CHAPTER 7

OBJECTIVE TEST METHODOLOGY EVALUATION

TABLE OF CONTENTS

7 FORWARD COLLISION WARNING SYSTEMS TEST PROCEDURES EVALUATION 7-5

7.1 Introduction 7-5

7.2 Instrumentation Selection Process 7-6
7.2.1 Required Measurements and Accuracy 7-7
7.2.2 Longitudinal Position, Speed, and Acceleration 7-8
7.2.3 Moving SV and POV Lateral Positions 7-11
7.2.4 Yaw Rate 7-13
7.2.5 Visibility 7-13
7.2.6 SV Brake Pedal Actuation Time 7-14
7.2.7 Roadway Horizontal Curvature 7-14
7.2.8 Roadway Super-Elevation on Curves and Vertical Curvature 7-14
7.2.9 Sampling Rate for Onboard Data Acquisition Systems 7-15
7.2.10 Ground Truth 7-15

7.3 CAMP Testing Equipment/Instrumentation 7-17
7.3.1 Basic Instrumentation 7-18
7.3.2 Equipment Location in the Vehicles 7-20

7.4 Evaluating the Test Methodology 7-22
7.4.1 Test Procedure Execution 7-23
7.4.2 Validation Results 7-45
7.4.3 Sensitivity Analysis 7-47
7.4.4 Correlation With Performance During Typical Driving 7-49

7.5 Summary 7-51

7.6 Acknowledgments 7-51

7.7 References 7-52

List Of Figures

Figure 7-1 Instrumentation Plan Development Process 7-6
Figure 7-2 Block Diagram of In-Vehicle Instrumentation 7-7
Figure 7-3 Comparing Actual Warning Range to the Minimum Required Warning Range 7-9
Figure 7-4 Tolerance Stackup for Lateral Position Measurements with Stationary Object Outside the Alert Zone 7-12
Figure 7-5 Use of Vehicle Instrumentation for a Complex Test 7-17
Figure 7-6 Driving Cues for Test C-3 7-28
Figure 7-7 Vehicle Motions and Alert Requirements During a Test Trial: Test C-3 100 kph to POV Braking Moderately From 100 kph 7-29
Figure 7-8 Required Test Maneuver for Test C-6 7-32
Figure 7-9 Test Site at Transportation Research Center for Test C-6 7-33
Figure 7-10 Test Site at GM Milford Proving Ground for Test C-6 7-33
Figure 7-11 SV Lateral Position and the Azimuth Angle To The POV: Test C-6 Parked Car in Transition to a Curve 7-35
Figure 7-12 Sequence of Required Vehicle Motions for Test C-9 (Cut-In) 7-36
Figure 7-13 Test Choreography for Test C-9 (Cut-In) 7-37
Figure 7-14 Vehicle Motions and Alert Requirements During a Test Trial: Test C-9 60 kph POV Cuts in Front of 90 kph SV 7-39
Figure 7-15 Staging Test C-13: Greater Size and Equal Distance 7-40
Figure 7-16 Vehicle Maneuver for Test N-7, Slow Cars in Adjacent Lanes 7-41
Figure 7-17 Cone Placements Used to Perform Test N-7, Slow Cars in Adjacent Lanes 7-43
Figure 7-18 Vehicle Motions and Imminent Alert Requirements During a Test Trial Test N-7 Slow Cars in Adjacent Lanes 7-44

List Of Tables

Table 7-1 Summary of Required Measurement Accuracy and Data Rates 7-8
Table 7-2 High-Priority Crash Tests Selected for Evaluating the Test Methodology 7-24
Table 7-3 High-Priority Nuisance Alert Test Selected for Evaluating Test Methodology 7-25
Table 7-4 Sites and Countermeasures Used to Execute High-Priority Tests 7-25
Table 7-5 Test Procedure Execution Time Estimates 7-46
Table 7-6 Average Distribution of Driving Conditions 7-50

7 FORWARD COLLISION WARNING SYSTEMS TEST PROCEDURES EVALUATION

7.1 Introduction

This chapter describes activities that focused on validating and improving the objective test methodology described in Chapters 6 and 7. The methodology includes twenty-six vehicle-level tests designed to evaluate the compliance of a FCW system with the set of minimum functional requirements developed in Chapter 4. There are several areas of the methodology that were evaluated.

The philosophy set forth when the test procedures for FCW systems were developed was that the tests should be executable by a variety of organizations and at a variety of existing track facilities. This required test specifications that would be interpreted the same way by different test engineers and that would accommodate the differences in the tracks and standard practices at different testing facilities. In addition, the tests were designed to be independent of the sensing technology used by the FCW system. In particular they need to be applicable to systems based upon millimeter wave radar, laser radar or video sensors. A major consideration was to devise tests that would produce consistent results when executed at different locations. Three sites were selected as representative of those accessible by the organizations that would execute the tests. These were the G.M. Milford Proving Ground near Milford, MI, the Ford Motor Company's Michigan Proving Ground near Romeo, MI, and the Transportation Research Center near East Liberty, Ohio.

The primary focus of the evaluation reported here is to provide an initial assessment as to whether the tests are practical to execute and provide a reasonable certainty that a FCW system which passes the tests actually satisfies the minimum functional requirements. Another concern addressed is whether the test results will be repeatable.

A major focus of the validation work was the execution of five key tests from among the twenty-six proposed. These tests were conducted using both a laser radar system and a microwave radar FCW system. The laser radar FCW system was installed on a vehicle instrumented to collect independent estimates of vehicle motion and position. The microwave radar system was installed on a different vehicle with identical instrumentation. The FCW systems were acquired from Mitsubishi Electronics of America (laser radar) and Eaton Vorad (microwave radar) solely for the purpose of validating the methodology. Performance evaluation of those specific systems was not the focus of the testing and no performance results are reported here.

Section 7.2 describes the process of selecting instrumentation for the vehicle testing activities. Section 7.3 presents the resulting testing setup. Section 7.4 describes the validation procedure and activities. This includes both the testing work and the work away from the track. The work reported here led to improvements in several test procedures presented in Chapter 5. The methodological approach and scope, however, remain intact.

7.2 Instrumentation Selection Process

Included in this section are discussions of measurements, props, test track facility requirements, challenges and a brief description of the process used to determine the instrumentation.

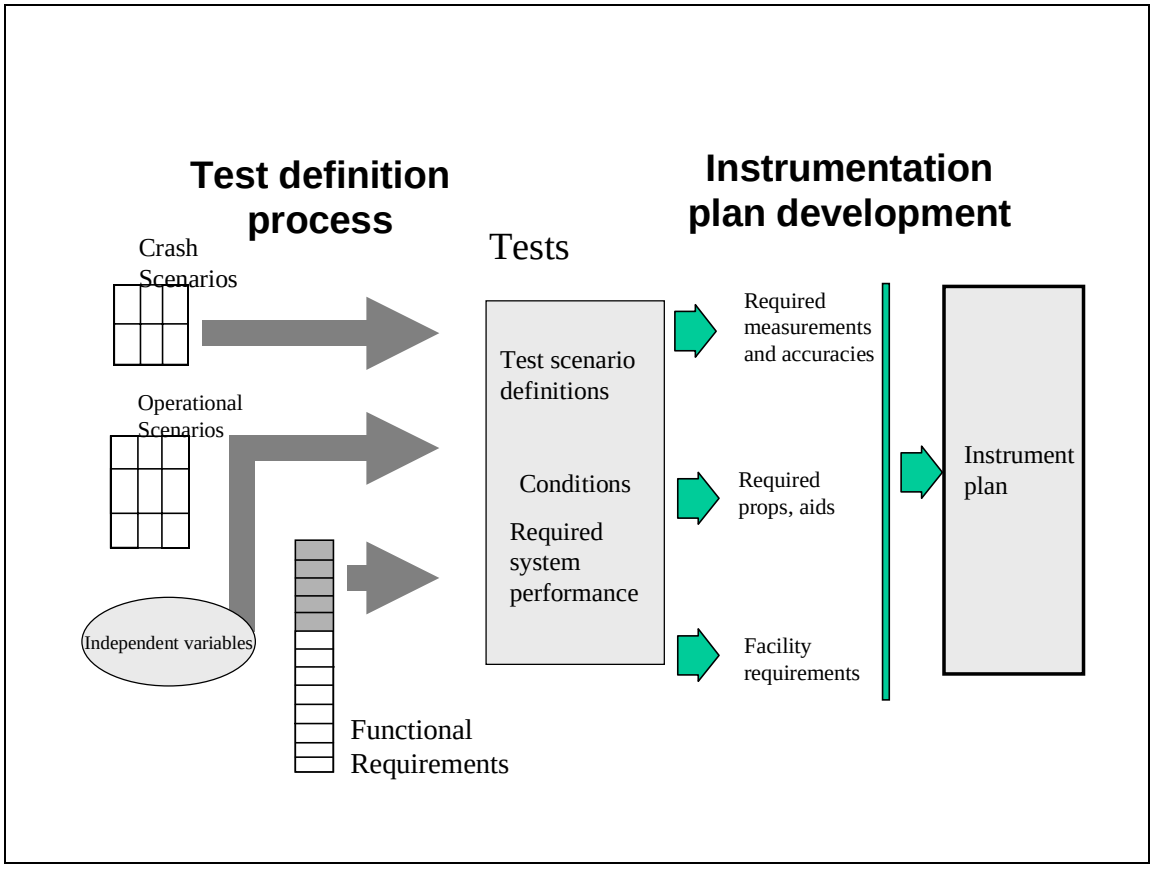


Figure 7-1 Instrumentation Plan Development Process

Figure 7.1 illustrates the process used to develop the tests and the list of instrumentation. The test procedures include variations of the Crash and Operational Scenarios. The variations are selected so that the ranges of values of each of the independent variables are represented adequately amongst the tests. The test definitions include the test scenario definitions, conditions that must be controlled when running the test, and the required system performance. These were then used to define the required measurements and accuracy's documented herein.

The purpose of conducting the tests is to evaluate the test procedures. The required measurements were selected so that it could be determined, first, whether a system passed the test, and second, that the test was conducted properly. This process required measurements of sufficient accuracy to both exercise the procedures (through evaluation of two FCWs) and to evaluate the procedures themselves. The test conditions, passing criteria, and background for each test were analyzed to determine the accuracy requirements for each measurement. Finally, alternative instrumentation approaches for each type of measurement were evaluated to determine which could satisfy the accuracy requirements. The resulting list of instrumentation used for the CAMP testing is provided in Appendix E.

7.2.1 Required Measurements and Accuracy

This section presents and justifies required measurements, accuracy, and data rates to support the testing. The abbreviation "SV" refers to the "subject vehicle," the vehicle equipped with the FCW under test. The abbreviation "POV" refers to "principal-other-vehicle," which includes any other vehicles in the immediate vicinity.

Figure 7-2 is a schematic of the onboard instrumentation on the test vehicles. Table 7-1 summarizes the required measurements and the corresponding accuracy and data rates. These results are developed in the remainder of the section, with supporting materials included in Appendix E.

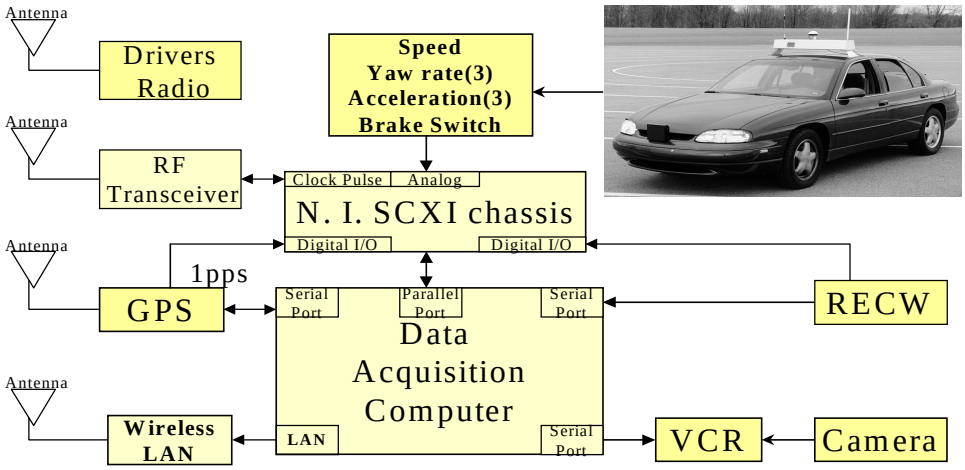


Figure 7-2 Block Diagram of In-Vehicle Instrumentation

Table 7-1 Summary of Required Measurement Accuracy and Data Rates

Measurement	Accuracy (3 sigma)	Onboard Data Rate Required	Supporting Section
Longitudinal position of SV, POVs, and clutter	6 cm	10 Hz	7.2.2
Longitudinal speed of SV and POVs	0.09m/s	10 Hz	7.2.2
Longitudinal acceleration of SV and POVs	0.10 m/s/s	10 Hz	7.2.2
Lateral position of clutter, stationary POVs and road	3 cm	NA	7.2.3
Lateral position of SV and moving POVs	10.5 cm	4 Hz	7.2.3
Yaw rate of SV and POV	1.8°/s	20 Hz	7.2.4
Visibility	10 m	NA	7.2.5
Brake pedal actuation time	0.10 sec	10 Hz	7.2.6
Roadway horizontal curvature (direction change)	1°	NA	7.2.7
Roadway elevation change (for super-elevation and vertical curvature)	5 mm/5m	NA	7.2.8

Note that Table 7-1shows requirements in terms of *absolute* positions or speeds, whereas the requirements addressed position and speed variables which are primarily *relative* quantities. The requirements in Chapter 4 define an “Alert Zone”, which is a zone stretching in front of the SV and following the shape of the road. Objects within this zone must trigger alerts under certain conditions (based on the range and range rate). Objects outside the Alert Zone should not trigger alerts. Therefore, when evaluating the performance of a FCW system, it is important to know whether objects or POVs are within the Alert Zone, as well as knowing the range and range rate to the object or POV. These are *relative* measurements, e.g., lateral position of a roadside object with respect to the SV.

During the process of developing measurement strategies, accuracy and instrumentation concepts, it became clear that the use of Differential Global Positioning System (DGPS) would best meet the combined set of requirements, including accuracy for these relative measurements, cost, flexibility during testing and testing design, availability, and schedule. Thus, Table 7-1 and the remainder of Section 7.2 are based on the approach of measuring motion with respect to an earth-fixed frame. Section 7.2.10 discusses the selection of a GPS approach and addresses the issues of choosing from among GPS solutions.

The following sections address the individual measurements listed in Table 7-1.

7.2.2 Longitudinal Position, Speed, and Acceleration

The requirements for measurement accuracy of longitudinal motion variables of the tes vehicles are driven by crash scenario testing. The crash scenario tests involve maneuvers designed to

trigger crash alerts. The FCW is then evaluated based on the range at which the alert occurred. For tests in which an alert in the SV is expected or desired, the crash alert timing criterion in Chapter 4 describes a minimum range at which the alert must occur (Section 4.2.3.1). The minimum required range is a function of range rate and parameters of a model describing the driver's anticipated reaction time and braking level. The FCW meets the requirement as long as the alert occurs at a range that is equal to, or greater than, the minimum range given by the requirements in Chapter 4. The required minimum range for an alert may be as small as 2.2 meters or as great as 100 meters (these are, respectively, the minimum and maximum longitudinal extents of the Alert Zone suggested in Chapter 4).

Figure 7-3 shows an SV and a POV at the moment a FCW issues an alert. To evaluate whether a FCW system meets this requirement, the difference between the actual range at alert onset, R, and the minimum required range for the situation, R_{warn}, is computed. If $R \geq R_{warn}$, then the FCW passes the test trial. If, however, $R < R_{warn}$, then the FCW fails the test trial. Let ε_R denote the difference, $\varepsilon_R = R - R_{warn}$. This difference is the basic metric to be used in evaluating the FCW system's compliance with the minimum warning range requirement.

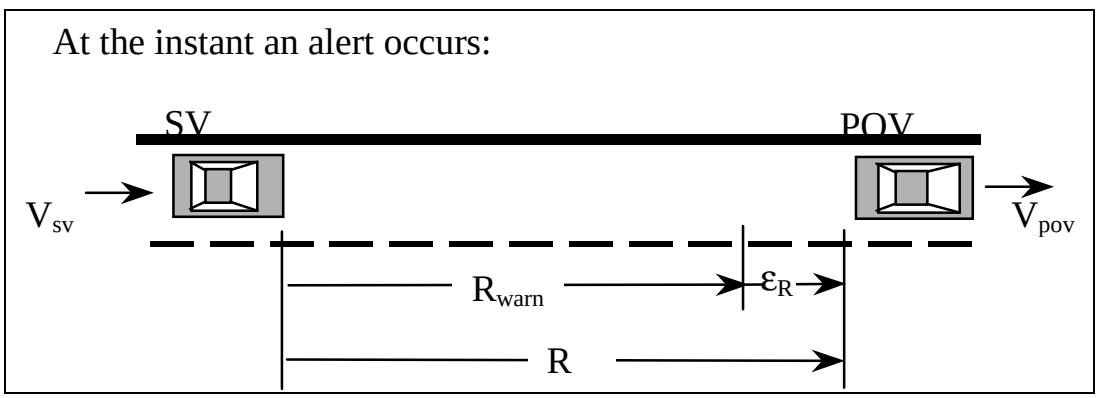


Figure 7-3 Comparing Actual Warning Range to the Minimum Required Warning Range

Measurement accuracy's should support the computation of the metric ε_R so that evaluation of the FCW system's warning range performance on a trial will be correct "almost always." When using data from an individual test trial to determine whether the FCW passed the trial, the following requirement is suggested:

The following 3-sigma requirement is levied: measurement error effects on the computation of the difference between the true range at the instant of alert and the minimum warning range cannot be greater than 5% of the minimum warning range, or 2.0 meters, whichever is greater.

Let $\hat{\varepsilon}_R$ denote the computed value of the metric, based on measurements. Then data from a test trial would be evaluated as follows:

If $\hat{\varepsilon}_R > max(0.05 * R_{warn}, 2.0m)$, then FCW passes trial (high confidence),

If $\hat{\varepsilon}_R < max(-0.05 * R_{warn}, -2.0m)$, then FCW fails trial (high confidence), and

If $|\hat{\varepsilon}_R| \leq max(0.05 * R_{warn}, 2.0m)$, then there may not be enough confidence to state that the FCW passed or failed the trial.

The "high confidence" is quite high – if the error in the metric is assumed to follow a normal distribution, for instance, the probability that the conclusion is correct is 99.7%.

The third condition above corresponds to cases in which the estimated range at alert time is quite close to the estimated minimum required range at alert time, and the effect of measurement uncertainties is large enough to call into question any conclusions. The frequency with which results fall into this region depends on both the measurement accuracy and the closeness of the FCW performances to the required warning ranges. By tightening measurement accuracy, this region of uncertainty can be shrunk but not eliminated.

There is a tradeoff, however, between tightening measurement requirements and keeping equipment cost and testing feasibility within practical ranges. Appendix E lists the equipment selected for validation testing of the test procedures; the equipment choices are largely driven by requirements of ground-truthing lateral positions during lateral maneuvers.. The boxed requirement above can be met with the equipment listed in Appendix E, *assuming that the minimum warning range is closing-speed dependent.* Testing occurred with a draft set of alert timing requirements that depended on closing speed. Appendix E, Section E.3 demonstrates that the boxed requirement above is satisfied for the draft set of timing requirements. The analysis in the appendix develops an analytical expression for the metric of warning range performance, then computes a 3-sigma value for the uncertainty in the metric, given instrument accuracy and data rates:

- Vehicle position, longitudinally: 0.06m, 3 sigma (SV, all POVs)
- Vehicle speed, longitudinally: 0.09m/s, 3 sigma (SV, all POVs)
- Longitudinal acceleration: 0.10 m/s^2, 3 sigma (SV, POV – only one vehicle brakes during testing at any one time)
- Time at which the alert occurred: 0.050 sec, 3 sigma

The analysis assumes upper bounds on the following test conditions and variables:

- Range rate < 33 m/sec (120kph),
- Relative acceleration between vehicles in the longitudinal direction, magnitude no greater than 0.3g,
- Time between onset of alert and collection of measurements of vehicle positions, speeds, and accelerations: <0.250 sec

The above requirements are also sufficient for tests with a stationary POV since the location of the POV can be surveyed to within a few centimeters. The above requirements on longitudinal motions are also more than adequate to provide measurements for documenting test execution, for purposes of investigating anomalies, proving “acceptable” execution of the tests, or for validating the test procedures

7.2.3 Moving SV and POV Lateral Positions

Most of the test scenarios require measurement of the lateral position of the SV. However there are two types of tests with much tighter requirements. These are (1) the tests that involve the SV driving by stationary objects that are just outside the Alert Zone, and (2) the tests that involve lateral maneuvers, either by the SV or the POV. Although the analysis shows that the lateral maneuvers have the tightest position measurement requirements, the development of both requirements are presented here for review.

The requirements state that the Alert Zone extends along the path of the road with a width that extends beyond the width of the SV on either side (maximum width of 3.6 meters). An alert should occur if a POV is in the Alert Zone and the longitudinal distance and relative velocity requirements are met. Furthermore, alerts should not occur due to objects that are outside the Alert Zone.

7.2.3.1 Lateral Position Relative to Stationary Objects

For scenarios with stationary objects that always remain outside of the Alert Zone, the procedures will require that the SV pass within some distance from the other object. There is an implicit lateral tolerance on how accurately the SV must be driven. The requirement is that the SV drive by the stationary objects so the Alert Zone stays between 0.0 m and 0.5 m lateral offset from the objects.

The measurements must be accurate enough to provide assurance that the actual path of the SV was within this 0.5 m band. However, the accuracy with which the SV can be driven has an impact on the accuracy requirements for the lateral position measurements (Figure 7.4).

For now we can assume that the position of the stationary objects can be determined much more accurately than the position of the moving SV. Surveying techniques that measure the position of stationary objects with a 3σ accuracy of 3 cm should be used.

Suppose that the SV can be driven so that the maximum lateral deviation from the desired path is 10 cm. To allow for the variation in the actual path and the uncertainty of the position measurements, the desired path is selected to put the Alert Zone 0.25 m from the stationary object. Then it is required that the 3 sigma measurement error be such that a vehicle that is 10 cm from the desired path should produce measurements that are inside the 0.0 m to 0.5 m limits. This would be accomplished if 3σ = 25 cm – 10 cm or 15 cm.

Then, for the stationary object tests, a 3σ lateral offset accuracy of 15 cm is required.

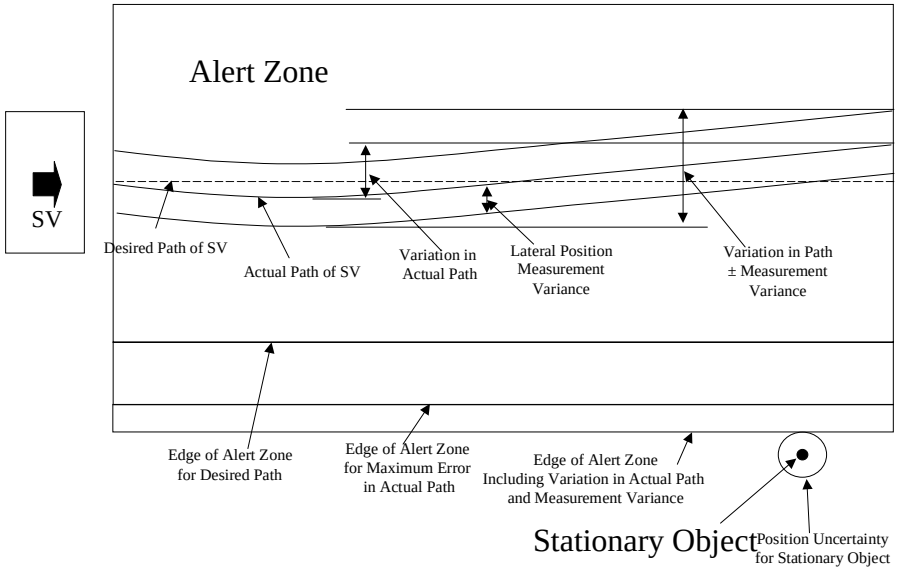


Figure 7-4 Tolerance Stackup for Lateral Position Measurements with Stationary Object Outside the Alert Zone

7.2.3.2 Lateral Position During Lateral Maneuvers

In section 4.3.1, the requirements state that the Alert Zone extends along the path of the road with a minimum width corresponding to the width of the vehicle and a maximum width that extends beyond either side of the SV to a maximum width of 3.6 meters. The requirements indicate an alert should occur no later than when the path of the SV or the POV are such that the POV crosses into the minimum width of the Alert Zone from the side (see Figure 4.6).

Considering the likely vehicle width, these requirement might allow a lateral tolerance of 0.5 m for when the alert must occur on a cut-in. In other words, an alert should not occur before a POV enters the outer limit for the Alert Zone from the side and it must occur before the side of the POV gets less than the inner limit of the Alert Zone, if the speed and distance conditions are met.

Next, engineering judgment suggests that the measurement uncertainty be less than 10% of the width of the tolerance zone. This will provide a high level of confidence that, when an alert occurs, it is certain whether the side of the POV was between the limits for the width of the Alert Zone. Then σ = 0.1 x 50 cm = 5 cm. Therefore, the instrumentation must provide a lateral offset accuracy less than 5 cm. Since absolute position measurements from 2 vehicles will be required to achieve the lateral offset calculation, each must have an accuracy of 0.707 x 5 cm = 3.5 cm.

So, for lateral maneuvers, the required measurement accuracy for lateral position would be 3.5 cm for each vehicle.

7.2.4 Yaw Rate

Yaw rate is required to measure vehicle positions when GPS is not available and to improve position interpolation between GPS readings. The maximum yaw rate can be estimated by assuming a maximum turn rate with a lateral acceleration of 0.3g. Experts at Ford and GM have suggested that this is the highest comfortable value for most drivers. For a curvature, R, and speed, V, the lateral acceleration is V^2/R. The yaw rate, ω, is $V/R=a/V$.

The yaw rate accuracy requirement is derived from the need to know the lateral position of a vehicle relative to the road or another vehicle. The lateral position of the Alert Zone relative to the road depends on the lateral position of the SV. Consider the simple case where the vehicle is supposed to be going straight. If the actual lateral yaw rate of the SV is ω then the lateral offset, l, that occurs between samples is:

$$l = (V/\omega) \{ \cos\theta_o - \cos(\theta_o + \omega T) \} + l_o$$

Where T is the time between samples, θ_o is the initial yaw angle and l_o is the initial lateral offset. The sensitivity, s_ω, of the lateral offset estimate to errors in ω is:

$$s_\omega = dl/d\omega = -(V/\omega^2) \{ \cos\theta_o - \cos(\theta_o + \omega T) \} - (V/\omega) T \sin(\theta_o + \omega T)$$

The standard deviation in lateral position estimates, σ_l, that occurs between samples would be:

$$\sigma_l = |s_\omega| \sigma_\omega$$

$$\sigma_\omega = \sigma_l / |s_\omega| = \sigma_l / |-(V/\omega^2) \{ \cos\theta_o - \cos(\theta_o + \omega T) \} - (V/\omega) T \sin(\theta_o + \omega T)|$$

Assuming that T=0.25 sec, σ_l = 2 cm; that ω, and θ_o are zero; and that V is 110 kph then

$$\sigma_\omega \cong \sigma_l / (VT^2)$$

$$\sigma_\omega \cong 0.0105 \text{ rad/s} = 0.600°/\text{s}$$

So a yaw rate sensor with a 3σ accuracy of 1.8°/s would be adequate.

7.2.5 Visibility

Visibility measurements are required to provide repeatability for the low visibility tests. Fog, rain, or dust should be generated to simulate low visibility conditions. Instrumentation is required to measure visibility of approximately 200m. The requirements state that the systems must either operate normally or indicate that they cannot function properly under the current conditions. It seems reasonable that a 10% variation in the visibility conditions will still produce repeatable

results. Therefore the visibility instrumentation must have an accuracy that is better than 10% at 200m visibility.

7.2.6 SV Brake Pedal Actuation Time

SV brake activation time is needed to determine whether a test driver suppressed an alert by applying the brake (perhaps in maneuvering for safety). The brakes are not to be applied, except for evasive maneuvers required after the desired test results have been collected. To ensure this is the case, a brake pedal switch is recommended. The 0.1-second accuracy will be adequate.

7.2.7 Roadway Horizontal Curvature

Roadway curvature measurements are required to determine the speeds at which test vehicles must be driven around curves. The AASHTO policy defines guidelines for the relationship between design speed, radius of curvature, and super-elevation. Tables III-7 to III-11 of the AASHTO Policy on Geometric Design of Highways and Streets indicate radius of curvature for various design speeds and super-elevation slopes.

The test procedures call for curves similar to a tight highway cloverleaf. They also specify limits on the curvature for tests intended for straight roads. The Federal Highway Administration Highway Performance Monitoring System (HPMS) database indicates that 85% of the curves on rural highways, freeways, and arteries have a curvature of less than 4.4°/100m. This corresponds to a radius of curvature of 1302 meters.

Although it might be argued that an 85th percentile curve is adequate for testing of FCW systems, it was decided that tight cloverleaf curves are important for testing the number of nuisance alarms produced by a system. Observations on local highways indicate that a curve corresponding to a 40 kph design speed should be included in the test scenarios. The AASHTO guidelines suggest that the radius of curvature for a curve with a design speed of 40 kph with a 4% super-elevation should be no less than 60 meters.

Therefore the instrumentation should be able to measure radius of curvature between 60m and 1300m. For a small radius of curvature, the angle change over a fixed distance of road can be measured. For longer radii, the distance can be measured for which a 1° change in road direction occurs. In either case, the ability to measure distances up to 300 m to 1 cm and angles to 1° will provide adequate information to determine the design speed of a curve.

7.2.8 Roadway Super-Elevation on Curves and Vertical Curvature

Super-elevation measurements are required to determine the speeds at which test vehicles must be driven around curves. The AASHTO Policy on Geometric Design of Highways and Streets defines guidelines for the relationship between super-elevation, design speed, the radius of curvature, and side friction factor of a road. Tables III-7 to III-11 of the policy guidelines indicate super-elevation requirements to 0.1 % for design speed increments of 10 kph. Therefore, slope

measurements with an accuracy of 0.1 percent will be needed to determine the design speed of a curve to within ±5 kph.

Vertical curvature measurements will also be required to determine the speed at which test vehicles must be driven at a sign at the top of a hill. The AASHTO policy defines guidelines for the relationship between vertical curvature (sag & crest curves) and design speeds. The vertical curvatures are expressed in meters per percent change in grade. To distinguish whether a vertical curve is for a design speed of 110 kph vs 120 kph, the measurements must be accurate enough to distinguish between roads with curvatures of 202 m/% and 151 m/%.

Since the test specifies a constant car speed, the curvature only needs to be measured often enough to know that the car was at the right speed about once a second. If the car is traveling 120 kph then the grade only needs to be measured at points separated by 0.5 to 1 second or approximately every 15 to 30 meters.

Another way to determine how often the grade needs to be measured is to assume it should be about 20% of the maximum length of the Alert Zone, or 20 m. Over 20m the slopes for hills designed for 110 kph and 120 kph would have a change of grade of 0.099% and 0.132% respectively. Putting this in terms of angles the difference in slopes that must be distinguished is between 0.0567 degrees and 0.0756 degrees, a difference of 0.0189 degrees.

The simplest way to measure the vertical radius of curvature would be to measure elevation relative to the top of the hill at various points along the road. If elevation is measured every 5 meters then the change in slope over 20 meters can be measured. Over 5 meters a slope measurement with an accuracy of 0.1% would require measuring the change in elevation to 5mm.

Therefore, equipment is required that can measure changes in elevation with an accuracy of 5 mm over distances of 5 meters and to measure distances of up to 20 meters between elevation measurement locations.

7.2.9 Sampling Rate for Onboard Data Acquisition Systems

The most pressing data rate requirement for the onboard acquisition system is driven by the need to measure vehicle-to-target lateral offsets during tests with lateral maneuvers, for instance, for a test with a POV cutting into the host SV's lane. Since the critical vehicle handling bandwidth will be less than 2 Hz, the required data rate is selected as ten times that bandwidth, or 20 Hz.

Appendix E develops the individual data rate requirements for each required measurement of Table 2.1. This demonstrates that the 20 Hz rate is sufficient.

7.2.10 Ground Truth

As part of the FCW test procedure validation, measurements were recorded to verify that the alerts occurred at the appropriate relative distance. The FCW systems could provide this information, but due to system delays and other limiting information, a separate independent

method was needed. Several differential Global Positioning Systems were found to have the potential measurement and accuracy capability to meet the requirement.

For these instruments, the advertised DGPS accuracy is 3cm with baseline distances less than 10km to a base station. By placing a DGPS receiver on each moving vehicle and having a stationary reference base station, the position of the moving vehicles and stationary objects can be recorded during the test procedure.

7.2.10.1 DGPS Data Collected at a 4 hz Rate

The data output rate from a DGPS receiver depends on the type of receiver. If a dual frequency, real-time position measurement is used, then a 4 Hz output can be expected. For a single frequency with only data logging then a 20 Hz output can be expected.

For the best accuracy, it was decided to post-process the DGPS data. Post–processing eliminates errors from communication delays between base and mobile receivers. Commercial software was used to process the GPS information.

7.2.10.2 GPS Options

A comparison of three GPS receivers was made for the purpose of selecting a receiver that would meet the measurement accuracy requirements. All three are specified to be dual frequency, real-time kinematics, and high accuracy receivers. Each receiver was selected from a different manufacturer. They are Trimble model 7400Msi, Ashtech Z-12, NovAtel Millenium RT-2. The estimated cost shown in the table below is for four receivers that are needed to perform the testing.

	Trimble	Ashtech	NovAtel
Position Accuracy	3 cm	3 cm	2 cm
Data Rate	5 Hz	10 Hz	4 Hz
Velocity Accuracy			0.03 m/s
Est. Cost	$77,800	$80,700	$79,400

7.2.10.3 GPS Selection

All receivers selected for the comparison would have met the needs. The estimated costs are about the same. It appears that the selection of a DGPS receiver is not critical, but limited to dual frequency, real time kinematics for the best accuracy.

7.2.10.4 Required Supporting Measurement

Interference of GPS satellite signals by trees, bridges, and tunnels are a common problem. Other GPS users recommend that other vehicle state sensors be used to help bridge the gap when the satellite signals are not available for short periods of time. For this reason the following sensors were used in addition to the DGPS for ground truth metrics: accelerometers, ABS wheel speed sensors, and gyros for vehicle yaw, pitch, and roll rates.

7.2.10.5 Software Development

The integration of vehicle state information, DGPS, and radar information into one data file was a custom software job. Each device had its own unique format that was combined to a common data format. Synchronization of the data had to be addressed because some of the devices had different update rates.

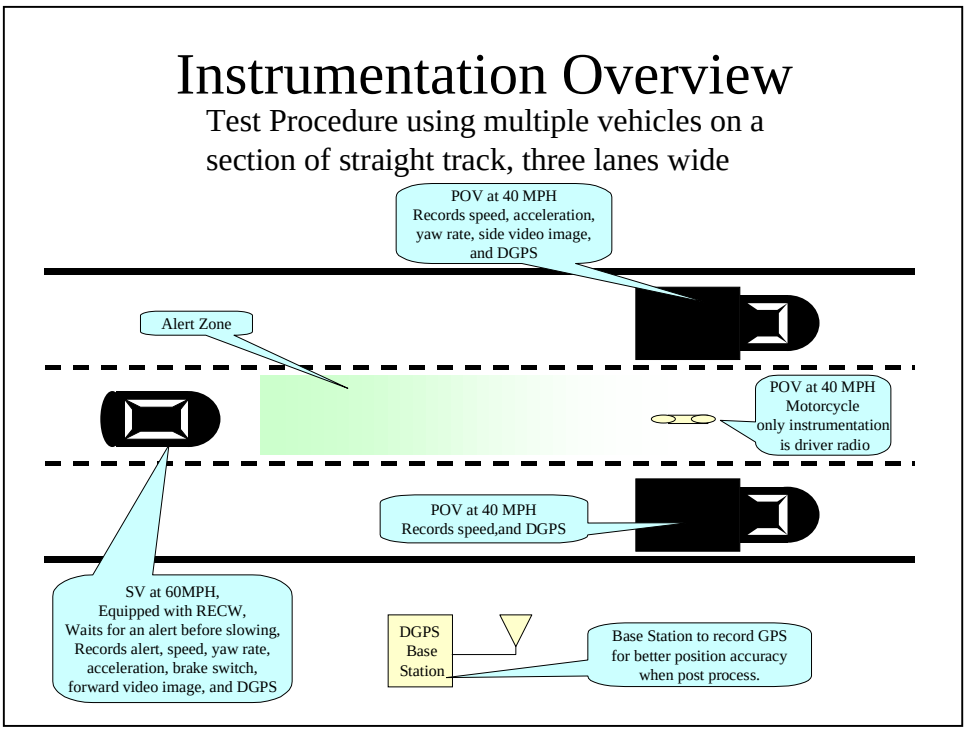


Figure 7-5 Use of Vehicle Instrumentation for a Complex Test

7.3 CAMP Testing Equipment/Instrumentation

The test procedures place requirements upon the type of information that must be collected and the accuracy of the measurements. Validating the test procedures imposed additional

instrumentation requirements. The instrumentation was selected to meet these requirements. The data collection rates were selected by considering the vehicle dynamics limits.

Figure 5 illustrates how the vehicle instrumentation was used for a complex test scenario. Vehicle motion during dynamic testing was determined by vehicle speed, brake pedal switch, yaw-pitch-roll rates, acceleration in three axis, and relative position on a test track from DGPS. By knowing the precise vehicle motion and relative position during the testing, the motion of the Alert Zone was calculated. Evaluation of the data collected during the test procedure showed when objects moved into and/or out of the Alert Zone during the dynamic testing. The FCW systems provided real-time feed back to aid in performing the test procedures.

The photographs that follow illustrate how the equipment was installed into the test vehicles. Appendix E includes a list of equipment used and selected manufacturers' data sheets.

7.3.1 Basic Instrumentation

The data collected from the vehicles includes vehicle speed and brake pedal action. An accelerometer is installed to provide acceleration in three axes and rotation rates about the axes. This information is collected as analog inputs through a signal conditioning front-end to the data acquisition computer. The video recorder, Global Positioning System (GPS) receiver, and countermeasure device are interfaced to the computer through serial ports. When multiple cars are used for a test, the data acquisition computer establishes a network link to control the beginning and end of each test from one car. Communication with other drivers is through hand-held radios.

The data acquisition program was developed using National Instruments LabView software. When the data acquisition program is started, the operator in each vehicle identifies which vehicle the equipment was installed (SV, POV1, POV2). The operator in the SV uses that computer to control the computers in the other vehicles. The driver of the SV selects a data rate and controls the start and stop of data collection for the GPS receivers and all other instruments. A reference GPS site was used to collect data at the same time so correction can be made to the GPS data during post processing. The GPS site is referred to as the base station and is not shown here.

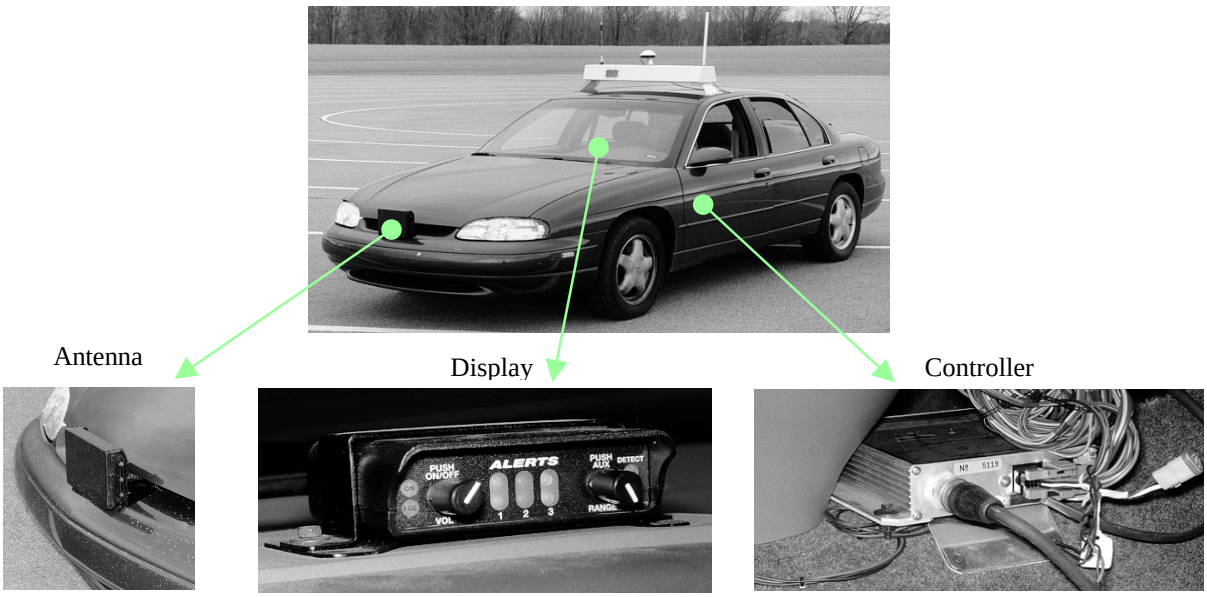
7.3.1.1 Photographs of Instrumented Vehicles

This photograph shows the three CAMP Test Cars. From left to right, they are the 1996 Mitsubishi Diamante 30RSE, and the two 1997 Chevrolet Lumina LTZs.

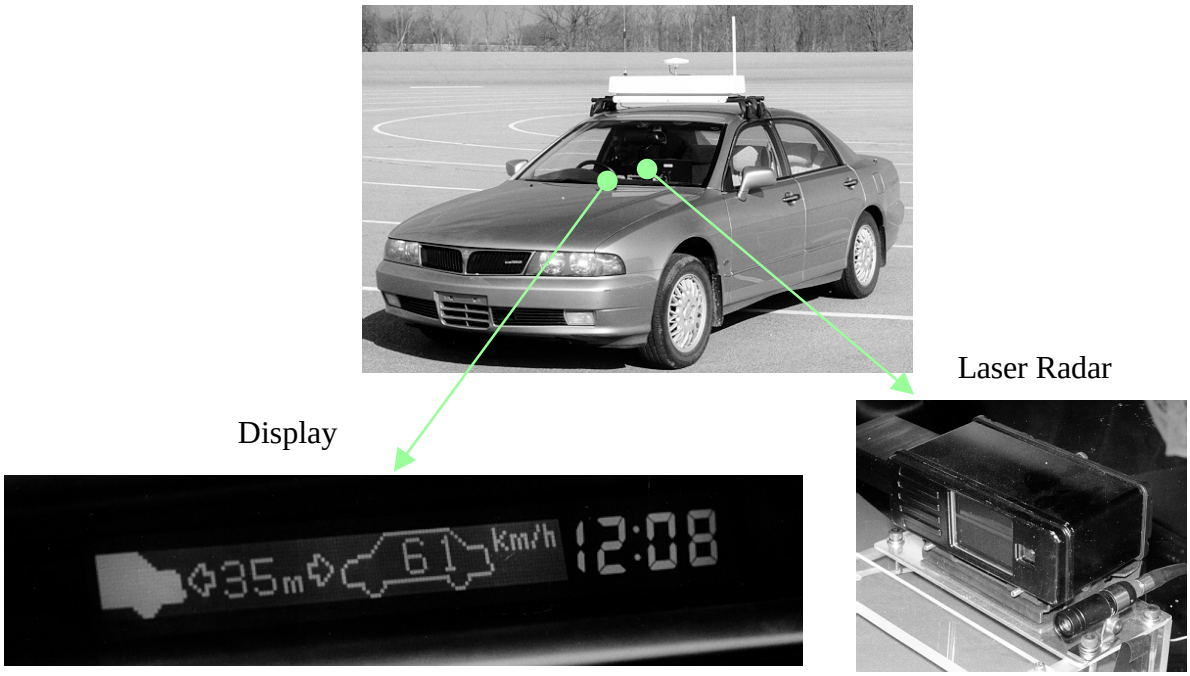
This photograph shows the two trucks and a motorcycle used for testing. These vehicles were rented for one week of testing.

7.3.1.2 Countermeasure Systems Installation

The Chevrolet Lumina LTZ was equipped with a microwave radar FCW system commercially available, the Eaton Vorad EVT-200. These photographs show where the equipment was installed. The display is on top of the instrument panel to the right of the driver. The controller is located under the instrument panel on the hump between the driver's and passenger's feet. The wires are on the passenger side of the vehicle to prevent interference with the driver's pedals.

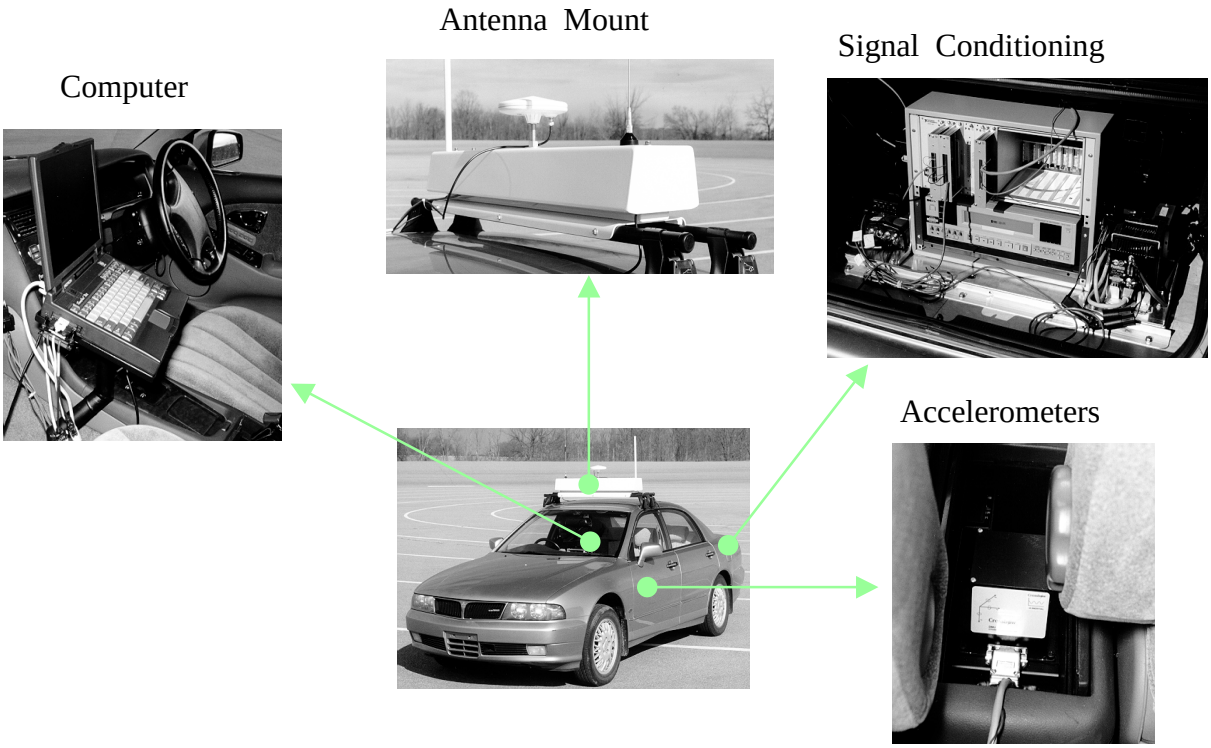


The Mitsubishi Diamante 30RSE is equipped with a Laser Radar FCW System. The FCW system was acquired from Mitsubishi Electronics of America, and was a specially enhanced version of the system sold on the vehicle in Japan in the 1996 model year. The display was an integrated part of the instrument panel next to the clock. The Laser Radar was mounted on top of the instrument panel on the passenger's side of the vehicle.



7.3.2 Equipment Location in the Vehicles

Shown in this group of photographs is the typical equipment installation in a car. The data

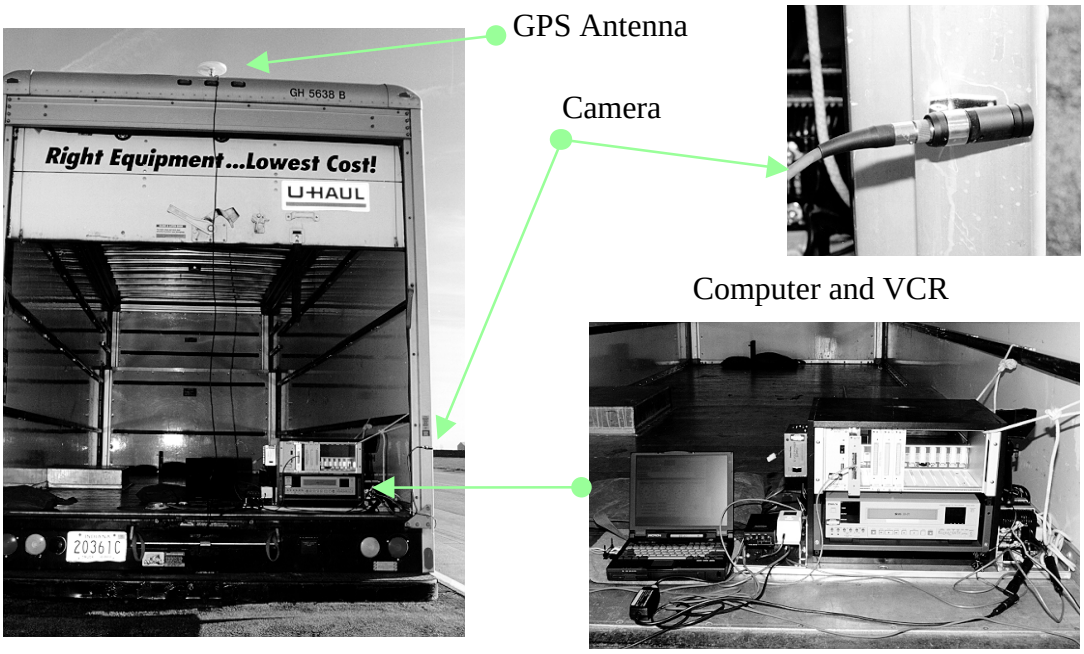


acquisition computer is placed on a pedestal on the passenger side of the car, and is positioned so the driver can operate the program. The antennas were mounted over the center of the car so the GPS antenna was directly over the accelerometer. The accelerometer was mounted in the center of the car between the driver and passenger seats. The rest of the equipment was mounted to a rack and placed in the trunk of the car.

7.3.2.1 Truck One Installation

These photographs show how the equipment was installed in the trucks for executing Test C-13, for which the POV is a motorcycle travelling between two trucks.

The Truck in the Left Lane



It was important to place the GPS antenna at the back of the truck and have the camera looking in the direction of the motorcycle. This provided relative information for the location of the motorcycle during the test.

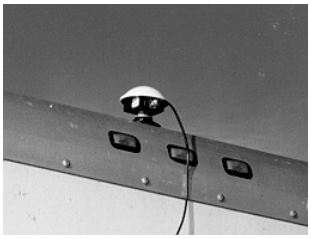
7.3.2.2 Truck Two Installation

Only GPS information was necessary for the second truck. The GPS antenna was mounted over the cab. The drivers of the trucks were instruction to maintain a relative position with each other by being able to observe the other driver during the test.

Truck in the Right Lane

Computer and GPS Receiver

GPS Antenna



7.4 Evaluating the Test Methodology

This section describes the approach that was used to evaluate the FCW system test procedures and data analysis methods developed by CAMP. There are several areas that were evaluated. The primary focus of the evaluation is whether the tests provide a reasonable certainty that a FCW system satisfies the minimum functional requirements. Additional concerns are that the tests be repeatable and practical to execute. Execution of the plan described provides an initial assessment of how well the test procedures and data analysis procedures satisfy these concerns. Chapter 5 covered the Test Methodology and Chapter 6 covered the Vehicle Countermeasure Data Analysis. The test procedures are to evaluate whether a FCW system complies with the minimum functional and performance requirements developed in Chapter 4. For completeness, the test procedures were evaluated to determine whether there is at least one test for each of the requirements included in Chapter 4.

The philosophy set forth when the test procedures for FCW systems were developed was that the tests should be executable by a variety of organizations and at a variety of existing track facilities. This required test specifications that would be interpreted the same way by different test engineers and that would accommodate the differences in the tracks and standard practices at different testing facilities. In addition, the tests were designed to be independent of the sensing technology used by the FCW system. In particular they need to be applicable to systems based upon millimeter wave radar, laser radar or video sensors. The tests are for use by FCW system

suppliers during the development of products, by vehicle manufacturers to qualify systems, and by independent organizations to evaluate FCW systems.. A major consideration was to devise tests that would produce consistent results when executed at different locations. Three sites were selected as representative of those accessible by the organizations that would execute the tests. These were the G.M. Milford Proving Ground near Milford, MI, the Ford Motor Company's Michigan Proving Ground near Romeo, MI, and the Transportation Research Center near East Liberty, Ohio.

Evaluations were performed in five areas:

Completeness of the tests (coverage of all requirements)

Correlation to performance during typical driving

Test procedure understandability

Test procedure executability, including driving maneuvers, cost, and time required

Test procedure sensitivity, including sensitivity to site and props, test team, path tolerances, FCW system settings and pass/fail criteria.

Some aspects of the Testing Methodology were evaluated by executing tests while others were done by expert review and analysis. The evaluation issues that did not require actually executing tests included the following:

Determining conflict between the test procedures and established practices at each of the proving grounds

Verification that sites exist for all tests at all three test facilities

Analysis of cost

Analysis of sensitivity of final pass/fail to selected test weights

Public road testing to verify that the tests reflect real-world countermeasure performance

In addition, this section covers the results of the evaluation and suggested improvements to the functional requirements and test procedures based upon the experience of actually running some of the tests on two different FCW systems.

It is noted that the performance of the countermeasures used during testing is not discussed. The performance of specific systems is not a primary interest in this project, except for the insight or understanding that unexpected behaviors provide. Furthermore, agreements with the countermeasure suppliers prevent any performance data from being released.

7.4.1 Test Procedure Execution

This section describes the details of the evaluations that were conducted by executing tests on a test track. To select the tests that were executed, candidate tests were rated as to how likely it was that their execution would expose issues that would suggest improvements to the test methodology. This rating was done by the staff at CAMP after consultation with the staffs at the GM and Ford proving grounds. The issues that were considered included (1) safety, (2) driving

maneuver tolerances, (3) set-up and execution time, and (4) sensitivity to site, props, testing team, path or FCW system settings. This ranking identified five tests that were highly likely to expose issues that would suggest improvements to the test methodology. The highlighted tests in Table 7-2 and Table 7-3 are those that were selected and executed.

Test	Test name	Use to Address	Priority
C-1	100 kph to POV stopped in travel lane	Sens. to props	low
C-2	80 kph to POV at 16 kph		
C-3	100 kph to POV braking moderately from 100 kph	Safety	HIGH
C-4	100 kph to POV parked under overhead sign		
C-5	100 kph to slowed or stopped motorcycle		
C-6	SV to POV stopped in transition to curve (wet)	(a) Safety (b) Sens. to teams	(a) HIGH (b) medium
C-7	SVto POV parked on a curve		
C-8	SV to slower POV, in tight curve	(a) Sens. to site (b) Sens. to teams	(a) medium (b) low
C-9	POV at 67 kph cuts in front of 100 kph SV	(a) Safety (b) Sens. to path (c) Executability	(a) HIGH (b) HIGH (c) HIGH
C-10	SV at 72 kph changes lanes and encounters parked POV		
C-11	100 kph to stopped POV, with poor visibility.		
C-12	POV brakes lightly while SV tailgates at 100 kph.		
C-13	Greater size and equal distance (2 trucks, 1 m'cycle)	Safety	HIGH
C-14	Greater size and greater distance (1 truck, 1 m'cycle)		
C-15	100 kph to 32 kph Truck		
C-16	C-6, but with dry pavement and poor markings		
C-17	24 kph to stopped vehicle	Sens. to FCW setting	medium

Table 7-2 High-Priority Crash Tests Selected for Evaluating the Test Methodology

Test	Test name	Use to address	Priority
N-1	Overhead sign at crest of hill	Sens. to site	medium
N-2	Road surface objects on flat roads	Sens. to props	very low
N-3	Grating at bottom of hill		
N-4	Guardrails and concrete barriers	(a) Sens. to path (b) Sens. to FCW setting	low low
N-5	Roadside objects along straight and curved roads (wet)	(a) Sens. to prop design (b) Sens. to site	(a) medium (b) low
N-6	U-turn with sign		
N-7	Slow cars in adjacent lane, in curve	(a) Sens. to site, (a) Sens. to team	(a) HIGH (b) HIGH
N-8	Trucks in both adjacent lanes		
N-9	N-5, except with poor lane markings		

Table 7-3 High-Priority Nuisance Alert Test Selected for Evaluating Test Methodology

The five selected tests were executed at the sites indicated in Table 7-4. They were all executed with two different commercial FCW systems, one based upon a microwave radar and the other based upon a laser radar and video camera. A combination of engineers from CAMP and test drivers from the proving ground was used to execute the tests.

The following sections describe the execution of the five tests. Findings that affected the final set of proposed test procedures are reported.

Test	Site(s)	Tests Executed?	
		Radar	IR
(C-3) 100kph to POV braking moderately hard from 100kph	GM	Yes	Yes
(C-6) SV to POV stopped in transition to curve (wet)	TRC GM	Yes	Yes
(C-9) POV at 67kph cuts in front of 90kph SV	GM	Yes	Yes
(C-13) Greater size, equal distance (2 trucks & motorcycle)	TRC	Yes	Yes
(N-7) Slow cars in Adjacent Lanes	TRC	Yes	Yes

Table 7-4 Sites and Countermeasures Used to Execute High-Priority Tests

7.4.1.1 Test C-3: 100 kph to POV Braking Moderately Hard from 100 kph

Validation Issues and Findings

In Test C-3, the SV follows at a fixed headway behind a POV at 100 kph (see Chapter 5 for detailed test procedures). The POV begins to brake moderately hard and the SV continues at constant speed until either the crash alert is triggered or the range drops to less than the “too late” onset cutoff of Chapter 4. This test explores the ability of the countermeasure to function as required with a decelerating lead vehicle. The test is also used to collect data for use in estimating expected exposure to in-path nuisance alerts for the countermeasure.

This test was selected for inclusion in the validation work to determine whether such a maneuver was safe for execution by professional drivers. In this test, the POV initiates the conflict, so careful coordination is required. The result of the test track validation experiments was an understanding that the maneuver is safe, with care and planning.

Test Execution and Discussion of Data

Test C-3 has been revised since it was performed for validation purposes; the maneuvers are now milder than those that were executed and reported in this section. The test was executed with a lead vehicle deceleration of –0.4g; the revised procedures use –0.32g. (The revision was to accommodate the alert onset timing requirements based on the human factors experiments of Chapter 3.)Thus the finding that the test is executable at the higher deceleration level ensures that the test is executable at the lower deceleration level.

The test involves the SV and POV traveling on a straight, level, dry road with clear lane markings at approximately 100 kph with the SV lagging behind the POV by 2 to 2.5 seconds. The POV suddenly begins to brake at approximately 0.4 g while the SV continues at a constant speed. The test ends when the most imminent crash alert occurs or the SV comes within 90% of the minimum acceptable most imminent crash alert distance, whichever comes first. If the test conditions are nominal then the minimum acceptable most imminent crash alert distance would occur when the vehicles are about 40 meters apart, using the requirements at the time. They reach a condition of 90% of the minimum distance (as the POV continues to decelerate) when they are 34 meters apart. The test procedure includes tolerance for the speeds, range at braking onset, lateral offset, lateral position in the lane, and heading angle. There are also tolerances on the flatness and straightness of the roadway. (With revision of the test, the target range is 54 m, compared to the 34 m assumed in this section.)

The test trials were conducted on the 1.6 km (1 mile) long Military Straightaway at GM's Milford Proving Ground. Both the TRC and Ford's Romeo Proving Ground have straight tracks of similar length. Each trial began at one end of the track with the SV and POV stationary and about 65 meters apart. The data recording equipment was started and then the drivers would accelerate to 100 kph. The driver of the POV would then engage the cruise control, drive to the other end of the track and then brake at 0.4 g. While the POV was at a constant speed, the driver of the SV

would adjust the cruise speed or use the accelerator until the SV was between 60 and 65 meters behind and traveling the same speed as the POV. When the POV began to brake, the driver of the SV would continue driving at the POV at a constant speed until the minimum alert distance was achieved.

To achieve the desired headway, the driver of the SV would engage the cruise control at slightly under 100 kph. The range between the SV and POV was continuously displayed to the driver of the SV. This range reading was used to guide the driver who would adjust the cruise control speed or use the accelerator to achieve the target distance. Typically, this synchronization could be achieved by the time the vehicles had traveled 1 km from the start.

To guide the drivers in the braking maneuver, markers (construction cones) were placed by the side of the road as shown in Figure 7-6. On the right side of the road was a marker (A) at which the driver of the POV was to start braking. The digital display from an accelerometer was placed on the dashboard of the POV so the driver could have real-time feedback for controlling the deceleration. Further down the road was a marker (B) at a distance corresponding to the travel if the POV braked for four seconds at 0.4 g. When the POV came abreast of this marker the driver would take his foot off the brake and swerve ½ lane to the right. The four second delay between the first marker and the second marker on each side were calculated to bring the relative speeds and distances between the POV and SV to a condition such that the range at that time was less than 90% of the minimum acceptable most imminent crash alert distance. On the left side was a marker (A) 62.5 meters before the first marker on the right. The driver of the SV would check that the SV was even with this marker at the time the POV began braking. Further down the road was a second marker (B) on the left side of the road. This marker was at a distance corresponding to the travel of the SV at 100 kph for four seconds. When the SV came abreast of this marker the driver would swerve ½ lane to the left and then begin braking.

For practice runs, the position of the second marker was placed closer to the first. Practice began with a delay of 1 second from the onset of braking until the evasive maneuver. The second cone on each side was moved down the track between trials until the delay from onset of braking to the evasive maneuver was four seconds.

It was found that the digital display of the lead vehicle deceleration was updated too slow to provide good real-time adjustment of the braking level. Instead, the driver of the POV would read the braking level during a trial and use that to adjust the pressure he placed on the brake during the next trial. A mechanical acceleration indicator such as those which use a fluid in a U-shaped glass tube has been found to provide better real-time feedback to the driver. Another alternative would be to install an automatic braking system in the POV as was done for the human factors studies in this project.

Test C-3: 100 kph to POV braking moderately from 100 kph

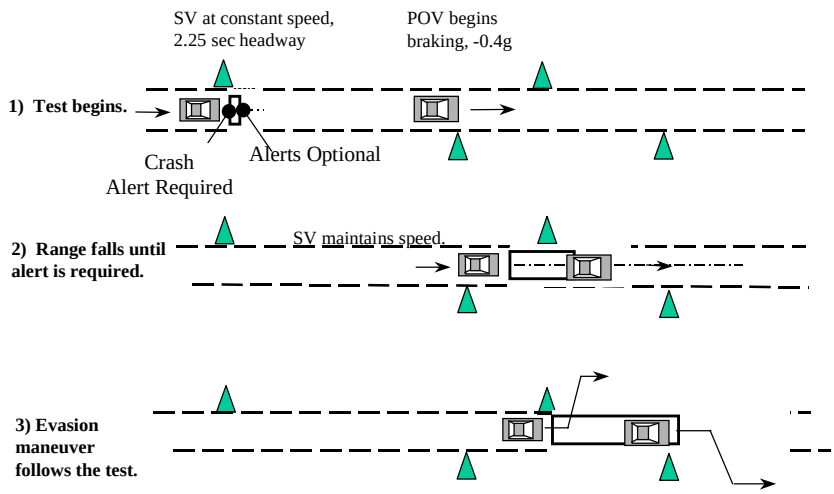


Figure 7-6 Driving Cues for Test C-3

Seventeen trials were performed once the orchestration and practice phases were complete, including 7 trials with the radar-based countermeasure and 10 with the laser radar system. An example of the vehicle motions and alert requirements during the trials is shown in Figure 7-7. Data showing the longitudinal motions and requirements are shown in the top plot of the figure, and lateral components are shown in the bottom half. In this example, the SV and POV speeds are initially near 100kph and the range between the vehicles is approximately 61 meters, per the specifications in the interim test procedures. The POV begins to brake near the 8 second mark in the plots, as shown by the deceleration levels and the falling POV speed. The range between the vehicles also begins to fall.

The lower plot in Figure 7-7 includes two traces representing the lateral positions of the center of the vehicles, measured relative to the road. In this example the SV runs slightly to the right of the POV as they approach the point of braking, but within the test specifications of 0.5 meter.

In both plots, notice the vertical line at about 11.5 seconds. This indicates the moment that the most imminent alert becomes allowed by the requirements in Chapter 4. This change is due to the decrease in the range that is caused by the slowing lead vehicle. A bar running along the abscissas changes from light shading (most imminent alert prohibited) to a hatched pattern to indicate that the most imminent alert is now permissible. About one second later, a second vertical line indicates that the most imminent alert is now required. The bar changes from hatched to solid black. The alert requirement changes in this test due to the decreasing range.

Consider the kinematic conditions at the moment that the most imminent alert becomes required: the SV is closing on the POV at 50kph (13.9 m/s) and the range for the various trials falls between

35 and 38 meters. Thus the time to collision is less than three seconds. As the POV continues to brake, the range and the time to collision drop quickly; the drivers of these 17 trials felt safe with this test, but there is a need for careful orchestration and execution.

Returning to Figure 7-7, as the goal of reaching the crash alert minimum required range is achieved, the POV steers to its right and the SV to its left in the planned evasive maneuver.

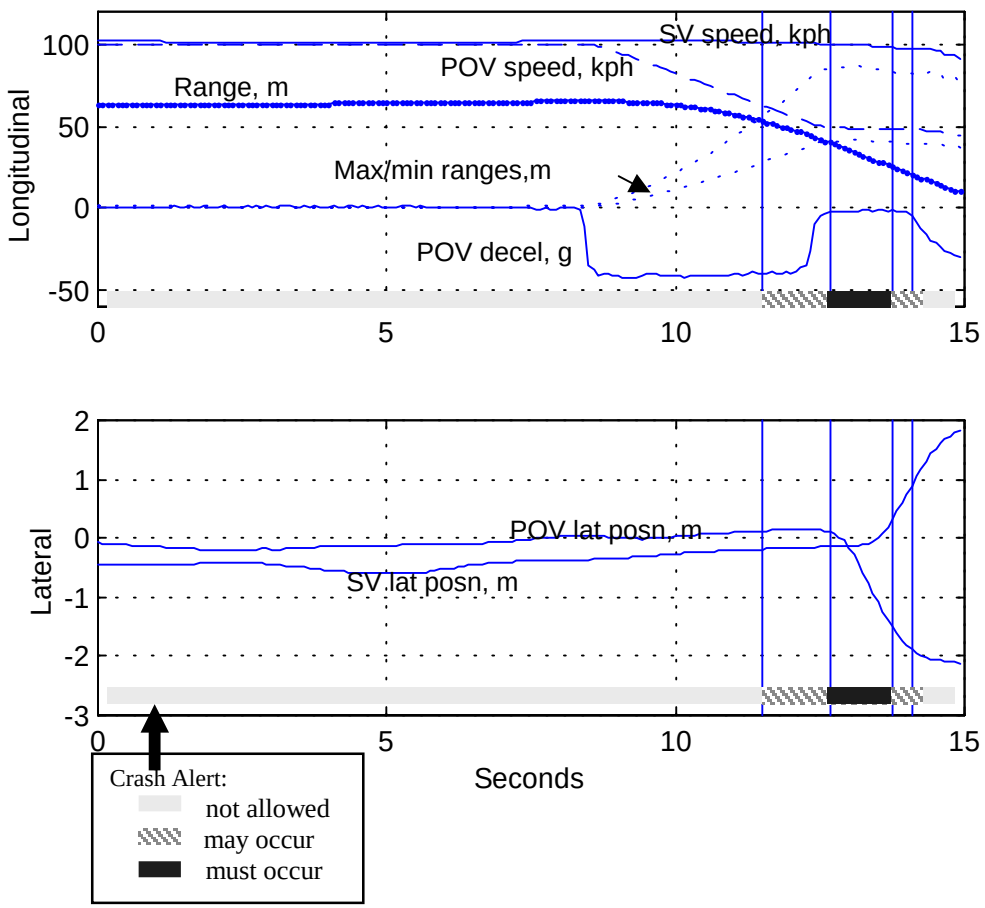


Figure 7-7 Vehicle Motions and Alert Requirements During a Test Trial: Test C-3 100 kph to POV Braking Moderately From 100 kph

The POV has released its brakes slightly before this goal. In the 17 trials, several trials showed one or both vehicles beginning there evasive maneuver slightly early (80 to 250 msec early). This can be avoided by placing the evasion cue cones slightly further down the road – the difference between an ideal step input braking maneuver and the actual first-order type response left the POV traveling slightly faster than predicted by the simple cone-placement analysis.

To evaluate the definition of the Test C-3 test maneuver that was given in the Chapter 5, the trial data was examined closely. Specified values and tolerances had been proposed for ten variables, including SV and POV speeds, headway, POV deceleration profile, SV heading angle, SV and POV lateral positions, SV brake switch, and the required range to achieve before beginning the evasive maneuver. The data shows that three requirements were sometimes not satisfied during execution. None of these, however, suggest substantive changes to the test. Two requirements sometimes violated are the average speeds of the vehicles before braking begins. This was caused by the POV speedometer being in error by a few kph at the test speeds, and so both vehicles typically traveled 102 kph with deviations of less than 0.5 kph. A speedometer calibration or more accurate in-vehicle speed indicator would correct this. The third requirement sometimes violated was the requirement that the range should drop to 90% of the minimum required range before any evasive maneuver occurs. The cause and solution for this issue were described earlier.

7.4.1.2 Test C-6: SV to POV Parked in Transition to Curve (wet)

Validation Issues and Findings

In Test C-6, the SV, initially in a straightaway, approaches a curve. The POV is a stopped car approximately 60 to 90 m into the curve. This test studies the countermeasure's ability to track targets through changes in curvature. A wet road is used to ensure that the FCW system is able to sense the curvature change with wet roads, a common condition that may challenge some sensing modalities.

This test was selected for execution during the validation phase in order to investigate two key issues: executability and sensitivity to the test site (curve radius). The primary concerns regarding executability were (1) the safety of running a test involving an evasive lateral maneuver in a curve on wet pavement, and (2) the ability to hold a prescribed lateral position in a transition to a curve. The primary concern involving test site curvature was to minimize the possibility that a test executed on different curves would give different pass/fail results. Executing this test would require addressing the availability of curves at the different sites. allowed the opportunity to to determine how to promote repeatability of the test across different test sites (proving grounds). The test procedures proposed in the interim report required that this test be run at a fixed speed (72 kph) on a track with a radius of curvature that falls within a prescribed bound. The data from executing this test was expected to provide feedback regarding this approach.

Data is presented and discussed in detail below, but the key findings are now stated. The executability issues did not lead to any revisions of the test procedures. It was found that the evasive maneuver (steering around the POV) involves no discomfort for the driver and presents no significant safety concerns beyond common testing work. It is argued that drivers can meet the required lateral position tolerance (0.5 m) with the help of driver aids, even though a tendency to "cut the curve" appears at the transition to the curve.

Significant revisions were motivated by the investigation of curvature issues, however. These revisions are incorporated in the test procedures of Chapter 5, and follow from two findings. First, the available curves at the test track sites considered are rather limited and are not representative of public roads either in the radius of curvature values or the superelevations. This is especially true when looking for transitions into or out of curves. The available curves are typically tighter than required in the first proposed test procedures, with larger superelevations than assumed in the original instructions (which used AASHTO guidelines for speed/curve/superelevation relationships). The second finding was that the radius of curvatures available at the different facilities are quite different in some cases, and without care the procedures will not provide a FCW system the same "look" at different sites. For example, at the moment of required alert, the POV may appear 8 deg to the left of the SV's heading at one test site and 4 deg at another. This is considered an important element of tests involving curves, and the variation was considered unacceptable.

The speed and radius of curvature requirements were revised (e.g., Test C-6) to resolve these concerns. See the test description of Test C-6 in Chapter 5 for the approach taken. With the new approach, the azimuth angle to the POV at critical moments in the test is approximately the same across a wide range of allowed curvatures. SV heading angle tolerances were tightened to improve the repeatability of these tests between trials at the same site. Together, the revisions based on these findings provide requirements that allow testing on a wider set of curves, provide the FCW similar "looks" at different curves, and still involve curvature/speed settings that are realistic public road scenarios.

A secondary observation involved lane markings at the testing sites. It was found that the pavement geometry at both locations satisfied the test requirements but the lane markings at those locations did not meet the requirements. At the GM Proving Ground there was a distance of about 100 m between the end of the lane markers on the straight section and the beginning of the curve. Furthermore, the SV had to cross over markings for the curve that lead into the black lake area. At the TRC there was a jog of about 1.5 m in the lanes at the transition and there was a spiral section between the straight and circular sections of the path. These conditions are not consistent with normal public road marking conventions and were, therefore, not within the test requirements. These deficiencies could be remedied by changing the lane markers (either permanently or with temporary striping techniques) at each location to meet the test requirements.

Test Execution Description and Data Discussion

The test is conducted on a track with a straight section that leads into a curved section. The POV is parked in a traffic lane on the curve near the end of the straight section (see Figure 7-8). The

straight and curved track leading up to and around the POV are wet. A trial begins with the SV traveling down the straight track - the validation trials were executed at 72 kph, as required by the original test procedures. (Changes to the speed and curvature requirements of the test, based on the validation work, are discussed below.) A trial ends when either the crash alert occurs or the SV has come within 90% of the minimum allowed distance for crash alert onset. Once the trial has ended the SV driver steers to avoid the POV.

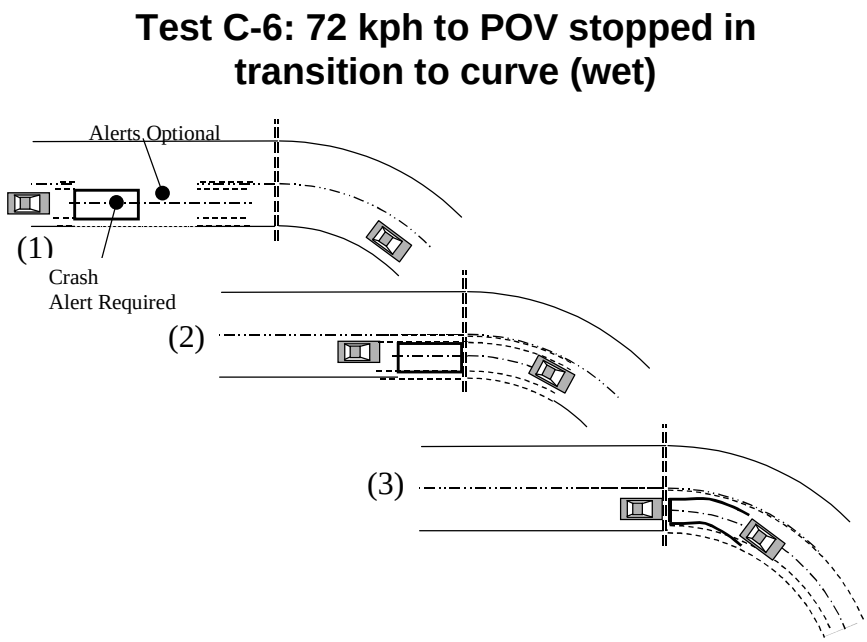


Figure 7-8 Required Test Maneuver for Test C-6

The tests were conducted at two site: the Vehicle Dynamics Test Area (VDTA) at GM's Milford Proving Ground, and the Vehicle Dynamics Area (VDA) at the TRC. Both locations include a large paved “black lake” area with loops at opposite sides of the rectangle (see Figure 7-9 and Figure 7-10). At both locations there is a marked two-lane straight section on the black-lake area of the track. This straight section leads into the 2-lane curved section of road. A similar track exists at Ford's Michigan Proving Ground.

The POV was placed 100 m from the beginning of the curve. A traffic cone was placed where the SV could begin its avoidance maneuver (90% of the minimum allowed crash alert onset distance). Since the trials were run assuming the original timing requirements, this was 64.2 m from the POV, as shown in Figure 7-8. For each trial, the SV accelerated to speed. The driver engaged the cruise control and the SV approached and entered the curve while staying near the center of the lane. When the marker was along side the SV, the driver would turn to avoid the POV. It was raining when the test was run at the GM Proving Ground. At the TRC, a water truck was used to keep the track wet.

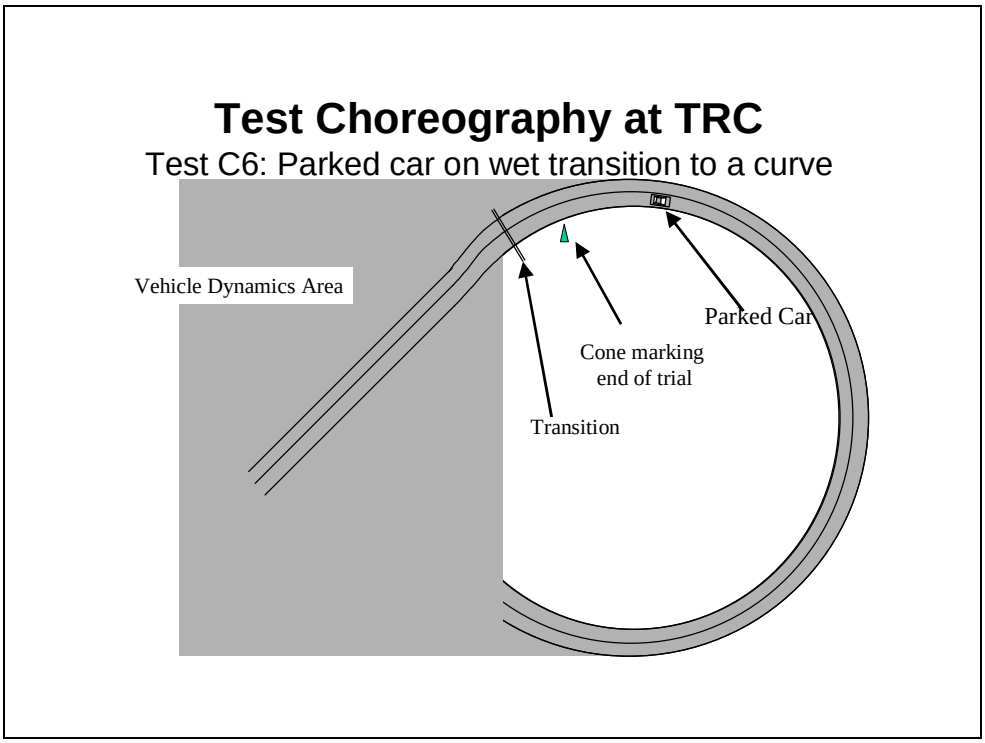


Figure 7-9 Test Site at Transportation Research Center for Test C-6

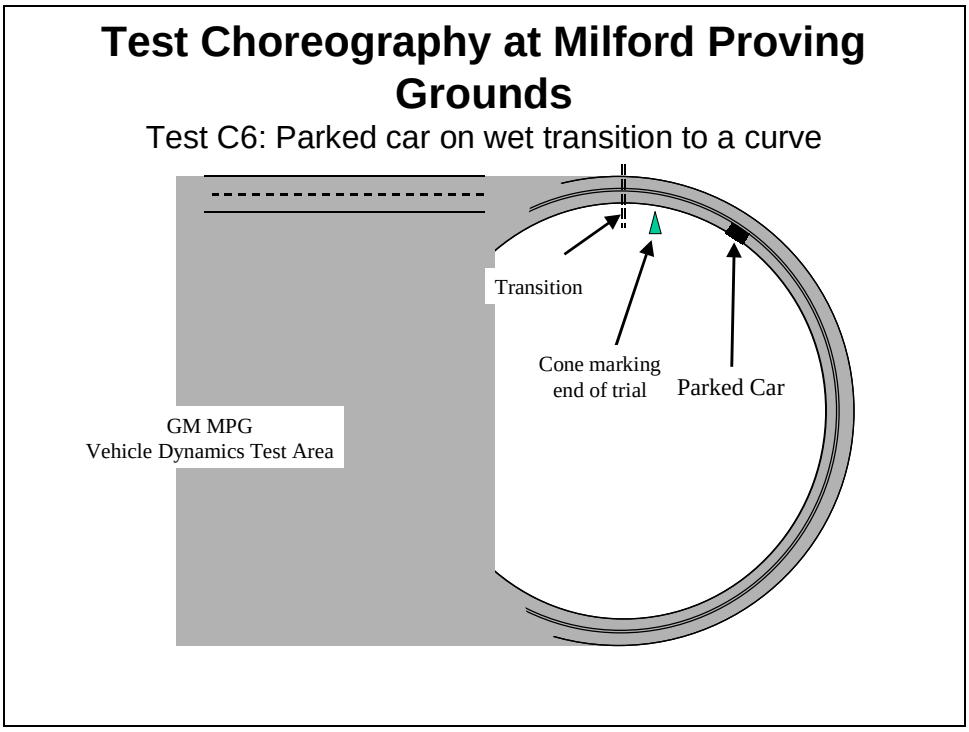


Figure 7-10 Test Site at GM Milford Proving Ground for Test C-6

Sixteen trials were executed at the original SV speed of 72 kph at the TRC. This included eight each for the laser radar and the microwave radar FCW systems. Another 8 trials total were run at 88 kph (55 mph) and six trials total for 56 kph (35 mph), again split evenly between the two FCW systems. Figure 7-11 shows results from eight of the 72 kph trials, split evenly between the FCW systems..

The top plot in Figure 7-11 shows the lateral position of the SV, relative to the road, plotted against the distance the SV has traveled along the road from an arbitrary reference point ("down-road distance"). Both values are computed from onboard DGPS measurements and a survey of the test site. The path of the SV for a particular trial is represented by a trace that begins at the left of the figure and moves to the right as the SV travels toward the POV. The trace moves downward when the SV drifted right in the lane, and moves upward when the SV drifted left. The leftmost vertical line on the plot indicates the down-road position at which the SV front bumper crosses the transition from straightaway to curve, which is close to the 760 m point. At that point, it is 100 m from the rear of the POV, which is represented by the rightmost vertical line (at 860 m). As the trials begin (left region), the range from the SV to the POV is great enough that crash alert onset is not allowed, using the requirements of Chapter 4. It is not until the SV crosses the transition to the curve and travels another 10 m that a crash alert onset is allowed, and yet another 15 m before the crash alert onset is required. The middle two vertical lines indicate these points, which are approximately 90 and 75 m from the POV. Note that 72 kph is 20 m/sec, so that the crash alert onset must begin within a 0.75 sec window.

Two results are clear from the top plot in Figure 7-11. First, driving the SV to within the required distance (63m here) involves no discomfort for the drivers, who usually went within 50 m before beginning the maneuver. Second, the requirement on SV lateral position (within 0.5m of the lane center) is not met. The variation in the lateral position among the eight trials shown, at any given down-road position, does remain within 0.5m of a downroad position-dependent offset, but this offset varies. Two factors contribute to this. First, "cutting the curve" is seen in the data here and in other tests. Without aids for lane-keeping, drivers tend to cut the curves by a fraction of a meter. Second, the survey of the road geometry was hindered by the non-standard lane markings described above. The surveying involved dead reckoning of lane position near the transition. Both of these are considered by-products of the pilot nature of this testing, and did not lead to revisions of test procedures.

The bottom figure plots an "azimuth" angle against the down-road distance. The azimuth angle is defined here as the angle, at the SV, between the SV heading direction and the line of sight between the SV and the POV. (The heading direction is computed using DGPS position estimates of the CG.) Azimuth angle is important because FCW sensing modalities currently have limited field of views that may be challenged by this test. As the POV approaches the transition to the curve, the azimuth builds to a maximum value of about 6 degrees (positive indicates the POV appears "to the right" from the SV perspective). The azimuth then drops as the SV begins to turn toward the POV. The avoidance maneuver is clearly seen in this trace at about 800 to 820 m, as the SV turns toward its left.

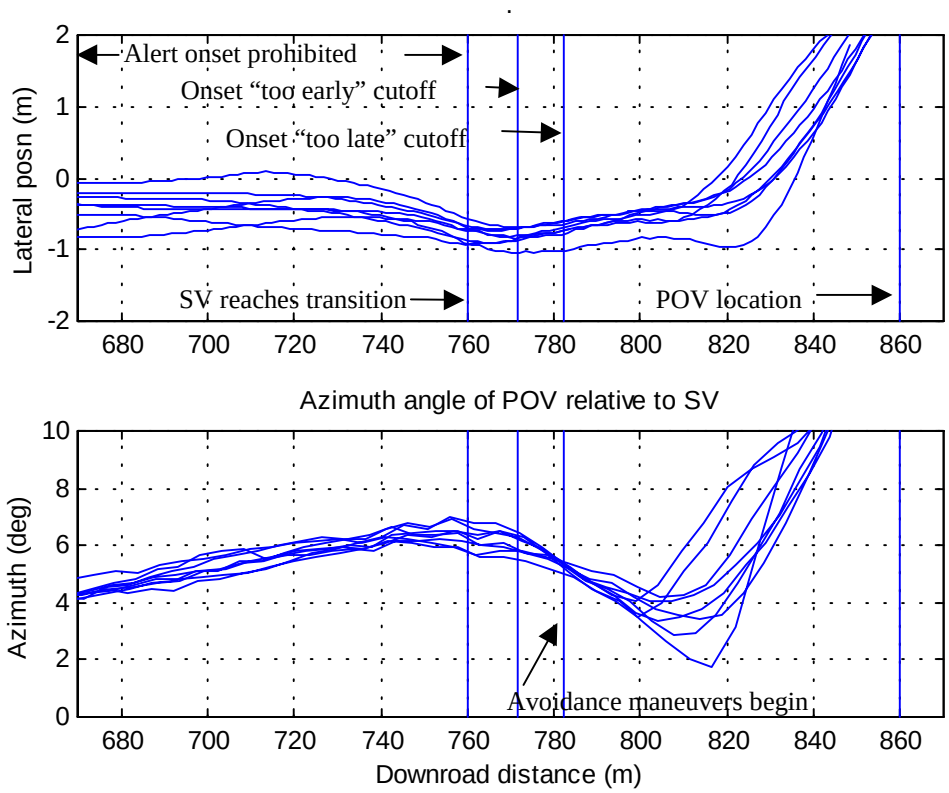


Figure 7-11 SV Lateral Position and the Azimuth Angle To The POV: Test C-6 Parked Car in Transition to a Curve

7.4.1.3 Test C-9: 67 kph POV Cuts in Front of 100 kph SV

In this test, the SV is initially traveling at constant speed in a given lane on a straight, flat, dry road. A slower-moving POV, which is initially traveling in an adjacent lane, changes lanes so that it cuts in front of the SV. The POV enters the Alert Zone at a range which is less than the minimum required range for a crash alert, as shown in Figure 7-12 below. The test determines whether the countermeasure crash alerts occur at appropriate times. The appropriate times are a function of both the lateral position of the POV, relative to the SV, and the combination of range, range rate, and perhaps relative longitudinal acceleration between the two vehicles.

The test specification requires that the slow vehicle (the POV) travel at 65 kph while the fast one travels at 100 kph. The test requirements include tolerances on the range and lateral speed of the POV when it crosses the outer and inner boundaries of the Alert Zone. It also includes tolerances on the speeds and the heading angle of the SV.

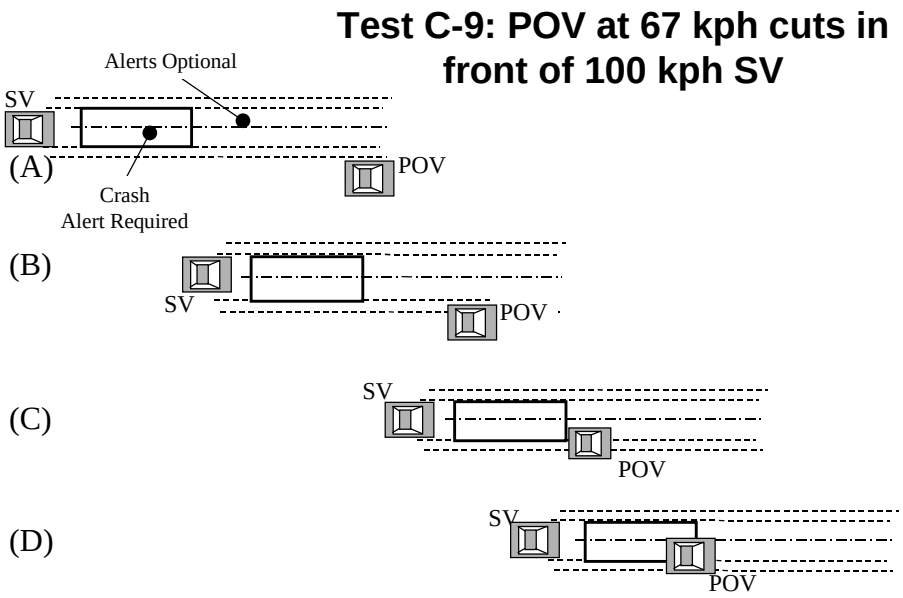


Figure 7-12 Sequence of Required Vehicle Motions for Test C-9 (Cut-In)

The test trials were conducted using the north end of the Vehicle Dynamics Test Area at GM's Milford Proving Ground. This test is more difficult to stage than the two described previously. Vehicles traveling at different speeds must arrive simultaneously at their respective locations for the start of the lateral maneuver. To accomplish this a circular track was set up with markings that helped the drivers get synchronized. There were 8 marks around the circle for the SV and 12 marks around the circle for the POV. The vehicles would be synchronized if they were passing their respective markings simultaneously. Each trial began with the vehicles parked at the location marked start. The data recording equipment was started and then the drivers would accelerate to their respective speeds. The drivers of the vehicles would then engage their cruise control. A radio was used to communicate between the drivers so that one could tell the other each time a mark was passed. The other driver could then adjust the speed slightly to get synchronized. The POV would travel around the circle 1 ¾ times and then head into the straight track section of track. The SV would travel around the circle 2 ¾ times and then head into the straight section of track.

In the straight section of track there were markers indicating where each vehicle should be when the POV began its lateral maneuver (B). There were also markers to indicate the lateral position and location where the POV should reach its maximum incursion into the lane of the SV (C). Finally there were markers that indicated where both vehicles should be when the distance between the POV and SV had reached 90% of the minimum acceptable crash alert distance (D). This last marker was used as the location where the POV would turn to exit the lane of the SV.

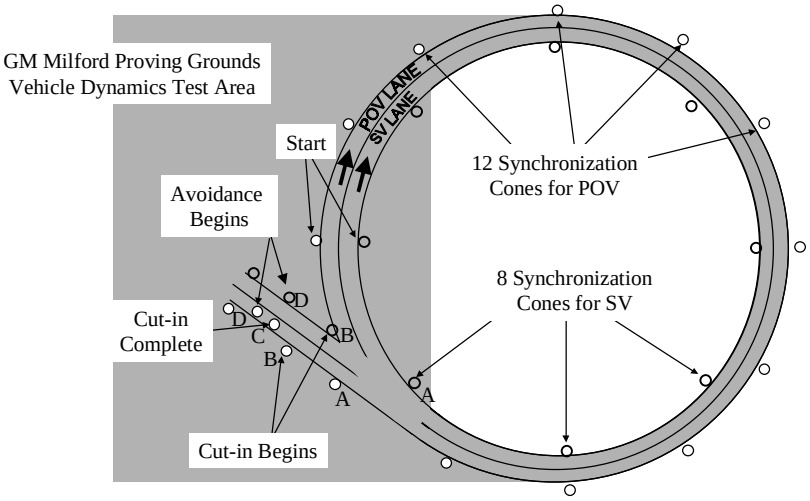


Figure 7-13 Test Choreography for Test C-9 (Cut-In)

The primary concern regarding execution of this test was safety. Therefore, the final test condition was approached in steps. First, the vehicles traveled the course without a cut-in maneuver. This assured that the proper synchronization had been achieved. Once synchronization was accomplished repeatedly the next set of trials included a small lateral maneuver. Immediately after the lateral maneuver was initiated both vehicles would turn away from each other. After several trials the lateral maneuver was increased until the POV was about half way into the lane of the SV. Once there was confidence that this could be done repeatedly then the turn to get out of the lane was delayed in stages. The final choreography had the POV move about half way into the lane of the SV and stay there long enough for the SV to approach within 90% of the minimum acceptable most imminent crash warning. Under the conditions used to execute the test, this distance was 9.94 meters. At that point the POV would move back out of the lane of the SV while the SV continued on a straight path.

Several issues were identified when planning and executing this test. One concern is that the maneuver was performed on a blacktop surface that does not have typical road edges nearby. Furthermore, there were no lane markings to mark the straight section of the course. The lack of lane markings could be corrected with temporary or permanent lane stripes. However, the lack of typical roadside features could not be corrected so easily.

Another concern is that the rules at the GM proving ground limited traveling the circle to 88.5 kph (55 mph). This is less than the 100 kph specified in the test procedure. Furthermore, the SV and POV traveled the circle in different lanes. This caused the speeds to be different than those specified in the test procedure. The nominal speeds used in the validation were 88.5 kph for the

SV and 60 kph for the POV. These limits suggest that the test procedures should be modified to allow a wider range of speeds to be used in the tests.

Several alternatives to the staging of this test are possible. First, the SV and POV could travel the circle in the same lane. This would cause them to be driving the same radius and make the ratio of their speeds independent of the radius of the circle. Another alternative could be to use a long straight track to provide the time to synchronize. The total distance traveled by the SV when driving around the circle to achieve synchronized was 2.4 miles. A 2 mile straight track would likely provide adequate distance for synchronization before the lateral maneuver.

Fourteen trials were performed once the orchestration and practice phases were complete, including 10 trials with the radar-based countermeasure and 4 with the laser radar system. An example of the vehicle motions and alert requirements during the trials is shown in Figure 7-14. The top plot in the figure shows variables describing the longitudinal motions and requirements; lateral components are shown in the bottom plot in the figure. The figure begins with the vehicles emerging from the circular synchronizing loop onto the straightaway. The SV and POV speeds are approximately 90 and 60 kph, respectively, and the range decreases at about 9 m/sec, beginning on the plot at 62 meters at the 0 second mark. The difference between the SV and POV vehicle speeds is fixed during this test. Because the requirements for alert timing used in this validation depend only on closing speed, the maximum and minimum allowable ranges at onset of the most imminent alert remain constant, at about 39 and 20 meters, respectively, as shown in the top plot of Figure 7-14. Because the POV is initially in the left lane and the SV in the right lane, however, the range falls below these requirements-related ranges and still no alert is required.

Near the 4 second mark in Figure 7-14, the POV initiates the cut-in maneuver. Near the 5.2 second mark, the POV has shifted far enough toward the SV that an alert is permissible (indicated by the leftmost vertical line and the changing of the bar from lightly shaded to hatched). The POV continues to move farther into the SV's lane and soon the alert is required. At this point the test is over and the SV begins its evasive maneuver, steering to its right. The POV also steers away so that by the time the range drops to zero the vehicles are once again in different lanes.

As with the previous tests, Chapter 5 specifies several variables to define the vehicles' paths and the test maneuver. The unique requirements for this test include the definition of the POV's lateral motion and requirements for the ranges at which the POV encroaches into the Alert Zone. One minor change is suggested by experience executing the test. The test procedures called for the POV to execute a complete lane change and settle into the center of the SV's lane. This is not required, since the most imminent alert is required before the POV reaches the lane center, and thus the test is effectively over. For this reason, and to increase the safety margin, the POV now aborts the lane change at a time when the test is complete.

Regarding the remainder of the requirements unique to this test, the data shows mixed success in satisfying these. Generally the lateral velocity during the cut-in is acceptable, but often at times the range does not fall within the specified bounds as the POV crosses the two Alert Zone boundaries. Sometimes the range is too large, sometimes too small, sometimes it is acceptable. This does not suggest a flawed test or even a flawed method of orchestrating the scenario. The test can be executed successfully by running two to five trials to get one "acceptable" trial, and/or

the drivers' aids can be improved to create a tighter synchronization and a more repeatable vehicle-to-vehicle spacing.

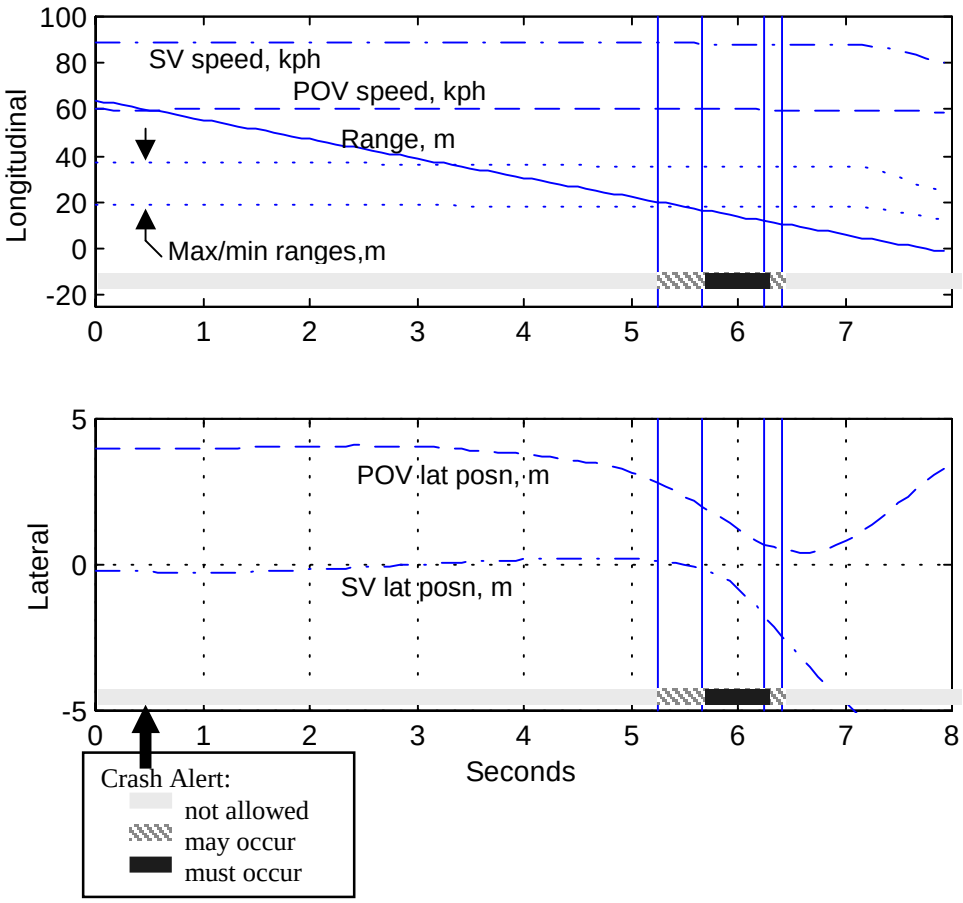


Figure 7-14 Vehicle Motions and Alert Requirements During a Test Trial: Test C-9 60 kph POV Cuts in Front of 90 kph SV

7.4.1.4 Test C-13: Greater Size and Equal Distance

This test requires that the SV travel at 100kph as it approaches a motorcycle between two trucks traveling at 32kph. The test is one of two, which explore the countermeasure's ability to resolve in azimuth a target with a small sensor cross-section, while traveling in traffic. (The other test is a nuisance alert test, without the motorcycle.) All three POVs are traveling at the same speed, and each POV is near the center of its lane. The SV is moving faster, and approaches the three POVs

at constant speed while traveling in the same lane as the motorcycle. The test must be conducted on a three lane straight, flat, dry track.

Each trial begins with the SV 200 meters behind the other vehicle. The trial ends when the most imminent crash alert occurs or the SV comes within 90% of the minimum most imminent crash alert distance, whichever comes first.

Test C-13: Greater size and equal distance

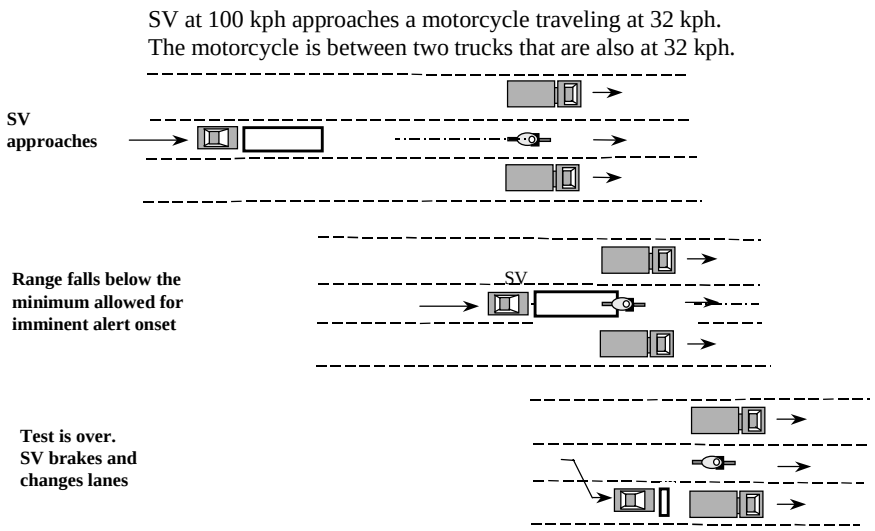


Figure 7-15 Staging Test C-13: Greater Size and Equal Distance

The test trials were conducted at the Skid-Pad area of the TRC. This is a 6 lane straight track approximately 1.5 km long. Two Ford 1995 Model F-700 trucks (24 ft beds, 18,000 lb GVW) were used. The motorcycle was a 1985 Honda Nighthawk, 650 cc motorcycle provided by the TRC. The instrumentation package in the left truck was as previously described for the POV. The video camera was attached to the right rear of the truck so that it could monitor the location of the motorcycle between the trucks. The GPS antenna was placed at the center-rear on top of the truck. A GPS antenna was also placed on the roof of the center-front on top of the right truck with a receiver and computer in the cab to record the GPS data.

Each trial began with the SV parked at one end of the track in the center lane. The other vehicles drove down the track in formation at 32 kph. The trucks stayed in the center of their lanes with their front ends even. The motorcycle would maintain a position in the center of its lane so that its rear end was even with the rear end of the trucks. When the other vehicles were about 500 meters down the track the SV would accelerate to 100 kph and engage the cruise control. A passenger in the SV would monitor a range sensor. As the SV approached the other vehicles the passenger would read the distance between the SV and POVs to the driver. When the distance reached 45 to

50 meters, the driver of the SV would brake hard. This distance was calculated to bring the distances between the POVs and the SV to less than 90% of the minimum acceptable most imminent crash alert distance. As the SV slowed the driver would change lanes to be behind one of the trucks. The lateral maneuver was to make sure the motorcyclist was safe, even if the brakes of the SV failed.

The staging of this test was straight forward. There were two desirable improvements to the instrumentation that were identified. First, the specified speed of the POVs is below the minimum set speed for the vehicles. It would be advisable to provide a cruise control that could be set at the specified speed or to provide a better speed measurement device so that the speed could be controlled more easily. Second, the range measurements used to guide the timing of the braking in the SV were those provided by the countermeasures. It would be advisable to provide an alternative range measurement device, preferably one with a fast update rate (e.g., 10 Hz) and analog gage for the display.

7.4.1.5 Test N-7: Slow Cars in Adjacent Lane at Transition into a Curve

This test is used to determine the sensitivity of a FCW system to slower moving traffic in adjacent lanes. The test requires that a faster moving SV pass two slower vehicles as the SV enters the inner lane of a curve. The test is conducted on a 2-lane track with a straight section that leads into the curved section, as shown in Figure 7-16.

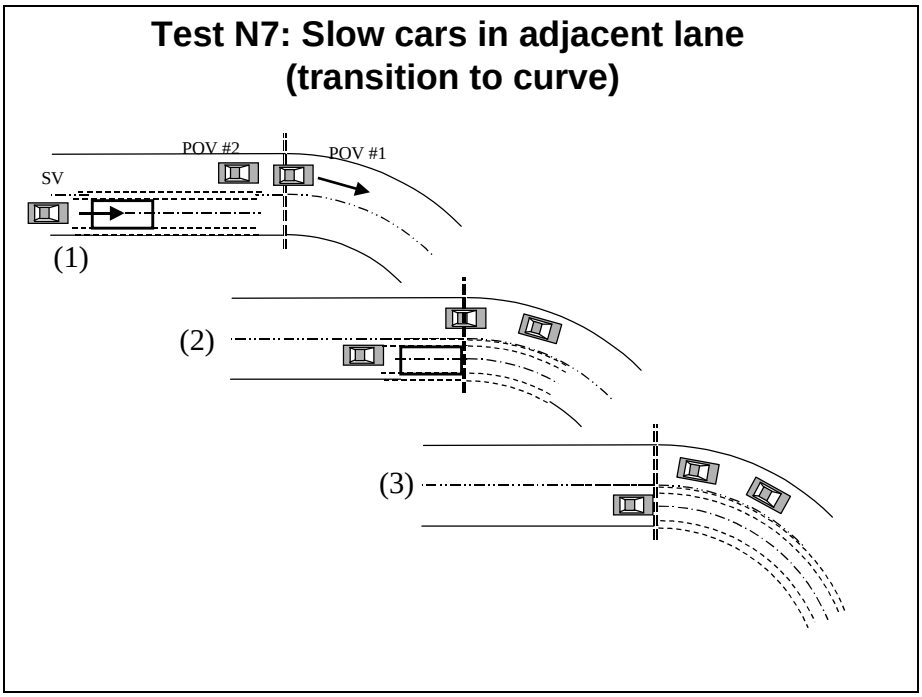


Figure 7-16 Vehicle Maneuver for Test N-7, Slow Cars in Adjacent Lanes

This test was conducted at two locations, GM's Milford Proving Ground and the TRC. At the Milford Proving Ground a track called the Hill Loop was used. This includes a 4.2% down hill grade leading into a curve with approximately a 90 meter radius. The superelevation in the curve was small, similar to that found on public roads.

At TRC a route marked on the VDA was used. It includes two lanes with white solid lines on the outside and a dashed lane marking between the lanes. It includes a straight section that leads into a 110 meter radius curve.

In both locations a set of markers was placed along the track leading to the curve. It was found that at least 45 seconds of travel was necessary to achieve synchronization. One minute would have been better. The markers were placed at intervals beginning at 10 seconds, decreasing to 5 seconds and then to 2 seconds as the vehicles approached and entered the curve.

There were several issues identified while staging this test. The workload on the drivers is high for this test. The drivers of the POVs must maintain their lateral position in the lane as they enter and traverse the curve. At the same time they must maintain a constant speed, a set distance between the first and second POV, and must communicate their position to the driver of the SV so that it can get synchronized. The difficulty is increased because the target speeds for the POVs were below the minimum set point for their cruise control systems. Therefore the driver of the lead POV had to maintain speed and lateral position manually. The workload was decreased somewhat by putting a passenger in the lead POV who would communicate the position to the driver of the SV as the POV passed the markers. The workload could have been reduced further if the POVs were modified so the set speed on their cruise control could be set as low as 15 mph. This combined with an adaptive cruise control on the second POV would have left the drivers only to watch their lateral position in the lane. It would still leave the driver of the SV with a heavy workload; controlling lateral position and adjusting the speed so the SV passes the marks synchronized with the times the POV passes its marks. A longer approach, perhaps a minute or two, would make this more practical.

Finally, this test is a nuisance alert test. As such it needs to be repeated hundreds of times to demonstrate that the frequency of nuisance alerts will be less than the maximum. The current test specification indicates that there should be 567 exposures representing 3 weeks of typical driving. Since several POVs can be used the number of pass can be reduced accordingly. If two POVs are used, as was done in these experiments, and if it takes approximately 2 to 3 minutes per pass, then it would take approximately 9.5 to 14.2 hours to perform this test.

Over 20 trials were performed once the orchestration and practice phases were complete; these trials were split evenly between the radar-based countermeasure and the laser radar system. An example of the vehicle motions and alert requirements during a test trial is shown in Figure 7-18. The top plot in the figure shows variables describing the longitudinal motions and requirements; lateral components are shown in the bottom plot in the figure.

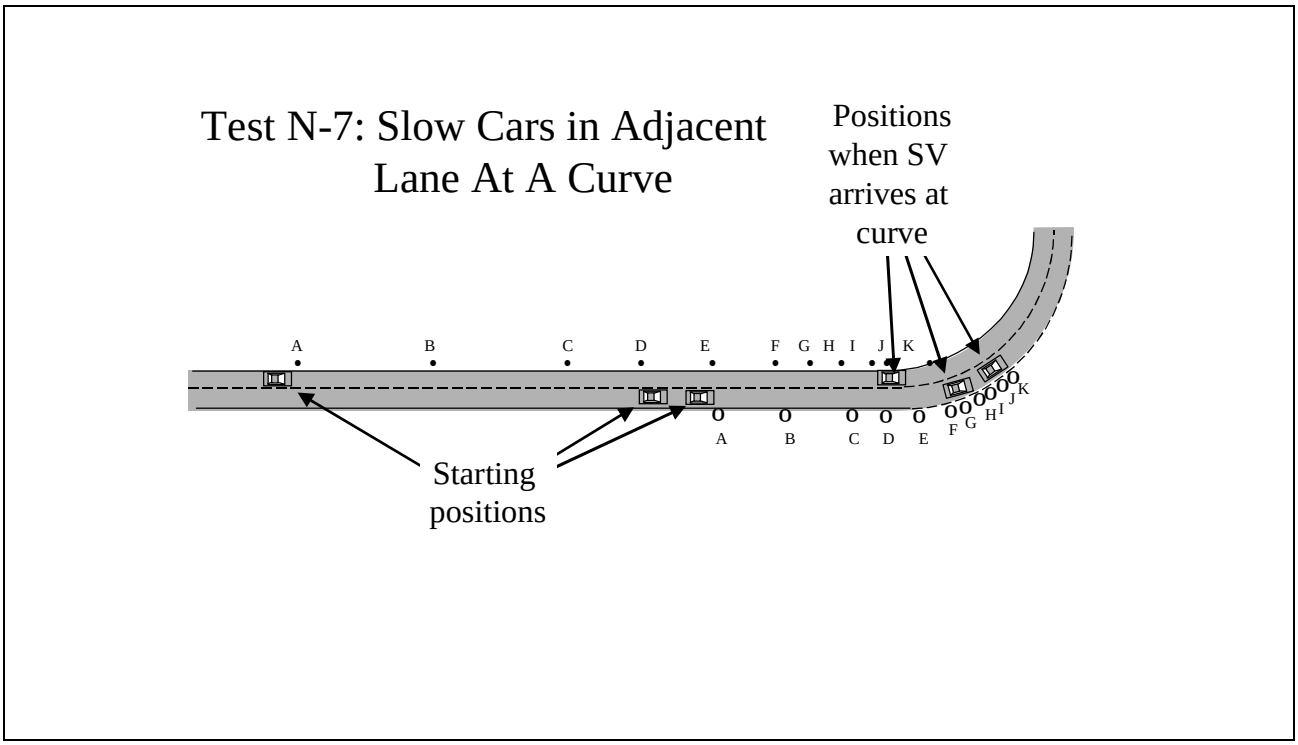


Figure 7-17 Cone Placements Used to Perform Test N-7, Slow Cars in Adjacent Lanes

Figure 7-18 shows data for the SV and both POVs. The top plot shows that the SV and POV speeds are approximately 57 and 28 kph, respectively; the range falls at about 8 m/sec. The top plot shows the range to the rear of both POVs (the difference in the ranges is approximately 15m). Also shown on the plot are ranges associated with the alert timing requirements, as described in earlier sections. The maximum and minimum ranges at alert onset are approximately 18 and 35 meters, respectively. For this test, the single vertical line in the plots indicates the moment when the front of the SV crosses the transition of this track from a straightaway to a constant-curvature curve; this occurs near 5.5 seconds in the figure.

No alert is ever permissible or required in this trial because the POVs keep to the center of the right lane and the SV passes while traveling in the center of the left lane. The second plot in the figure shows the lateral positions of the vehicles, with the SV approximately a lane width (3.6m) to the left of the POVs. Note that all vehicles maintain lateral position rather well, even through the transition.

A major goal of this test is to present a countermeasure with the challenging but common situation in which a vehicle in a different lane briefly appears to be immediately in front of the SV at the same time as the SV is about to encounter a change in road curvature. The example trial was successful in creating this situation with the lead POV. The second set of traces in the bottom plot represent the azimuth angle of the line of sight from the SV to the two POVs during the trial. The angle is measured relative to the SV's instantaneous heading, and is positive when the POV is to the right. The plot shows that the azimuth angle to the lead vehicle initially undergoes a transition that is due to a bend in the track, and then settles to about 2 degrees between 1 and 4

seconds in the plots. As the POV begins the turn it appears to swing in front of the SV, thus the azimuth drops toward zero between 4 and 5 seconds. When the SV reaches the transition, the lead POV is almost directly in front of it (azimuth near zero), which is the intended situation. After that moment, the SV begins its turn and with the small range, the POV appears to swing rapidly away to the right as the SV begins to pass.

As with the previous tests, Chapter 5 specifies several variables to define the vehicles' paths and the test maneuver. The unique requirements for this test are the need to control speeds and synchronize the SV and POV longitudinal positions at low speeds; and the need for simultaneous manual control of both POV speed and lateral position. Suggestions above addressed these items. The data indicates variability in speeds and lateral positions, as well as variations in the azimuth angles when the SV crossed the transition in curvature. Assuming these drivers' aids issues are addressed, however, test execution data does not appear to require significant changes to the test.

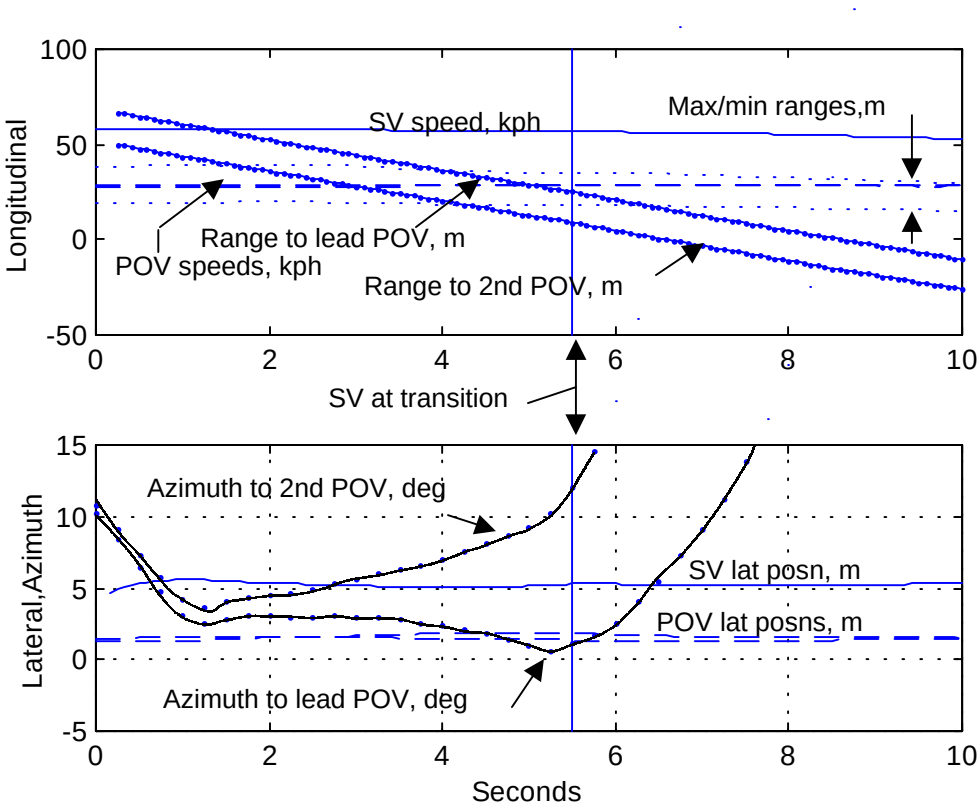


Figure 7-18 Vehicle Motions and Imminent Alert Requirements During a Test Trial Test N-7 Slow Cars in Adjacent Lanes

7.4.2 Validation Results

7.4.2.1 Understandability

The test methodology contained in Chapter 5 is a framework that can be adapted as the functional and performance requirements are refined and as FCW systems improve. It is considered a draft that will be refined and adjusted. Even so, as part of the test procedure evaluation, a review of the procedures was conducted by staffs at the proving ground of each of the partner companies.

Test engineers at Ford and GM were given a copy of the contents of Chapter 5 and a briefing summarizing the contents. They were asked to use the descriptions to determine if there were tracks at their facilities that meet the requirements for the tests. They were also asked to determine if the test procedures could be run within the safety and other work environment standards at their facility.

There was one area identified where the test procedure descriptions should be improved. The first is that the track geometry descriptions for the Nuisance Alert Tests include many references to the AASHTO Guidelines. In particular, there are references to tables in the guidelines that should be used to determine the speed at which tests should be run. The speeds depend upon the radius of curvature and super-elevation of the curves available at the testing facility. The next version of the procedures should summarize the guidelines and provide tables that are more easily interpreted by anyone who want to run the test.

Other observations included that the procedure descriptions need to be clarified and made more consistent. The test engineers thought that most of the procedures could be executed at their facilities. An exception was that the Ford engineers thought their work rules would prohibit placing the guardrails close enough to the track to satisfy the requirements for test N-4.

7.4.2.2 Executability

Five of the tests proposed in Chapter 5 were executed. Some of the tests were selected because they were considered to be potentially challenging tests to perform. The selected tests were demonstrated to be executable, in terms of the critical events of the tests. Regarding the overall paths the vehicles were required to follow, the execution suggests some changes to the test methodology and tolerances. Some changes to the roadway configuration requirements were made to make it possible to use existing tracks. The individual sections 7.4.1.1 through 7.4.1.5 address some possible specific changes; analysis and discussion was used to propagate the changes to all tests.

7.4.2.3 Cost

The total cost to create and integrate the instrumentation packages for the SV and two POVs was approximately $257,000. This included approximately $134,000 for commercially available

equipment listed in Appendix E. The remainder of the cost was for custom brackets, assembly, and on-board data acquisition software. Not included is the cost for CAMP software development for post-test data analysis.

Some instrumentation and props that would be necessary for full implementation of the test procedures were not necessary for the tests that were executed for this study. One significant piece of instrumentation would be necessary for test C-11, to measure the visibility. Visibility meters such as those used in meteorology studies, can be acquired for around $10,000. If they did not already exist at the testing facility, full implementation of the test procedures would have to include purchase of additional props, including some portable concrete barriers, metal guardrails and an overhead sign.

7.4.2.4 Time Required

The time required could be divided into planning, setup, execution, and data analysis. The total time to execute and analyze a complete set of tests is estimated to be less than 4 weeks. The initial planning, surveying, and construction of props is not included in the 4 weeks. The table below provides estimates of the time required to execute the selected tests. Estimates include surveying the initial and repeat placement of cones, driving practice time, and test maneuver execution for one trial and for all trials.

Test	Survey	Repeat Setup	Practice	Execute Once	Total Execution
C-3: Lead vehicle braking	1 hour	15 minutes	½ day	5 minutes	½ day
C-6: Stopped vehicle in transition to wet curve	½ hour	5 minutes	1 hour	5 minutes	2 hours
C-9: Cut in	½ day	1 hour	1 day	15 minutes	½ day
C-13: Greater Size, Equal Distance (2 trucks & M'cycle)	none	none	1 hour	5 minutes	2 hours
N-7: Slow cars in adjacent lane at a curve	2 hours	½ hour	2 hours	3 minutes	15 hours

Table 7-5 Test Procedure Execution Time Estimates

Data analysis time is not included in the table. Data analysis time for these tests will depend on the overall system design for data acquisition, file transfer, and data analysis. If the tests become an accepted means for evaluating countermeasures, it is reasonable to expect that software will be developed to provide a semi-automated means to transform the raw test measurement data into a results sheet documenting test trial validity and countermeasure performance. With this assumption, the data analysis time is expected to fall within the estimated 4-week duration of testing.

The level of data reduction assumed above was not achieved during testing activities -- the data analysis software was developed only to support the validation efforts, and the software needed to be a flexible analysis and learning tool to support study of the procedures themselves.

7.4.3 Sensitivity Analysis

The results of testing an FCW system should not vary, as long as the execution of the tests satisfies the requirements given in the test procedures. To look for undesirable sensitivities of testing results, Chapter 6 suggested that five areas of sensitivity be examined. These areas are discussed below.

7.4.3.1 Site & Props

The sensitivity of the test results to differences in test sites and to variations in the props is studied. Sensitivity to sites relates to three characteristics, (1) differences in surrounding clutter, (2) differences in road geometry, and (3) differences in road markings.

The site chosen for execution of test C-13 demonstrated that surrounding clutter can cause unexpected results. A sprinkler system designed to wet the test track tended to cause one of the countermeasures to generate alerts as it was passed. Once the cause of the alerts was identified, it was simple to run the tests on a different part of the track. There were no other instances where surrounding clutter seemed to affect test results.

The primary concern regarding road geometry is whether differences in horizontal or vertical curvature can impact test results. Two tests (C-6 and N-7) were each run at two locations. In test N-7 (slow cars in adjacent lanes) the vehicle speeds are a function of the radius of curvature of the available track. In test C-9 (parked car on a wet transition to a curve) the speed of the SV is constant while the requirements place bounds on the curve that can be used.

The last concern regarding sites was whether test results would be sensitive to the type or quality of the road markings. In the tests performed, only the Laser Radar system has optical sensors to detect the road markings. There was no observed sensitivity to the differences in the qualities of the lane markings at the test tracks. However, it is recognized that differences in road markings could become more important for future FCW systems.

The only props used during the execution of the tests were the other vehicles. It was observed that there is some sensitivity to the characteristics of the POVs. This led to the conclusion that the test specifications must be more specific regarding the characteristics of the vehicles that are used in the tests.

7.4.3.2 Test Team

The sensitivity of test results to changes in the particular team of engineers and drivers who would execute the tests. This proposal was part of the overall desire to look for possible failures of the test methodology to produce repeatable results. Consider three ways in which the evaluation of a countermeasure’s performance in a test may vary among teams of testing staffs:

1. Different interpretations of the testing maneuvers and prop layouts could occur.

2. Different ways of conducting a test could occur if organizations use different assumptions about how tests are conducted.

3. Different vehicle motions could result from individual differences in driving patterns.

These three separate pieces were addressed in different ways. For the first two items, (1) and (2), feedback from proving ground staff at each company was received after they reviewed an interim version of the test procedures document, as described earlier. There were no clear differences in interpretation between the two companies, though it is possible that such differences would become apparent if the groups executed the tests. For item (3), test execution of both Tests C-6 and N-7 was done using different drivers. No significant effect of using different drivers was seen in the countermeasure evaluation results.

7.4.3.3 Path Tolerances

The differences in test results stemming from allowed differences in vehicle path is to be minimized. Consider three elements of the vehicle paths: vehicle speeds, vehicle decelerations, and vehicle lateral positions. Let us consider these elements individually.

First, there is not likely to be sensitivity of test results to allowed variations in vehicle speeds. In practice, vehicle speed variations are quite small due to cruise control systems. Also, for crash-alert timing, performance criteria are given as a function of vehicle speeds, thus compensating for the small differences in speed that are seen. For nuisance alert tests, it is thought to be unlikely that the small changes allowed in vehicle speed (2 kph) will affect the occurrence of nuisance alerts.

Second, the sensitivity of results to vehicle decelerations addresses possible passing or failing of systems during the two tests that include lead vehicle decelerations (Tests C-3 and C-12). Any answers to this are likely to be analytical products because such a sensitivity is likely to be possible only if either the timing requirements or the countermeasure itself include a dependence on vehicle accelerations. Indeed, real sensitivity is likely to result if only one of these (requirements, or countermeasure algorithms) include vehicle deceleration effects. For now, however, the proposed requirements for alert timing depend only on the closing speed and not accelerations. With countermeasures that use only speeds in their timing algorithms, there can be sensitivity to deceleration levels only when the deceleration tolerances allow significant variations in speed profiles, which is not allowed in the procedures. With countermeasures that employ estimates of vehicle accelerations, there may be variations in performance, but the relative significance of the amount is not available from the evaluation work conducted here.

7.4.3.4 System Settings

Some FCWs include driver-adjustable settings to control, for example, the relative timing of alerts. One of the systems used by CAMP includes a rotary dial to adjust alert timing; the other system does not. The Chapter 5 suggested the following approach to testing a system that

includes adjustable settings: Testing is conducted with the system set at minimum sensitivity. The reasoning was that crash alerts must occur soon enough, per the minimum requirements, no matter how a driver adjusts the system, and that the driver should be able to maintain that performance while not encountering too many nuisance alerts. Thus there can be no sensitivity of a countermeasure's assessment to any ability to adjust system settings.

Another possible advantage of conducting tests at different settings during the test procedure evaluation phase is to look for unwanted sensitivities within particular tests. Because there was no electronic access to one of the systems alert timing signals, however, such an investigation is not possible.

7.4.3.5 Pass/Fail Criteria

Chapter 6 included an analysis of the impact of small changes in the results from individual tests upon the overall results. A related concern is whether any of the pass/fail criteria have an inordinate impact upon the overall results. There was no indication from the tests that were executed, that small changes in the pass/fail criteria would alter the overall assessment of the unites used in the testing. It was found that, for any particular test, the countermeasures used in this study either passed the tests easily or had far more alerts than would be acceptable. This suggests that small changes in the weights would not change whether a system passes or fails.

7.4.4 Correlation With Performance During Typical Driving

The work described in this section was performed to demonstrate that the test procedures subject FCW systems to a set of scenarios similar to public road situations that may trigger crash alerts. The two FCW systems described in 7.3.1 – a laser radar-based system, and a microwave radar-based system -- were each driven on roads with normal traffic to identify conditions that frequently produce alerts. The vehicles were driven in both urban and rural areas, on residential, feeder, arterial and limited access roads in heavy and light traffic conditions during the day and at night. Data similar to that collected from the SV during track tests was collected during these driving conditions. The videotapes and collected data were analyzed to identify conditions that produce alerts. The test procedures were analyzed to determine if these conditions are represented. Subjective judgments were made regarding whether the results from the track tests are similar to the results from driving on public roads.

A route was selected through southeastern Michigan that is approximately 320 km (200 miles) long. This corresponds to the average distance traveled by a passenger car in one week (Horowitz, 1986). The route characteristics closely approximate the distribution of local, arterial, and highway miles in urban and rural areas during the day and at night, as reported in Stewart and Burgett, 1989. The breakdown of the road types included in the route is shown in Table 7-6. A detailed description of the route is included in the Appendix E, Section E.2.

Road Type	Daytime distance (km)	Nighttime distance (km)	Total (km)
Urban-Local	32.2	7.8	40.0
Urban-Arterial	87.2	17.7	104.9
Urban-Highway	44.4	7.5	51.9
Rural-Local	22.9	6.6	29.5
Rural-Arterial	43.7	11.0	54.7
Rural-Highway	34.4	6.7	41.1
Total for all highways:	264.8	57.3	322.1

Table 7-6 Average Distribution of Driving Conditions

The data collection and analysis were performed by CAMP staff members who have worked on the human factors aspects of the project. The daytime route was driven between 8 a.m. and 4 p.m. on December 14, 1998. The night time route was driven between 7 p.m. and 9 p.m. on December 15, 1998. During the drive one of the researchers drove while the other recorded the time of each alert and the apparent cause.

While driving the selected route the following types of data were collected:

- GPS to provide approximate location
- Vehicle speed
- Video showing movement of vehicles ahead of the SV and roadway clutter in the field of view of the sensor. The video was time stamped to correspond closely with GPS time (within 2 seconds).
- Lateral and longitudinal location of all objects, as observed by the FCW sensor.
- Time and level of each FCW system alert.
- The lateral and longitudinal offset of the primary object when each alert occurs.

Once the data was collected the researchers reviewed the collected data to identify any alerts that occurred for which the cause was not clear. For each of these alerts the ancillary data was reviewed to identify the likely causes. For example, the lateral and longitudinal information about the cause of the alert and the time history of observed objects was used to determine the location and motion of the cause of the alert. Then the video was examined to see what objects had similar motion. This analysis produced a list of conditions that caused alerts. To determine the total exposure to similar conditions the video and other data were again reviewed to determine the total number of times each set of conditions was encountered (including those times when an alert was not generated).

To validate part of the specifications for Test C-9, the cut-in test, the video tape was used to estimate lateral velocities when vehicles changed lanes in front of the SV. While reviewing the video tape, the researchers looked for cut-in instances. They measured how fast the POV made the cut-in by noting how long it took to cross the lane markers in each instance and the approximate width of the vehicle. These provided an estimate of the distribution of lateral velocities when vehicles change lanes in traffic.

The proposed test procedures were reviewed to determine whether they include scenarios similar to those that triggered alerts on the public roads. Two alert-producing conditions were found that were not represented at the time in the test procedures. Modifications to the test procedures were made to include these situations. (Disclosure of the specific conditions is prohibited by agreements with the suppliers of the FCW systems.)

7.5 Summary

This chapter describes activities and testing conducted to validate a test methodology proposed to provide an objective vehicle-level assessment of forward collision warning systems (FCWs). This methodology is described in Chapter 5.

The primary purpose of the validation effort is to assess whether the test procedures are practical to execute and provide a reasonable certainty that a FCW system that passes the tests satisfies the preliminary minimum functional requirements. The proposed methodology is intended to provide repeatable assessments of FCW systems. The tests are designed to be independent of the sensing technology used by the FCW system – in particular, to systems based on millimeter wave radar, laser radar, or computer vision sensors. The tests are for use by FCW system suppliers during the development of products, by vehicle manufacturers to qualify systems, and by independent organizations to evaluate FCW systems. A major consideration was to devise tests that would produce consistent results when executed at different locations. Three sites were selected as representative of those accessible by the organizations that would execute the tests. These were the General Motors Milford Proving Ground near Milford, MI, the Ford Motor Company's Michigan Proving Ground near Romeo, MI, and the Transportation Research Center near East Liberty, OH.

A subset of the proposed tests was executed as part of this validation work. Five tests were conducted; each test was performed using two different countermeasure systems installed on separate test vehicles. The countermeasures included a microwave radar-based system and a laser radar-based system. Testing was done at two proving ground facilities. This report describes the testing and subsequent test data analysis that was used to study whether the tests are practical and repeatable. Other activities not associated with the execution of tests included cost and time analyses, comparison of proposed test procedures with a study of public road experiences, and investigations into whether the test requirements are inconsistent with existing test track facilities. The work conducted to date provides reason to expect that the test methodology, with minor revisions and refinements, can meet the initial set of goals.

The results and conclusions contained herein reflect the current best judgment of the Project.

7.6 Acknowledgments

The CAMP participants acknowledge the valuable cooperation of Eaton Corporation, Mitsubishi Electronics of America Inc., NovAtel Inc., Steve Lieber & Associates Inc., Transportation Research Center Inc., and VI Engineering Inc. A special thanks to Doug Fesko of VI Engineering for assisting with test execution and analysis, and Marie Cassar and Tina Burnetti-Sayer for help with the Public Road Study.

7.7 References

American Association of State Highway and Transportation Officials (AASHTO 1995). *Policy on Geometric Design of Highways and Streets: 1994.*

Horowitz, A. D. (1986). *Automobile usage: A factbook on trips and weekly travel.* Report No. GMR-5351. Warren, MI: General Motors Research Laboratories.

Knipling, R. R., Wang, J., and Yin, H. (1993). *Rear-end crashes: Problem size assessment and statistical description.* Report No. DOT-HS-807-995. Washington, DC.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Society of Automotive Engineers (July 1976). *Vehicle dynamics terminology*. SAE recommended practice SAE J670e. Warrendale, PA: Society of Automotive Engineers.

Stewart and Burgett, A. (1989). Consideration of Potential Safety Effects for a New Vehicle-based Roadway Illumination Specification. *Proc. Twelfth International Technical Conference on Experimental Safety Vehicles,* (pp. 1209-13). Goteborg, Sweden.

U.S. Department of Transportation: Federal Highway Administration. (1988). *Manual On Uniform Traffic Control Devices For Streets and Highways (MUTCD).* US DOT FHWA-SA-89-006 HTO-21/2-89(15M)P.