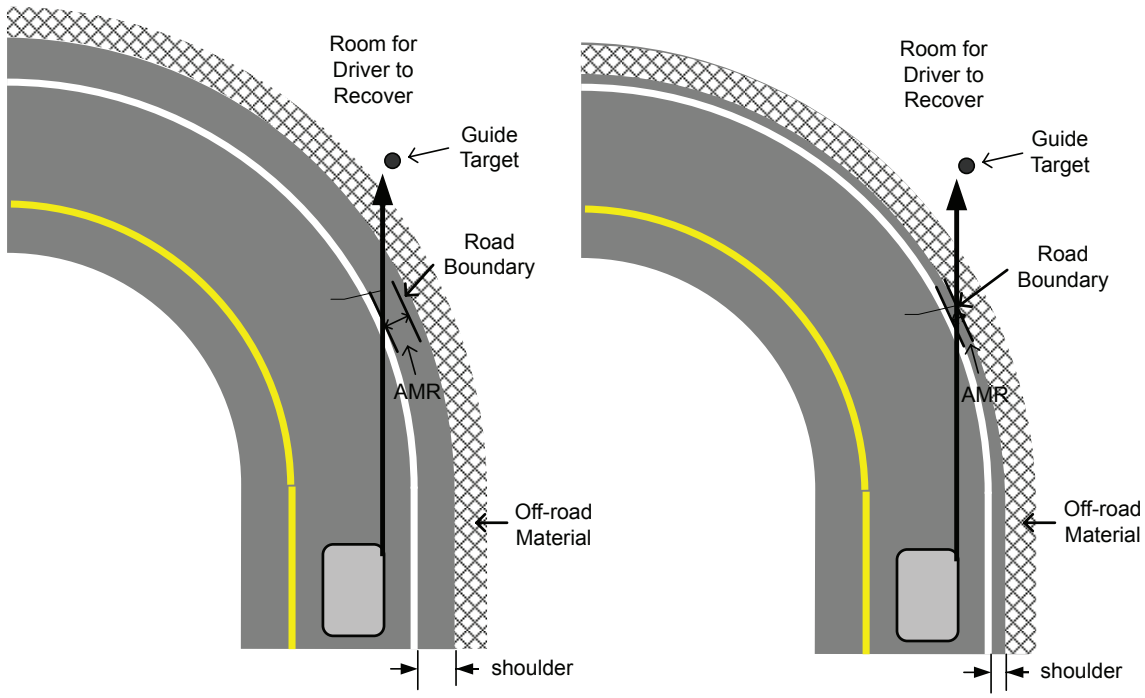


Figure 42. Curved Road with Shoulder Test Trajectory

7.2.1 Events and System Response

The following table defines the events for this test and the correct warning signal the system shall provide. See the figure above to locate the event.

ID	Event	Correct Response
A1	Road departure	1. Issue road departure warning
B1	Same as A1	1. Same as A1 except earlier

7.2.2 Test Conditions

The conditions for this test include the following.

7.2.2.1 Road Geometry

The curve radius for this test is appropriate for the low-speed, medium-speed and high-speed conditions. The following equation calculates the curve radius for each speed condition using lateral acceleration limits (a_{lat}) from section 2.3.5.

$$r = \frac{v^2}{a_{lat}}$$

For the test, the curve radius falls within a range of radii by using the lateral acceleration limits for sensitivities 2 and 4.

Road Geometry	Dimension
Low-speed curve, 64 km/h (40 mph)	91 m - 136 m
Medium-speed curve, 89 km/h (55 mph)	172 m - 257 m
High-speed curve, 113 km/h (70 mph)	278 m - 417 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the geometry.

7.2.2.2 Available Maneuver Room

In this test, shoulder width affects the AMR. However, the test limits the AMR to a default maximum value to prevent large variations in warning location due to large variations in shoulder width.

Available Maneuver Room	Comment
1 m (39 in.)	Default maximum AMR

7.2.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

7.2.2.4 Shoulder Width

This test uses two shoulder widths. The small shoulder is one half the maximum AMR and the large shoulder is twice the AMR. Update these values if the default minimum or maximum AMR changes.

Shoulder Width Name	Shoulder Width Dimension
Small Shoulder	0.5 m (19.5 in.)
Large Shoulder	2 m

7.2.2.5 Off-Road Material

These tests use two types of material to simulate off-road surfaces. The operator places the material on a wide shoulder to reduce the visual width of the shoulder to the widths specified above.

Off-road	Characteristics
Dirt	Brown or variations.
Grass	Green artificial grass material

7.2.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions
3. Determine the amount of time the warning gives driver

7.2.3.1 Time of Warning

See section 2.3.9.

7.2.3.2 Longitudinal Speed

See section 2.2.2.

7.2.3.3 Distance to Road Edge

See section 2.2.7. For this test, the road edge is the base of the barrier.

7.2.3.4 Distance to Curve Entry Point

See section 2.2.10.

7.2.4 Test Procedure

The test repeats a series of road departure trajectories as depicted in Figure 42.

7.2.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. Measure the geometry if it is unknown (see Appendix II-A, Methods for Determining Road Dimensions and Geometry).
2. Ensure lane marker characteristics meet the test conditions (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure GPS has sufficient satellite signals.
8. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.
9. Set the AMR width with dirt off-road material.

7.2.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed. The driver may use cruise control if the vehicle is properly equipped.
2. Straighten vehicle and center vehicle in the lane before entering the curve. The driver centers the vehicle in the lane using the lane markers as a visual guide. The vehicle remains in the center until the start of the curve.
3. Maintain straight trajectory into the curve. As the vehicle enters the curve, the driver uses a guide target to maintain the straight lane trajectory through the departure.
4. Depart road. The driver crosses over the lane marker and then recovers from the departure.
5. Repeat steps 1-4 for:
   a. Five right departures.
   b. Five left departures.
6. Repeat steps 1 - 5 for the middle-speed curve.
7. Repeat steps 1 - 5 for the high-speed curve.
8. Repeat steps 1 - 7 with the small shoulder width.
9. Repeat steps 1 - 8 with the grass off-road material.

7.2.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

7.25 Evaluation Methods

Use the following methods to evaluate warning system performance.

7.2.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

7.2.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. The desired location varies with the departure rate and forward speed.

1. Locate the time of warning in the video data (for example, by locating video frame where alert is first displayed).
2. Measure lateral position and lateral velocity to the road edge at time of warning.
3. Use equation (5) in section 5.1.2 to determine the desired location for a warning on a curve.

7.2.5.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.1.1. The results of the timeliness evaluations are accumulated according to section 5.3.

7.2.6 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Departure on Curved Road with Shoulder
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors					Results					
Off-road Mat.	**Curve**	**Speed mph**	**Direc-tion**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**y_m m**	**x_w m**	**T OT/E/L**
Dirt	LS	40	Left	5	1					
"	"	"	"		2…					
Dirt	LS	40	Right	5						
Dirt	MS	55	Left	5						
Dirt	MS	55	Right	5						
Dirt	HS	70	Left	5						
Dirt	HS	70	Right	5						
Grass	LS	40	Left	5						
Grass	LS	40	Right	5						
Grass	MS	55	Left	5						
Grass	MS	55	Right	5						
Grass	HS	70	Left	5						
Grass	HS	70	Right	5						

Curve = Low-speed curve, medium-speed curve and high-speed curve

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.

v_f = vehicle forward speed

y_m = the measured lateral distance between the vehicle front tire and the road boundary at the time of warning

x_w = the desired distance to curve entry point at the time of warning using equation (5)

T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	Probable Cause
1	Example: shadows on road misinterpreted as road edge
…	…

II-8 Tests for Departures Toward an Obstacle

These tests evaluate warning system response to road departures toward an obstacle on the shoulder. The warning system detects the obstacle, decreases the available maneuver room, and issues a warning based on the location of the obstacles. These tests do not assess the system's ability to determine whether the shoulder ends before the obstacle (i.e., the obstacle is off-road). Therefore, a warning system must also pass the "Tests for Departures on Roads with Maximum AMR" that appear in Section II-7.

These tests evaluate the system's ability to detect an obstacle and to warn when there is a potential for a lateral collision. A map may provide information regarding obstacles, but this information may be incomplete, inaccurate, or unavailable. Thus, a warning system must use a real-time sensor (e.g., radar) to detect obstacles. The warning system deals with longitudinal barriers and discrete objects.

A longitudinal barrier appears as one long continuous obstacle, such as a Jersey barrier. The vehicle drifts slowly toward the barrier much like a lane departure. The warning system uses a side-looking sensor to detect these obstacles.

A discrete object appears on the shoulder ahead of the vehicle. Examples of discrete obstacles include parked cars, bridge supports, and the beginning of a longitudinal barrier. If the vehicle drifts too far outside the lane, it will collide with the object. After a warning, the driver steers away from the obstacle to avoid a collision. The system uses a side-forward sensor (i.e., aimed forward and to the side) to detect these obstacles.

The sensors used by the system must detect a wide range of obstacles with varying properties. Small obstacles, such as pedestrians and motorcycles, pose the greater challenges. The tests use similar sized obstacles made of safer material to reduce the risk of serious damage.

The tests involve placing the obstacles at two distances (i.e., offsets) from the lane edge. The large offset is twice the maximum AMR. The system should detect the large obstacle offset but limit the AMR to the maximum in order to provide consistent warnings. The small obstacle offset is half the maximum AMR. The system should detect the small offset and adjust the warning accordingly. The earlier warning indicates the system successfully detected the obstacle.

The test scenarios include obstacles on a straight road and on a curved road.

8.1 Barrier on Straight Road

The Barrier on Straight Road test assesses the warning system's ability to detect the location of a barrier and to adjust the warning location on a straight road departure.

The figure below illustrates the test scenario. Left-side collision tests position the barrier outside of the yellow line.

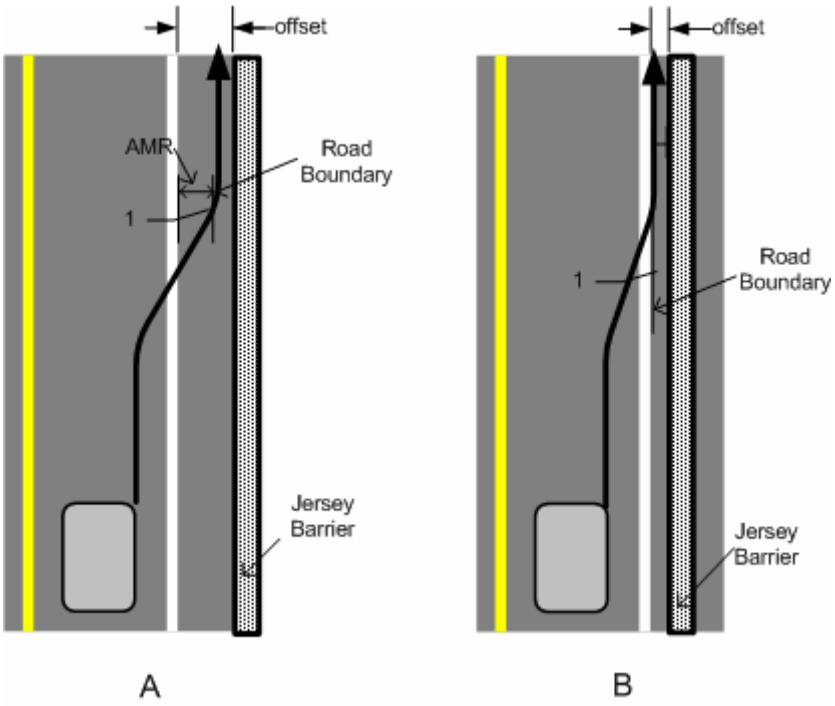


Figure 43. Barrier on Straight Road Test, Vehicle Trajectory

8.1.1 Events and System Response

The following table defines the events for this test and the correct system response. See the figure above to locate the event (e.g., ID A1 is label 1 in figure A).

ID	Event	Correct Response
A1	Lateral collision	1. Issue lateral collision warning
B1	Lateral collision	1. Same as A1

8.1.2 Test Conditions

The conditions for this test include the following.

8.1.2.1 Road Geometry

The road geometry for the test is:

Road Geometry	Dimension
Straight (defined using radius of curvature)	> 1,000 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the road geometry.

8.1.2.2 Available Maneuver Room

In this test, obstacle offset affects the AMR. However, the test limits the AMR to a default maximum value to prevent large variations in warning location due to large variations in obstacle offset.

Available Maneuver Room	Comment
1 m (39 in.)	Maximum AMR

8.1.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

8.1.2.4 Departure rate

The vehicle departure rates during the tests fall within two ranges. These rates are comparable to the rates suggested in the ROR report and in the ISO standard for testing lateral drift warning systems.

Low Departure Rate	High Departure Rate
≤ 0.75 m/s	> 0.75 m/s

8.1.2.5 Barrier

For safety purposes, this test uses a plastic, water-filled Jersey barrier as shown in Figure 44.

Figure 44. Water-Filled Plastic Jersey Barrier

8.1.2.6 Barrier Offset

The tests involve placing the obstacles at two offsets measured from the outside edge of the lane marker. The small offset is one half the maximum AMR and the large offset is twice the AMR. The system evaluator updates these values if the default minimum or maximum AMR changes.

Barrier Offset Name	Dimension
Small Offset	0.5 m (19.5 in.)
Large Offset	2 m (79 in.)

8.1.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions
3. Determine the amount of time the warning gives driver

8.1.3.1 Time of Warning

See section 2.3.9.

8.1.3.2 Longitudinal Speed

See section 2.2.2.

8.1.3.3 Distance to Road Edge

See section 2.2.7. For this test, the road edge is the base of the barrier.

8.1.3.4 Lateral Velocity

See section 2.2.4.

8.1.4 Test Procedure

The general procedure for the test repeats a series of road departure trajectories depicted in Figure 43.

8.1.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. Measure the geometry if it is unknown (see Appendix II-A, Methods for Determining Road Dimensions and Geometry).
2. Ensure lane marker characteristics meet the test conditions and measure the characteristics if it is unknown (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0 and repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure GPS has sufficient satellite signals.
8. Assemble the barriers at the desired offset (large distance for first test set).
9. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.

8.1.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed. The driver may use cruise control if the vehicle is properly equipped.
2. Execute departure. The driver steers toward the barrier at the prescribed departure rate (high or low) until a warning occurs or the driver decides to avoid the barrier. Section 2.2.8 provides a method to achieve the prescribed departure rate.
3. Record departure rate. The assistant records the estimated departure rate as either low or high.
4. Go to start of next collision trajectory. The driver brings the vehicle back around in preparation for the next collision trajectory.
5. Repeat steps 1-4 for:
   a. Five right-side collisions at the low departure rate.
   b. Five left-side collisions at the low departure rate.
   c. Five right-side collisions at the high departure rate.
   d. Five left-side collisions at the high departure rate.
6. Repeat steps 1 - 5 for the prescribed middle speed.
7. Repeat steps 1 - 5 for the prescribed high speed.
8. Repeat steps 1 - 7 with the barriers at the small offset.

8.1.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

8.1.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

8.1.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

8.1.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. The desired location varies with the forward speed and curve radii.

1. Locate the time of warning in the video data (for example, by locating video frame where alert is first displayed).
2. Measure lateral position and lateral velocity to the road edge at time of warning.
3. Use equation (2) in section 5.1.1 to determine the desired location for a warning on a straight road.

8.1.5.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.1.1. The results of the timeliness evaluations are accumulated according to section 5.3.

8.1.6 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Collision With Barrier on Straight Road
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors						Results						
Offset m	**Speed mph**	**Departure Rate m/s**	**Direction**	**Signal**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**v_l m/s**	**y_m m**	**y_w m**	**T OT/E/L**
0.5	40	≤ 0.75	Left	No	5	1						
0.5	"	"	"	"		2…						
0.5	40	≤ 0.75	Right	No	5							
0.5	40	> 0.75	Left	No	5							
0.5	40	> 0.75	Right	No	5							

0.5	40	> 0.75	Left	On	1							
0.5	55	≤ 0.75	Left	No	5							
0.5	55	≤ 0.75	Right	No	5							
0.5	55	> 0.75	Left	No	5							
0.5	55	> 0.75	Right	No	5							
0.5	55	> 0.75	Left	On	1							
0.5	55	> 0.75	Right	On	1							
0.5	70	≤ 0.75	Left	No	5							
0.5	70	≤ 0.75	Right	No	5							
0.5	70	> 0.75	Left	No	5							
0.5	70	> 0.75	Right	No	5							
0.5	70	> 0.75	Left	On	1							
0.5	70	> 0.75	Right	On	1							
2.0	40	≤ 0.75	Left	No	5							
2.0	40	≤ 0.75	Right	No	5							
2.0	40	> 0.75	Left	No	5							
2.0	40	> 0.75	Right	No	5							
2.0	40	> 0.75	Left	On	1							
2.0	55	≤ 0.75	Left	No	5							
2.0	55	≤ 0.75	Right	No	5							
2.0	55	> 0.75	Left	No	5							
2.0	55	> 0.75	Right	No	5							
2.0	55	> 0.75	Left	On	1							
2.0	55	> 0.75	Right	On	1							
2.0	70	≤ 0.75	Left	No	5							
2.0	70	≤ 0.75	Right	No	5							
2.0	70	> 0.75	Left	No	5							
2.0	70	> 0.75	Right	No	5							
2.0	70	> 0.75	Left	On	1							
2.0	70	> 0.75	Right	On	1							

Offset = Offset distance (in meters) of barrier from outside edge of lane marker

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.

v_f = measured vehicle forward speed

v_l = measured vehicle lateral speed (departure rate)

y_m = measured lateral distance between the vehicle front tire and the road boundary at the time of warning

y_w = the desired lateral distance at the time of warning using equation (2)

T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	**Probable Cause**
1	Example: shadows on road misinterpreted as road edge
…	…

8.2 Barrier on Curved Road

The Barrier on Curved Road test assesses the warning system's ability to detect the location of a barrier and to adjust the warning location on a curved road departure.

The figure below illustrates the test scenario. The left-side collision avoidance test uses a right turn curve.

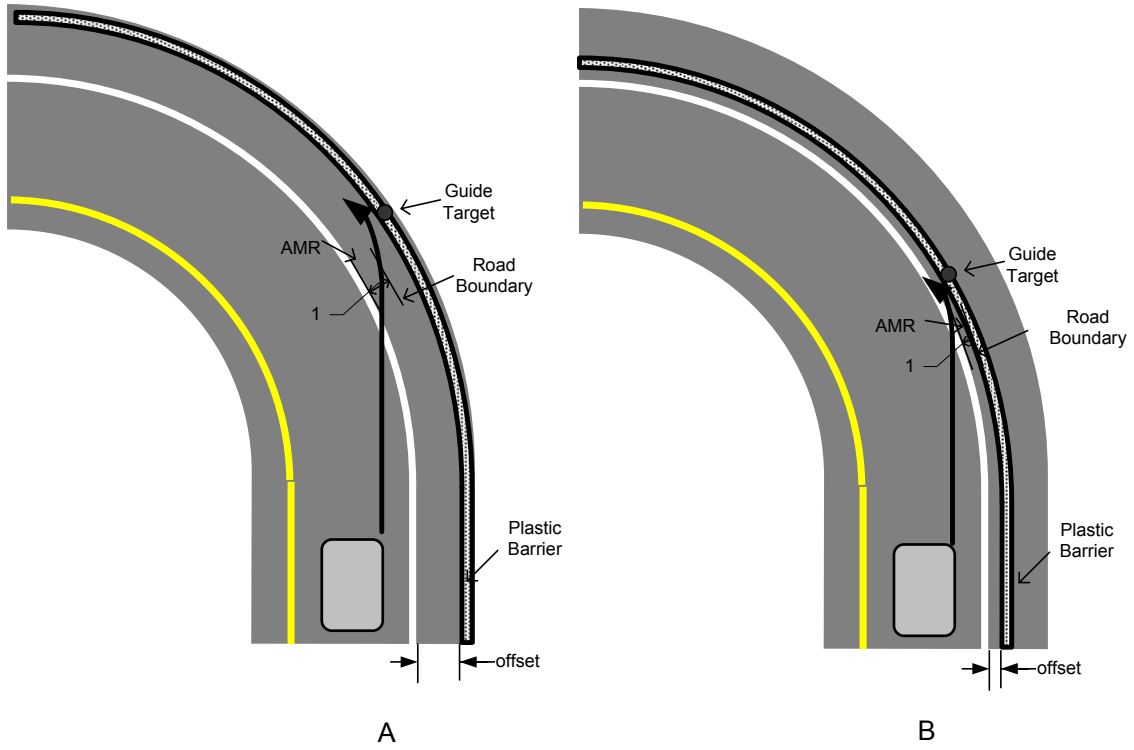


Figure 45. Barrier on Curved Road Test Vehicle Trajectory

8.2.1 Events and System Response

The following table defines the events for this test and the correct system response. See the figure above to locate the event (e.g., ID A1 is label 1 in figure A).

ID	Event	Correct Response
A1	Lateral collision	1. Issue lateral collision warning
B1	Lateral collision	1. Same as A1 except earlier

8.2.2 Test Conditions

The conditions for this test include the following.

8.2.2.1 Road Geometry

The curve radius for this test should be appropriate for the low-speed, medium-speed, and high-speed conditions. The following equation calculates the curve radius for each speed condition using lateral acceleration limits (a_{lat}) from section 2.3.5.

$$r = \frac{v^2}{a_{lat}}$$

For the test, the curve radius falls within a range of radii by using the lateral acceleration limits for sensitivities 2 and 4.

Road Geometry	Dimension
Low-speed curve, 64 km/h (40 mph)	91 m - 136 m
Medium-speed curve, 89 km/h (55 mph)	172 m - 257 m
High-speed curve, 113 km/h (70 mph)	278 m - 417 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the road geometry.

8.2.2.2 Available Maneuver Room

In this test, obstacle offset affects the AMR. However, the test limits the AMR to a default maximum value to prevent large variations in warning location due to large variations in obstacle offset.

Available Maneuver Room	Comment
1 m (39 in.)	Maximum AMR

8.2.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

8.2.2.4 Barrier

For safety purposes, this test uses a plastic, water-filled Jersey barrier (see Figure 44).

8.2.2.5 Barrier Offset

The tests involve placing the obstacles at two offsets measured from the outside edge of the lane marker. The small offset is one half the maximum AMR and the large offset is twice the AMR. The test operator updates these values if the default minimum or maximum AMR changes.

Barrier Offset Name	Dimension
Small Offset	0.5 m (19.5 in.)
Large Offset	2 m (79 in.)

8.2.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions
3. Determine the amount of time the warning gives driver

8.2.3.1 Time of Warning

See section 2.3.9.

8.2.3.2 Longitudinal Speed

See section 2.2.2.

8.2.3.3 Distance to Road Edge

See section 2.2.7. For this test, the road edge is the base of the barrier.

8.2.3.4 Distance to Curve Entry Point

See section 2.2.10.

8.2.4 Test Procedure

The general procedure for the test repeats a series of road departure trajectories depicted in Figure 45.

8.2.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. The operator measures the road geometry as per Appendix II-A, Methods for Determining Road Dimensions and Geometry, if required.
2. Ensure the lane marker characteristics meet the test conditions. The operator measures the characteristics if it is unknown (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure the GPS has sufficient satellites and operates properly.
8. Assemble the barriers and position for test (use large offset for first test set).
9. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.

8.2.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed (low-speed curve is 64 km/h [40 mph]). The driver may use cruise control if the vehicle is properly equipped.

2. Straighten and center vehicle before entering curve. The driver centers the vehicle with the lane markers as a visual guide. The vehicle remains in the center until the start of the curve.
3. Maintain straight trajectory into the curve. As the vehicle enters the curve, the driver uses a guide target to maintain a straight trajectory toward the collision.
4. Collide with obstacle. The driver continues straight until a warning takes place or the driver aborts before a collision.
5. Repeat steps 1-4 for:
   a. Five right-side collisions.
   b. Five left-side collisions.
6. Repeat steps 1 - 5 for the collision on the middle speed curve.
7. Repeat steps 1 - 5 for the collision on the high-speed curve.
8. Repeat steps 1 – 7 with the obstacles at the small offset.

8.2.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

8.2.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

8.2.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

8.2.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. The desired location varies with the forward speed and curve radii.

1. Locate the time of warning in the video data (for example, by locating video frame where alert is first displayed).
2. Measure lateral position and lateral velocity to the road edge at time of warning.
3. Use equation (5) in section 5.1.2 to determine the desired location for a warning on a curve.

8.2.5.3 Timeliness of Warning

The evaluator determines the timeliness of each warning (*early*, *late,* or *on time*) and compiles statistics according to section 5.3.

8.2.6 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Collision With Barrier on Curved Road
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors					Results					
Offset m	**Curve**	**Speed mph**	**Direc-tion**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**y_m m**	**x_w m**	**T OT/E/L**
0.075	LS	40	Left	5	1					
"	"	"	"		2…					
0.075	LS	40	Right	5						
0.075	MS	55	Left	5						
0.075	MS	55	Right	5						
0.075	HS	70	Left	5						
0.075	HS	70	Right	5						
2.0	LS	40	Left	5						
2.0	LS	40	Right	5						
2.0	MS	55	Left	5						
2.0	MS	55	Right	5						
2.0	HS	70	Left	5						
2.0	HS	70	Right	5						

Offset = Offset distance (in meters) of barrier from outside edge of lane marker
Curve = Low-speed curve, medium-speed curve and high-speed curve
CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.
v_f = vehicle forward speed
y_m = the measured lateral distance between the vehicle front tire and the road boundary at the time of warning
x_w = the desired distance to curve entry point at the time of warning using equation (5)
T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	**Probable Cause**
1	Example: shadows on road misinterpreted as road edge
…	…

8.3 Obstacle on Shoulder on Straight Road

This test assesses the warning system's ability to detect an obstacle on the shoulder ahead of the vehicle and to adjust the warning location on a straight road departure.

The figure below illustrates the test scenario. Reverse the vehicle's direction to test a left-side collision.

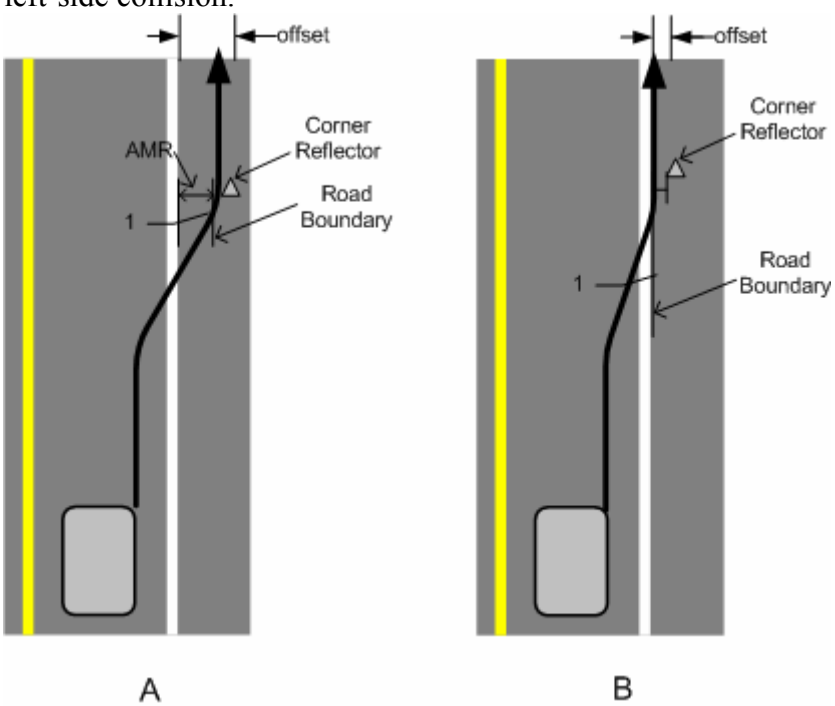


Figure 46. Obstacle on Shoulder on Straight Road Test, Vehicle Trajectory

8.3.1 Events and System Response

The following table defines the events for this test and the correct system response. See the figure above to locate the event (e.g., ID A1 is label 1 in figure A).

ID	Event	Correct Response
A1	Lateral collision	1. Issue lateral collision warning
B1	Lateral collision	1. Same as A1 except earlier

8.3.2 Test Conditions

The conditions for this test include the following.

8.3.2.1 Road Geometry

The road geometry for the test is:

Road Geometry	Dimension
Straight (defined using radius of curvature)	> 1,000 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the road geometry.

8.3.2.2 Available Maneuver Room

In this test, obstacle offset determines the AMR. However, the AMR is limited to a maximum value to prevent large variations warning location caused by large variations shoulder width.

Available Maneuver Room	Comment
1 m (39 in.)	Maximum AMR

8.3.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

8.3.2.4 Departure rate

The vehicle departure rates during the tests fall within two ranges. These rates are comparable to the rates suggested in the ROR report and in the ISO standard for testing lateral drift warning systems.

Low Departure Rate	High Departure Rate
≤ 0.75 m/s	> 0.75 m/s

8.3.2.5 Obstacle

For safety purposes, this test uses a plastic traffic barrel (see Figure 47).

Figure 47. Traffic barrel

8.3.2.6 Obstacle Offset

The tests involve placing the obstacles at two offsets measured from the outside edge of the lane marker. The small offset is one half the maximum AMR and the large offset is

twice the AMR. The operator updates these values if the default minimum or maximum AMR changes.

Barrier Offset Name	Dimension
Small Offset	0.5 m (19.5 in.)
Large Offset	2 m (79 in.)

8.3.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions
3. Determine the amount of time the warning gives driver

8.3.3.1 Time of Warning

See section 2.3.9.

8.3.3.2 Longitudinal Speed

See section 2.2.2.

8.3.3.3 Distance to Road Edge

See section 2.2.7. For this test, the base of the obstacle defines the road edge. The obstacle will not be adjacent to the front wheel at the time of warning. The evaluator calculates the distance to the road edge using the distance to the lane marker plus the obstacle offset (see figure below). To take into account the departure angle (θ requires departure rate, see section 2.2.9), the evaluator uses the following equation (see Figure 48):

$$y_w = l + h = l + \frac{o}{\cos\theta}$$

Where:

y_w = the lateral distance between the vehicle front tire and the road boundary
l = the measured lateral distance to the lane marker
o = the known offset of the obstacle
θ = the departure angle

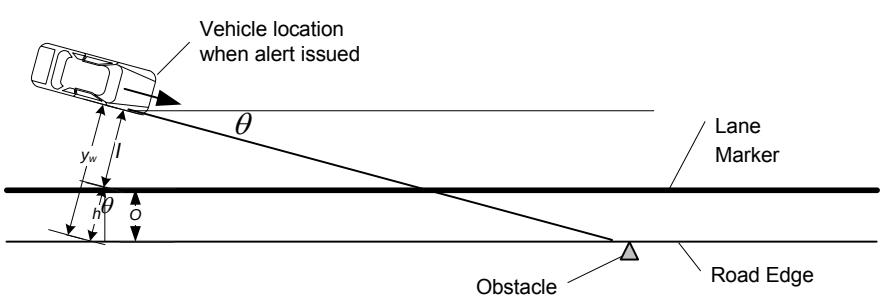


Figure 48. Indirect Distance to Road Edge

8.3.3.4 Lateral Velocity

See section 2.2.4.

8.3.4 Test Procedure

The general procedure for the test repeats a series of road departure trajectories depicted in Figure 46.

8.3.4.1 Pre-Test Procedures

The procedures before the test consist of the following steps:

1. Ensure road geometry meets the test condition. Measure the geometry if it is unknown (see Appendix II-A, Methods for Determining Road Dimensions and Geometry).
2. Ensure lane marker characteristics meet the test conditions and measure the characteristics if unknown (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure GPS has sufficient satellite signals.
8. Assemble the barrels at the desired offset (large distance for first test set).
9. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.

8.3.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed. The driver may use cruise control if the vehicle is properly equipped.
2. Execute departure. The driver steers toward the obstacle at the prescribed departure rate (high or low) until a warning occurs or the driver decides to avoid the obstacle. Section 2.2.8 provides a method to achieve the prescribed departure rate.
3. Go to start of next collision trajectory. The driver brings the vehicle back around in preparation for the next collision trajectory.
4. Repeat steps 1-3 for:
   a. Five right-side collisions at the low departure rate.
   b. Five left-side collisions at the low departure rate.
   c. Five right-side collisions at the high departure rate.
   d. Five left-side collisions at the high departure rate.
5. Repeat steps 1 - 4 for the prescribed middle speed.
6. Repeat steps 1 - 4 for the prescribed high speed.
7. Repeat steps 1 - 6 with the barriers at the large offset.

8.3.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

8.3.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

8.3.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

8.3.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. This will vary depending on the measured departure rate and forward speed.

1. Locate the time of warning in the video data (for example, by locating video frame where alert is first displayed).
2. Measure lateral position and lateral velocity to the road edge at time of warning.
3. Use equation (2) in section 5.1.1 to determine the desired location for a warning on a straight road.

8.3.5.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.1.1. The results of the timeliness evaluations are accumulated according to section 5.3.

8.3.6 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Collision With Obstacle on Shoulder on Straight Road
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors						Results						
Off-set m	**Speed mph**	**Depar-ture Rate m/s**	**Direc-tion**	**Sig-nal**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**v_l m/s**	**y_m m**	**y_w m**	**T OT/E/L**
0.5	40	≤ 0.75	Left	No	5	1						
0.5	"	"	"	"		2…						
0.5	40	≤ 0.75	Right	No	5							
0.5	40	> 0.75	Left	No	5							
0.5	40	> 0.75	Right	No	5							
0.5	40	> 0.75	Left	On	1							
0.5	55	≤ 0.75	Left	No	5							
0.5	55	≤ 0.75	Right	No	5							
0.5	55	> 0.75	Left	No	5							

0.5	55	> 0.75	Right	No	5							
0.5	55	> 0.75	Left	On	1							
0.5	55	> 0.75	Right	On	1							
0.5	70	≤ 0.75	Left	No	5							
0.5	70	≤ 0.75	Right	No	5							
0.5	70	> 0.75	Left	No	5							
0.5	70	> 0.75	Right	No	5							
0.5	70	> 0.75	Left	On	1							
0.5	70	> 0.75	Right	On	1							
2.0	40	≤ 0.75	Left	No	5							
2.0	40	≤ 0.75	Right	No	5							
2.0	40	> 0.75	Left	No	5							
2.0	40	> 0.75	Right	No	5							
2.0	40	> 0.75	Left	On	1							
2.0	55	≤ 0.75	Left	No	5							
2.0	55	≤ 0.75	Right	No	5							
2.0	55	> 0.75	Left	No	5							
2.0	55	> 0.75	Right	No	5							
2.0	55	> 0.75	Left	On	1							
2.0	55	> 0.75	Right	On	1							
2.0	70	≤ 0.75	Left	No	5							
2.0	70	≤ 0.75	Right	No	5							
2.0	70	> 0.75	Left	No	5							
2.0	70	> 0.75	Right	No	5							
2.0	70	> 0.75	Left	On	1							
2.0	70	> 0.75	Right	On	1							

Offset = Offset distance (in meters) of obstacle from outside edge of lane marker

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.

v_f = measured vehicle forward speed

v_l = measured vehicle lateral speed (departure rate)

y_m = measured lateral distance between the vehicle front tire and the road boundary at the time of warning

y_w = the desired lateral distance at the time of warning using equation (2)

T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	**Probable Cause**
1	Example: shadows on road misinterpreted as road edge
…	…

8.4 Obstacle on Shoulder on Curved Road

The Obstacle on Shoulder on Curved Road test assesses the warning system's ability to detect an obstacle on the shoulder ahead of the vehicle and to adjust the warning location on a curved road departure.

The figure below illustrates the test scenario. The left-side collision avoidance test uses a right turn curve.

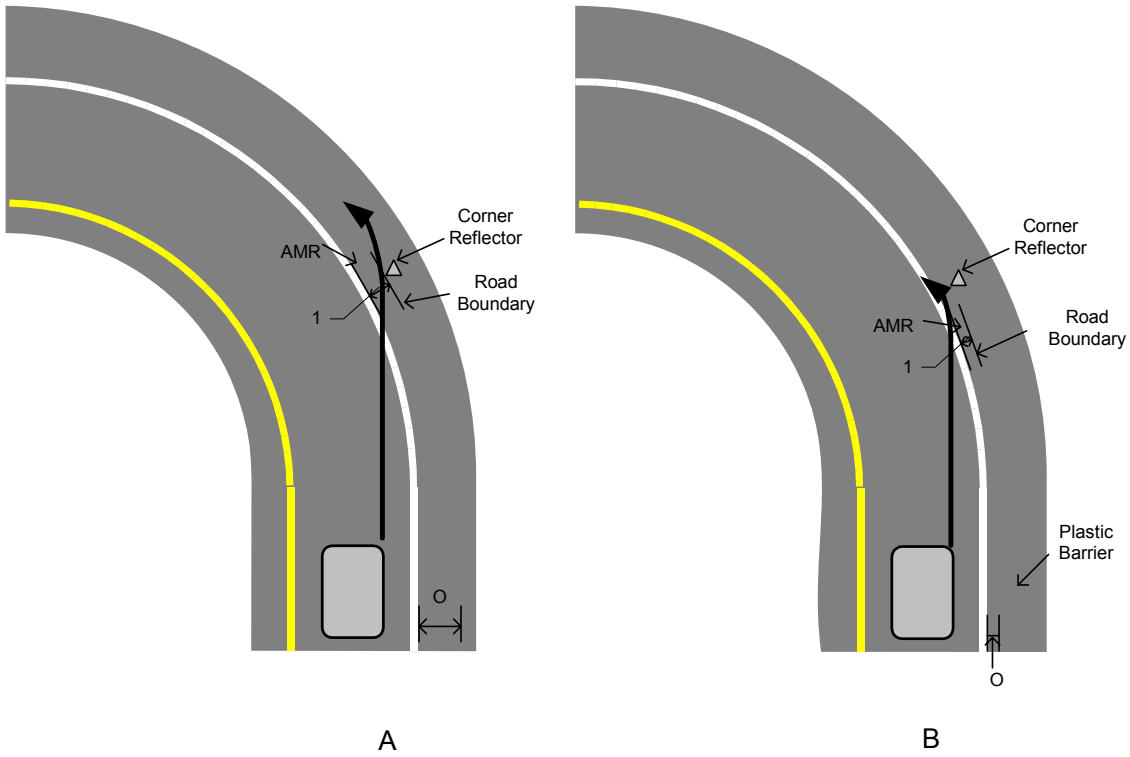


Figure 49. Obstacle on Shoulder on Curved Road Test, Vehicle trajectory

8.4.1 Events and System Response

The following table defines the events for this test and the correct system response. See the figure above to locate the event (e.g., ID A1 is label 1 in figure A).

ID	Event	Correct Response
A1	Lateral collision	1. Issue lateral collision warning
B1	Lateral collision	1. Same as A1

8.4.2 Test Conditions

The conditions for this test include the following.

8.4.2.1 Road Geometry

The curve radius for this test should be appropriate for the low-speed, medium-speed and high-speed conditions. The following equation calculates the curve radius for each speed condition using lateral acceleration limits (a_{lat}) from section 2.3.5.

$$r = \frac{v^2}{a_{lat}}$$

For the test, the curve radius falls within a range of radii by using the lateral acceleration limits for sensitivities 2 and 4.

Road Geometry	Dimension
Low-speed curve, 64 km/h (40 mph)	91 m - 136 m
Medium-speed curve, 89 km/h (55 mph)	172 m - 257 m
High-speed curve, 113 km/h (70 mph)	278 m - 417 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the road geometry.

8.4.2.2 Maximum Available Maneuver Room

In this test, obstacle offset determines the AMR. However, the AMR is limited to a maximum value to prevent large variations warning location caused by large variations shoulder width.

Available Maneuver Room	Comment
1 m (39 in.)	Maximum AMR

8.4.2.3 Speed

The vehicle speeds during the tests cover the warning system operating range.

Low Speed	Medium Speed	High Speed
64 km/h (40 mph)	89 km/h (55 mph)	113 km/h (70 mph)

8.4.2.4 Obstacle

For safety purposes, this test uses a plastic, traffic barrel (see Figure 47).

8.4.2.5 Obstacle Offset

The tests involve placing the obstacles at two offsets measured from the outside edge of the lane marker. The small offset is one half the maximum AMR and the large offset is twice the AMR. The test operator updates these values if the default minimum or maximum AMR changes.

Barrier Offset Name	Dimension
Small Offset	0.5 m (19.5 in.)
Large Offset	2 m (79 in.)

8.4.3 Measurements

Measurements determine whether a warning was given, the desired location of a warning given the conditions and the amount of time the warning gives driver.

8.4.3.1 Time of Warning

See section 2.3.9.

8.4.3.2 Longitudinal Speed

See section 2.2.2.

8.4.3.3 Distance to Road Edge

See section 2.2.7. For this test, the base of the obstacle defines the road edge. If the obstacle is not adjacent to the front wheel at the time of warning and a direct measurement is not possible, then the evaluator calculates the distance to the road edge using the distance to the lane marker plus the obstacle offset (see Figure 48). To take into account the departure angle (θ requires departure rate, see section 2.2.9), use the following equation:

$$y_w = l + h = l + \frac{o}{\cos\theta}$$

Where:

y_w = the lateral distance between the vehicle front tire and the road boundary
l = the measured lateral distance to the lane marker
o = the known offset of the obstacle
θ = the departure angle

8.4.3.4 Distance to Curve Entry Point

See section 2.2.10.

8.4.4 Test Procedure

The general procedure for the test repeats a series of road departure trajectories depicted in Figure 49.

8.4.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition. The operator measures the road geometry as per Appendix II-A, Methods for Determining Road Dimensions and Geometry, if required.
2. Ensure the lane marker characteristics meet the test conditions. The operator measures the characteristics if it is unknown (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Check Ensure recording system is working properly.
7. Ensure the GPS has sufficient satellites and operates properly.

8. Assemble the barrels and position for tests (use large offset for first test).
9. Verify road boundary for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, departure rate, etc.) until accomplished safely and reliably.

8.4.4.2 Test Procedures

The procedures during the test are:

1. Achieve speed. The driver brings the vehicle to the prescribed speed (low-speed curve is 64 km/h (40 mph)) and sets the cruise control at the speed.
2. Straighten and center vehicle before entering curve. The driver centers the vehicle with the lane markers as a visual guide. The vehicle remains in the center until the start of the curve.
3. Maintain straight trajectory into the curve. As the vehicle enters the curve, the driver uses the obstacle as a guide to maintain a straight trajectory toward the collision.
4. Collide with obstacle. The driver continues straight until a warning takes place or the driver aborts before collision.
5. Repeat steps 1-4 for:
   a. Five right-side collisions.
   b. Five left-side collisions.
6. Repeat steps 1 - 5 for the collision on the middle speed curve.
7. Repeat steps 1 - 5 for the collision on the high-speed curve.
8. Repeat steps 1 - 7 with the obstacles at the large offset.

8.4.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

8.4.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

8.4.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the road boundary is crossed.
- The rating is a false negative if the system does not respond with a warning before the road boundary is crossed.

8.4.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning. The desired location varies with the forward speed and curve radii.

1. Locate the time of warning in the video data (for example, by locating video frame where alert is first displayed).

2. Measure lateral position and lateral velocity to the road edge at time of warning.
3. Use equation (5) in section 5.1.2 to determine the desired location for a warning on a curve.

8.4.5.3 Timeliness of Warning

The evaluator determines the timeliness of each warning (*early*, *late,* or *on time*) and compiles statistics according to section 5.3.

8.4.6 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Collision With Obstacle on Curved Road
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors					Results					
Offset m	**Curve**	**Speed mph**	**Direc-tion**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**y_m m**	**x_w m**	**T OT/E/L**
0.075	LS	40	Left	5	1					
"	"	"	"		2…					
0.075	LS	40	Right	5						
0.075	MS	55	Left	5						
0.075	MS	55	Right	5						
0.075	HS	70	Left	5						
0.075	HS	70	Right	5						
2.0	LS	40	Left	5						
2.0	LS	40	Right	5						
2.0	MS	55	Left	5						
2.0	MS	55	Right	5						
2.0	HS	70	Left	5						
2.0	HS	70	Right	5						

Offset = Offset distance (in meters) of obstacle from outside edge of lane marker
Curve = Low-speed curve, medium-speed curve and high-speed curve
CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.
v_f = vehicle forward speed
y_m = the measured lateral distance between the vehicle front tire and the road boundary at the time of warning
x_w = the desired distance to curve entry point at the time of warning using equation (5)
T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	Probable Cause
1	Example: shadows on road misinterpreted as road edge
…	…

II-9 Tests for Departures on Curves at Excessive Speed

The tests for Departures on Curves at Excessive Speed evaluate the warning system's ability to detect whether the vehicle is traveling too fast for an approaching curve and to warn the driver in time to slow the vehicle to a safe speed. Since the curve may be beyond visual limits, curve-speed warnings rely on a map to obtain the curvature of upcoming road segments and a positioning system (e.g., GPS) to provide the vehicle location relative to the curve. The system estimates the amount of deceleration required to slow the vehicle to a safe speed given the distance to the curve. The safe speed takes into account the radius of the curve and other available data such as temperature and precipitation (e.g., windshield wiper on or off), which provides an indirect measure of road friction. The speeds and curve radii are consistent with a rural road scenario where this type of crash most often occurs.

The curve-branch test examines the system's ability to correctly determine whether the vehicle is taking the curve or straight branch when a road network splits. Curve-speed warnings for the curve-branch of the road are a nuisance when the vehicle is heading toward the straight branch of the road.

9.1 Excessive Speed on Curved Road

The Excessive Speed on Curved Road test examines the performance of the curve speed warning system for the scenario where a vehicle is traveling too fast for an upcoming curve in the road. This scenario falls under the "negotiating a curve on undivided non-freeway with two lanes at non-junction" scenario identified in the NHTSA test scenario report as one of the major settings for road departure crashes [15]. This test assumes the warning system uses GPS and a digital map to determine the distance to approaching curves and the radius of the curve.

The figure below illustrates the test scenario.

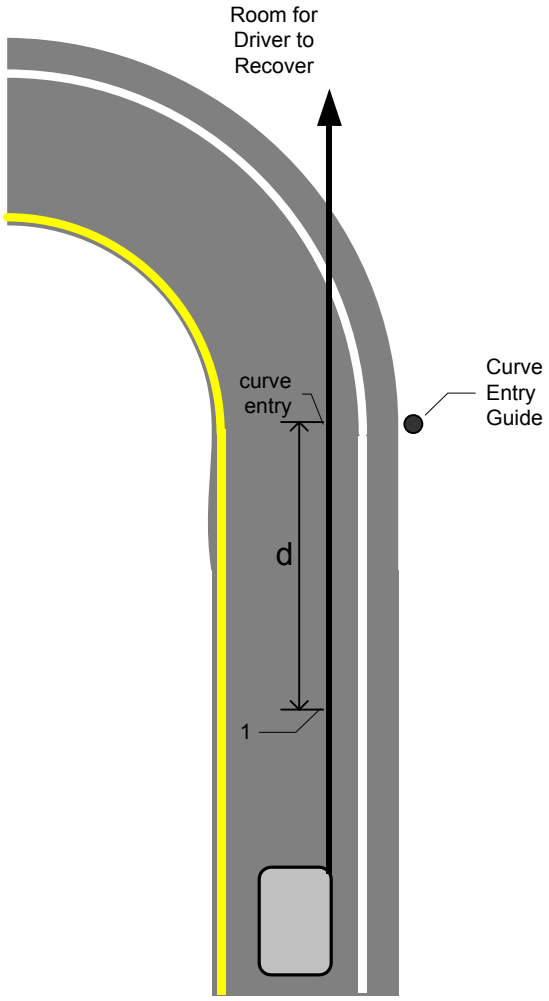


Figure 50. Excessive Speed on Curved Road Test, Vehicle Trajectory

9.1.1 Events and System Response

The following table defines the events for this test and the correct warning signal the system shall provide. The primary event is the vehicle reaching a distance from a curve

where the current speed is too fast for the driver to safely negotiate the curve. See the figure above to locate the event.

ID	Event	Correct Response
1	Excessive speed for curve	1. Issue excessive speed for curve warning

9.1.2 Test Conditions

The conditions for this test include the following.

9.1.2.1 Road Geometry

The test examines two types of curves suggested in (II-1). A range of curve radii provides flexibility in selecting suitable test sites.

Road Type	Dimension
Non-freeway	50 m – 100 m
Freeway	200 m – 350 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the road geometry.

9.1.2.2 Temperature

The temperature condition for the test falls within the following ranges:

Condition	Temperature
Cold	0° C - 3° C (32° F - 38° F)
Warm	4° C - 7° C (39° F - 45° F)

Artificial means to achieve the temperature at the sensor are acceptable (e.g., ice).

9.1.2.3 Precipitation

The precipitation during the test is either dry or wet. The warning system determines precipitation from windshield wiper status.

Condition	Windshield Wiper
Dry	Off
Wet	On

9.1.2.4 Speed

The test requires the driver to approach the curve at a speed in excess of the safe speed for the curve. Use equation (7) to compute the safe speed for the curve. Use 3 m/s^2 (0.3 g) lateral acceleration limit (sensitivity = 3) for warm, dry condition. Use 1 m/s^2 (0.1 g) for cold, wet condition ([20] page 10.27). The following table provides an example of the speeds to use for a test on two radii chosen for freeway and non-freeway roads.

Road Type	Curve Radius	Condition	Safe speed	Over-speed 1 (115 %)	Over-speed 2 (130 %)
Freeway	200 m	Warm, dry	87 km/h (54 mph)	100 km/h (62 mph)	113 km/h (70 mph)
		Cold, wet	50 km/h (31 mph)	58 km/h (36 mph)	68 km/h (41 mph)
Non-Freeway	75 m	Warm, dry	53 km/h (33 mph)	61 km/h (38 mph)	33 km/h (38 mph)
		Cold, wet	31 km/h (19 mph)	35 km/h (22 mph)	40 km/h (25 mph)

9.1.3 Measurements

Measurements collected during the test support the following:

1. Determine whether a warning was given
2. Determine the desired location of a warning given the conditions
3. Determine the amount of time the warning gives driver

9.1.3.1 Time of Warning

See section 2.3.9.

9.1.3.2 Longitudinal Speed

See section 2.2.2.

9.1.3.3 Distance to Curve Entry Point

See section 2.2.10.

9.1.4 Test Procedure

The general procedure for the test repeats a series of road departure trajectories depicted in Figure 50.

9.1.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition and measure the geometry as per Appendix A, if required.
2. Ensure the lane marker characteristics meet the test conditions. The operator measures the characteristics if it is unknown (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in 0. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.

7. Ensure the GPS has sufficient satellites and is operating properly.
8. Establish proper initial sensor conditions (initial test is a warm, dry, non-freeway scenario).
9. Verify curve entry point for test (i.e., outer lane marker plus AMR) and practice vehicle trajectories (speeds, decelerations, etc.) until accomplished safely and reliably. Ensure recovery area exists in case driver is not able to keep vehicle in lane through curve.

9.1.4.2 Test Procedures

The procedures during the test are:

1. Achieve temperature. Set the system's temperature sensor too output prescribed condition (warm or cold).
2. Achieve precipitation condition. Set the windshield wiper to the prescribed condition (dry = off, wet = on).
3. Achieve speed. The driver brings the vehicle to the over-speed condition.
4. Maintain vehicle centered in lane until past curve entry point. Vehicle may depart out of lane into recovery area if traveling too fast.
5. Document the warning type and result.
6. Repeat steps 1- 5 five times.
7. Repeat steps 1 – 6 for over-speed 2 (130 % of maximum)
8. Repeat steps 1 - 7 for cold, wet condition
9. Repeat steps 1 - 8 for freeway

9.1.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

9.1.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

9.1.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a true positive if the system responds with a warning before the vehicle has completed travel through the curve.
- The rating is a false negative if the system does not respond with a warning before the vehicle exits the curve.

9.1.5.2 Desired Location of Warning

For each test run, the evaluator determines the desired location of the warning.

1. Locate the time of warning in the video data (for example, by locating video frame where alert is first displayed).
2. Measure distance to curve entry at time of warning.

3. Use equation (8) in section 5.2 to determine the desired location for a warning when traveling too fast for an approaching curve.

9.1.5.3 Timeliness of Warning

For each test run, the evaluator determines whether the warning is *early*, *late,* or *on time* using steps described in section 5.2. The results of the timeliness evaluations are accumulated according to section 5.3.

9.1.6 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Curve Speed Warning Test
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors			Results					
Condition	**Speed mph**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**x_m m**	**x_w m**	**T OT/E/L**
Warm/Dry	67	10	1					
"	"	"	2…					
Cold/Wet	52	10	1					

CR = System gave correct response (T) or failed to give correct response (F). Refer to subsection 1.1 above to determine correct response.
v_f = measured vehicle forward speed
x_m = The measured distance to the curve at the time of warning
x_w = the desired distance to the curve at the time of warning using equation (8)
T = Timeliness of warning (*early*, *late,* or *on time*)

Test Run Summary Results (see section 5.3)

Combined Results for All Runs	**# of runs**	**# CR**	**# OT**	**# E**	**# L**	**% OT**	**% E**	**% L**
Date/time of test runs								

False Alarm Incident Report

Run #	**Probable Cause**
1	Example: shadows on road misinterpreted as road edge
2	Example: longitudinal road joint misinterpreted as road edge
…	…

9.2 Curve-Branch Detection

The Curve-Branch Detection test examines whether the curve-speed warning system accurately predicts whether a vehicle is about to travel on a straight or curved branch of a road that splits. This test assumes the warning system uses GPS and a digital map to determine the distance to approaching curves and the radius of the curve. The scenario for this test requires a two-lane road that splits into a straight road and a curved road.

The curve-branch requires sufficient radius to generate a warning at a reasonable approach speed. For test purposes, the rural road curve used in the curve-speed warning test may be adapted for the curve-branch test.

During the curve-branch test, the system issues a warning if the vehicle is in the lane headed toward the curve at a high speed (see B in figure below). Conversely, the system does not issue a warning if the vehicle is in the lane headed straight (see A in figure below). The test verifies correct operation in both lanes. The driver uses the procedure in section 9.1 for the test in the curve lane and the procedure below for the straight lane.

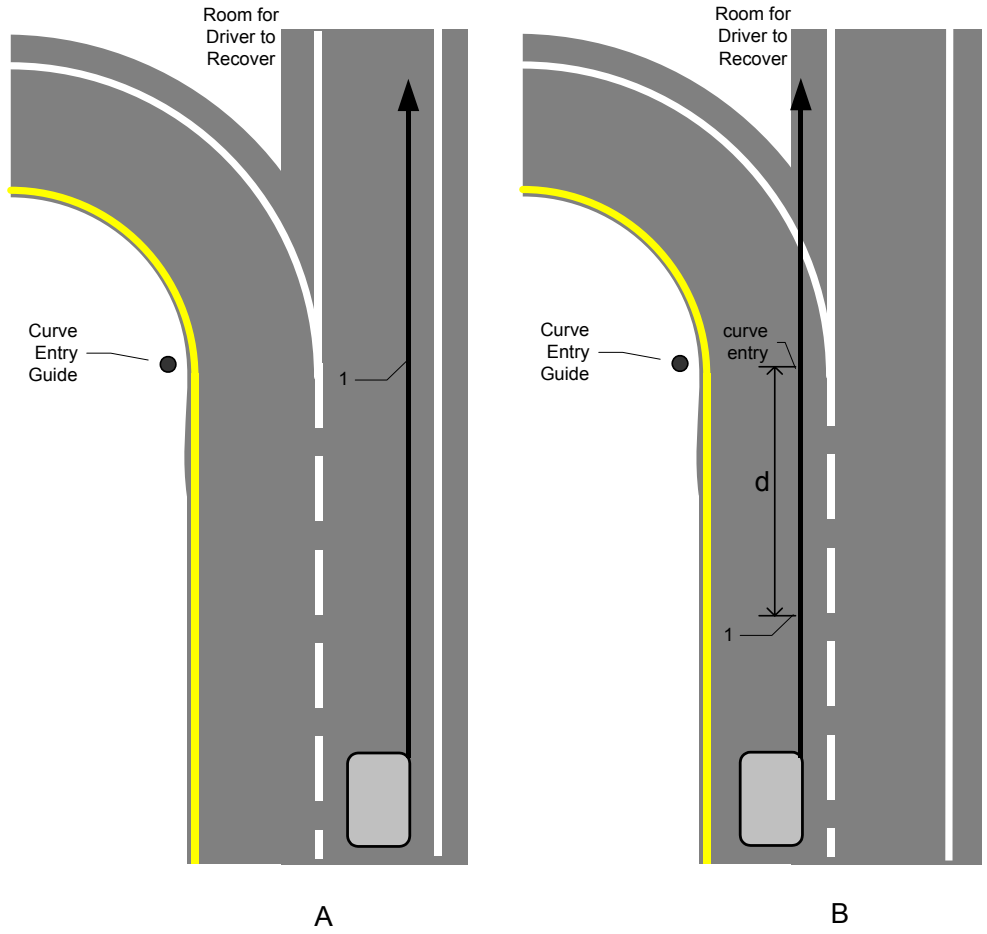


Figure 51. Curve-Branch Test, Vehicle trajectory

9.2.1 Events and System Response

The following table defines the events for this test and the correct warning signal the system shall provide. The primary event is the vehicle reaching a distance from a curve where the current speed is too fast for the driver to safely negotiate the curve. See the figure above to locate the event.

ID	Event	Correct Response
A1	Reached Curve	1. No warning should be given

9.2.2 Test Conditions

The conditions for this test include the following.

9.2.2.1 Road Geometry

The road geometry for this test consists of a straight lane adjacent to a curved lane. See section 9.1.2.1 for the curved lane radii. It is sufficient to test the freeway curve only. The straight lane has the following geometry:

Road Geometry	Dimension
Straight lane (radius)	> 1,000 m

Appendix II-A, Methods for Determining Road Dimensions and Geometry contains the recommended method to verify the road geometry.

9.2.2.2 Temperature

Use same temperature conditions as in section 9.1.2.2.

9.2.2.3 Precipitation

Use same precipitation conditions as in section 9.1.2.3.

9.2.2.4 Speed

The speeds in the straight lane are the same as those for the curved lane. See section 9.1.2.4.

9.2.3 Measurements

Measurements determine whether a warning was given and whether the test speed was within limits.

9.2.3.1 Time of Warning

See section 2.3.9.

9.2.3.2 Longitudinal Speed

See section 2.2.2.

9.2.4 Test Procedure

The general procedure for the test repeats a series of road departure trajectories depicted in Figure 51. The driver conducts this test after the curve over-speed test.

9.2.4.1 Pre-Test Procedures

The procedures before the test are:

1. Ensure road geometry meets the test condition and measure the geometry as per Appendix II-A, Methods for Determining Road Dimensions and Geometry, if required.
2. Ensure the lane marker characteristics meet the test conditions. The operator measures the characteristics if it is unknown (see sections 2.1.1-2.1.12).
3. Check speedometer accuracy (see section 2.2.2).
4. Verify IMS camera calibration according to recommendations in [17]. Repeat camera calibration if camera has moved.
5. Ensure microphone detects warning system alerts and driver speech.
6. Ensure recording system is working properly.
7. Ensure the GPS has sufficient satellites and is operating properly.
8. Establish proper initial sensor conditions (initial test is a warm, dry, non-freeway scenario)

9.2.4.2 Test Procedures

The procedures during the test are:

1. Achieve temperature. Set the system's temperature sensor to prescribed condition.
2. Achieve precipitation condition. Set the windshield wiper to the prescribed condition (dry = off, wet = on).
3. Achieve speed. The driver brings the vehicle to the over-speed condition.
4. Maintain vehicle centered in lane until past the split.
5. Document the warning type and result.
   a. Repeat steps 1-5 five times.
6. Repeat steps 1 – 5 for cold, wet condition

9.2.4.3 Post-Test Procedures

The procedures after the test are:

1. Verify IMS camera orientation has not changed. Repeat tests if changed.

9.2.5 Evaluation Methods

Use the following methods to evaluate warning system performance.

9.2.5.1 Rate System Response

Examine the video and audio data and rate each warning scenario.

- The rating is a false positive if the system responds with a warning while the vehicle approaches the split while inside the straight lane markers.

9.2.6 Reporting

The evaluator completes the following tables from the data in each test.

Name of Test	Curve Speed Warning Test
Date of Test	
Warning System ID	Name and Version Number

Test Run Results

Factors			Results			
Condition	**Speed mph**	**# of runs**	**Run #**	**CR T/F**	**v_f mph**	**Possible causes of false alarm**
Warm/Dry	67	10	1			
"	"	"	2…			

CR = System gave correct response (T if no warning) or failed to give correct response (F if false alarm).

v_f = measured vehicle forward speed

Appendix II-A – Methods for Determining Road Dimensions and Geometry

This section contains recommended methods to verify that road segments satisfy the geometry specifications prescribed for the test.

A.1 Lane Marker Dimensions

Use a tape measure to verify lane marker dimensions before the test. Alternatively, use the IMS to measure lane marker dimensions.

A.2 Lane Width

Use a tape measure to verify lane width before the test. Alternatively, use the IMS to measure lane width.

A.3 Curve Radius

Calculate the curve radius of the road segment over the entire road segment or over the portion of the road segmented or at the point of road departure.

Calculate the curve radius from vehicle speed and a yaw rate sensor (gyro) using the following formula (derived from arc length formula):

$$r = \frac{v}{\theta'},$$

Where:

r = radius of curve (m)
v = vehicle forward speed (m/s)
θ' = the yaw rate (radians/s).

If a GPS is used, calculate the curvature using a three points measured on the curve using the Independent Measurement System to visually measure road edge points.

Appendix II-B – Methods for Determining Lane Marker Characteristics

This appendix provides standards for measuring and attaining color and reflectivity properties of horizontal pavement markings to ensure that lane markings provide appropriate conspicuity for the warning system sensor. The performance of pavement markings is determined by the coefficient of retro-reflected luminance, R_L, the coefficient of retro-reflected luminance for wet roadways, $R_{L\text{-}Wet}$, the coefficient of retro-reflected luminance under continuous wetting, $R_{L\text{-}Rain}$, or the luminance coefficient under diffuse illumination, Q_d. Under the same conditions of headlight illumination and driver's viewing, larger values of these coefficients correspond to higher levels of visual performance at corresponding geometry. Reapply the lane markings when they measure outside of the specified value.

The following standards apply for lane-marker reflectance specifications:

- ASTM D 6628 – 01, "Standard Specification for Color of Pavement Marking Materials"
- ASTM D 6359 – 99, "Standard Specification for Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments"
- ASTM E 1710, "Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-prescribed Geometry Using a Portable Retroreflectometer"
- ASTM E 2177, "Standard Test Method for Measuring the Coefficient of Retroreflected Luminance of Pavement Markings in a Standard Condition of Wetness"
- ASTM Designation E 2176, "Standard Test Method for Measuring the Coefficient of Retroreflected Luminance of Pavement Markings in a Standard Condition of Continuous Wetting"
- European Standard EN 1436:1997/prA1:2002 "Road marking materials – Road Marking Performance for Road Users"

B.1 Terminology

1. *Luminance coefficient under diffuse illumination, Q_d* – the ratio of the luminance, L, of field of the road marking in the given direction by the illuminance, E , on the field, expressed in millicandelas per square meter per lux (mcd•m^{-2}•lx^{-1}).
2. *Coefficient of retroreflected luminance, R_L* – the ratio of the luminance, L, of the field of the road marking in the direction of observation by the normal illuminance, $E\perp$, the field perpendicular to the direction of the incident light, expressed in millicandelas per square meter per lux (mcd•m^{-2}•lx^{-1}).
3. *Checkpoint area* – the evaluation area within each zone of measurement.
4. *Portable Retroreflectometer* – an instrument that can be used in the field or laboratory for measuring the coefficient of reflected luminance, R_L , and complies with Test Method ASTM E 1710.

5. *Condition of wetness* – the test condition created by liberally wetting the road marking and waiting a certain time period after wetting for the water to run off.
6. *Coefficient of retroreflected luminance on a wet surface,* $R_{L\text{-}Wet}$ – retroreflectivity of horizontal pavement markings in a standard condition of wetness. This condition typically exists after a rainfall has ended and the pavement markings are still wet or as the markings are still wet from dew or humidity.
7. *Coefficient of retroreflected luminance on a continuously wetted surface,* $R_{L\text{-}Rain}$ – retroreflectivity of horizontal pavement markings in a standard condition of continual wetting. This condition typically exists during a rainfall.
8. *Zone of measurement* – the road length to measure containing the marking units that appear similar in a visual inspection.

B.2 Measurement Frequency

The majority of Run-Off-Road sensor validation tests occur in a limited area of a test track or roadway. In such limited areas, the test area, the zone of measurement and the checkpoint area are equivalent.

Validate longer zones of measurement (> 300 m) via two checkpoint areas 100 m long each and separated by at least 100 m for each kilometer of the test zone. The initial and final 100 m of the test zone must be included as check point areas. Carry out the necessary remediation and re-verification procedures if a test zone fails to meet the required specifications.

Within each checkpoint area, measure reading sites approximately every 5 m.

Measurements along Broken Longitudinal Horizontal Pavement Markings shall be the same as for continuous markings except there shall be two reading sites per mark and no readings between marks.

B.3 Measurements

All measurements obtained in the sampling areas are in the direction of traffic flow, the direction of the vehicle motion during the sensor test. Single and double lines were measured to determine compliance with prescribed dimensions and the acceptance criteria applied individually to both.

The measurement geometry used to determine the average coefficient of reflective luminance and the luminance coefficient under diffuse illumination shall be 88.76° for the entrance angle (β_1),(β_2=0°) and 1.05° for the observation angle. The aperture angles for both the source (if appropriate) and receiver shall not exceed 0.33°. These measurement methods specify the use of portable or mobile reflectometers that can measure pavement markings in accordance with ASTM Test Method E 1710 or CEN 1436. The standard measurement condition (see Figure 52) represents the angles corresponding to a distance of 30 m for the driver of a passenger car with an eye height of 1.2 m and a headlight height (if any) of 0.65 m above the road, commonly called the "CEN 30 meter geometry.."

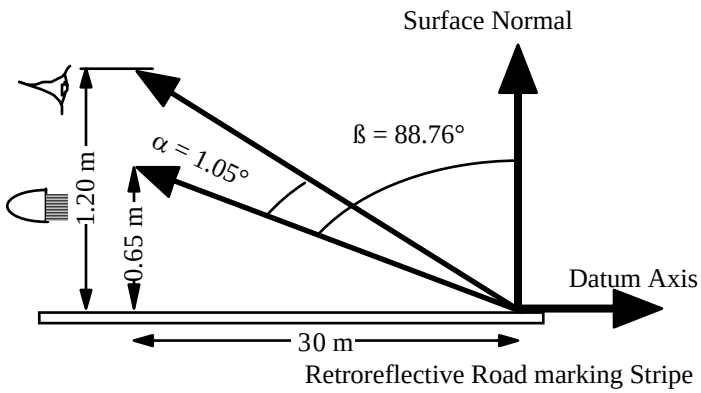


Figure 52. CEN 30 Meter Geometry

Measurements shall be in accordance with the retroreflectometer manufacturer's specification for operation and calibration. When possible a two-point calibration is preferred. The operator shall position the retroreflectometer squarely on or in front of the pavement marking material with the illumination in the direction of the sensor test such that the illuminated measurement area fits within the width of the road marking.

Take measurements within 30 days of the Run-Off-Road sensor test when the road is clean. If using salt, dirt, or a wetting agent to adjust the luminance of the markings, take measurements within 24 hours providing there is no precipitation, high winds, or road cleaning in the test zone between the luminance measurements and the Run-Off-Road sensor test.

B.4 Performance Requirement

The pavement marking material shall be retroreflecting white or yellow, and shall be readily visible as white or yellow when viewed from the sensor position with automobile headlights at night. Measure the pavement marking after removal of all excess glass spheres. Optionally, use light debris, such as dirt or salt, to retard the marking's reflectivity to achieve a value within the desired range.

The use of the sampling procedure and tables for inspection by attributes (see US Mil-Std 105D "Sampling Procedure and Tables for Inspection by Attributes") forms the basis of the acceptance criteria. Measurements shall proceed until the decision point for rejection is reached, in which case the probability is 95 percent that more then 20 percent of the pavement markings will fall below or more then 20 percent of the pavement markings will fall above the requirement. If less the acceptance number of readings fall below or above the requirements, the probability is 95 percent that less then 5 percent of the pavement marking will fall below or more then 20 percent of the pavement markings will fall above the values specified and the pavement marking is accepted.

B.4.1 Dry Day Road Tests

The method measures the wet retroreflectivity of horizontal pavement markings. Measurements shall be taken after a sustained period without precipitation (rain, drizzle, or fog) and the roadway and markings appear dry to the touch, and there is no evidence of residual wetting.

Measure the luminance coefficient under diffuse illumination, Q_d, in accordance with European Standard EN1436: 1997 Annex A. For any set of contiguous 20 readings (approximately 100 m), not more then 3 readings may be greater then 130 mcd m^{-2}/lx, and not more then 3 readings may be less then 100 mcd m^{-2}/lx for the markings to be acceptable for Run Off Road Sensor testing.

B.4.2 Dry Night Road Tests

The method measures the wet retroreflectivity of horizontal pavement markings. Measurements shall be taken after a sustained period without precipitation (rain, drizzle, or fog) and the roadway and markings appear dry to the touch, and there is no evidence of residual wetting.

Measure the coefficient of retroreflected luminance in accordance with ASTM E 1710. For any set of contiguous 20 readings (approximately 100 m), not more then 3 readings may be greater then 130 mcd m^{-2}/lx, and not more then 3 readings may be less then 100 mcd m^{-2}/lx for the markings to be acceptable for Run-Off-Road Sensor testing.

B.4.3 Wet Road Tests

This method measures the wet retroreflectivity of horizontal pavement markings in a standard condition of wetness. This condition typically exists after a rainfall has ended and the pavement markings are still wet or as the markings are still wet from dew or humidity. Measurements for tests involving wet roads are similar to methods prescribed in ASTM E 2177. "Standard Test Method for Measuring the Coefficient of Retroreflected Luminance of Pavement Markings in a Standard Condition of Wetness."

The operator shall wet the target area with a hand sprayer or bucket. The target area includes the marking and the surrounding area. When using a hand sprayer, wet the area (the stripe and the road surface) for 30 s. The marking and road surface are to be completely flooded. When a hand sprayer is not available, the operator shall slowly pour approximately 10 liters of clean water from a bucket over the measurement area (an approximately 20 ± 2 in diameter circle). Pour an even crest of water to temporarily flood the test surface area.

Measure the coefficient of retroreflected luminance of the wetted marking 45 ± 5 s after completion of the wetting. For any set of 20 readings (approximately 100 m), not more then 3 readings may be greater then 50 mcd m^{-2}/lx, and not more then 3 readings may be less then 25 mcd m^{-2}/lx for the markings to be acceptable for Run-Off-Road Sensor testing.

B.4.4 Continuous Wetting Tests

This method of measuring of the wet retroflective properties of pavement markings utilizes a method of continuously wetting the marking during measurement with the retroreflectometer and closely follows ASTM E 2176, "Standard Test Method for Measuring the

Coefficient of Retroreflected luminance of Pavement markings in a Standard Condition of Continuous Wetting."

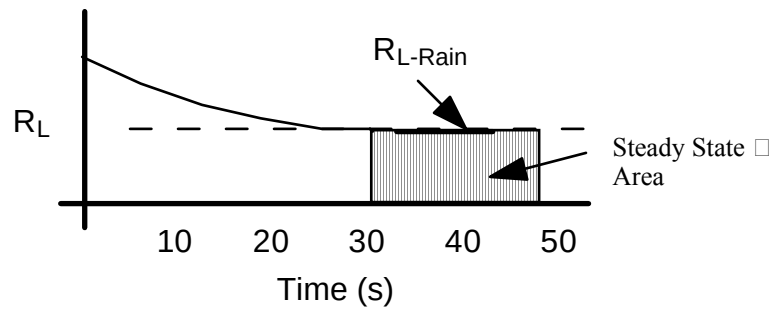


Figure 53 Definition of $R_{L\text{-}Rain}$

The operator shall position and adjust the water spray with the nozzle such that it provides an even spray covering the whole area. The spray shall cover an area that is 25 percent greater then the measuring field measured (generally a 20 ± 2 in diameter circle). The variation between the greatest and lowest intensity within the area shall not be greater then the ratio 1.7:1. The average spray shall be approximately 20 mm/h (heavy rain).

The operator shall take retroreflectometer readings every 10 s until steady state occurs (commonly between 30 s and 60 s). For any set of 20 readings (approximately 100 m), not more then 3 readings may be greater then 50 mcd m^{-2}/lx, and not more then 3 readings may be less then 25 mcd m^{-2}/lx for the markings to be acceptable for Run Off Road Sensor testing.

B.5 Reporting

The test report shall include:

1. The date and time;
2. The location of the test in the form of roadway number, cardinal points, linear distance from the cardinal points, traffic direction, and line identification;
3. The description of the instrumentation and the test method used;
4. The intended road condition (dry, wet, wetting); and
5. The readings recorded in millicandelas per square meter per lux ($mcd \cdot m^{-2} \cdot lx^{-1}$).

Part III:
An Independent Measurement System for Performance Evaluation of Road Departure Crash Warning Systems

III-1 Introduction

The Independent Measurement System is a general-purpose measurement system developed by the National Institute of Standards and Technology for collecting and analyzing data needed for evaluation of intelligent vehicle systems. The IMS consists of sensors, data collection hardware and analysis software independent of the system under test. This provides objectivity, quality assurance, and redundancy to data collection and testing activities. The following version of the IMS supports testing and performance evaluation of the road departure crash warning system developed for a U.S. Department of Transportation Field Operation Test under the Intelligent Vehicle Initiative [27]. Details of the test procedures developed for the FOT appear in [28] and [29].

In the RDCWS program Phase 1 verification test, NIST used the IMS to evaluate the RDCWS on a series of track-based tests. The program proceeded with Phase 2 only after successful verification tests. The IMS also supported a Volpe National Transportation Systems Center task to characterize warning system performance in on-road real-world conditions. NIST collected and processed data and performed analysis of lateral drift warning scenarios.

This document describes the current IMS version and contains the following information:

Section III-2 describes the IMS hardware (a four-camera system with video multiplexor with digitally inserted DGPS and audio recorded on a digital video recorder) and installation.

Section III-3 describes the visual targets for camera calibration and their proper use.

Section III-4 describes the camera calibration process.

Section III-5 describes how evaluators process the data to produce the final video, GPS and support files.

Section III-6 describes the data analysis tools including controls and displays for scrolling through the video, plotting vehicle trajectory, viewing time, and making a variety of road measurements.

Section III-7 describes the procedure to locate video frames taken at a specific GPS time. This procedure supports analysis of warning system data collected by the University of Michigan Transportation Research Institute data collection system.

Section III-8 describes the lateral drift warning analysis procedure used to support Volpe's on-road characterization of the RDCWS.

Section III-9 describes a tool for measuring lane marker contrast.

Section III-10 describes how to display IMS data on a MapPoint map.

The analysis software is written in LabView. An executable-only version of the software is available at ftp://ftp.nist.gov/pub/mel/szabo/AnalyzeDataDistribution/. The software requires a run-time license from LabView. Contact Sandor Szabo (sandor.szabo@nist.gov) to obtain the license.

III-2 Data Collection System

This section describes the data collection system used during the RDCWS FOT verification tests between May 2003 and March 2005.

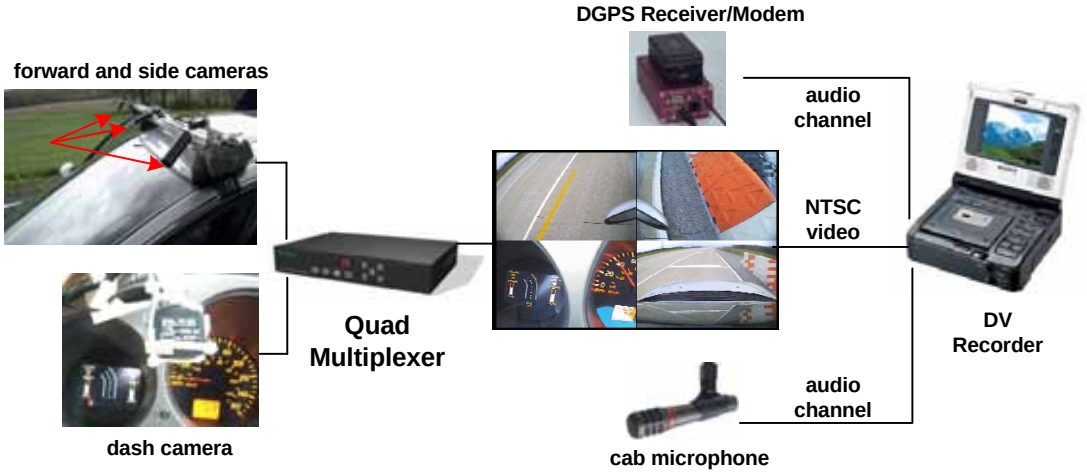


Figure 54. System diagram of data collection system.

The on-board data collection system (see Figure 54) consists of four cameras, a quad multiplexer, a microphone, a DGPS receiver/modem, and a digital video tape deck. Three cameras mount to a removable roof rack. Two roof cameras view the lanes to the right and left of the front wheels. These cameras have infrared LEDs for nighttime illumination. The center camera records a view similar to the warning system view. The fourth camera mounts to the dash and views the warning system display and the speedometer (useful if GPS data is not available). A microphone in the cab captures the audible warnings and voice feedback from the driver.

The dash camera and audible alerts pinpoint, from the perspective of the driver, an alert event. Figure 55 through Figure 58 show cautionary and imminent lateral drift and curve speed warnings. In these figures, the upper left and right quads show the left and right side of the vehicle (centered on front wheels) respectively. The lower right quad shows the view in front of the vehicle. The lower left quad shows the warning system display and the dash speedometer. The IMS multiplexes the quad images with the GPS data and audio in real-time. Thus, the data suffers minimal errors due to misalignment of data streams. The recorded data correlates the vehicle position and motion with the warning system events.

The box shown in Figure 59 contains the data collection system's electronic components. A VMS-200 DGPS receiver/modem interfaces with a roof-mounted GPS antenna and the digital video (DV) recorder. The VMS outputs satellite data as an audio signal to one of the DV recorder's audio channels. This function is similar to overlaying GPS data graphically on the video signal, except the "overlay" is in a computer readable format. Later, a suite of software extracts the GPS data from the tape using the VMS, performs differential correction to the GPS data, and stores the GPS locations into a file. When

viewing a video file, the analysis software uses the tape time to search for the DGPS location that corresponds to a particular video frame.

Figure 55. Lateral drift cautionary warning indicated by arrow at 2 o'clock.

Figure 56. Lateral drift imminent warning indicated by arrow at 3 o'clock.

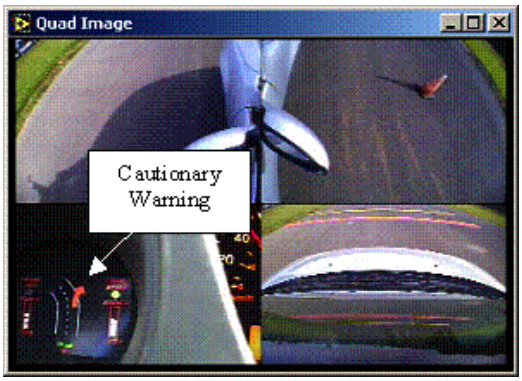


Figure 57. Curve speed cautionary warning indicated by short arrow.

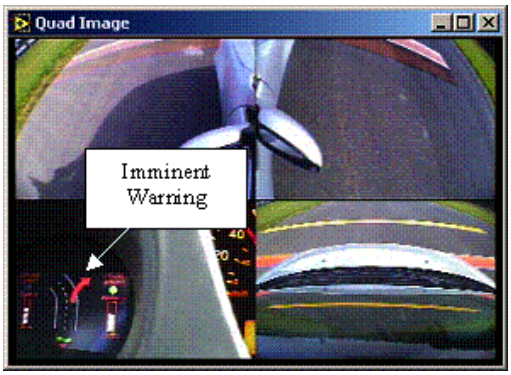


Figure 58. Curve speed imminent warning indicated by long arrow.

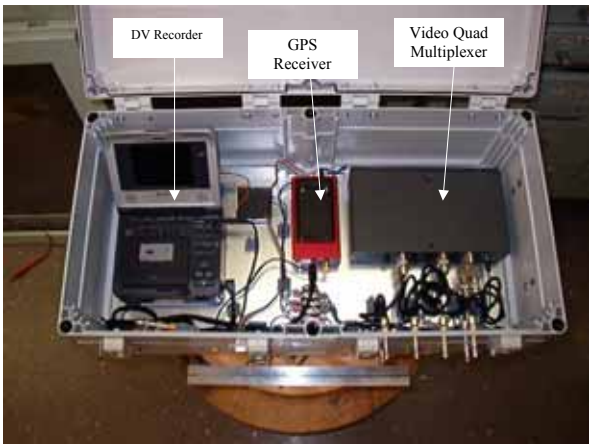


Figure 59. The electronics box installed in the vehicle for data collection.

III-3 Camera Calibration Setup

Camera spatial calibration defines the transformation between image points (i.e., pixel coordinates) and world points on the road surface surrounding the vehicle. This section describes the data collection procedures for the calibration process. This section primarily concerns the data collectors (data users may want to skim this section). However, users should be aware of how to check the calibration as described in Section 4.5 (Calibration Verification).

NIST implemented two forms of calibration techniques for the RDCWS FOT. A non-linear calibration technique took measurements over a large area (see Appendix III-D). However, the large grid system required careful assembly and handling. Although measurements on the grid points were accurate, the measurements between grid points suffered distortion.

A simpler calibration scheme supports measurements along a single line on the ground. The line is a series of meter sticks (called cal sticks). The sticks have alternating black and white segments. The transition between black and white is a control point for calibration purposes. The widths of the segments vary to compensate for distortions in the image. Narrow segment sticks lie closer to the camera and wide segment sticks lie farther from the camera. Figure 60 shows the calibration sticks for the right side camera. The calibration uses four 1-meter sticks. The first two (starting from closest to the vehicle on the right side of the image) have 10 cm segments. The third and fourth sticks have 25 cm and 50 cm segments, respectively. Note in Figure 60 how the 50 cm segments appear the same width as the closest 10 cm segments. The forward calibration (Figure 61) uses six alternating black and white 1-meter sticks.

Figure 60. Calibration sticks for side view camera.

Figure 61. Forward camera calibration using one-meter sticks.

The calibration procedure identifies the pixels corresponding to the control points (i.e., segment endpoints). The computer software displays the control point pixels with red circles. The first circle (furthest left) correlates to 0 m from the right wheel. The last red circle (furthest right) correlates to the combined lengths of the cal sticks or 4 m. Meas-

urements in the image are valid only along the red circles. A linear interpolation generates the measurement value between the circles.

3.1 Side-View Calibration Sticks

The following steps describe the camera and calibration stick set-up for the side-view cameras on the Nissan Altima used in the FOT.

1. Place 4 1-meter sticks end-to-end in line parallel to the front axle and adjacent to the front wheel (see Figure 60 for right side of vehicle). Use the sticks with alternating 10 cm black and white segments for the two closest to the wheel. For the third and fourth sticks, use the stick marked with 25 cm segments and 50 cm segments, respectively.
2. Center the sticks vertically in the camera image. When centered, the sticks appear straight as opposed to parabolic (which is due to the radial distortion of the lens).
3. Align the inside stick with camera image edge. Ensure the image includes the vehicle door and the mirror. The stick alignment produces ideal measurements close to the vehicle and the mirror provides a landmark to detect if the camera moves. (Note: for other vehicles, one may need to add a visual landmark.)
4. Using a video display to view the camera output, mark the location of the mirror (or other visual landmark) using a fine-tip pen to trace the mirror's contour. If the camera moves later, the location of the mirror in the display will not align with the original tracing. Before collecting video data, verify the alignment of the mirror with the tracing. In most cases, if the camera moves the user can realign the camera to match the original tracing. If not, the user must lay down meter sticks and perform another calibration.
5. Record several seconds of the calibration sticks.
6. Rewind the video and verify recording of calibration sticks.
7. Repeat Steps 1 through 6 for the opposite (in this case right) side view.

3.2 Front-View Calibration Sticks

The following steps describe the camera and calibration stick set-up for the front-view camera on the Nissan Altima used in the FOT. One significant difference from the side view cameras is the need to determine the translation and rotation of the sticks with respect to the vehicle. Another need is to have another person point to the control points, since they may be difficult to identify in the image.

1. Place six sticks in front of the vehicle in a straight line. Alternate a black meter and a white meter stick (the entire stick is the same color, not segmented). The sticks should lie just above the hood in the image (roughly 2 m in front). Place the sticks perpendicular to the vehicle heading and align the center of the six sticks with the center of the vehicle.
2. Measure the distance from the rear wheel to the edge of the sticks (line C in Figure 62), the distance from the rear wheel to the stick closest to the front wheel (line B in Figure 62), and the distance from the intersection of line B with the sticks to the edge of the sticks (line A in Figure 62. The calibration process uses the three values to determine the position and orientation of the cal sticks with respect to the vehicle's front

wheels. (Note that if not known already, the calibration requires the distance between the rear-wheel and the front wheel. Update the value if using a vehicle other than the Nissan Altima.)

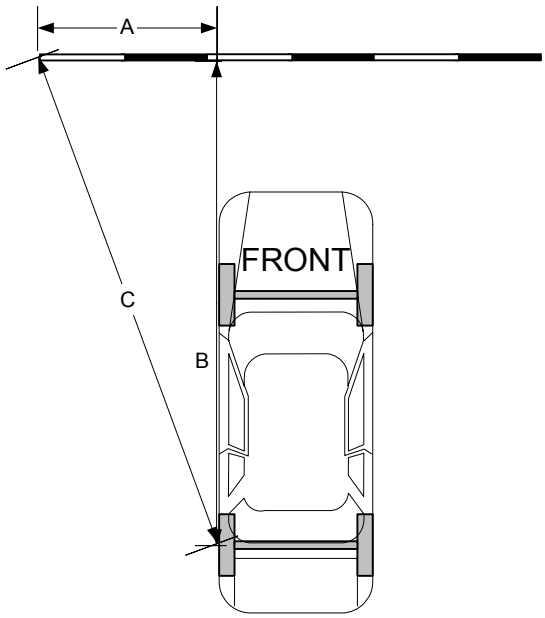


Figure 62. Three measurements to determine offset and rotation of front calibration stick with respect to the vehicle.

3. Manually adjust the camera to vertically center the sticks in the video image. When centered the sticks appear straight as opposed to parabolic (which is due to the radial distortion of the lens). The correct position includes the vehicle's hood and minimizes the sky (reduced sky limits image saturation from the sun).
4. Horizontally center the sticks in the camera image.
5. Using an external video display showing the camera's output (the lower right quad), cover the forward image of the car's hood with clear tape. Using a fine tip pen, outline (trace) the perimeter of the hood. Before collecting video data, verify alignment by comparing the hood with the traced perimeter. Realign the camera if the image does not align with the contour.
6. Turn on video.
7. Use a pointer (e.g., the white or black meter stick) and point out each control point (walk to each point, point at the control point and maintain for 2 seconds).
8. Rewind the video and verify that the tape contains the calibration sticks and that the pointer stick is visible. It may be hard to see the bottom of the pointer stick depending on the background and lighting. You may have to experiment a few times or wait for better lighting conditions.

III-4 Camera Calibration

The procedures in Section III-3 generate a videotape of the calibration sticks at specific places around the vehicle. The procedures in this section extract data from the videotape and create a calibration file. The calibration file maps the quad image pixels to the GPS coordinates and the distance offset of the pixel from either front wheel.

4.1 Creating the Calibration Video

The calibration procedures use video files in the AVI format. Several commercial software packages can translate a video image into such a file. Section 5.3 (Creating the AVI file using Adobe Premier) explains one such package. The file may be from a single video file or may be spliced from several video files but must contain video of all three sets of calibration sticks (left, right, and forward).

4.2 Using the Calibration Program

A program written by NIST researchers can assist with the extraction of calibration data from the AVI file of the calibration sticks. The program is a LabView virtual instrument (vi) called "Nonlinear Calibration.vi." The program produces the video calibration file for the cameras in the current position and orientation. If the camera view changes (i.e., the pixels do not align with the original pixels covering the calibration stick), then a new calibration file must be produced.

Figure 63 shows the "vi" control panel. The buttons on the left, labeled "Calibration Steps," step through the calibration process. The user must execute the steps in order from top to bottom. The user cannot skip steps nor return to a previous step. If an error occurs, the user starts over by using the "return" button. The following sections describe each step in the calibration process.

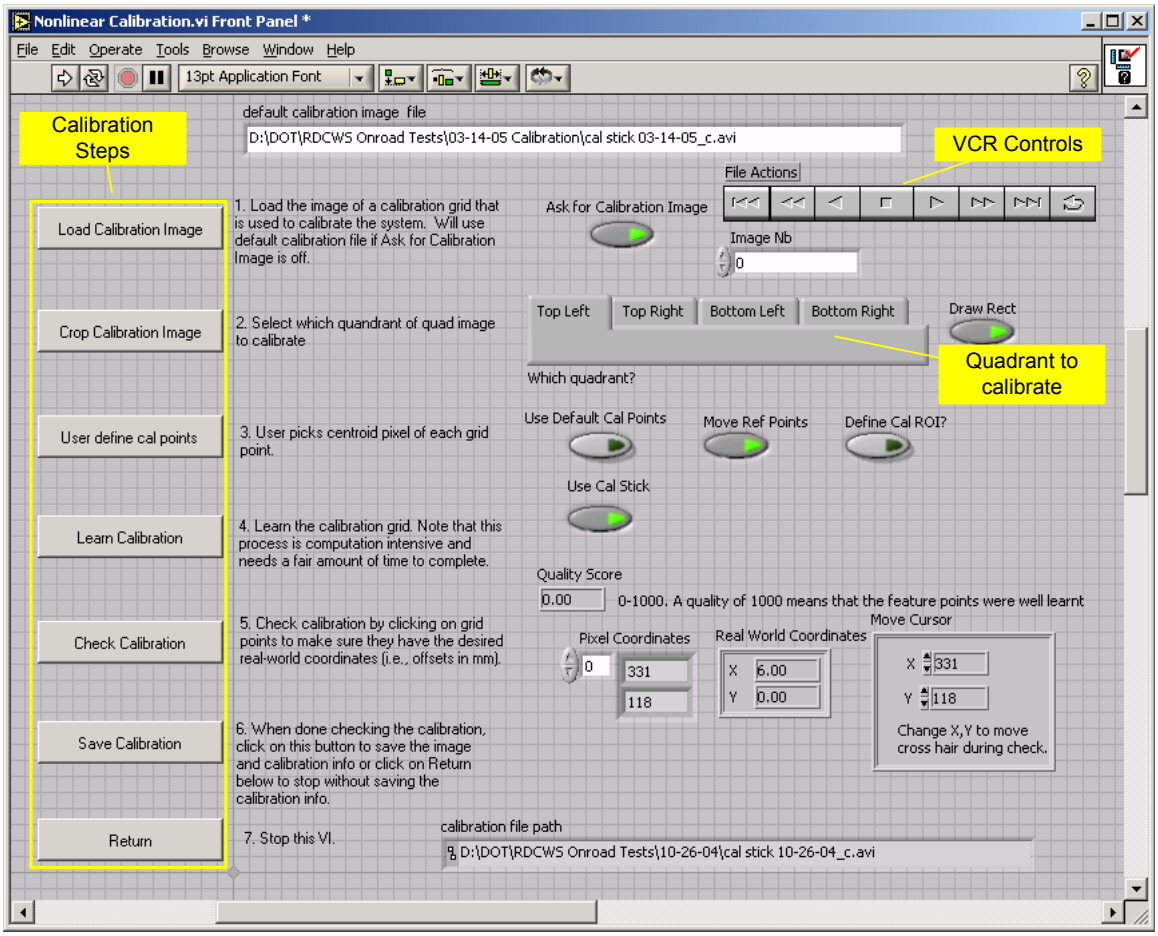


Figure 63. Control Panel for Calibrating Video.

4.2.1 Load Calibration Image

Click on the "Load Calibration Image" button to load the AVI file containing the calibration stick images. When "Ask for Calibration Image" is off (green area dark), the program uses the file listed in "default calibration image file." Otherwise, the program displays a file-load dialog box and loads the new file into "default calibration image file." To skip going through the file-load dialog box after calibrating the first quad (the process requires reloading the image file to calibrate each quad), turn "Ask for Calibration Image" on for the first quad, and off for the remaining quads. The program uses the same AVI file in the subsequent quads. When the image loads, a separate window appears with the quad image AVI (see Figure 64).

Figure 64. The first frame of the calibration AVI file.

4.2.2 Crop Calibration Image

The "Crop Calibration Image" button initiates a separate "vi" for interactively specifying the coordinates of one of the four quadrants. Before using the "Crop Calibration Image" button, the user selects the quadrant to calibrate. With the VCR controls ("File Action"), the user advances the AVI file to a frame that contains the calibration sticks. The frame in Figure 64 shows the calibration sticks in the right camera view. The remainder of this section describes the calibration of right side view in the top right quadrant.

"Which quadrant?" is a radio button switch. To calibrate the top right quadrant, the user selects "Top Right." (While the top left is similar, the bottom right quadrant has different steps described later.)

The "Draw Rect" button initiates an interactive box to define the region of the image that corresponds to the top right. When this button is off, the routine uses the "Top Right Default" coordinates that appear off the screen to the right. The routine saves this value when the user turns off "Draw Rect." If an error requires a re-run, the user can re-use the value without redrawing the box.

Click on "Crop Calibration Image" to define the quadrant. The image appears in a window as shown in Figure 65. Use the mouse to draw a rectangle around the quadrant. (Note: Figure 65 shows a box around the top right quadrant.) Adjust the box with the handles at the box's corners. Click on "OK" when finished. A dialog box asks if the co-

ordinates for this quad need to be reset. Click "yes" and the routine changes the default values to the current values. Click "no" if there was some type of error and saving these values is unnecessary. Afterwards, the top right quadrant appears in a separate window (Figure 66).

Figure 65. The crop image control panel.

Figure 66. The top right quadrant appears in separate window.

4.2.3 User Defined Calibration Points

The next step is to select the pixels corresponding to the endpoints of each segment in the meter sticks. If working with similar meter-stick configuration (e.g., when repeating a calibration or calibrating the side-view cameras), click the "Use Default Cal Points" button (see Figure 63). In most cases, the button loads circles closely aligned with the segments. The user then moves the circles with the control panel arrows. The steps below describe defining the segments from scratch. Afterwards, you can rerun the "vi" and use the default cal points to experiment with adjusting the pixel coordinates. This is useful if you are not satisfied with the original calibration.

When the "User define cal points" is selected, the "Get Grid Point.vi" panel pops up (see Figure 67) and a text box appears with reminder information. For the top right quadrant the box states:

1. First grid point should be at bottom left.
2. Check Real World Grid Dim (m)

The first comment indicates that the first grid point should be at the left (bottom is for a two dimensional grid used for nonlinear calibration. The second comment reminds you that you must set "Real World Grid Dim (m)" to the actual distance between grid points. As stated above, the cal sticks vary for the side views. The user adjusts the distance value when the distance changes between each segment. Click "OK" to remove the text box and to start selecting the segment pixel points.

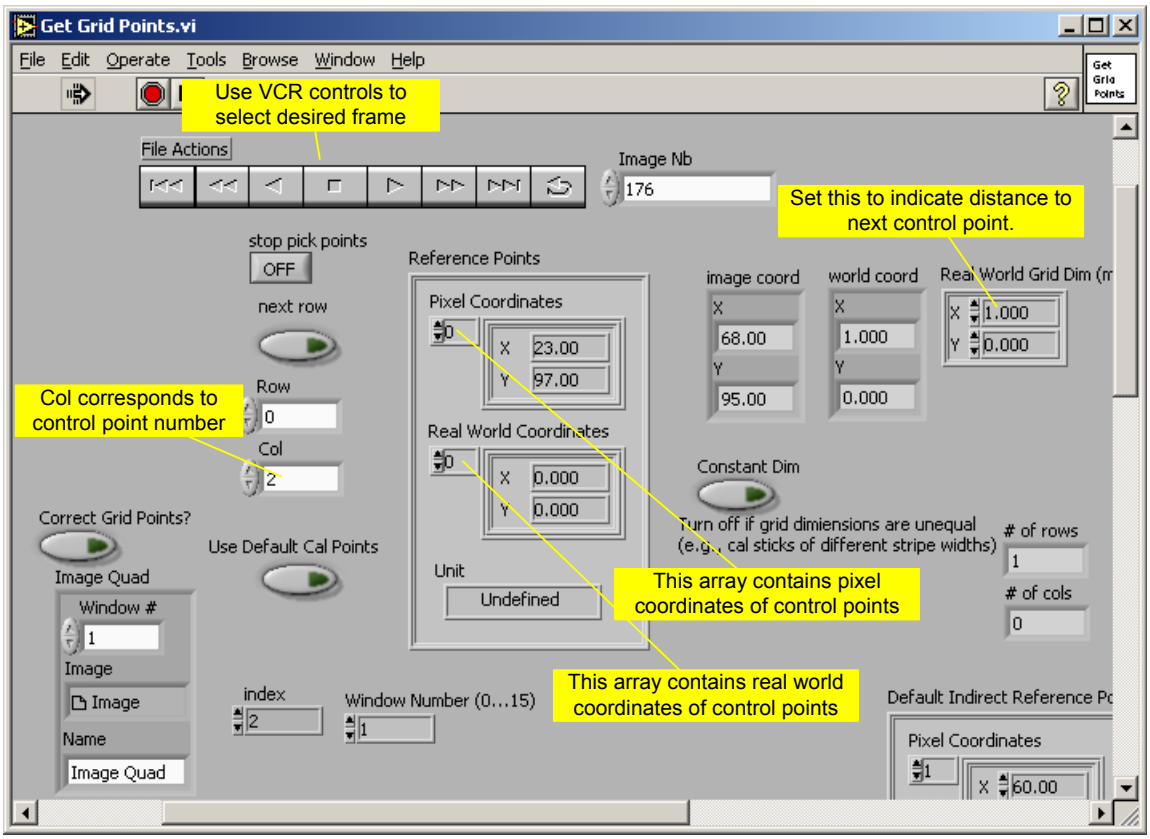


Figure 67. Control panel for selecting the cal stick pixels and strip dimensions.

To choose the first segment on the calibration stick, first make sure the "Image Quad" window is active by clicking on the blue bar above the image (see Figure 68). Then click on the pixel in the image that corresponds to the first point of the calibration sticks (in this case, the far left segment). The routine does not require perfect pixel selection. Select "Correct Grid Points" and the software will display a new panel with pixel adjustment directions. Grid adjustment is also available in a later step. Figure 68 shows the image with the first two calibrations segments marked.

Figure 68. User has selected the first two segments.

The "Reference Points" table (center box in Figure 67) contains two arrays: one for the pixel locations ("labeled "Pixel Coordinates") and the other for calibration stick dimensions ("labeled "Real World Coordinates"). In this case, array location 0 is the origin of the calibration sticks (X=0, Y=0) and the pixel location is (X=23, Y=97). The display labeled "Col" in Figure 67 increments after the user clicks on a segment pixel and is the index into "Reference Points" table arrays (0 corresponds to the first segment, 1 is the second segment and the next segment will be stored at index 2).

As noted previously, the first two meter-sticks (starting from closest to the vehicle) have 10 cm wide black and white segments. The third stick has 25 cm segments and the fourth stick has 50 cm segments. Thus, the user changes the X value in "Real World Grid Dim (m)" (see Figure 67) from 0.1 m to 0.25 m after Col is 20 (i.e., 0 to 20 are 0.1 m apart). Similarly, the user changes X value to 0.5 m when Col is 25. To check the calibration process, examine the "Real World Coordinates" after clicking on the end of the last meter stick. Set the array index to 26 (the value of "Col" minus 1) and examine the X value. It should be 4.0 m, corresponding to the length of the 4 meter-sticks.

The operator concludes cal point selection with "stop pick points." The software automatically displays the "Move Reference Points.vi" control panel (Figure 69). Using this vi, the operator adjusts the pixel locations and/or changes the segment width. The control

panel includes instructions in the upper left corner. The operator selects a single red circle with "Point #" and moves the circle with the sliders. Figure 70 shows control point number 3 highlighted (large green circle). The operator moves all the points simultaneously with "Move all points." The "stop" button concludes point correction and returns the operator to the "Nonlinear Calibration.vi" control panel.

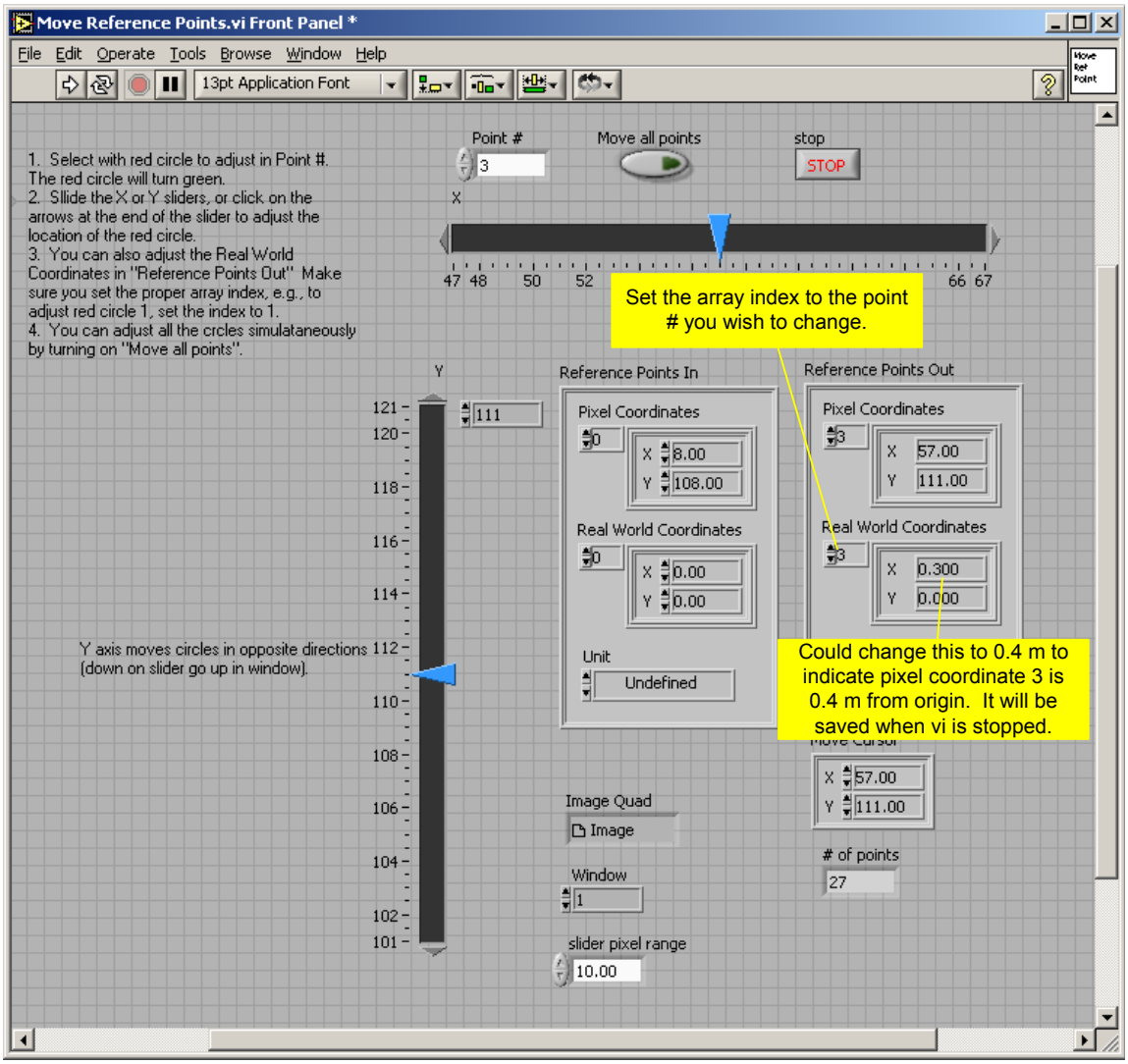


Figure 69. Control panel to move calibration points (red circles).

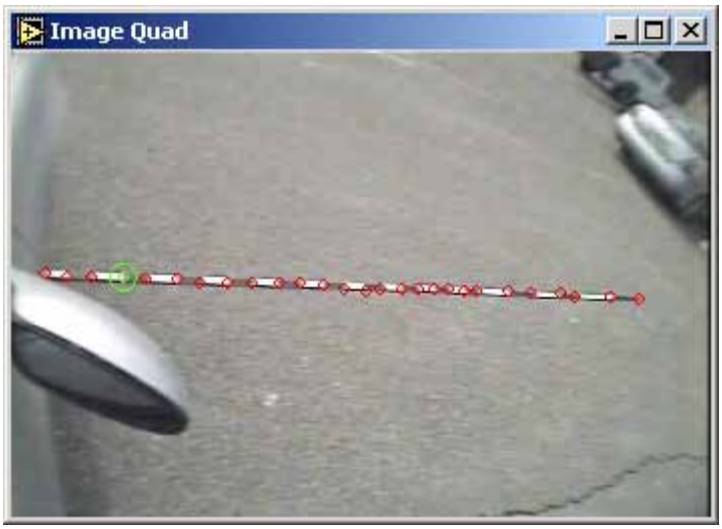


Figure 70. Red circles show pixels corresponding to segments on cal stick. Use the "Move Reference Points" control panel to adjust circle locations. Green circle is one being moved after setting "Point #" to 3 (see Figure 69).

4.2.4 Learn Calibration

The operator next clicks "Learn Calibration." For the nonlinear calibration, this invokes a complex nonlinear calibration routine that may take some time. For the cal stick calibration, the step executes immediately.

4.2.5 Check Calibration

The operator verifies the calibration with "Check calibration." The operator selects a pixel and observes the reported distances in the "Real World Coordinates" display. The operator also clicks pixels between the circles and verifies the linear interpolation (e.g., pixels at the mid point between circles should return the mid point distance in units of length).

4.2.6 Save Calibration

When the operator clicks on "Save Calibration" the software writes out an INI file containing the pixels and corresponding distance measurements. Subsequent software procedures use this file for measurements in other AVI files.

A pop-up window asks if this calibration should become the default for the "Use Default Cal Points" described in section 4.2.3.

4.2.7 Return

Return ends the program. The operator re-runs the program for the other quadrants.

4.3 Considerations for Calibrating the Front View

As indicated earlier, the front view calibration varies slightly from the side calibration.

1. The front view calibration uses meter wide segments (see Figure 67). Therefore, the "Real World Grid Dim (m)" is 1.0 m.
2. The forward view control points often blend into the background. The operator uses the frame that best distinguishes the control point. To assist the calibration, users identify the points with a perpendicular stick during the recording (Section 0). Figure 71 shows the procedure and the corresponding pixel marked (red circle). The operator selects the video frame via the VCR controls (see "File Actions" in Figure 67).

Figure 71. A user pointing to the control points using a colored meter stick.

4.4 Creating an INI File for the Video Calibration

This file contains calibration information. The section above creates the file and the operator adds more information. The root file name is the same name as the calibration AVI file (e.g., the INI file for "cal stick 03-14-05_c.avi" is "cal stick 03-14-05_c.ini"). The INI file contains subjects and values of the form:

```
[FRONT_ABC_DIM_METERS]
A=2.144
B=5.95
C=6.3245
[SIDE_GRID_LENGTH_METERS]
GRID_LENGTH=4
[GPS_ANTENNA_MEASUREMENTS]
TO_FRONT=2.8
TO_PASSENGER_SIDE=0.855
TO_GROUND=0.0
[VEHICLE]
NAME=Altima
WIDTH=1.71
WHEEL_BASE=2.82
FRONT_AXLE_TO_FRONT=0.96
```

REAR_AXLE_TO_REAR=0.00

The INI file data definitions are:

FRONT_ABC_DIM_METERS	The section ID for the three dimensional parameters (in meters) of the triangle defining the offset and orientation of the front cal sticks (see Figure 62 on page 144).
A	The distance (m) between the left end of the cal sticks and the intersection with dimension B
B	The distance (m) between the left rear wheel-axle and the closest point on the cal sticks. The tape measure should touch the front wheel in order to be parallel with the vehicle.
C	The distance (m) from the left rear wheel (at the axle) and the left end of the cal sticks.
SIDE_GRID_LENGTH_METERS	The section ID for the length of the side cal sticks. If four 1-meter sticks are used, then the length is 4 m.
GRID_LENGTH	The total distance (m) of the array of side cal sticks.
GPS_ANTENNA_MEASUREMENTS	The section ID for GPS antenna measurements (antenna position on vehicle).
TO_FRONT	Distance (m) from center of antenna to front of vehicle bumper.
TO_PASSENGER_SIDE	Distance (m) from center of antenna to outside of vehicle on passenger size.
TO_GROUND	Distance (m) from center of antenna to ground (in example above set to 0 since this is not used in any of the analyses).
VEHICLE	Section ID for vehicle parameters.
NAME	Vehicle name (generally the model name).
WIDTH	Vehicle width (m)
WHEEL_BASE	Distance between axles (m) measured from centers of each wheel.
FRONT_AXLE_TO_FRONT	Distance (m) between front axle and front bumper.
REAR_AXLE_TO_REAR	Distance (m) between rear axle and rear bumper (in example above set to 0 since this is not used in any of the analyses).

4.5 Calibration Verification

Between tests, or even during a test run, a camera may move. The video image contains fixed features such as hood, fender, and mirrors. The operator verifies the calibration legitimacy through the constant position of these features. The operator may correct misalignment during data collection by realigning the camera. The calibration process described in the previous sections is invalid for a misaligned camera. Unfortunately, due to

the non-linear nature of the image, the operator cannot discern the proper calibration from the images taken by the misaligned camera.

The misalignment may be very slight; Figure 72 shows an example of video collected with the front-view camera misaligned. The lower quadrant picture is the calibration and the top quadrant picture is a nighttime test. Notice the left shift of the windshield sprayer nozzle on the hood. Lateral measurements using the front camera are therefore invalid and the evaluator may only use the side cameras. Fortunately, the operators detected the misalignment during data collection and corrected the camera before the subsequent run.

Figure 72. Example of camera misalignment.

III-5 Data Processing

Data processing prepares the data for analysis in LabView. The original data is on videotape. The first step transfers the video to a computer. NIST uses commercial software for the transfer (e.g., Adobe Premier). The evaluator examines the video and locates interesting segments (called clips). Clips capture a lateral drift with a warning, a missed warning (false negative), a specific run of a test identified in the RDCWS test procedures document, or some incident of interest. The commercial software locates the start point and stop point of the clip, encodes the video (DV format, e.g., Microsoft MPEG-4 Video Decompressor), and transfers the clip onto the disk.

The second processing step extracts the GPS data from the videotape's audio track. This step requires a VMS, a box that connects to the tape player, and Mediamapper software. The Mediamapper software extracts the GPS data and Easydiff software computes differential corrections. The software stores the GPS data in a file associated with the video clip file.

As implied above, data processing requires multiple files. Table 10 contains an example of the types of files created during data processing. The remainder of this chapter explains the data processing procedures.

Table 10. Data Processing File Examples

File Name	File Contents
10-09-03 Test 3.2..1.4.avi	An AVI video clip containing video and audio from a run on 10-09-03 of Test 3.2.1.4 from the Visteon validation test plan.
10-09-03 Test 3.2..1.4_c.avi	A compressed version (see the _c at the end of the name) of the clip.
10-09-03 Test 3.2..1.4_c.ini	A text file containing information that is used during data processing. Important information contained in the file includes: • The video calibration file • The clip's location on the tape (time code of the clip; called "In Point" in Premier), which is used to synchronize the clip with GPS data
10-09-03 Test 3.2..1.4_c.vms	A text file containing GPS and tape time code information. Clips may not have a VMS file associated with it.

5.1 Time codes

The data processing uses various time codes (Table 11).

Table 11. Time Codes

Name	Source	Format
UTC	Universal Time Code. Time at the Greenwich Meridian Extracted from GPS messages. Derived from GPS time (+ leap seconds) inserted by VMS onto tape.	UTC from VMS file is "day.fraction of day" This UTC is in seconds from start of day
UTC Local Time	Local time derived from UTC – (time zone offset & daylight savings).	Seconds from start of day
Time of Day	Entered into camcorder by user. This differs from UTC Local Time. The time is overlaid on tape but is not automatically transferred to computer upon capture (overlays do not transfer over firewire).	hh:mm:ss E.g., 3:40 p.m.
Tape Time code	Essentially the tape counter. Defines a specific frame on the tape relative to the beginning of the tape. This time is needed to access video on a tape.	hh:mm:ss:## where hh = hour, mm = minute ss = second ## is the frame count
Clip Time code	Defines a specific frame in a clip relative to the beginning of the clip. This time is used to access video in a clip.	hh:mm:ss:## where hh = hour, mm = minute ss = second ## is the frame count

5.2 Video and Data Timing

The following discussion describes the procedure for determining the UTC time (and subsequently, the corresponding GPS coordinates) of a particular video frame in an AVI file. The VMS inserts the UTC (from GPS data), the position (from GPS data), and the tape time code on the tape once per second. The tape time code is the time (from the start of the tape) when the VMS writes the GPS data. The tape time code does not align with the AVI time (seconds from the start of the AVI file) since the AVI may be a clip extracted from the tape. The VMS data relates the video frame number to the tape time code and thus to the GPS time and position.

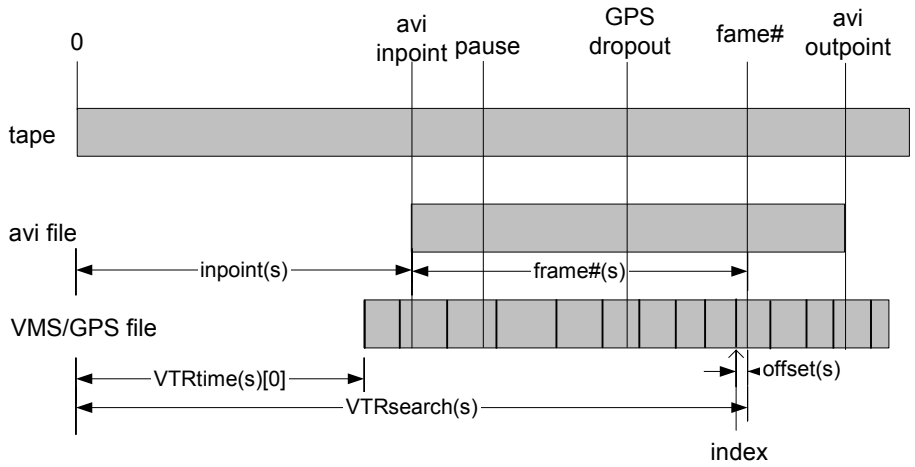


Figure 73. Timing diagram describing relationship between video tape, AVI file and VMS/GPS file.

Figure 73 shows the relationship between the different data streams. Table 12 describes the terms in the figure.

Table 12. Time Reference Terms

Term	Definition
Tape	Magnetic media that holds video and VMS data (GPS time and position, and tape time code) at 1 Hz.
avi file	Captured from some point on tape starting at AVI inpoint and ending at AVI outpoint. The points are stored in the INI file (discussed later) named after the AVI file.
VMS/GPS file	Captured from tape at some point before and after AVI in and out points. Contains VTRtime, UTC time and GPS coordinates. These are stored into individual arrays called VTRtime and UTC.
VTRtime[0]	The first element in VTRtime is the starting time on the tape where the first VMS data is available. The format is hh;mm;ss;## where ## is the frame count within seconds.

The following steps determine the UTC time for an AVI frame# and the index into the GPS position array corresponding to a video frame. Tape pauses or GPS dropouts do not affect the UTC time from these procedures. In the discussion, the string "(s)" indicates the data in seconds.

9. Convert frame# into frame#(s) based on frame rate.
10. Convert inpoint into inpoint(s).
11. Set VTRseach(s) = frame#(s) + inpoint(s). Want to search for this tape time code.
12. For each VTRtime[i=0..N]
    a. Calculate VTRtime(s) of VTRtime[i]
    b. Stop when VTRtime(s) is greater than VTRsearch(s) (i.e., went one record too far into tape)
6. Set index to i-1 (i.e., VTRsearch(s) falls between index and index+1)
7. Set offset(s)=VTRsearch(s) - VTRtime(s)[index]
8. Set Frame#(UTC)=UTC[index)+offset(s). This refines the UTC time based on the number of frames from the last UTC update.
9. Return index and Frame#(UTC).

5.3 Creating the AVI file using Adobe Premier

Use a DV capture program to transfer video from a tape to a computer file. The following contains directions for capturing video and creating an AVI file using Adobe Premier. Appendix III-A contains some Premier quirks and error conditions.

1. Open Premier and select the DV-NTSC Real-time Preview->Standard 48kHz setting.
2. Select File->Save as. This will bring up the save file window with an "Untitled.ppj" project file name. Create a folder that will have the same name as the tape name.
3. Create a bin. Within the project are bins. Typically, there is only one bin per project. Create a bin name according to the date of the videos were taken.
4. Select Edit->Preferences->Scratch Disks and Device Control. This selects where the clips are stored and the type of DV recorder used. The scratch disks should be the same folder as the project file. Set the "Same as Project File" to the project file. The Device should be a DV Device Control 2.0. Check the options to select the correct camera (see Figure 74).

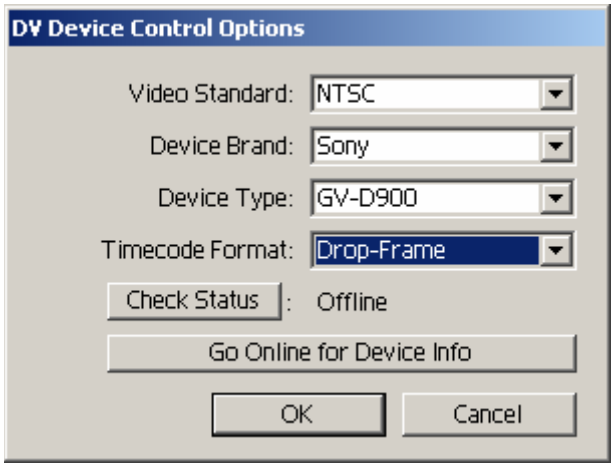


Figure 74. Settings for the Sony GV-D1000.

5. Select File->Capture->Batch Capture. This will bring up the Batch Capture window. Go through the tape and select start and stop points of various clips of interest. The clips will be stored in the batch capture window. When done, one batch run will capture all the clips. Save the batch window so that in the future the clips can be recaptured without having to search for the start/stop points. Immediately save this as "Batch List" in the project folder.
6. Select File->Capture->Movie Capture. This will bring up the Movie Capture window. Enter the name of the tape in the Reel Name field.
7. Use the controls to place the video at the start of the clip. Click on "Set In" to enter the start of the clip. Use the controls to place the video at the end of the clip and click on "Set Out." Then click on "Log In/Out." A window will come up asking for a name. Enter the name, such as "cal" or "test." Premier will automatically create new names for future clips by using the current name and adding an incrementing number. Repeat this process to log all the clips.
8. Go to the Batch Capture window and click on the record button (red button in lower tool bar). **Note: Do not click on anything outside of Premier or the capture will abort.**
9. To view a clip, drag into the Monitor Source window and press the play button. The play performance may be poor if the video is also being output to the camcorder or DV deck (you will see the video displayed on the camcorder's monitor). To turn off video output to an external device, select Project->Project Settings->General, click on "Playback Settings" and deselect "Playback on DV Camcorder /VCR."

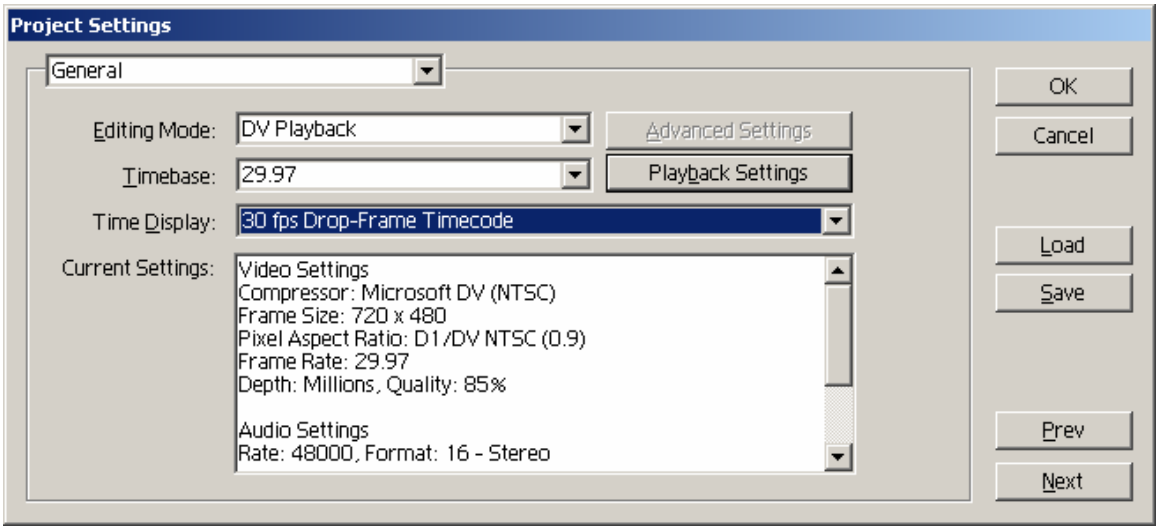


Figure 75. Project settings.

Insert the source video into the program. Drag the source window into the program window (both are located side by side in the Monitor window). The clip will also appear in the Timeline window.

For final output, it is desirable to remove the VMS data (a modem sound with bleeps every one second) from one of the stereo channels. This will make cabin sounds, driver instructions and audible warning much easier to hear. To eliminate the GPS audio channel, select an audio clip in the Timeline, right click and select audio op-

tions->duplicate right (or left). Alternatively, use the audio mixer (select Window->Audio Mixer) to only lower the VMS audio. First, select the middle button (looks like a pencil writing) above the Mute button to set the mixer to make permanent changes to the audio adjustments. Otherwise, all changes are lost when leaving the mixer window. Then adjust the balance (+98 works well, the VMS modem noise is barely audible). Then play through the entire clip (using the play button in the mixer) to write the new balance. The balance adjustment is lost if play is stopped before the end of the clip.

10. Compress the clip to save disk space.
    a. Drag video to start of timeline. Set the work area (yellow bar above time line) to enclose the clip.
    b. Select File->Export Timeline->Movie…
    c. Choose same name as original AVI with appended "_c" to indicate the file is compressed.
    d. Select Settings. Go through each setting (using Next button) and set the same as shown in the following figures. Make sure to set the compression frame rate to 29.97 frame/s (not 30 frames/s – see Figure 77 and Appendix III-A).

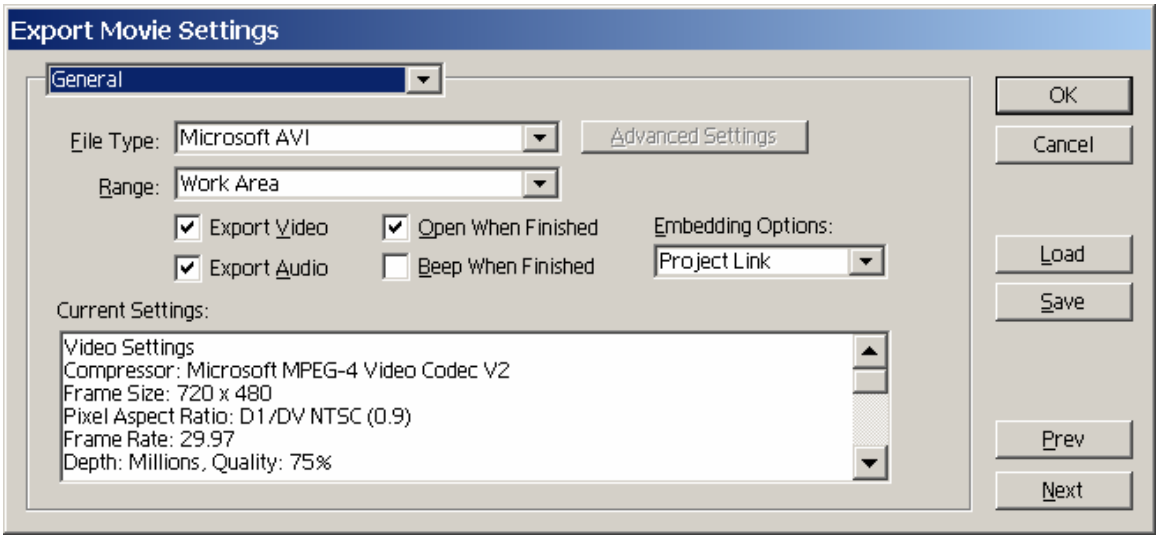


Figure 76. Export Movie Settings – General.

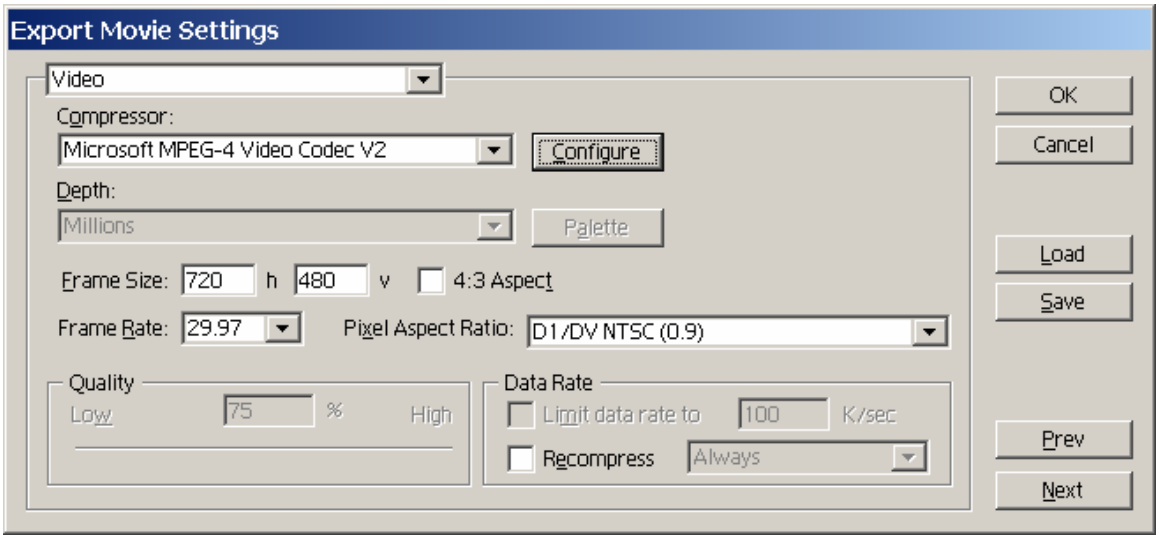


Figure 77. Export Movie Settings – Video.

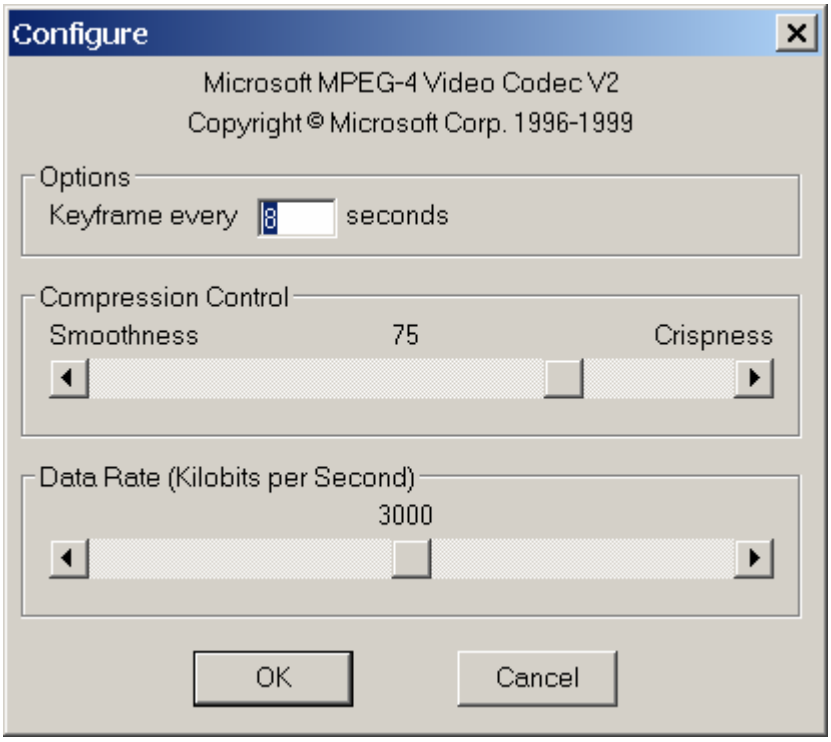


Figure 78. Export Movie Settings - Video->MPEG-4 Configure.

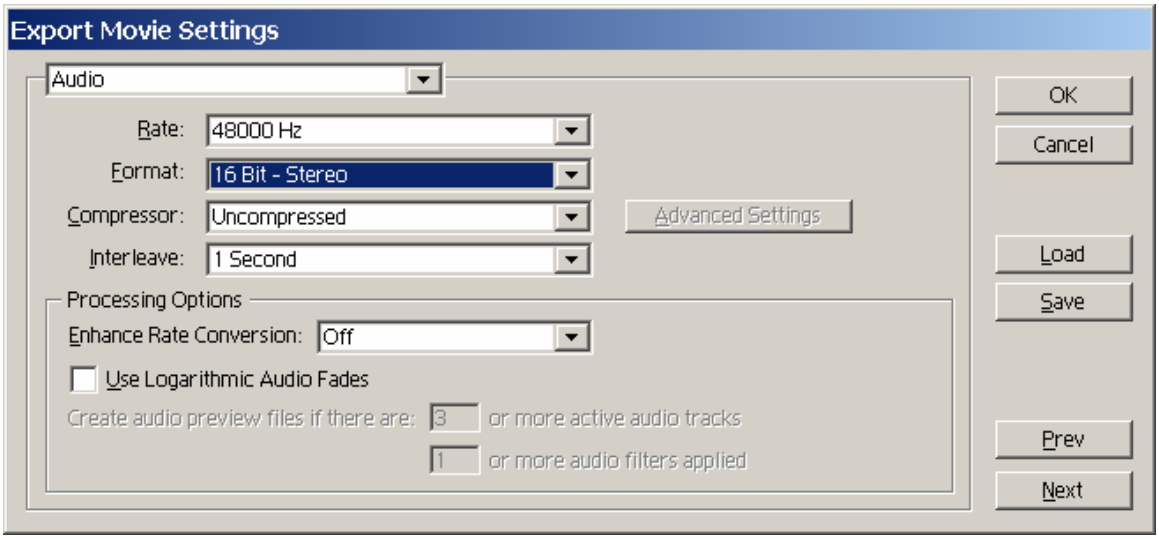


Figure 79. Export Movie Settings – Audio.

5.4 Creating the INI file

An INI file, created by the user (typically by modifying an existing INI file), stores data associated with the AVI file and has the following form:

[Video Data]
In Point=00;02;07;00
Out Point=01;25;11;00
Local Start Time="02:59:08 PM"
Date=03-14-05
Frame Rate=29.97
Number of Frames=149371
Calibration Video File Name="cal stick 03-14-05_c.avi"

In Point	Start timecode (i.e., in point) of video clip. The timecode is relative from the start of the tape. It is the same as the "set in" in the Premier capture window or batch file.
Out Point	Stop timecode of video clip. Same as the "set out" time in Premier.
Local Start Time	Start time of video clip as displayed on tape counter. Since this is typically set manually, it is not very accurate. If available, GPS data is used for generating the local time once the VMS file has been created.
Date	Date
Frame Rate	Found from Premier capture program or by right clicking on the AVI file in windows and clicking on properties (go to summary tab). Note that it is typically 29.97 frame per second and not 30 fps.

Number of Frames	Number of frames in AVI file. Also available from AVI properties.
Calibration Video File Name	Name of the AVI file used to generate the calibration information for this AVI file.

Table 13. INI File Definitions

5.5 Creating the VMS (GPS) file

The VMS file is a text file of latitude, longitude, speed, and tape time code. Each line contains one data set and represents one-second intervals. See Appendix III-C for directions on how to extract the GPS data from the videotape.

III-6 AnalyzeData Main Control Panel

The evaluator uses the AnalyzeData program, written by NIST researchers, to analyze IMS data (Figure 81).

Figure 80. The AnalyzeData control panel.

The following are the controls, displays, and procedures for the examination of data and the collection of measurements.

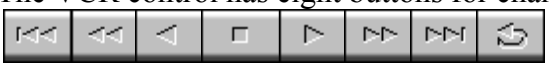
6.1 Starting and Stopping

The white arrow button in the upper left corner starts the program. The program begins with a file selection menu. The user selects the AVI file to analyze and a quad image appears in the upper right.

The arrow button turns black during program execution. The operator stops the program with the red octagonal button next to the arrow button.

6.2 Video Frame Controls

The "Video Frame Controls" provide controls and displays for manipulating the AVI file. The VCR control has eight buttons for changing the displayed frame (from left to right):



1. Move to beginning of file
2. Continuous backward play (may be slow depending on CPU and disk speed)
3. Move backward one increment (number of frames moved depends on "video advance increment" and "time advance."
4. Stop (when playing backwards or forwards)
5. Move forward one increment
6. Continuous forward play
7. Move to end of file
8. Continuous replay

Other video frame controls are:

- Frame # shows the number of the current frame (first frame is 0).
- The "video advance increment" and "time advance" controls set the increment value for the VCR controls. For example, to move by 10 s increments each time the play button is depressed, set "video advance increment" to 10 and "time advance" to "s." The other values for "time advance" are "f" (to increment by frames) and "m" (to increment by minutes).

6.3 Lateral Measurements

A click in the quad image generates the lateral offsets from the front wheels. The values are accurate only between the red circles in the image. The offsets appear in the panel labeled "Lateral Measurements." For example, the farthest right circle in the left camera view returns a 0.0 m in the "LW Lat Offset" (Left Wheel Lateral Offset) display and the negative of the vehicle width in the "RW Lat Offset." Similarly, clicking along the red circles in the forward view produces lateral distances from the left and right front wheels as well as the longitudinal distance from the front wheel axle (e.g., 3.13 m).

6.4 Lane Width and Vehicle Offset

The lane width and offset equations for the vehicle within the lane are (refer to Figure 81 for measurement descriptions):

```
LaneWidth( lw)= LeftOffset( l)+ VehicleWidth( vw) + RightOffset( r)
CenterOffset( co) = (RightOffset – LeftOffset)/2
```

$$lw = l + vw + r$$
$$lw/2 = l + vw/2 - co$$
$$co = lw/2 - l - vw/2$$
$$co = (l + vw + r)/2 - l - vw/2$$
$$co = r/2 - l/2 = (r - l)/2$$
NOTE: co is negative left of center

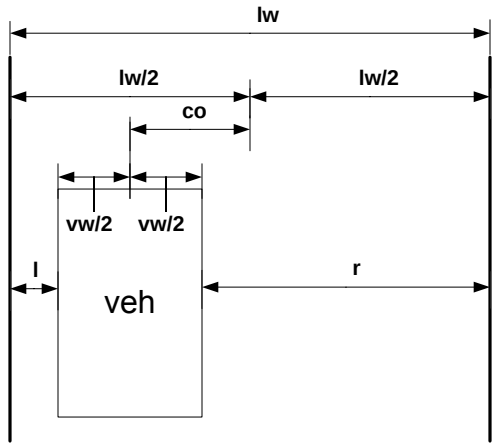


Figure 81. Lane width and vehicle center offset calculations and diagram.

The "Calculate Lane Width" controls (Figure 81) calculate the lane width and center offset. The operator uses the following procedure:

1. Click on inside of lane marker (aligned with red circles) on left side of vehicle (upper left quad. The value should appear in "Left Offset."
2. Click on inside of lane marker (aligned with red circles) on right side of vehicle (upper right quad. The value should appear in "Right Offset."
3. Click on "Calculate w&o"; the software writes the offset in "Center Offset" and the lane width in "width."

The software calculates the lane width with the vehicle width data from the video calibration INI file (see Section 4.4).

6.5 Longitudinal Measurements

The evaluator makes longitudinal measurements based on the GPS data. The Longitudinal Distance controls (Figure 81) compute a vector (straight-line) distance between any two video frames. For consistent measurements, the evaluator uses the same horizontal line in the two video frames, typically a red calibration circle. This measurement produces the vector distance and not the distance traveled on a curve (i.e., the arc length).

The longitudinal measurement procedure is:

1. Click on the "Start Vector Distance" button to start the distance measurement.
2. Advance the video frame. The straight-line distance is in "Vector Distance (m)"

6.6 GPS Data

The GPS data (position, velocity, heading, etc.) for each frame appears below the local map (see Figure 81). The local map also shows the vehicle's GPS location. The units are in meters. The origin is the lowest Universal Transverse Mercator (UTM) coordinates of the GPS data from the current video file (see 0 for information on the UTM system).

The GPS data updates at 1 Hz. The video data updates at 29.97 Hz. On the map, the black circles connected by lines show the actual GPS positions while the red circles are the interpolated positions. The software interpolates the GPS positions with a second order polynomial. The local map maintains a 1:1 aspect ratio and automatically shows all the positions (i.e., the user does not need to scroll). The auto-zoom feature occasionally causes the map to look far-off. The user corrects the perception and clears the map with the "Clear plots" button.

The circle dial in the lower left shows the vehicle heading. The heading is the tangent to the second order polynomial interpolation of three GPS positions.

6.7 Control Panels

"Control Panels" is a tab switch across the bottom of the display. Each Control Panels tab displays a sub-panel containing controls and indicators for specialized analyses. The next several sections explain various analyses performed using sub-panel displays and controls.

III-7 Locating Video Based on GPS Time

The following section describes a procedure for locating video frames specified by GPS time. The software uses this procedure extensively when analyzing warning system data collected by the UMTRI's DAS. The DAS records the time of each warning issued by the Road Departure Crash Warning System. For on-road test analysis, Volpe queries the DAS database and generates a spreadsheet containing GpsTime and CspGpsTime (from curve speed warning system) of each warning. The procedure below takes each GPS time and locates the corresponding IMS video frame. The warning appears in the dash video quadrant (lower left) at some time nearby.

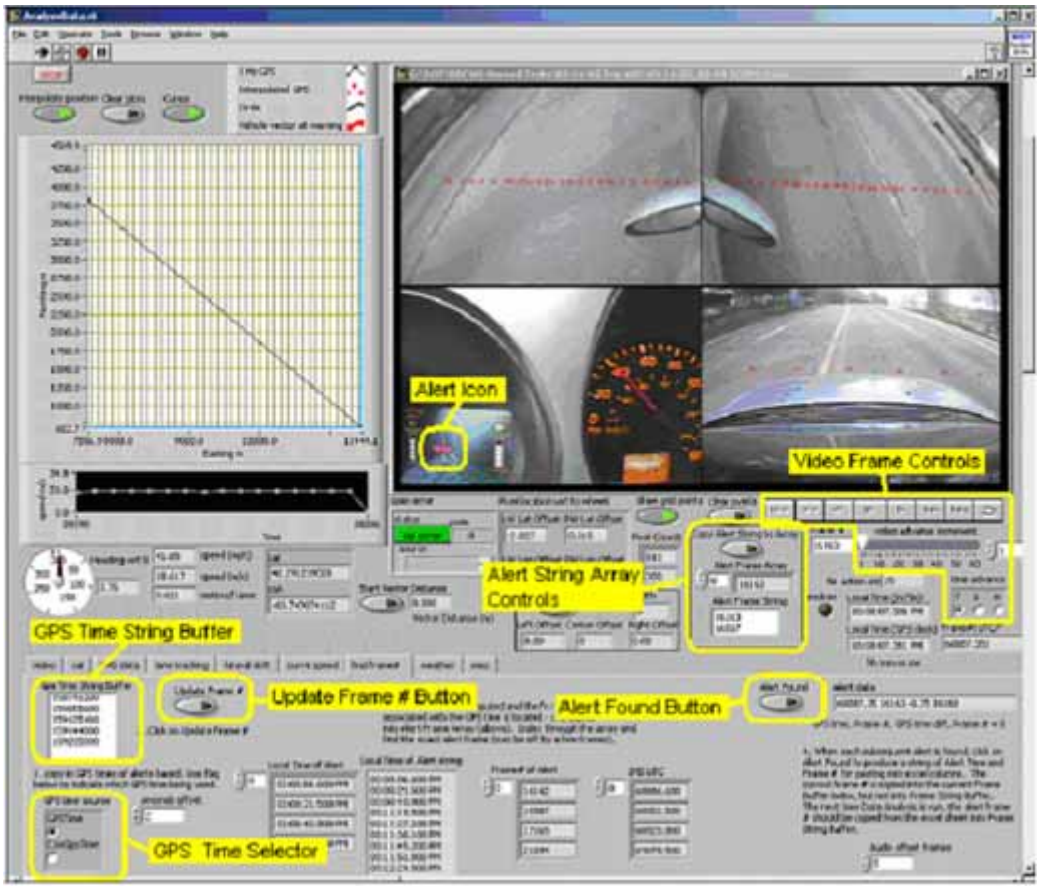


Figure 82. The "find frame #" Screen.

The frame to time correlation function is part of the AnalyzeData program. The evaluator uses the "find frame #" tab in AnalyzeData.vi (see Figure 82). The instructions appear on the tab and below.

1. Copy in GPS times "GPS Time String Buffer" (if values in buffer already, double click to highlight values and then paste to overwrite). The GPS times are a column in the Volpe spreadsheet.
2. Indicate the format of the GPS time with the "GPS time source" radio button. The choices are GPSTime and CswGpsTime from the Volpe spreadsheet header row.

3. Click on the “Update Frame #” button.
4. The local time and the frame# associated with the GPS time is computed and copied into the “Alert Frame Array.”
5. Use the up/down array control to select an element of the “Alert Frame Array.” The video frame automatically displays. Double check that the alert frame array number appears in “Frame #.” Sometimes the update will be slow due to delays in reading the video file.
6. If the alert icon is visible, rewind the video to the first instance of the icon. If the alert icon is not visible, advance the video to the first instance of the icon. The “first instance” is the first video frame that includes the icon image. If the icon appears faded or hashed, advance one more frame. The estimate should be close, but there may be mismatches. For example, a mismatch occurs if the videotape was paused during the test drive. During a pause, the GPS time advances but the tape time does not advance. Thus, there is a jump in GPS time when the tape (i.e., avi) resumes.
7. Click the “Alert Found” button when the video frame containing the alert appears. The software changes the value in the “Alert Frame Array” and generates a string containing the GPS Time, the Frame #, the GPS time difference (between the Volpe GPSTime and the video frame’s GPS time), and the value of frame# plus five. (The “5 +” corrects for a 0.17 s delay between the audio warning and the visual display.)
8. Paste the string into the spreadsheet (there is no need to copy since it is already in the clipboard).
9. Increment the “Alert Frame Array” index and repeat steps 6 through 9 until all of the Alert frame # are identified.

The “Alert Frame Array” is now ready for Lateral Drift Analysis.

III-8 Lateral Drift Analysis

The following lateral drift analysis uses the on-road characterization designed jointly by Volpe and NIST [30]. A Lateral Drift Analysis of a warning produces 23 values in six areas. The evaluator copies these values into a spreadsheet for a final report. Of the 23 values, two values deal with the time of the warning. Two more specify the nature of the warning. Three values deal with atmospheric conditions. Eight values describe the roadway's characteristics. Five values identify the vehicle's lane position and motion at the time of the warnings. The remaining three values describe the general operating conditions and the accuracy of the warning.

8.1 Overview

The following section gives a brief overview of the meaning of the values collected during a lateral drift analysis. See reference [30] for more details on these values. Section 8.2 presents a support tool for making measurements and generating entries.

8.1.1 Warning Time

The Lateral Drift Analysis records two warning times. The analysis presents both times by their video frame number. The first measure (Alert Frame #) is the frame when the alert icon is first fully visible on the video image. The second measure (Frame #) is the frame when the audible alert occurs. Evaluators identify the Alert Frame # through careful stepping through the video file (see Section III-7). The Frame # is derived from the Alert Frame # and is used in subsequent evaluations.

8.1.2 Weather Environment

The Lateral Drift Analysis records three values describing the atmospheric conditions. From the video image, the evaluator determines if the alert occurred during the day or night, whether the road surface was wet or dry, and whether the driver was using the windshield wipers (i.e., was it raining). The evaluators observe sunlight as described in Section 8.4.

The day/night value is determined by comparison between the local time and the time of civil twilight. The local time of the warning comes from the GPS data. Civil twilight, which is the time after sunset when the sky becomes dark, comes from the United States Naval Observatory (http://aa.usno.navy.mil/data/docs/RS_OneDay.html). If the alert time is between "Begin civil twilight" in the morning and the "End civil twilight" at night, the evaluator records a "0" in the analysis. Otherwise the warning occurred at night and the evaluator records a "1."

Road surface wetness is a subjective evaluation. The evaluator views the road surface through the forward and side images and estimates if the road surface is wet. The evaluator records a "1" when the road is wet and a "0" when the road appears dry.

Wiper use is very difficult to determine from the available data. In some cases, the vehicle's hood may reflect the wiper motion in the forward view image. This is an unreliable, but only available, source for the data. The evaluator enters a "1" when wiper motion is detected and a "0" otherwise.

8.1.3 Warning Type

The Lateral Drift Analysis contains two values to identify the alert. The warning system generates imminent and cautionary alerts in both the right and left directions. The alerts, captured by the dash camera (see lower left quadrant of video), appear as icons on the warning system display. The evaluator enters a "0" for a cautionary alert and a "1" for an imminent alert. For departure direction, enter a "-1" when the alert is to the left, and a "1" when the alert is to the right.

8.1.4 Road Type

The Lateral Drift Analysis produces eight values describing the road. The analysis describes the type, the color, and the condition of the pavement markings in the alert direction. Two values record the direction of a curve and the vehicle's position in a curve. One value records whether the road is a freeway. The remaining two values describe the Available Maneuver Room.

8.1.4.1 Marker Condition

The analysis uses a three-tier evaluation for marker condition. The evaluator records a "2" if the quality of the markings is good, a "1" if the quality is fair, and a "0" if the quality is poor. A good quality mark is clear, crisp and bright. If the marks are faded, have irregular edges, or contain tar stripes, the evaluator records them as fair. We consider the marking to be of poor quality if it is missing, broken, obscured by debris, or is partly faded beyond recognition. When the quality of the marking varies, the evaluator records the markings deemed more significant to the alert.

8.1.4.2 Marker Color

Pavements marking are either yellow or white. The evaluator records a "1" if the markings are yellow and a "0" if they are white. If the color is indistinguishable, the evaluator records the color typically found at the subject location based on the marker type.

8.1.4.3 Marker Type

The analysis recognizes five marker types. The evaluator records a "0" when the approach toward a single solid line triggers the alert. The evaluator indicates a single dashed line with a "1." A double solid line garners a "2." The evaluator records a "3" when the lane marker is solid-dashed indicating the test vehicle can legally pass. The evaluator records a "4" when there is a solid-dashed combination where the test vehicle cannot legally pass.

8.1.4.4 Curve Direction

A three-tier value records the direction of a curve. A "1" indicates a right curve. A "-1" indicates the road is curving to the left. A "0" indicates the road is straight. The evaluator determines the direction of the curve from the map. The approach commonly used

was to draw the curvature of the road by moving the vehicle from 1 second before to 1 second after the warning using one-second increments (use VCR controls and set increment to 1 second).

8.1.4.5 Curve Entry/Exit

The evaluator records the vehicle's relation to a curve at the time of the warning. When the alert occurs as the test vehicle enters the curve, the evaluator records a "1." The evaluator records a "3" if the test vehicle is exiting the curve. A "2" indicates the test vehicle is in the middle of a curve. The evaluator records a "0" when the alert occurred on a straight road section. Use the local map to determine the location of the vehicle relative to the curve.

8.1.4.6 Freeway Indication

A freeway is a road with a legal speed limit at or above 80 km/hr (50 mph) and a separation between the lanes going in opposite travel directions. The lane separation must have either a substantial vegetated area or a fixed barrier. The evaluator judges the road type from the video images and records a "1" for a freeway alert or a "0" for a non-freeway alert.

8.1.4.7 AMR

The Available Maneuver Room (AMR) is the distance between the inside edge of the lane marker and the nearest continuous obstacle or an opposing traffic lane. Continuous obstacles appear directly to the side of the vehicle. The vehicle approaches the obstacle at a slow rate. The warning system must be able to detect four types of continuous obstacles:

1. Concrete traffic barrier (i.e., Jersey barrier)
2. Guard rail
3. Fence
4. Wall

The evaluator uses the calibrated video image to make lateral measurements of the AMR measurement (see section 6.3). The outside of the AMR is the edge of pavement, the bottom of an obstacle or, for an opposing traffic lane, the middle of the double lane markers or outside edge of the single lane marker.

8.1.4.8 AMR Type

The lateral drift analysis provides extra information for a left warning. The evaluator uses the forward and left side images to assess the area adjacent to the travel lane. The evaluator records a "0" if the adjacent area is the roadway shoulder. A "1" indicates the adjacent lane is a travel lane in the same direction as the test vehicle. A "2" indicates the drift is towards a travel lane in the opposite direction as the test vehicle. The evaluator records a "3" if the adjacent lane is shared, such as for passing. A "4" indicates the adjacent lane is not a travel lane, but is used for turning.

8.1.5 Vehicle Lane Information

The Lateral Drift Analysis records up to five values describing the relationship of the vehicle to the lane and roadside objects. Two readings specify the vehicle position within the lane. Another reading is the lateral velocity of the vehicle. When the vehicle's radar units identify a discrete obstacle, two more readings identify the vehicle's position from the obstacle.

8.1.5.1 Lane Position

The Lateral Drift Analysis records the vehicle's lane position as two values: the distance from the left lane marker to the left wheel and the distance from the right lane marker to the right wheel. The evaluator uses the calibrated image to measure the distance to the lane marker from the wheel. The analysis software combines the left and right lane marker distances with knowledge of the vehicle's width to determine the lane width and the distance from the vehicle center to the lane center (see section 6.4), however, the width is not entered into the analysis spreadsheet (Volpe chose to calculate this value).

The lane width varies little over short sections of roadways. Therefore, once the analysis software has the lane width, only one lane marker is required to determine the distance from the center of the lane to the vehicle. The analysis software uses these facts to determine the distance to the lane edge when the lane marker is under the vehicle.

8.1.5.2 Lateral Velocity

The lateral velocity is the range rate, or average change in distance over time, between the vehicle and the lane edge. The video provides an excellent time stamp for lateral velocity calculations. The evaluator determines the lateral velocity from the lane offset from two video images. The evaluator selects images such that the lateral motion is easily discernable and consistent up to the alert frame.

8.1.5.3 Discrete Obstacles

For these tests, discrete obstacles are objects that appear on the shoulder ahead of the vehicle. The warning system must be able to detect five types of discrete obstacles:

1. Parked vehicle
2. Bridge structure
3. Sign Post
4. Pedestrian/Cyclist
5. Animal

The Road Departure Crash Warning System has a set of radars that alert the driver to approaching obstacles. UMTRI's analysis of the DAS data includes the source (spreadsheet column header AmrCriticalSource) of the alert and the approximate range (spreadsheet column header AmrCriticalBin). A source value of 2 indicates the radar generated the alert. The bin refers to half-second look-ahead times. A bin value of 1 (0 s to 0.5 s) indicates the object was detected in the side radar. A bin value of 2 (0.5 s to 1.0 s) and above indicates the object was detected in the forward radar. The evaluation includes the longitudinal and lateral position of the object.

The procedure for determining the longitudinal distance to an obstacle (requires GPS or speedometer data) is described in Section 6.5. The program enters the longitudinal distance in the XO column of the analysis spreadsheet. The obstacle's lateral offset is determined using the technique for measuring the AMR discussed above. The lateral distance is entered in the YO column of the analysis spreadsheet.

8.1.6 Warning Classifications

The Lateral Drift Analysis calls for three types of situation evaluations. The first describes the scenario of the alert. The second identifies any particularly challenging aspect of the environment or activity at the point of the alert. The third evaluation rates the accuracy of the alert.

8.1.6.1 Scenario Identification

The evaluator views the situation in the video and determines which scenario best describes the situation at the time of the alert. Table 14 lists the scenario identifications. The evaluator records the three-digit reference value based on the appropriate description.

Table 14. Scenario Identifications

Ref.	Description
2.4.a	Departure on rural roads with narrow shoulder ≤ 1 m
2.4.b	Departure on roads with medium shoulder 1–2m
2.4.c	Departure on highway with wide shoulder ≥ 2 m
2.4.d	Drift left towards solid lane boundary
2.4.e	Drift left towards striped lane boundary
2.4.f	Drift right towards striped lane boundary
2.6.a	Drift left towards vehicle traveling in adjacent lane
2.6.b	Drift right towards vehicle traveling in adjacent lane
2.6.c	Drift towards guard rails in close proximity (≤ 1 m) to lane edge
2.6.d	Drift towards jersey barriers in close proximity (≤ 1 m) to lane edge
2.6.e	Drift towards traffic barrels in close proximity (≤ 1 m) to lane edge
2.7.a	Drift towards vehicle parked on shoulder
2.7.b	Drift towards bridge abutment
2.7.c	Drift towards telephone pole
2.7.d	Drift towards obstacle in curve

The scenarios cover three basic categories: lane departures, drift towards close objects, and drift towards other objects. Some departure alerts may include more than one scenario. When there are conflicts, the evaluator selects the most specific scenario. Therefore, the "drift towards close objects" (2.6.a through 2.6.e) has the highest priority. "Drift towards other objects" (2.7.a through 2.7.d) have the second highest priority. Finally, lane departure scenarios (2.4.a through 2.4.f) have the least priority.

8.1.6.2 Challenging Environment

The second Lateral Drift Analysis situation evaluation describes any particularly challenging aspect of the environment or activity at the point of the alert. Table 15 shows the

codes for identifying challenging environments. The evaluator identifies and records the challenging environment.

Table 15. Challenging Environment Codes

Key	Environment
-1	None
0	Glare due to low sun angle
1	Shadows cast from trees
2	Nighttime streetlight lighting
3	Glare due to oncoming head-lamps
4	Roadside bushes
5	Roadside sign
6	Roadside guardrail
7	Adjacent vehicle
8	Roadside mailbox
9	Roadside barrier (leading edge)

8.1.6.3 Alert Ratings

The third Lateral Drift Analysis situation evaluation records the accuracy of the alerts generated by the warning system. The alert may be either positive or negative and may be either true or false. Positive indicates the warning system generated an alert. True indicates the alert, or lack of alert, reflected the activity on the road.

The evaluator assigns a "1" for a true positive. A true positive rating indicates the vehicle either departed its travel lane or made a substantial move to depart its travel lane and the warning system sounded on alert. The evaluator assigns a "-1" for a false positive indicating the driver received an alert but the vehicle was not departing the lane.

The test vehicle has a button that allows the driver to record a particular time as a point of interest. The points of interest generally do not coincide with the alerts from the warning system. Thus, most points of interest are negative alerts. When the system does not issue an alert when the test vehicle departs the lane, the evaluator records a "-2" for a false negative. The driver may mark a point in the run when the vehicle passes a potentially difficult situation and responds correctly. A true negative generates an analysis and assists subsequent evaluations by including specific situations in the experiment statistics. The evaluator leaves the Alert Ratings entry blank for a true negative.

On rare occasions, the evidence from the video file is not sufficient to evaluate the accuracy on an alert. The evaluator records a "0" to indicate further study is required. The "0" entry keeps the event from biasing subsequent statistics.

8.2 Positive Alert Measurement Procedure

The procedure below steps the operator through the evaluation of a lateral drift event. Figure 83 is the operator's window for lateral drift evaluation. Refer to Figure 83 for

component identification. Identify the starting video frame number when the alert occurs and enter the frame numbers into the Alert Frame String and Alert Frame Array before using this procedure.

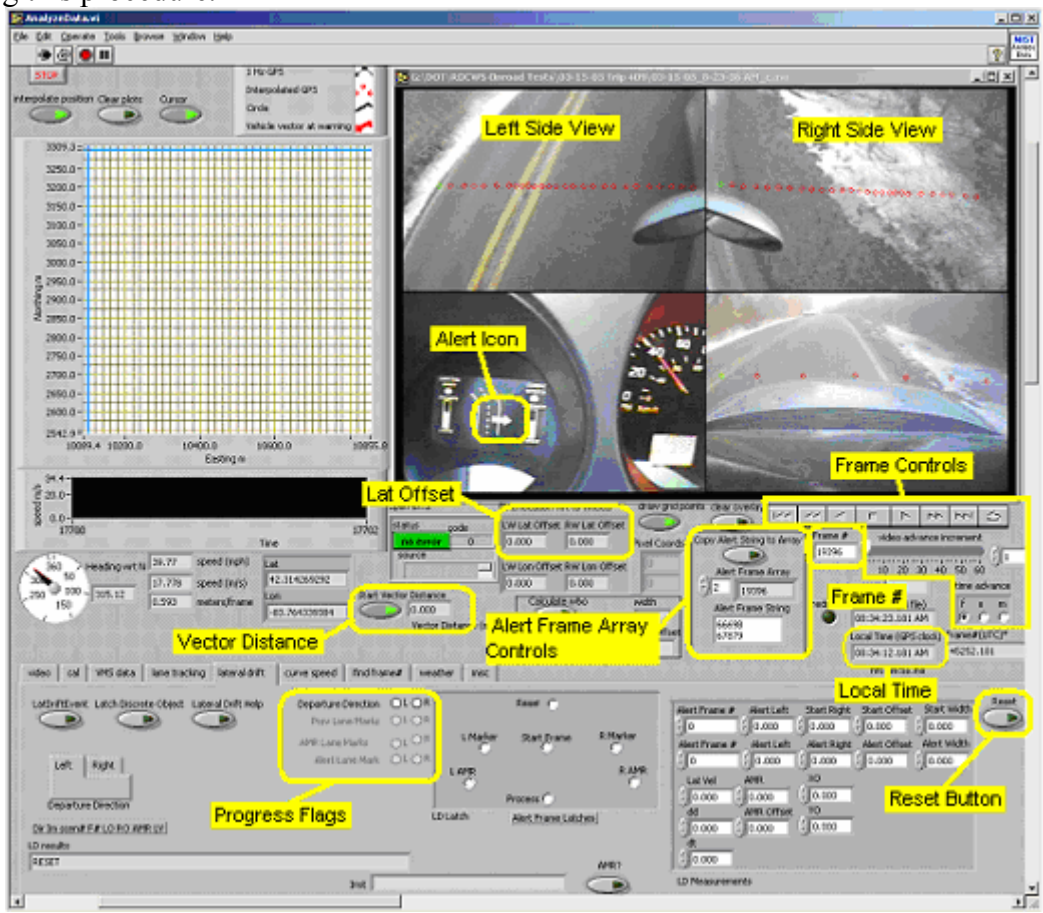


Figure 83. Lateral Drift Window, Method B.

1. Hit the "Reset" button (far right on "lateral drift" control panel) to clear all data from a previous analysis.
2. Select the next Alert Frame by either entering the number in the "Alert Frame Array" index or by clicking on the up triangle in the button next to the index (see Alert Frame Area in Figure 83).
3. Choose the Departure direction by clicking anywhere in the side-view display in the direction of the departure. The Departure Direction Flag will indicate your selection. If you select incorrectly, use the "Reset" button and start again.
4. Select the appropriate "Curve Info," "Alert Type," "Road Type," "Scenario," "Environment," "Marker," "Marker Quality," "Wiper," "Day/Night," and "Alert Rating" in the "drift filler" panel (see Figure 84). Reselect the values if cleared on Reset. Click on "keep values" to prevent the "Reset" button from clearing the "drift filler" values. This is helpful because it eliminates the need to continually re-select each value if the same scenario occurs several times. Note that the computer will beep if one or more of the evaluations are not complete.
5. Back up the AVI display about 20 frames. Continue backing until both the right and left lane markers are visible.

6. Using the side-view displays, select the left and right lane markers. The "Prev Lane Marks" flag will indicate your progress.
7. Using the side-view displays, select the AMR marker in the departure direction.
8. The AVI frame will advance to the audible alert frame.
9. Using the side-view display for the direction opposite the departure, select the lane marker.
10. If the warning stems from a discrete obstacle ahead (e.g., parked car on the shoulder), then use the procedure described in Section 6.5 to perform a longitudinal measurement to the object. The start of the measurement is the frame# of the warning and the end of the measurement occurs when the calibration circles in the side view align as close as possible to the object. Click on "Latch Discrete Object" to copy the measurement onto the clipboard for pasting into the result spreadsheet.
11. The program will load the operating system's clipboard with the lateral drift data. Select the next line on the spreadsheet containing the DAS warning data and paste lateral drift data.

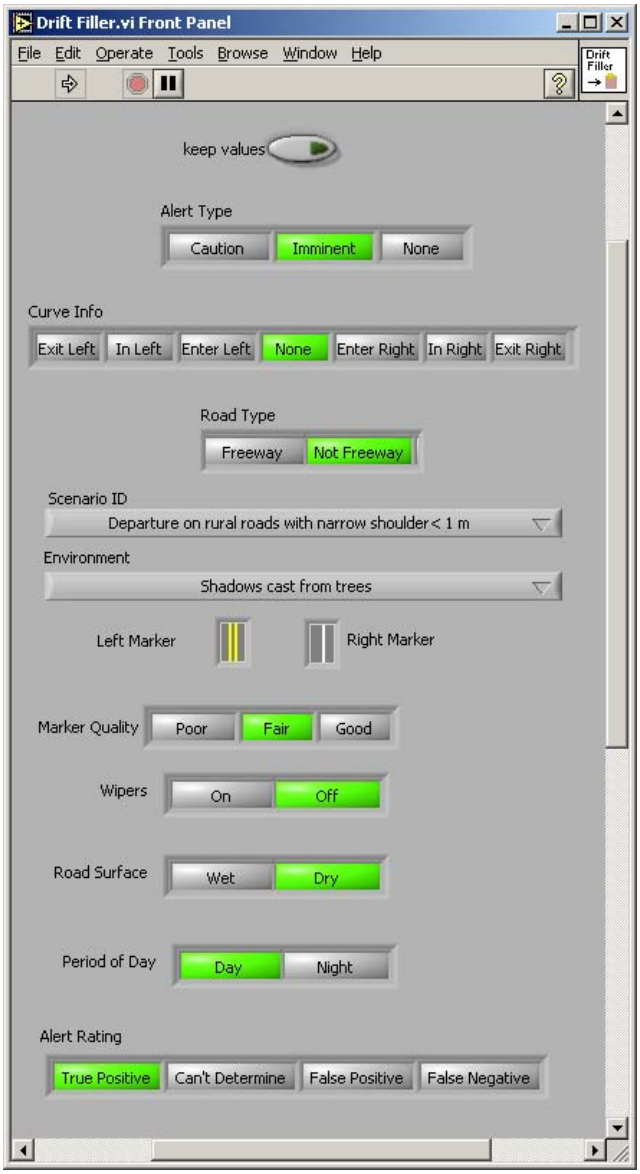


Figure 84. Drift Filler Window.

8.3 Negative Alert Measurement Procedure

The software coordinates the Positive Alert Measurement Procedure through the Alert Frame array and index. Negative alerts do not have an accurate Alert Frame. Negative alerts have only an approximate time of occurrence. The measurement procedure for negative alerts is similar to the positive alert measurement procedure with an initial step to determine the alert frame.

The first step in a negative alert measurement is to determine the alert time. Since the driver signaled the negative alert with the dashboard button after the alert system failed to warn of an event, the negative alert frame is before the recorded time. The evaluator begins with the recorded time. The evaluator adjusts the Frame # until the "Local Time (GPS clock)" matches the recorded time of the alert. The evaluator rewinds the video to the frame where the drift or departure stops. When the lane departure is a lane change, the desired frame is when the lane marker is half way across the hood in the forward camera view. For other departures, the desired frame is where the drift stops (since the evaluation is using a rewind, it will appear to be when the drift starts back to the lane). The evaluator records the desired frame at the end of the Alert Frame String, clicks on "Copy Alert String to Array," and selects the last "Alert String Array" index. Afterward the evaluation follows the Positive Alert Measurement procedure.

8.4 Atmospheric/Cloud Indication

Atmospheric/cloud indication classifies the relative sunlight by the presence or absence of a shadow around the vehicle. Shadows as well as diffuse lighting conditions when clouds are present can have a big impact on warning system performance. Clouds, hills, or large buildings may block the sun. The condition of the sunlight may explain warning system failures or highlight warning system performance. Analyze the entire video, not just during warnings. Volpe then uses the durations to determine the exposure time of the warning system to shadow and non-shadow conditions. This ensures a balanced, objective view of warning system performance (i.e., the system was barely tested in harsh sunlight).

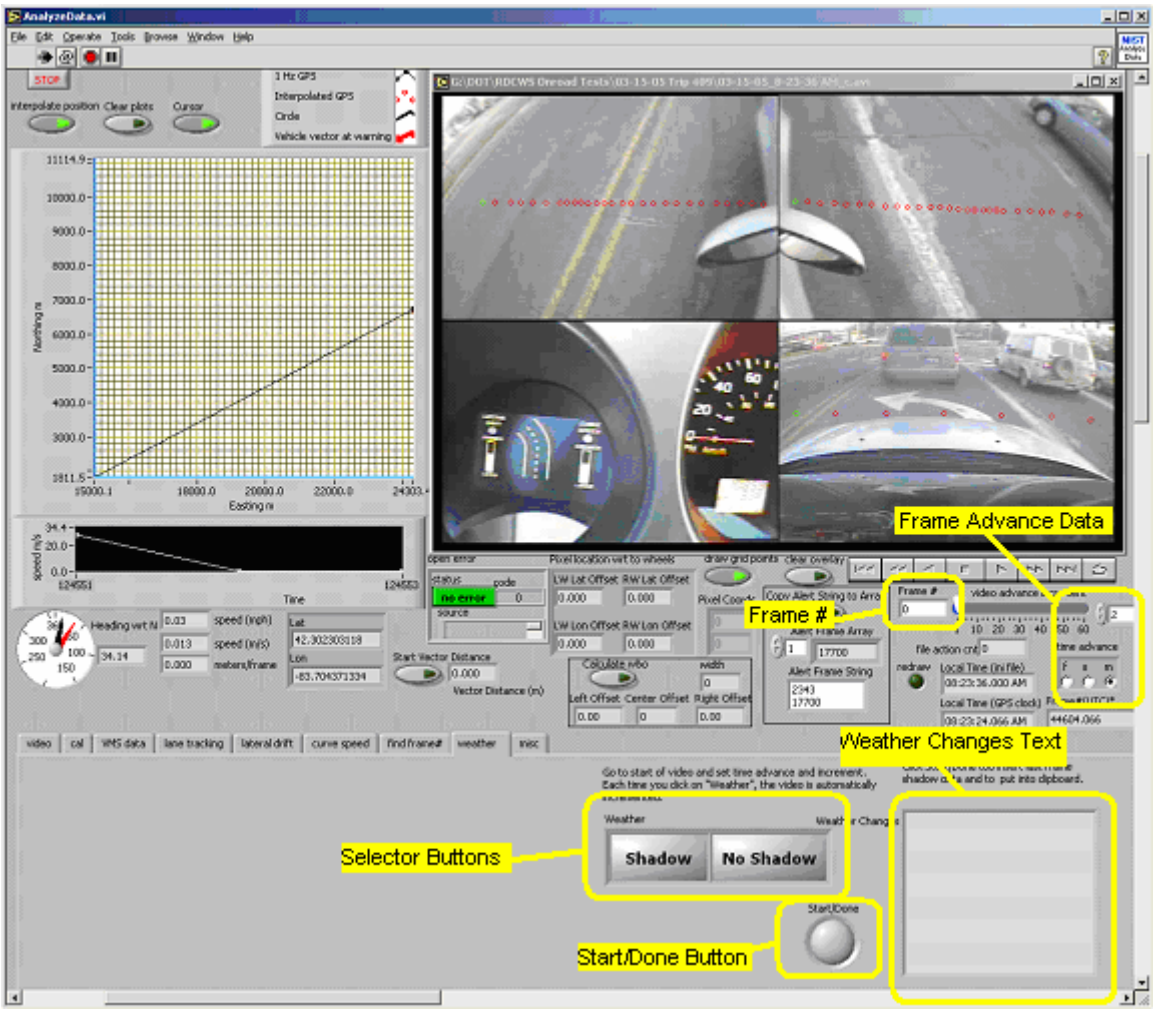


Figure 85. AnalyzeData "weather" Tab Display.

The weather analysis procedure uses the "weather" tab on the AnalyzeData VI. The analysis begins at frame zero and proceeds at 2-minute intervals through the AVI file. The analysis records the times when the shadow appears or disappears. The procedure requires a minimum amount of user motion and mouse clicks to collect the data.

1. Insert the number zero in the Frame # window.
2. Insert the number 2 in "video advance increment" and select "m" in "time advance."
3. Select the "weather" tab in the AnalyzeData.vi.
4. Click on the "Start/Done" button. The system will beep.
5. Check the AVI image for the presence or absence of a shadow. The image at frame zero in Figure 85 shows a faint shadow around the vehicles ahead of the test vehicle. However there is no shadow around the test vehicle. Therefore, we record "no shadow" for this interval.
6. The AVI display advances about 2 min when you select "Shadow" or "No Shadow."
7. Continue selecting Shadow or No Shadow as appropriate. Whenever there is a change, a new line will appear in the "Weather Changes" text window. The line

will include the GPS time, the local time, and a “1” for a shadow or a “0” when there is no shadow.

8. When the AVI image no longer advances, click the “Start/Done” button to add the final condition to “Weather Changes.” The program will automatically copy the “Weather Changes” text into the operating system’s clipboard. (For example see Figure 86)
9. Paste the clipboard into the appropriate spreadsheet for future analysis.

Sec (from midnight)	Local Time	Shadow=1
68886.601	3:08:07 PM	x
68347.970	2:59:08 PM	1
69069.777	3:11:10 PM	0
69189.874	3:13:10 PM	1
69790.473	3:23:10 PM	0
69910.603	3:25:11 PM	1
70030.712	3:27:11 PM	0
70150.842	3:29:11 PM	1
71712.396	3:55:12 PM	0
71832.525	3:57:13 PM	1
71952.655	3:59:13 PM	0
72072.785	4:01:13 PM	1

Figure 86. Typical Weather Changes Summary.

III-9 Lane Marker Contrast

Lane marker contrast is the difference between the average intensity of the marker and the average intensity of the adjacent road surface. Figure 88 shows the control panel for making contrast measurements.

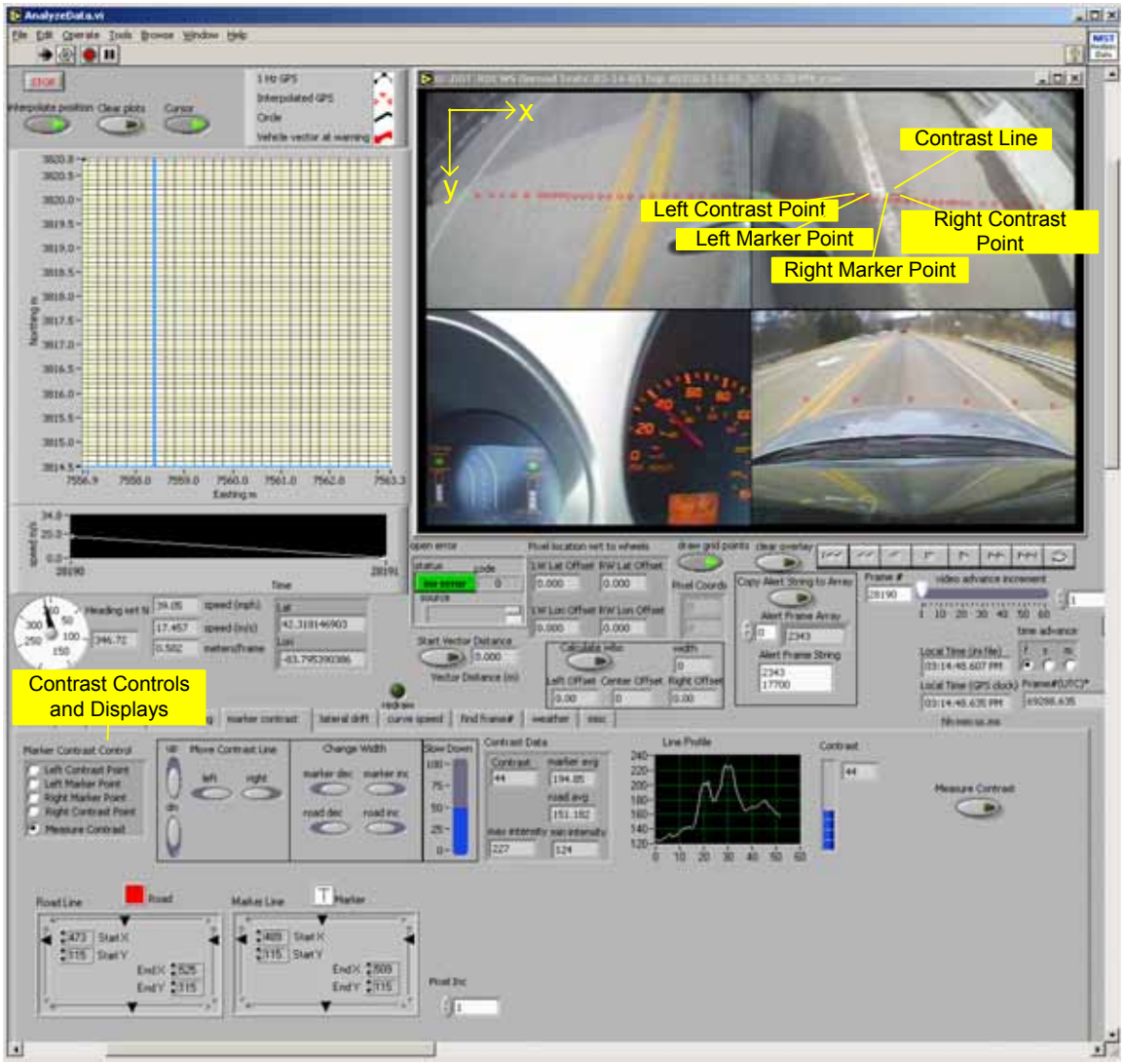


Figure 87. Control Panel for measuring lane marker contrast.

The "Contrast Line" in the video window shows the region in the image where the contrast measurement occurs. The line consists of two red segments, the left and the right road segments (if the segment is not visible, click on "Measure Contrast" to force a measurement and to cause the line to appear). The average of the pixel intensities of these segments produce the "road average." The region in between, which is transparent (no color), is the marker segment. The average of the pixel intensities of this segment produce the "marker average." The difference between the averages is the "contrast."

Note that for an RGB image, intensity is the average of the pixel's red, green, and blue components. Yellow may stand out in an image, but its intensity can be "low" and correspondingly, the contrast may be low.

The following components, starting from the upper left component in the control window, are available to make a contrast measurement and to view the results. Contrast measurements automatically occur whenever the frame changes or the line changes. Note that the location of the contrast line does not track the lane marker as the marker shifts. An automatic lane finder can track the lane, but the tracker usually degrades when the contrast decreases; typically, the instance the user desires a measurement.

Marker Contrast Control

Use this window to manually click on the pixels corresponding to the start and stop points of the contrast line (however, it may be easier to move the current contrast line using the controls described below). There are four points to the contrast line, as shown in Figure 87). To start, click on "Left Contrast Point" (in "Marker Contrast Control") and then click on the four pixels in the image in the following order:

1. Left Contrast Point
2. Left Marker Point
3. Right Marker Point
4. Right Contrast Point

After each click, "Marker Contrast Control" advances to the next point. To redefine a point, just select the appropriate valued in "Marker Contrast Control" and pick the pixel. After selecting all the pixels, set "Marker Contrast Control" to "Measure Contrast."

Move Contrast Line

Click on the buttons in this panel to move the contrast line.

Change Width

Click on the buttons in this panel to increase or decrease the width of the road and the marker segments.

Slow Down

Click in the slider region to increase or decrease the speed at which the contrast line moves or changes width.

Contrast Data

1. Marker avg – the average intensities of pixels corresponding to marker segment
2. Road avg - the average intensities of pixels corresponding to road segment
3. Contrast = "marker avg" – "road avg"
4. Max intensity – the maximum pixel intensity over the road and marker. Used to fix the scale of "Line Profile" so that it remains constant while viewing a video.
5. Min intensity – the minimum pixel intensity over the road and marker. Also used to fix the scale of "Line Profile."

Line Profile
This is a graph of intensities for each pixel in the contrast line.

Contrast
This is a bar graph of the contrast (same value in "Contrast Data").

Measure Contrast
Use this to force a contrast measurement in cases when one does not automatically occur.

Road Line
These are the coordinates of the Road line. Note these coordinates are the same as "Left Contrast Point" and "Right Contrast Point" described above. The split into two segments (left and right) uses the coordinates of the marker line.

Road
This is the color (currently red) to overlay for the road segment. Click in the box to bring up a menu of alternative colors.

Marker Line
These are the coordinates of the marker line. Note these coordinates are the same as "Left Marker Point" and "Right Marker Point" described above.

Marker
This is the color (currently transparent) to overlay for the marker segment. Click in the box to bring up a menu of alternative colors.

Pixel Inc
Another way to adjust speed when moving or resizing lines.

III-10 MapPoint Map Display

If the host computer has the Microsoft MapPoint application, the Lateral Drift Analysis software displays the GPS position on an external map. The software adds a pin at the coordinates of the frames displayed. If an alert frame occurred (as recorded in the Alert Frame Array) between the last pin and the current frame, the map plots a red pin, otherwise a blue dot. Figure 88 shows a typical run near Ann Arbor. The map shows a series of alerts along the lakeshore, no alerts in the downtown area, and a GPS jump at the intersection on the western side. NIST intends to integrate more functions with the maps in subsequent versions of the evaluation software.

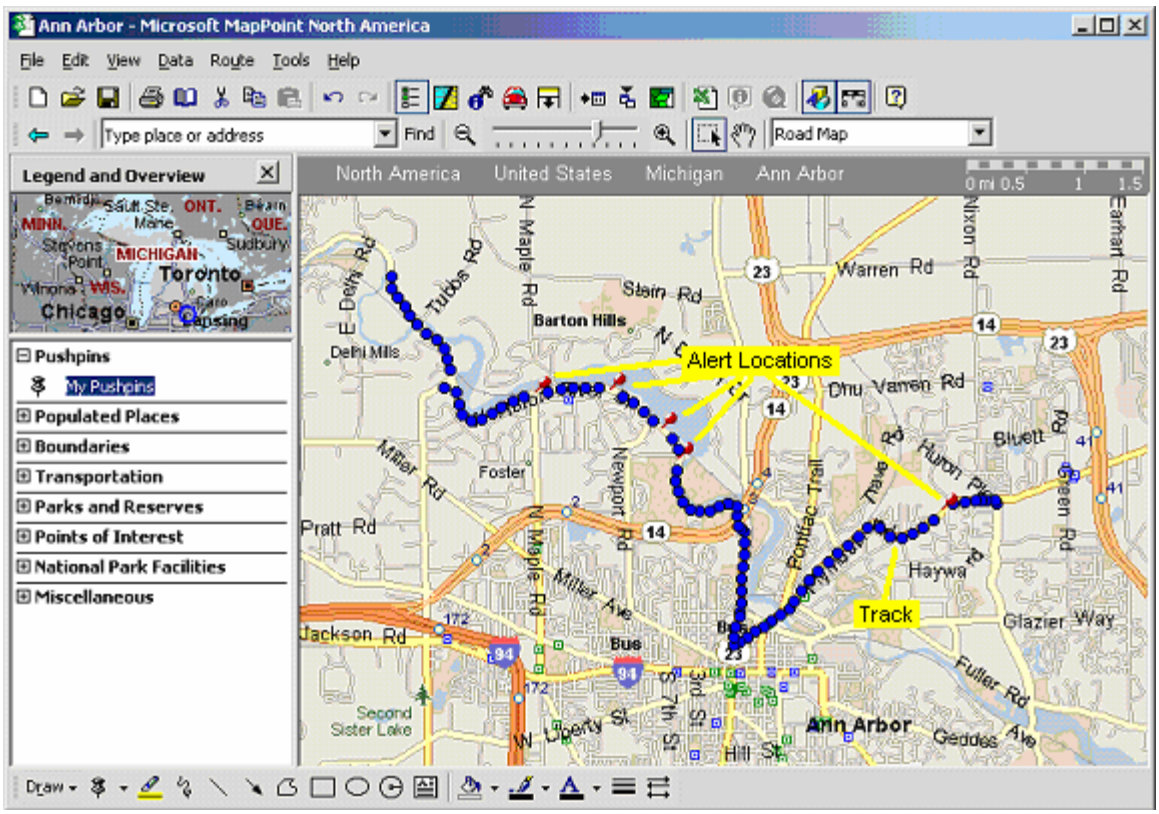


Figure 88. Map Point Display.

The analysis software requires the computer to have a map file saved on the disk. The operator specifies this file when MapPoint starts up. The operator may change the map file by using the "Select New Map" switch in the external map controls. If "Select New Map" is active, the software will ask for a new file the next time the operator starts a new track, otherwise the display reuses the previous map.

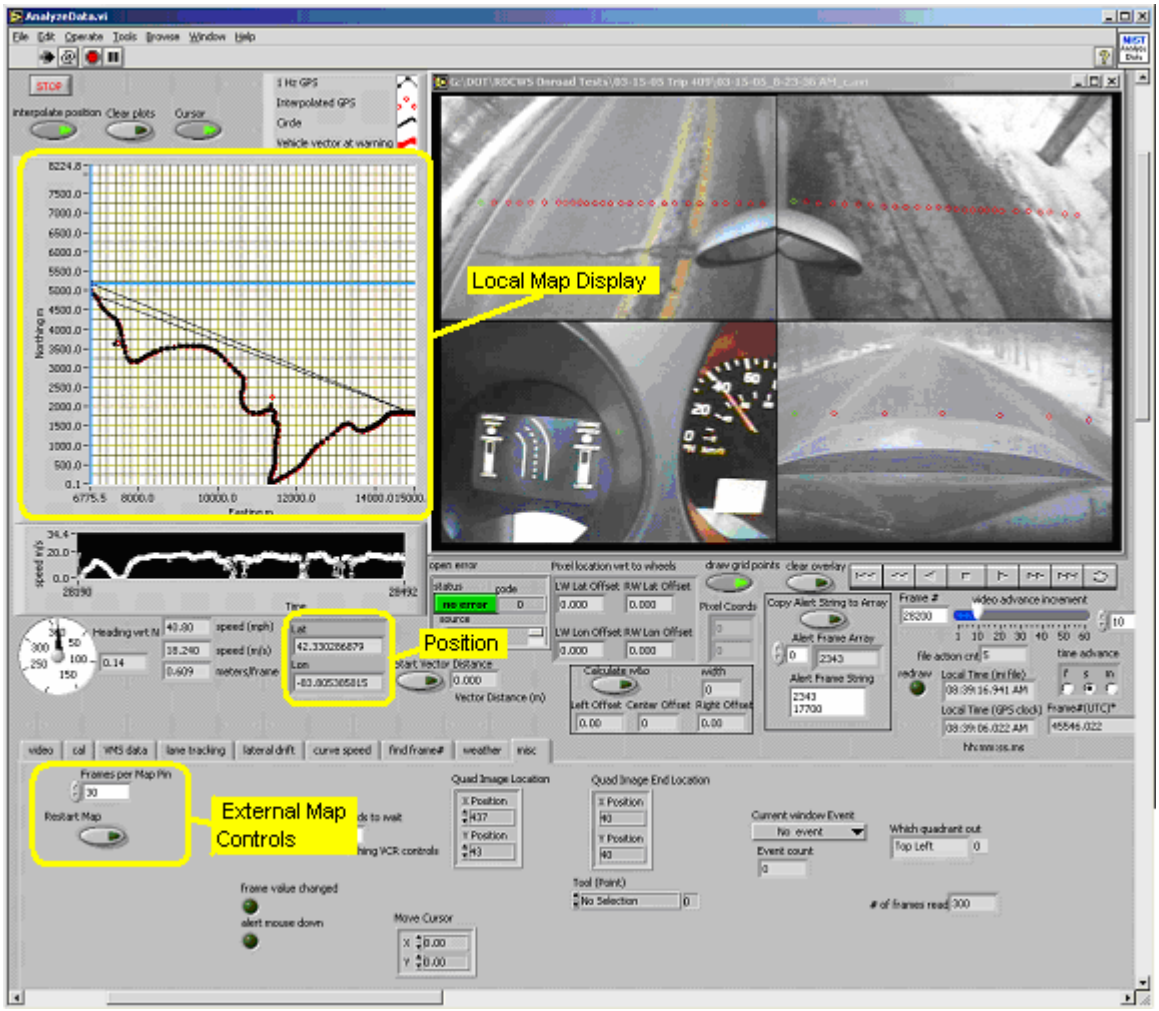


Figure 89. Map Interface.

The operator uses the "Restart Map" button in the external map controls to start a new track. The operator may first save the map for future reference by using the MapPoint controls. The operator may also clear the track with the delete function under "My Push-pins" on the MapPoint interface. After saving and clearing, the operator activates the "Restart Map" button on the external map controls on the data analyzing software display (see Figure 89).

The operator may limit the number of pins by setting the frames/pin selector under the "misc" tab (see Figure 89). The frames/pin selector instructs the software to add a pin only after the specified number of frames has passed. When the frame index rate is greater then the frames/pin selector, the software adds only one pin per index. The default rate is 30 frames per pin, which equals 1 pin per second of continuous running. The operator sizes, centers, and clears the map as required using the MapPoint controls.

Appendix III- A – Adobe Premier Notes

This section contains notes describing tips and quirks uncovered using Adobe Premier 6.0.

A.1 Differences in file lengths

The following is an inconsistency discovered in the length of an AVI file when viewed in Premier and in Labview. Differences in file length cause timing mismatches between the video and the inserted GPS/time stamp. By the end of a long video file, the GPS data indicating the position and velocity of the vehicle does not match the view of the vehicle's motion in the video (vehicle appears to stop yet the GPS position indicates the vehicle is still moving). The solution is to ensure the compression frame rate matches the capture frame rate. The following example describes the problem in more detail.

When looking at the clip "05-28-03 LDW Barriers_c.avi" in the Premier timeline, the monitor window indicates the last frame time as 00:41:43:02 (hours:minutes:seconds:frames). This translates to 75,092 frames.

However, when examining the properties of the clip (under the Premier file menu), the duration is 00:41:45:18 and the number of frames is 75,168. In addition, when looking at the file in LabView, the number of frames is 75,168.

There is a difference of 75 frames (approximately 2.5 s) between the timeline length and the properties/Labview length. The DV capture frame rate is 29.97 frames/s. The AVI file properties (viewed by Labview) shows 30 frames/s, which was the setting used during compression (all captured DV is compressed to save file space and improve throughput). To prevent a mismatch in timing between video frames and GPS data associated with each video frame, make sure the compression frame rate matches the capture frame rate.

Appendix III-B – Creating a DVD using DVDit!

The following section describes how to create a DVD using DVDit (www.sonic.com), which is bundled with Premier. The first step is to use Premier to create an m2v (video) file and a wav (audio) file (see the Premier help for creating these files).

Figure 90. The main window in DVDit

The next step is to import the files into DVDit and to build the DVD menus. The steps below refer to Figure 90.

1. Use default theme

2. Create menus
   - Select menu under Menu/Movie button
   - Select Background under Pallet window buttons
   - Drag a background into Menu/Movie placeholder in Menu/Movie list.
   - Edit menu name, e.g., “main menu”

3. Create menu entries (buttons or text).
   - Select menu under Menu/Movie button
   - Select appropriate menu (may already be visible in Video monitor)

- Select either Button (button 2) or Text (button 3) under Pallet window buttons
- Drag item onto menu and edit text appropriately

4. Import media
   - Select Media (button 4) under Pallet window buttons
   - Right click in window and select "add files to theme"
   - In pop-up browser, highlight .m2v and .wav files (should have same name) and click open. This will insert media into Pallet window

5. Select first play
   - Select movie under Menu/Movie button
   - Drag media (both video and audio files) onto First Play placeholder

6. Link media to menu buttons
   - Make sure menu is visible (select Menu under Menu/Movie button)
   - Drag media (mv2 and wav files) onto button

The following steps describe how to burn the DVD. These steps appear at http://support.sonic.com/kb/default.asp?type=desktop&product=dvdit

Title
Building a DVD Folder to your hard drive using DVDit! and then burning a DVD.

DVDit! can burn a project right to a DVD. However, creating a volume on a drive enables you to make additional copies without having to have the original DVD to make a copy. Attempting to create a volume on the disk failed with unknown error. The following procedure did work. Before you begin, create two new folders on the top level of a local hard drive. The hard drive must NOT be part of a RAID or network configuration. Name one folder "DVDit! Temp" and the other the name of you project, e.g. "Wedding Video." When you finish creating your session, build your session to your hard drive. You can do this by going to your Build Menu-->Make DVD Folder.

1) GENERAL TAB

Source: Current Project.
Output Options: Should be blank.
Path: Top Level of hard disk. NOTE: Make sure that the drive you select is local to your machine and not a RAID or network drive.

2) ADVANCED TAB

Uncheck all boxes

Path: Select your DVDit! Temp folder. Browse to this folder in your Path dialog and select it just in case you decide later down the line to save your cached files. This will make them easy to locate for later use or deletion if they become corrupt.

3) Click OK. The build process begins.

When finished, burn the Volume to DVD. Go to the drive you built the project on and place the AUDIO_TS and VIDEO_TS folders into the second folder you created for your project title (e.g. "Wedding Video"). This prevents errors in DVDit! from accidentally burning data files with your video files.

From here, you have two options: you can either burn your DVD using DVDit! Or you can burn your DVD using a third party data burning application such Roxio or Prassi.

NOTE: BE SURE THAT YOUR BURNING APPLICATION SUPPORTS YOUR BURNER AND YOUR DVD MEDIA TYPE!

OPTION 1--Using DVDit!:

1) Go into your DVDit! Build Menu-->Make DVD Disc.

2) GENERAL TAB

Source: DVD Volume. Click the browse button. Locate your session folder (e.g. "Wedding Video") and open it so you can see the AUDIO_TS and VIDEO_TS folders. These should be the only folders.

Output Options: Check this ONLY if you are creating a cDVD.

Recorder: Select your recorder

Number of Copies: 1

Options: Test and Create disc

3) Click OK.

Burning begins.

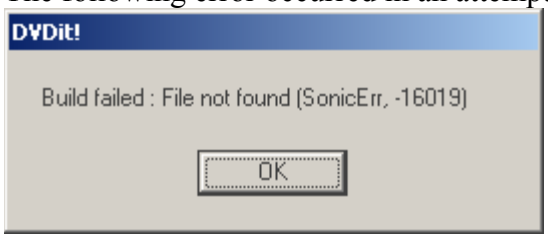
OPTION 2--Using a third-party application

1) Choose to create a Data disc in your burning application

2) Drag the AuDIO_TS and VIDEO_TS folders into your to-be-burned or data field. Be sure you have dragged the folders ONLY and no other files. These are the only two items (and their contents) to burn.

3) You may want to run in simulation mode if you haven't done this process before to make sure you have the proper buffer speed and RAM allocated to your machine for a clean burn. If it works, then burn the disc for real.

The following error occurred in an attempt to create a DVD.



The solution below appears on the Sonic website. Actually, this problem occurs when "current project" is not selected in Build->Make DVD folder->general->Source.

Title
DVDERR,-16019

Solution
This is bug that we are currently working on fixing in a new release in MyDVD/DVDit!. So far, we have been able to determine that it may have to do with where your files are placed on the hard drive and where they have come from. Usually, this happens when the audio_ts and video_ts folders from a pre-made DVD (either Hollywood or a consumer made) are dropped onto the hard drive and the user tries to replicate them into another DVD or "back up." Also, the error can be caused due to renaming the file, using non-alphanumeric characters (8 or less), or in-correct path settings as when the files has been moved while the session is in use.

You may also want to be sure that you are building your session to the top level of your hard drive as well. Please follow the links on this page on how to do this.

Appendix III-C – Extracting GPS data from video using VMS and MediaMapper

The VMS 300 is a device made by Redhen Systems (www.redhensystems.com) that consists of a DGPS receiver and electronics to convert the DGPS data into an audio signal for insertion on videotape. The VMS is also required to read the DGPS from the videotape.

MediaMapper is the software provided by Redhen Systems to read the GPS data off the video tape and perform differential correction using EZDIFF (from within MediaMapper). MediaMapper is not required to write GPS data to the tape. The VMS does this automatically when the VMS is on and connected to the VCR.

MediaMapper also contains EZDIFF to correct the GPS data if the VMS is running in differential mode (i.e., saves all satellite data).

The corrected data is stored in an ASCII file. The corrected data allows the user to determine vehicle position and speed in the AVI file at any point in time. The data is available once per second.

The following sections describe the steps for creating the corrected GPS data file.

C.1 VMS SetUp

Figure 91. Connecting the VMS to a VCR.

The VMS serves as an interface between MediaMapper and the VCR. There are two cables between the VMS and the VCR and one cable between the VMS and the host computer for MediaMapper. The VMS requires an audio connection to the VCR's au-

dio/video jack so that it can read the GPS data off the audio track (the GPS data sounds like a hiss and a beep every second). A LANC interface allows the VMS to send VCR controls commands (play, stop, etc.) to the VCR and to read the tape counter time from the VCR. An RS-232 cable connects to the back of the VMS to the host computer's COM port. MediaMapper uses the serial interface to read the GPS and tape counter data and to sends tape commands (stop, play, etc.) to the VCR (via the VMS Lanc interface).

C.2 Extracting GPS data with MediaMapper

The goal of this step is to extract the GPS data that corresponds to a video clip. The GPS data file and video clip have the same root name.

In MediaMapper, indexing a video means extracting the GPS data. The following steps are performed within MediaMapper. NOTE: MediaMapper only displays GPS points (i.e., the red points on the map) when indexing. When playing a tape you will only see an arrow move across the map without any trail of GPS points showing the previous positions.

1. File->Add GPS Index

2. Pick a name that corresponds to video file, e.g., 05-28-03 LDW Barriers_c. The program saves the file in the user/My Documents/Map Library by default. This is OK for now since the user will later convert the file into an Excel file and store it in the same directory as the video file.

3. Index parameters:
   Use same name as video file
   The start time for the example clip is:
   00:15:48:24
   The number 24 indicates the frame count. MediaMapper time resolution is only 1 s. Start the capture a few seconds early, you can always edit out the unwanted times later using Excel.

   MediaMapper always rewinds to the beginning of the tape so do not bother moving the tape to the capture point. In addition, you cannot set the stop point, so set your stopwatch to the duration of the clip.

   While indexing, you should be able to see the GPS data and the serial data if you enable the displays (satellite and cable icon buttons below map to right).

   Noted Problems:

1. The play button in MediaMapper would not cause VCR to play. Fix: rewind first, tape may have been at the end.

2. The GPS data does not display. Fix: The audio volume may be too high (recall the GPS data is stored as an analog signal on the audio channel). Lower to around 1/3 volume.

3. GPS drop out. Fix: Raise volume slightly. Dropouts still occurred. Went to tools->options->VMS setup->Camera Setup and checked box indicating RC time code or digital time (note that equipped with microphone power was also checked). No more dropouts occurred.

4. When indexing an entire tape, if tape ends, MediaMapper sometimes aborts with an access violation error (see Figure 92). Fix: The files are still useable. Go to Map Library directory and double click on the name of the map you created, for example "03-15-05_8-23-36 AM_c.vtc." When the map comes up, it contains no GPS points. To add the GPS data, go to File->Add Layers, go inside the index folder, and click on "03-15-05_8-23-36 AM_c.tab" (.tab files contain all the layers associated with a map file). Then you should see the trail of GPS points and can run post processing using EZDiff.

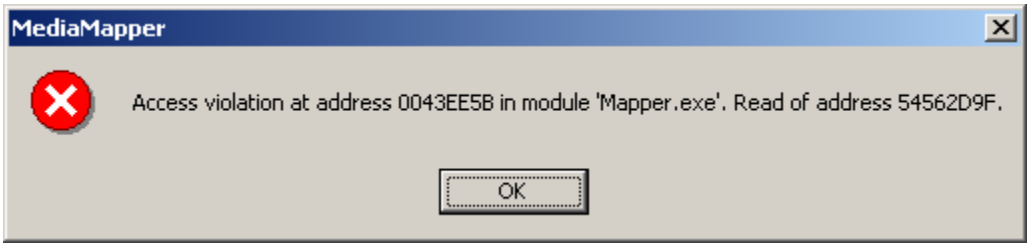


Figure 92. Mediamapper sometimes hangs while indexing GPS and the video ends.

C.3 Post process GPS data using EZDiff

EZDiff is a software tool packaged with MediaMapper. The tool downloads base station corrections used to correct GPS data from a roving receiver. The base stations are part of the National Geodetic Survey's Continuously Operating Reference Stations (CORS). To run EZDiff:

1. Select Tools->Differential Correction

Retry if there is an FTP error getting on the CORS site. Below is an example processing-log from a running of EZDiff.

After EZDiff performs corrections, it produces a DBF (database file) called 05-28-03 LDW Barriers_c.DBF (in C:\Documents and Settings\szabo\My Documents\Map Library\Indexes), which can be opened with Excel.

Noted Problems:

EZDiff produced the following error on 5/17/2004.

****

FTP Session Log File: 5/17/2004 2:37:16 PM EZdiff V2.0.0.18

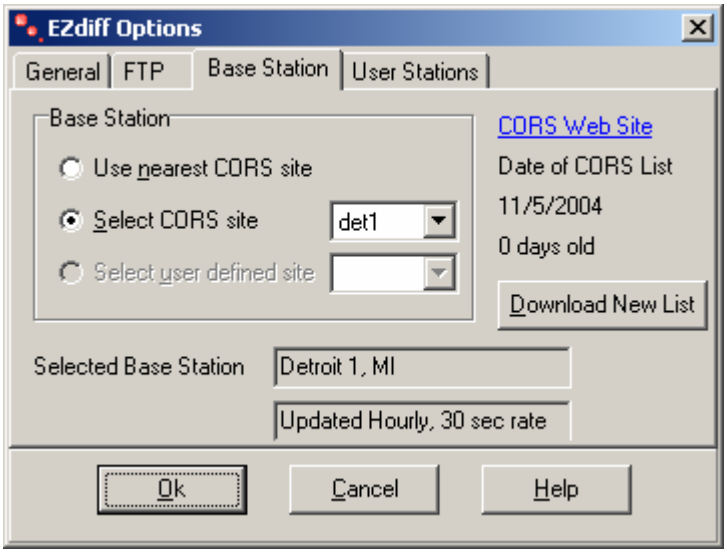
Connecting to [www.ngs.noaa.gov].

Setting mode to image (binary).

```
Changing directory to [/cors/rinex].
Successful directory change to [/cors/rinex].

Changing directory to [2004/118].
Successful directory change to [/cors/rinex/2004/118].

Get directory listing of [/cors/rinex/2004/118].
Successful download of directory listing for [/cors/rinex/2004/118].

Changing directory to [galb].

Get directory listing of [/cors/rinex/2004/118/galb].

Changing directory to [/cors/rinex/2004/118].
Successful directory change to [/cors/rinex/2004/118].

Changing directory to [stkr].

Get directory listing of [/cors/rinex/2004/118/stkr].

Changing directory to [/cors/rinex/2004/118].
Successful directory change to [/cors/rinex/2004/118].

Changing directory to [erla].

Get directory listing of [/cors/rinex/2004/118/erla].
Error: Rover data for today, hour [19] is too new to found on CORS FTP site.
Try again later.

Errors were found during FTP session.
```

Fix:

1. Went in to options and Selected nearest CORS site and it returned DET1. Received a similar error message as above (“to new to found on CORS FTP site”>
2. Downloaded New List – still got error
3. Clicked on Select CORS site and chose det1. This worked.



C.4 Create a JPEG of GPS Points

Follow the steps below to create a JPEG of the map showing the GPS points read from the videotape.

1. Use zoom and hand to draw a window on the portion of the map containing the GPS points.
2. Select window using rectangle tool.
3. Select file->export->graphic.
4. Pick save type, for example, JPEG.
5. Choose folder to save the JPEG.

C.5 Convert to LabView format using Excel

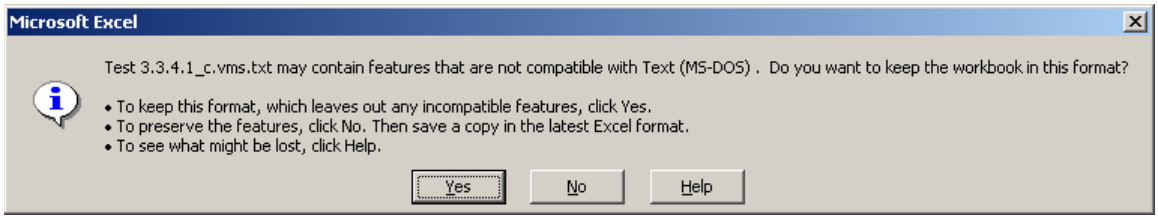
The next step converts the dbf file into a vms file, which is the format used in Labview.

1. Open a DBF file using Excel. The DBF file appears in My Documents\Map Library\Indexes.

2. Find and replace "Post Diff" with PostDiff (LabView string processing routines don't like spaces inside a string).

3. Remove last column called WAYPOINT if there is nothing in the column.

4. Save as .txt file (pull down Save as type: menu and select "Text (tab delimited) (*.txt)") with same name as video(.avi) file in the same directory as the video file



Click Yes

5. When you quit, Excel will ask if you want to save changes to the .txt file. Click No.

6. Go to directory, make a copy of the .txt file and give it a .vms suffix. This is what the LabView analyze data program will look for. Save the .txt file as a backup.

Appendix III-D – Nonlinear Camera Calibration

A non-linear calibration technique implemented in AnalyzeData makes measurements over a large area. Figure 93 illustrates aspects of the calibration process. A calibration grid is required to calibrate the camera. The operator examines an image of the grid and identifies each grid point (Figure 85). The operator also enters the actual distances between the grid points, in meters. A nonlinear calibration routine runs and produces the transformation parameters. The parameters remove distortions in the image (Figure 96). The procedure requires a large number of grid points, which requires substantial time for setup and takedown, and for processing. When possible, use the calibration stick method.

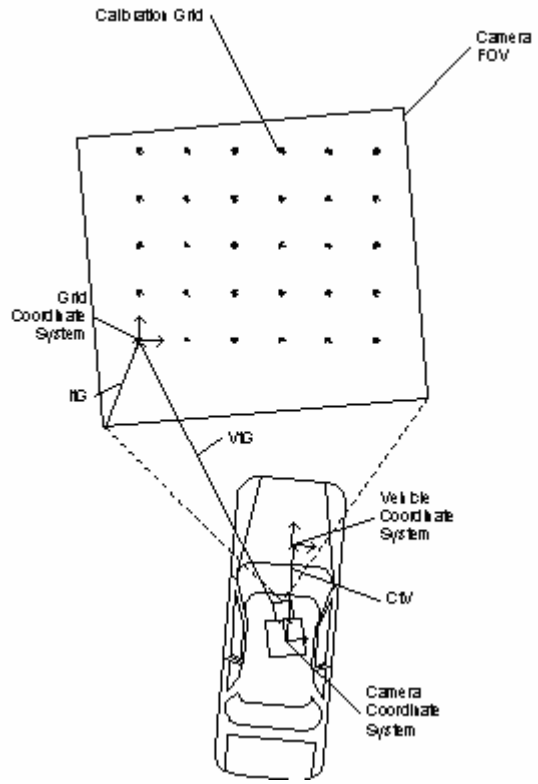


Figure 93. Camera calibration coordinate systems.

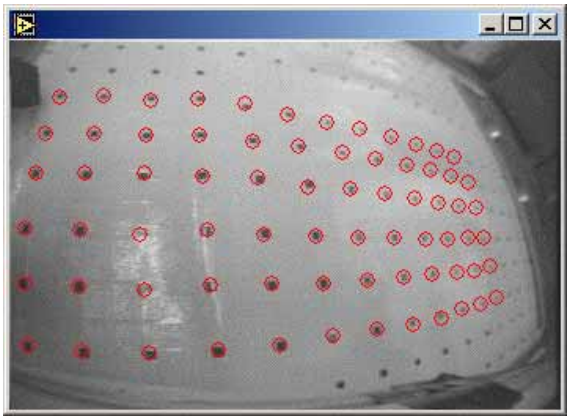


Figure 94. Nonlinear calibration grid with identified grid points (red circles).

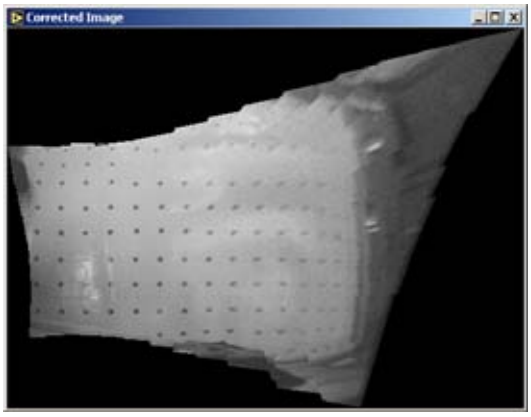


Figure 95. Nonlinear distortions removed after calibration.

Appendix III-E – UTM Conversions

Universal Transverse Mercator coordinates use a family of projections based on the Transverse Mercator projection. The projection consists of an ellipsoid divided into 60 longitudinal zones of 6° each. The X value, called the Easting, has a value of 500,000 meters at the central meridian of each zone. The Y value, called the Northing, has a value of 0 meters at the equator for the northern hemisphere, increasing toward the north pole, and a value of 10,000,000 m at the equator for the southern hemisphere, decreasing toward the south pole.

The conversion routines used in the IMS use the Geographic Translator software package. The source code is available from the National Geospatial-Intelligence Agency at http://earth-info.nga.mil/GandG/geotrans/.

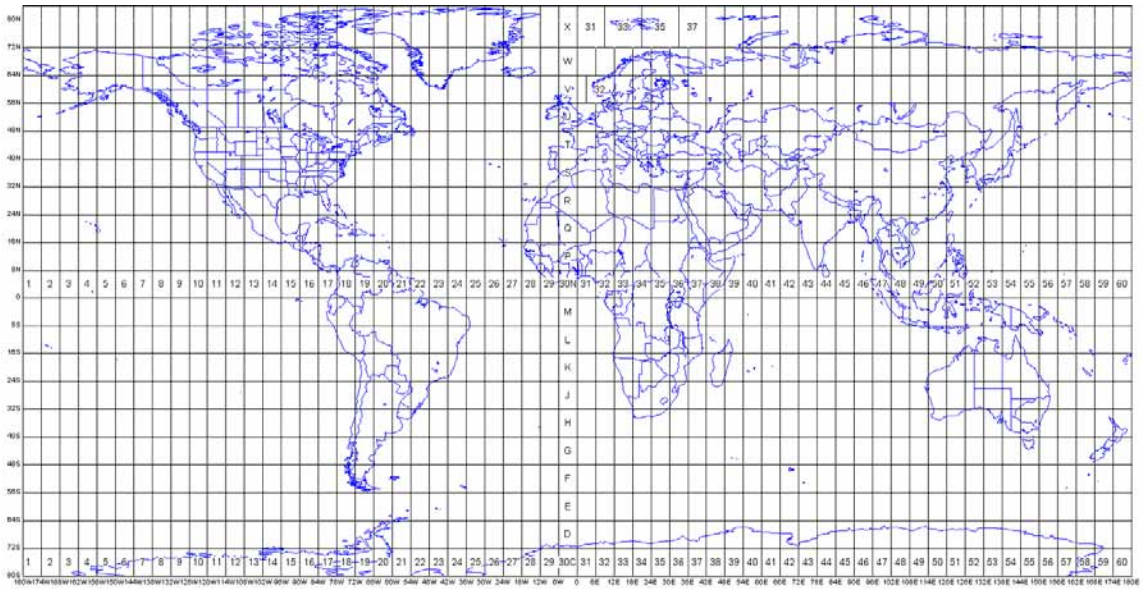


Figure 96. UTM and Military Grid Reference System zones. The UTM goes from 1-60 for each hemisphere. The MGRS divides the zone laterally using letters C-X.

References

[1] W. Najm, J. Koopmann, L. Boyle, & D. Smith, "Development of Test Scenarios for Off-Roadway Crash Countermeasures on Crash Statistics," May 2001, Report Number DOT-VNTSC-NHTSA-01-02. Washington, DC: National Highway Traffic Safety Administration.

[2] Request for Applications for Cooperative Agreement DTFH61-01-X-00053, "An Intelligent Vehicle Initiative Road Departure Crash Warning Field Operational Test," April 11, 2001.

[3] H. Scott, & S. Szabo, "Evaluating the Performance of a Vehicle Pose Measurement System," Proceedings of the Performance Metrics for Intelligent Systems (PerMIS) Workshop, National Institute of Standards and Technology, Gaithersburg, MD, August 13-15, 2002. http://www.isd.mel.nist.gov/documents/scott/PerMIS_2002.pdf

[4] D. Pomerleau et al., "Run-Off-Road Collision Avoidance Using IVHS Countermeasures, Final Report," Contract No. DTNH22-93-C-07023, National Highway Traffic Safety Administration, Office of Collision Avoidance Research, December 14 1999.

[5] "Standardization Working Draft for PWI14.8 - Lane Departure Warning Systems," International Standards Organization Technical Committee 204, Working Group 14, October 23, 2000. This can be obtained from Steven Shladover at sess@uclink4.berkeley.edu

[6] F. Deal, H. Men, & n. Phamdo, "Public LDW & CSW Algorithms Status Briefing," Presentation made at JHU/APL, February 24, 2004.

[7] S. Szabo, & R. Norcross, "Recommendations for Objective Test Procedures for Road Departure Crash Warning Systems," National Institute of Standards and Technology Internal Report 7288, January 30, 2006.

[8] S. Szabo, & R. Norcross, "An Independent Measurement System for Performance Evaluation of Road Departure Crash Warning Systems," National Institute of Standards and Technology Internal Report 7287, January 3, 2006.

[9] D. Bezzina, & D. Madau, "Road Departure Crash Warning Field Operations Test System Validation Test Plan," Document Number: RDCW-VP-4.7, Visteon Corporation.

[10] S. Szabo, "Results from Validation Tests of the Field Operational Test Road Departure Crash Warning System," NIST report submitted to NHTSA, November 18, 2003. Washington, DC: National Highway Traffic Safety Administration.

[11] S. Szabo, & B. Wilson, "Application of a Crash Prevention Boundary Metric to a Road Departure Warning System," Proceedings of the Performance Metrics for Intelli-

gent Systems (PerMIS) Workshop, National Institute of Standards and Technology, Gaithersburg, MD, August 24 - 26, 2004.
http://www.isd.mel.nist.gov/documents/szabo/PerMIS04.pdf

[12] B. Wilson & J. Koopmann, "Performance and Capability of a Road Departure Crash Warning System," in Intelligent Transportation Systems of America Annual Meeting, Palm Springs, CA, June 2007.

[13] Request for Applications for Cooperative Agreement DTFH61-01-X-00053, A Intelligent Vehicle Initiative Road Departure Crash Warning Field Operational Test, April 11, 2001, http://www.eps.gov/EPSData/DOT/Synopses/30/DTFH61-01-X-00053/DTFH61-01-X-00053.rtf

[14] "Run-Off-Road Collision Avoidance Using IVHS Countermeasures, Final Report," Contract No. DTNH22-93-C-07023, NHTSA Office of Collision Avoidance Research, December 14, 1999. Washington, DC: National Highway Traffic Safety Administration.

[15] W. Najm, J. Koopmann, L. Boyle, & D. Smith, "Development of Test Scenarios for Off-Roadway Crash Countermeasures on Crash Statistics," May 2001, Report Number DOT-VNTSC-NHTSA-01-02. Washington, DC: National Highway Traffic Safety Administration.

[16] "Standardization Working Draft for PWI14.8 - Lane Departure Warning Systems," International Standards Organization Technical Committee 204, Working Group 14, October 23, 2000. This can be obtained from Steven Shladover, sess@uclink4.berkeley.edu

[17] S. Szabo, & R. Norcross, "An Independent Measurement System for Performance Evaluation of Road Departure Crash Warning Systems," August 14, 2005. Can be obtained from Sandor Szabo, sandor.szabo@nist.gov.

[18] "Vehicle Dynamics Terminology," SAE J670e, July 1976.

[19] F. Deal, H. Men, & N. Phamdo, "Single Vehicle Roadway Departure Prevention Program – Public Curve Speed Warning (CSW) and Lateral Drift Warning (LDW) Algorithms Design and Performance," Draft report prepared by Johns Hopkins Applied Physics Laboratory, April 2004.

[20] A. Burgett, "DOT's Approach to ITS Safety Evaluations," invited papers to ITS America Safety Evaluation Workshop, May 1, 1995.

[21] A. Burgett & K. Gunderson, "Crash Prevention Boundary for Road Departure Crashes--Derivation," Research Note DOT HS 809 399, September 2001. Washington, DC: National Highway Traffic Safety Administration.

[22] B. Wilson & A. Burgett, "Crash Prevention Boundaries for Road Departure," In Ninth World Congress on Intelligent Transportation Systems, Chicago, IL, October 2002.

[23] A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, 1994.

[24] R. Lamm, B. Psarianos, & T. Mailaender, Highway Design and Traffic Safety Engineering Handbook, McGraw-Hill NY, 1999.

[25] ASTM D 6628 – 01, "Standard Specification for Color of Pavement Marking Materials."

[26] European Standard EN 1436:1997/prA1:2002 "Road marking materials – Road Marking Performance for Road Users."

[27] Request for Applications for Cooperative Agreement DTFH61-01-X-00053, A Intelligent Vehicle Initiative Road Departure Crash Warning Field Operational Test, April 11, 2001, http://www.eps.gov/EPSData/DOT/Synopses/30/DTFH61-01-X-00053/DTFH61-01-X-00053.rtf

[28] S. Szabo, & R. Norcross, "Recommendations for Objective Test Procedures for Road Departure Crash Warning Systems," National Institute of Standards and Technology Internal Report 7288, January 30, 2006.

[29] D. Bezzina, & D. Madau, "Road Departure Crash Warning Field Operations Test System Validation Test Plan," Document Number: RDCW-VP-4.7, Visteon Corporation, April 29, 2004.

[30] B. Wilson & J. Koopmann, "Performance and Capability of a Road Departure Crash Warning System," in Intelligent Transportation Systems of America Annual Meeting, Palm Springs, CA, June 2007.

DOT HS 810 829
August 2007

U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

NHTSA
www.nhtsa.gov