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Objective Tests for Forward Looking Pedestrian Crash Avoidance/Mitigation Systems

Final Report

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16. Abstract

This report documents the work completed by the Crash Avoidance Metrics Partnership (CAMP) Crash Imminent Braking (CIB) Consortium during the project titled "Objective Tests for Forward Looking Pedestrian Crash Avoidance/Mitigation Systems." Participating companies in the CIB Consortium were Continental, Delphi Corporation, Ford Motor Company, General Motors, and Mercedes-Benz. The purpose of the project was to attempt to define minimum performance requirements and objective test procedures for pedestrian crash avoidance and mitigations systems. Two types of tests were examined in this study. Functional tests evaluate the intended performance of pedestrian crash avoidance/mitigation (PCAM) systems in their ability to avoid or mitigate a potential pedestrian crash. Operational tests assess the propensity of a PCAM system to trigger false (unintentional) activations where no system activation is desired. Based on data obtained during test track and on-road testing, test procedures were recommended for both types of tests.

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Executive Summary

This report describes the work completed by the Crash Avoidance Metrics Partnership (CAMP) Crash Imminent Braking (CIB) Consortium during the project titled "Objective Tests for Forward Looking Pedestrian Crash Avoidance/Mitigation Systems." The participating companies in the CIB Consortium were Continental, Delphi Corporation, Ford Motor Company, General Motors, and Mercedes-Benz. The project was sponsored by the National Highway Traffic Safety Administration through NHTSA Cooperative Agreement No. DTNH22-05-H-01277, Work Order No. 0006.

The goal of the project was to define objective test procedures and minimum performance requirements for pedestrian crash avoidance and mitigation (PCAM) systems. The focus of the study was on forward-looking systems addressing in-traffic pedestrian crashes. Two types of objective tests were studied in this project. First, functional tests evaluated the intended performance of PCAM systems in their ability to avoid or mitigate a potential pedestrian crash. In other words, functional tests evaluated whether a PCAM system correctly activates when system activation is warranted. Second, operational tests assessed the propensity of a PCAM system to trigger false (unintentional) activations where system activation was not likely to be desired.

The first phase of the project involved the definition of pedestrian crash scenarios that would serve as the foundation for the remainder of the project. Work conducted in this phase involved an analysis of the U.S. national crash databases by the Volpe National Transportation Systems Center (Volpe). From this effort, four pedestrian crash scenarios were defined by the PCAM Project Team. The scenarios, illustrated in Figure ES 1, included:

- S1 - Vehicle traveling straight with pedestrian crossing perpendicular to the vehicle path from either the left or right side (approximately 84% of the estimated functional years lost (FYL) and 59% of the estimated fatalities);
- S2 - Vehicle turning right at an intersection with pedestrian crossing perpendicular to the turning vehicle's path from either the left or right side (approximately 1% of the estimated FYL and less than 1% of the estimated fatalities);
- S3 - Vehicle turning left at an intersection with pedestrian crossing perpendicular to the turning vehicle's path from either the left or right side (approximately 1% of the estimated FYL and none of the estimated fatalities); and
- S4 - Vehicle traveling straight with pedestrian moving in line with the vehicle path either toward or away from the vehicle (approximately 10% of the estimated FYL and 8% of the estimated fatalities).

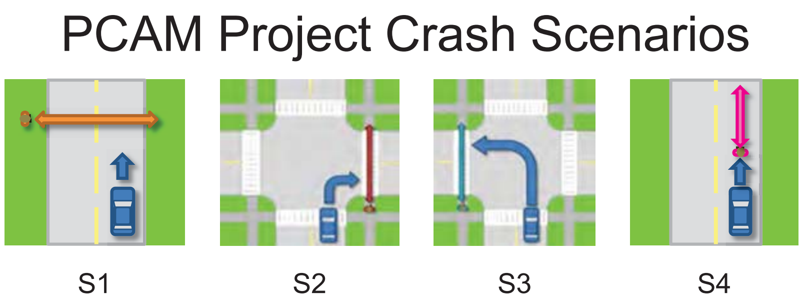

Figure ES 1: Four Pedestrian Crash Scenarios Defined

An analysis of pedestrian observational data collected during the previous CAMP CIB Project (Carpenter et al., 2011a, b) was conducted during the initial phase of the project to analyze benign pedestrian encounters (i.e., no crash) observed during actual driving. The primary purpose of this effort was to identify factors associated with pedestrian events that may not be readily available in the national databases.

Collectively, these efforts produced two important sets of outputs. First, an understanding of the pre-crash factors associated with pedestrian crashes led to the development of the initial objective test methods and a preliminary test plan for evaluating the methods. Second, a set of preliminary requirements for the test equipment was identified. This led to the development of the equipment needed to simulate the defined crash scenarios. The test apparatus developed during the project is shown in Figure ES 2. The mannequin shown in the figure was made from closed-cell foam and represented a 50th percentile adult male.

Figure ES 2: Test Apparatus Used to Simulate Pedestrian Crashes During Testing

The second phase of the project included all of the testing conducted during the project. Three sets of tests were performed in this phase to evaluate and refine the test methods, test equipment and system performance requirements for the project. The testing phase included the following:

- **Baseline Testing –** This activity was conducted on a closed-course test track to evaluate the initial test method proposals and the test equipment with production vehicles equipped with PCAM systems. These vehicles could not be equipped to monitor PCAM sensing system output, which limited the ability to evaluate these PCAM systems. The baseline vehicles, nonetheless, permitted preliminary evaluations to be made while the project vehicles with the ability to monitor sensor data were being built. As a result of the baseline tests, significant refinements to the test equipment were made to reduce test variability. Refinement of the preliminary test plan also resulted from this work.

- **Validation Testing –** This closed-course test track activity was conducted following equipment refinement. The primary objectives were to refine and finalize the test methods, verify the suitability of the test methods and test equipment for assessing PCAM system performance, and confirm that the test methods were capable of differentiating levels of PCAM system performance across various vehicle implementations. The three instrumented project test vehicles used were equipped with data logging equipment capable of recording all of the PCAM sensor data, the vehicle electrical bus signals, and the GPS ground-truth data.
- **PCAM Real-World Operational Assessment Data (ROAD) Trip –** This work involved collection of data surrounding real-world pedestrian encounters on public roadways. Two PCAM project vehicles were used, both equipped with forward-looking pedestrian sensors and data recording capabilities (including road scene video). This instrumentation gathered information about the pedestrian encounters and the environments where they occurred. This data collected was used to identify driving conditions that could lead to false activations in PCAM systems and to develop the corresponding operational test methods.

Finally, two additional support activities were undertaken as part of the project's third phase. In the first activity, the PCAM Project provided support to NHTSA and Volpe in their development of a methodology for estimating potential safety benefits for PCAM technologies. The PCAM Project efforts included collaborating to identify target crash scenarios for PCAM systems and providing exemplar PCAM data from on-track and road testing for NHTSA/Volpe to use in exercising their proposed methodology. In the second activity, the PCAM Project provided support to NHTSA toward harmonizing the pedestrian crash scenarios, test equipment, and test methods used to assess system performance. The role of the PCAM Project in this effort involved participation in working meetings with NHTSA and European-based research groups to describe the specific test methods and equipment developed within the project.

The following are the recommendations which resulted from the testing conducted in the project.

S1 test scenarios are recommended for evaluating functional performance. These test scenarios represent 84 percent of all FYL from Volpe's analysis of 2005 – 2009 GES data. Test data shows that even the basic configuration for this test scenario (10 mph vehicle speed with unobstructed walking mannequin) is capable of measuring PCAM system performance differences. Including multiple vehicle test speeds also evaluates upper activation limits and the avoidance versus mitigation capabilities.

Running mannequin tests (10 km/h) proved difficult for eliciting PCAM system response for all three project vehicles. This can be attributed to two major factors. First, the combination of running mannequin speed and 10 mph vehicle speed chosen for testing yields initial movement of the mannequin which follows a path that is just outside or along the edge of the sensors' fields of view. Second, assuming for demonstration purposes an on-center collision at any vehicle speed, the running mannequin does not enter the vehicle path until approximately 400 ms time-to-collision (TTC). This equals the range of response time of conventional brake systems and does not allow for time needed for target detection and classification or system signal processing. For these reasons, running mannequin tests are not recommended at this time. Further assessment with other mannequin and vehicle speed combinations may be needed to refine this test scenario.

For obstructed S1 test cases, PCAM system performance notably degraded with reduced mannequin reveal times. While minimal difference in performance was noted between unobstructed tests and obstruction tests with 2.7 s reveal times, performance for all three vehicles significantly degraded with a reveal time of 1.3 s (less than 20% speed reduction). Volpe's analysis of 2005 to 2009 GES crash data showed that approximately 16 percent of S1 cases are obstructed by objects outside the vehicle and approximately 61 percent are unobstructed. However unobstructed tests are simpler tests to set-up, and a 2.7 s TTC reveal time is consistent with current proposals from projects sponsored by the Federal Highway Research Institute of the Republic of Germany (Bundesanstalt für Straßenwesen, or BASt). A reveal time of 1.3 s would be the shortest reveal time that should be considered if obstructed tests are included in minimum performance requirements testing and significant reduction in performance should be expected.

S2/S3 turning test scenarios are not recommended for evaluating functional performance. Collectively, S2 and S3 represent approximately 2 percent of all FYL and less than 1 percent of fatalities from Volpe's analysis of 2005 – 2009 GES data. Test parameters for turning cases are also difficult to define due to the large variety of ways that turning scenarios can unfold and the wide variety of intersection geometries available on the roadways. Additionally, test conditions for turning cases are extremely difficult to control in a repeatable manner. Introducing turning scenarios as functional performance assessments could also lead to increased exposure to potential false activations.

S4 test scenarios are also not recommended for evaluating functional performance of PCAM systems. S4 scenarios represent 10 percent of FYL and 8 percent of fatalities, whereas S1 makes up 84 percent (and highest portion) of FYL and 59 percent of fatalities from Volpe's analysis of 2005 – 2009 GES data. S4 test results indicated that project vehicles achieved better performance overall than the S1 scenarios, suggesting that S4 scenarios would be less challenging tests from a minimum performance criteria perspective. PCAM systems that address S1 cases should reasonably be expected to also address S4 cases. Finally, including S4 scenarios with moving mannequins drives additional complexity to the test equipment with little benefit to system evaluation. This issue could be mitigated by using a stationary mannequin. The benefits of a stationary mannequin S4 test are not as great as the benefits of using the S1 scenario for PCAM system evaluation.

For the Dynamic Brake Support (DBS) functional tests, the current NHTSA DBS test proposal for vehicle-vehicle crashes (NHTSA, 2012) was adaptable to pedestrian S1 test scenarios. Measureable differences were observed in the test results from DBS versus CIB performance in pedestrian test scenarios. The 0.3 g pre-braking provided by the brake robot changes the geometry of the scenario in such a way that the mannequin could be detected earlier and braking initiated by the PCAM system was more effective, leading to a higher performance. Vehicles that feature a higher braking authority for DBS than CIB are expected to show a higher performance difference. Specific performance specifications, however, are not available from the project test results since only one PCAM Project vehicle could be evaluated under these conditions.

Operational test methods should be included in order to have a balanced assessment of PCAM system performance. The operational test methods developed within the project are recommended for assessing PCAM system performance. It is further recommended that the operational tests be run as a series of repeated tests with randomly distributed physical characteristics that are within the wide ranges observed in real-world situations. The medium and high priority test methods included:

- A test procedure in which a moving mannequin stops short of the moving vehicle path or clears the vehicle's path before a collision occurs (high priority). This operational procedure was adapted from Scenario S1.
- Two procedures in which a turning vehicle encounters a stationary mannequin on the outside of the vehicle's curved path (high priority). These procedures were adapted from Scenarios S2 and S3.
- Two lane change scenarios (short and long lane changes) with a mannequin moving in a path parallel to but outside of the actual vehicle path (medium priority).

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List of Acronyms

AAAM	Association for the Advancement of Automotive Medicine
AIS	Abbreviated Injury Scale
BASt	Federal Highway Research Institute of the Republic of Germany (Bundesanstalt für Straßenwesen)
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CDC	Centers for Disease Control and Prevention
CDS	Crashworthiness Data System
CIB	Crash Imminent Braking (synonymous with Advanced Emergency Braking or AEB)
CMOS	Complementary Metal Oxide Semiconductor
DBS	Dynamic Brake Support
DGPS	Differential Global Positioning System
DOT	Department of Transportation
FARS	Fatality Analysis Reporting System
FCW	Forward Collision Warning
FYL	Functional Years Lost
GES	General Estimates System
GHz	Gigahertz
GPS	Global Positioning System
IIHS	Insurance Institute for Highway Safety
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
NSF	National Science Foundation
OEM	Original Equipment Manufacturer
NASS	National Automotive Sampling System
PCAM	Pedestrian Crash Avoidance/Mitigation
PLC	Programmable Logic Controller
RF	Radio Frequency
RCS	Radar Cross Section
ROAD	Real-World Operational Assessment Data
RTK	Real-Time Kinematic
TMT	Technical Management Team
TTC	Time-to-Collision
vFSS	Advanced Forward-Looking Safety Systems (Project)

VRTC	Vehicle Research and Test Center
Wi-Fi	Wireless Fidelity (Wireless Local Network)

1 Introduction

This document presents the final report for the Pedestrian Crash Avoidance/Mitigation (PCAM) Project. The project was conducted by the Crash Avoidance Metrics Partnership (CAMP) Crash Imminent Braking (CIB) Consortium, which consists of Continental, Delphi Corporation, Ford Motor Company, General Motors and Mercedes-Benz. The project was sponsored by the National Highway Traffic Safety Administration through NHTSA Cooperative Agreement No. DTNH22-05-H-01277, Work Order No. 0006. From inception in May 2011, the PCAM project ran 26 months to June 2013.

1.1 Objectives

The goals of the PCAM project were to develop and validate minimum performance requirements and objective test procedures for forward-looking PCAM systems intended to address in-traffic, pedestrian crash scenarios. Two categories of test procedures were developed to evaluate the performance of PCAM systems. First, functional tests evaluated the intended performance of PCAM systems in their ability to avoid or mitigate a potential pedestrian crash. In other words, functional tests evaluated whether a PCAM system correctly activates when system activation is warranted. Operational tests, on the other hand, assessed the propensity of a PCAM system to trigger false (unintentional) activations where system activation was not likely to be desired.

1.2 Project Organization

The PCAM project consisted of six tasks. Task 1, the project management task, ran throughout the project and involved the activities needed for technical oversight. The remaining five tasks were divided into three project phases.

The first phase, encompassing Tasks 2 and 3, focused on the identification of pedestrian crash scenarios that would serve as the basis for functional test method development conducted in the second phase of the project. This approach ensured that the resulting functional test methods are representative of the pedestrian crash types that occur on U.S. roadways. The first phase also included the preliminary planning for project testing and the acquisition of test equipment and vehicles with PCAM systems. The initial work in this phase featured an analysis of the national crash databases as well as data collected during the previously completed CAMP CIB Project (Carpenter et al., 2011a, 2011b). The latter effort involved analysis of benign pedestrian encounters (i.e., no crash) observed during actual driving to identify factors associated with pedestrian events that may not be available in the national databases. The summary of the data analyses is provided in Section 2 of the report. Section 3 describes the equipment used during testing.

The second phase of the project covered Task 4 and included all of the testing conducted during the project. Three sets of tests were performed in this phase to evaluate and refine the test methods, test equipment and system performance requirements for the project. The testing phase, discussed in Section 4 of the report, included the following:

- **Baseline Testing –** This activity was conducted from February to April 2012 on a closed test track to evaluate and refine the initial test method proposals and test equipment. PCAM-equipped, production vehicles were provided by NHTSA for this test phase.
- **PCAM Real-World Operational Assessment Data (ROAD) Trip –** This was conducted between June and August 2012 and involved collection of data surrounding real-world pedestrian encounters on public roadways. Two of the three PCAM Project test development vehicles were used, both equipped with forward-looking pedestrian sensors and data recording capabilities with road scene video. This instrumentation provided information about the pedestrian encounters and the environments where they occurred. The data collected was used to identify driving conditions that could lead to false activations in PCAM systems and develop the corresponding operational test methods.
- **Validation Testing –** This closed-course test track activity was conducted from September through November 2012. The primary objectives of this work were to finalize the test methods, verify the suitability of the test methods and test equipment for assessing PCAM system performance, and confirm that the test methods were capable of differentiating levels of PCAM system performance among different vehicle implementations. Three instrumented project test development vehicles were used for this work. All three vehicles were equipped with PCAM systems and data logging equipment capable of recording all of the PCAM sensor data, the vehicle electrical bus signals, and the GPS ground-truth data. The output from this effort was a final recommended test procedure for PCAM systems along with minimum performance requirements.

The third phase of the project involved Tasks 5 and 6. In Task 5, the PCAM Project team provided consultation to NHTSA in support of their efforts to estimate the safety benefits of PCAM systems. Coordination with other PCAM-related activities underway globally was provided in Task 6. Section 5 summarizes the work conducted in this phase of the project.

2 Definition of Crash Scenarios for Study and Functional Requirements

To develop field-relevant test methods, this project began with the identification of crash scenarios that were deemed to be most applicable to /PCAM systems. This analysis was conducted using U.S. vehicle crash databases by NHTSA and the Volpe National Transportation Systems Center (Volpe) with support from the PCAM Technical Management Team (TMT). These crash scenarios provide the basis for preliminary functional requirements and served as input for developing the test procedures.

The objectives for this section include:

- Define in-traffic, pedestrian crash scenarios for PCAM testing through analysis of the national crash databases.
- Examine pedestrian scenarios observed in the CIB ROAD Trip to identify factors associated with pedestrian observations during actual driving that may not be available in the national databases.
- Review available pedestrian detection sensors and active braking technologies to support procurement of test vehicles and preparation of test methods. This objective focused on selecting sensor technologies that are either currently in production or under development for potential production deployment within the next five years.
- Define preliminary pedestrian target (i.e., mannequin) characteristics.
- Develop preliminary plans and procedures for the tests conducted later in the project. The planned tests involve three phases, including baseline tests, PCAM ROAD Trip tests and validation tests.

2.1 Identification of Crash Scenarios From National Databases

Pedestrian crash data and the pre-crash parameters associated with pedestrian crashes in the national databases available in the United States were examined for the five-year period 2005 - 2009. This analysis focused on pedestrian crashes for which PCAM systems could potentially provide safety benefits and identifying crash conditions which could be used in developing the test scenarios used in the project. This ensured that the PCAM project test scenarios and related parameters are applicable to real-world pedestrian crashes. For the purpose of this project, pedestrian crash scenario development and assessment was based on an estimate of the functional years lost associated with the pre-crash scenarios identified from the National Automotive Sampling System General Estimates System crash database. FYL is an estimate of aggregate years of life lost for fatalities and the years of functional capacity lost from nonfatal injuries (Miller et al., 1991). The FYL measure is computed based on the Maximum Abbreviated Injury Scale values of 2 and higher of any persons involved in the crash (i.e., AAIS2+ injuries). The Abbreviated Injury Scale is a classification system for assessing impact injury severity developed and published by the Association for the Advancement of Automotive Medicine and is used for coding single injuries, assessing multiple injuries or assessing cumulative effects of more than one injury.

The pedestrian crash scenario analysis identified the most frequently occurring scenarios that later formed a basis for the PCAM test methods. This analysis was conducted by Volpe. It is expected that Volpe will prepare and issue a separate detailed report on their analyses and the scenario definition process. The following provides a summary of the work conducted.

Volpe's analysis of the 2005 – 2009 GES crash database estimated that approximately 300,000 pedestrian crashes for the five-year period are contained within 67 pre-crash scenarios identified for the PCAM project (excluding any cases classified as "vehicle/pedestrian no action," "other action," or "unknown action"). An analysis of the Fatality Analysis Reporting System data was also conducted in a similar manner. However, FARS was found to contain limited vehicle-pedestrian maneuver information. This restricted the usefulness of the FARS data in determining critical crash scenario parameters that were needed for defining potential test conditions for the project. Consequently, no further action was taken based on this data for developing PCAM tests.

The pre-crash scenarios from the GES crash database were sorted by Volpe's estimate of FYL. The resulting list of 67 scenarios, and their associated estimates of FYL, are presented in Appendix A. The top 20 of these 67 scenarios were found to contain an estimated 139,000 crashes which accounted for 98 percent of the FYL for all pedestrian crashes and 67 percent of the estimated pedestrian fatalities in GES. These 20 scenarios are presented in Table 1. The information contained in Table 1 is based on the combined five-years of GES data. The estimates shown are not annual estimates.

An analysis was then performed by the PCAM TMT to determine what common scenario characteristics preceded the crash events in these 20 scenarios. As a result, the 20 scenarios were subsequently classified into one of four sub-groups based on these common pre-crash scenario characteristics. The four scenario groups are depicted in Figure 1 and are defined as scenario S1, S2, S3, and S4. These scenario designations are used throughout the remainder of the report. The four scenarios represent the PCAM Project test scenarios which formed the primary focus of the activities in the remainder of the project. A description of each scenario sub-group is presented in the material which follows Figure 1. Table 2 presents a summary of the percent of FYL and the percent of fatalities associated with each of the four PCAM Project scenarios. The information in Table 2 is based on the combined five years of GES data. The estimates shown are not annual estimates.

Table 1: Twenty Pedestrian Crash Scenarios Identified by the Volpe Center Ranked by Functional Years Lost (Based on the Combined 2005 – 2009 GES Data)

Rank	Maneuver (Vehicle and Pedestrian)	FYL	Percent of FYL	PCAM Scenario Classification
1	Going Straight & Improper Crossing of Roadway or Intersection	237,571	48	S1
2	Going Straight & Darting or Running into Road	99,661	20	S1
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. in Roadway	48,339	10	S1
4	Going Straight & Walking With Traffic	36,873	7	S4
5	Going Straight & Inattentive (Talking, Eating, Etc.)	11,983	2	S1
6	Negotiating a Curve & Improper Crossing of Roadway or Intersection	7,892	2	S1
7	Negotiating a Curve & Walking With Traffic	7,744	2	S4
8	Going Straight & Walking Against Traffic	7,235	1	S4
9	Turning Left & Improper Crossing of Roadway or Intersection	4,621	1	S3
10	Changing Lanes & Playing, Working, Sitting, Lying, Standing, etc. in Roadway	2,889	1	S1
11	Turning Right & Improper Crossing of Roadway or Intersection	2,788	1	S2
12	Passing or Overtaking Another Vehicle & Darting or Running into Road	2,733	1	S1
13	Going Straight & Non-Motorist Pushing a Vehicle	2,406	0	S4
14	Decelerating in Traffic Lane & Darting or Running into Road	2,272	0	S1
15	Changing Lanes & Improper Crossing of Roadway or Intersection	1,837	0	S1
16	Decelerating in Traffic Lane & Improper Crossing of Roadway or Intersection	1,673	0	S1
17	Turning Left & Darting or Running into Road	1,668	0	S3
18	Turning Left & Playing, Working, Sitting, Lying, Standing, etc. in Roadway	1,519	0	S3
19	Starting in Traffic Lane & Playing, Working, Sitting, Lying, Standing, etc. in Roadway	1,106	0	S1
20	Entering a Parking Position & Improper Crossing of Roadway or Intersection	984	0	S1

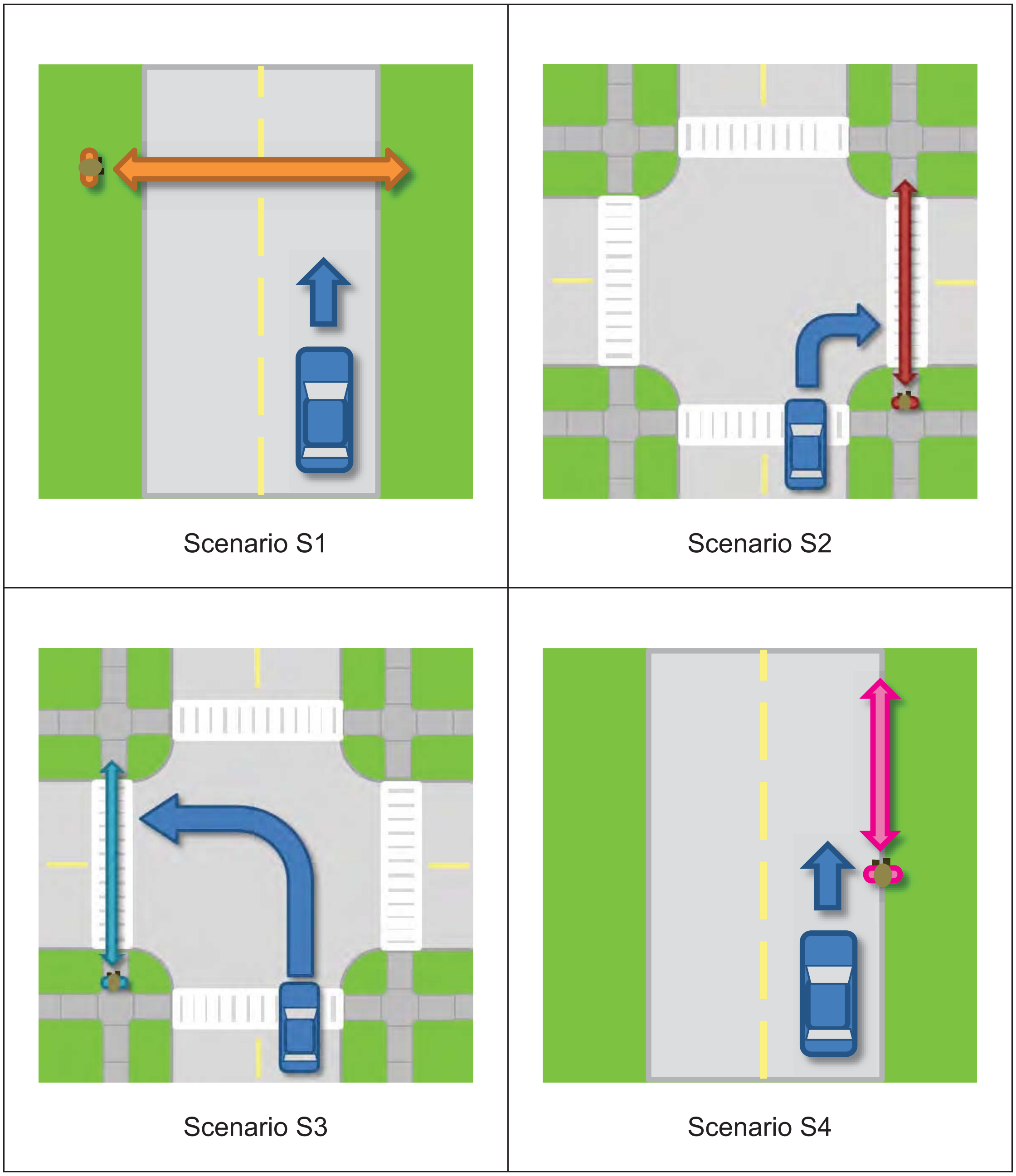

Figure 1: Four Scenario Groups Studied in PCAM Project

S1 - Vehicle traveling straight with pedestrian crossing perpendicular to the vehicle path from either the left or right side

S2 - Vehicle turning right at an intersection with pedestrian crossing perpendicular to the new vehicle path from either the left or right side

S3 - Vehicle turning left at an intersection with pedestrian crossing perpendicular to the new vehicle path from either the left or right side

S4 - Vehicle traveling straight with pedestrian moving in line with the vehicle path either toward or away from the vehicle

Table 2: Functional Years Lost and Fatalities for Defined PCAM Test Scenarios (Based on Volpe's Analysis of 5 Years of GES Data)

Scenario	Cases	% All FYL	Fatalities	% of Fatalities (of 67% in 20 Scenarios Identified by Volpe)
S1	115,000	84%	7,000	88%
S2	2,000	1%	16	<1%
S3	9,000	1%	0	0%
S4	13,000	10%	1,000	12%

2.2 Pedestrian Scenarios Observed During the CIB ROAD Trip

Following Volpe's data analysis, the final step in analyzing the pedestrian crash scenarios was determining the specific roadway, environment, driver speed and other factors most frequently associated with those crashes. CIB ROAD Trip information was used to supplement the GES crash data by providing measureable details associated with driver and pedestrian actions that were not available in the crash databases.

The CIB ROAD Trip was a data collection effort conducted as part of the previously completed CAMP CIB project (Carpenter et al., 2011a). In this effort, two CIB Project vehicles equipped with video cameras, GPS instrumentation, CIB sensors and data acquisition systems were driven on public roads throughout the United States during a six-week period from July 24 to September 3, 2009. Although the original purpose of this effort was to acquire data for use in developing test methods for CIB systems, the pedestrian encounters contained in this data provide quantifiable details associated with pedestrian and driver actions that do not exist in the GES crash data analysis. Such information proved helpful in defining representative test methods for the PCAM *functional* scenarios. Within the PCAM Project, functional tests evaluate whether a PCAM system correctly activates when system activation is warranted.

During the PCAM Project, the CIB ROAD Trip data was analyzed to extract specific test parameter information where pedestrians were observed in order to enhance the confidence in the PCAM test methods. The analysis results are presented in Appendix B. The observations of this task were used as a supplement to Volpe's estimated FYL and crash data assessment from the U.S. GES database. A separate and distinct PCAM ROAD Trip data collection effort was also conducted to acquire information that was used to develop the *operational* test methods for PCAM systems. Operational tests assess the potential of a PCAM system to trigger false activations where no system activation is desired. The PCAM ROAD Trip is discussed further in Section 4.3 of the report.

2.3 Scenarios Factors for Test Method Definition

Once the basic project crash scenarios were identified, additional information was needed to more fully define the preliminary test methods. These additional test factors were obtained through two sources. First, GES crash types identified in the Section 2.1 were further analyzed to identify additional parameters recorded most frequently for each crash type. Since GES has limited available data with respect to the specific driver and pedestrian actions necessary for fully defining representative test methods, operational data collected during the CIB ROAD Trip was used to supplement the GES crash data by providing further details associated with driver and pedestrian actions. Appendix B provides a detailed description of the CIB ROAD Trip data analysis and results while Appendix C provides examples of pedestrian encounters observed during the CIB ROAD Trip.

A number of crash factors were identified within the GES data as potentially influential to the definition of preliminary PCAM test scenarios. These included factors such as roadway conditions and details, environmental conditions, pre-crash vehicle control and dynamics, and pre-crash driver actions.

Appendix D contains tables of crash factors relative to the 20 GES crash types (as described previously in Section 2.1) that were identified by Volpe as resulting in the highest FYL. The S1 – S4 scenario classification is also shown next to each of these crash types (for later application to the specific test types shown in this appendix). Table 3 provides an example data set from this analysis.

Table 3: Sample GES Crash Factor Data for Test Method Definition

Rank (FYL)	Maneuver	Scenario Classification	Roadway Alignment: Straight	Curve	Grand Total
	OTHER SCENARIOS		153,675	7,509	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	49,625	544	50,169
2	Going Straight & Darting or Running Into Road	S1	47,584	344	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	8,480	168	8,649
4	Going Straight & Walking With Traffic	S4	8,231	232	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	2,631	15	2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	14	1,090	1,105
7	Negotiating a curve & Walking With Traffic	S4		750	750
8	Going Straight & Walking Against Traffic	S4	2,828	271	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	5,662	116	5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	228		228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,935	31	1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	294	307	601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	198		198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	1,051		1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	838		838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	644	14	658
17	Turning left & Darting or Running Into Road	S3	1,474	32	1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	1,486	16	1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	1,005		1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	462		462
	Total		**288,346**	**11,440**	**299,786**

While conducting this analysis, it was noted that some of the crash parameters considered proved to have little or no apparent influence on the available cases. Roadway alignment, for example, was listed as "Straight" for approximately 288,000 of the 300,000 listed cases (96%), as shown in Table 3. These factors, therefore, were represented with fixed test parameters (e.g., "straight" roadway alignment) based on their apparent limited influence on the crash types and/or physical limitations in the ability to vary the factor in a practical manner during testing. The factors that remained fixed during PCAM project testing included:

- "Straight" roadway alignment.
- "Level" roadway profile.
- "Dry" roadway surface.
- "No Adverse Atmospheric Conditions" weather conditions.
- Minimum of two travel lanes based on available test facilities.

Remaining test parameters were identified and applied only to those scenarios for which that parameter occurred most frequently in the relevant pedestrian crash data. This was done in an effort to control the size of the initial test matrix, and focus on varying only the factors that substantially influenced a particular crash type. These factors included conditions such as pedestrian travel direction, ambient lighting conditions, obstructions affecting the visibility of pedestrians, vehicle and pedestrian travel speeds, and the PCAM system functions that align with the evaluated crash types.

2.3.1 Pedestrian Direction

Very little information was available in GES to indicate in which direction pedestrians were traveling prior to being struck. Based on CIB ROAD Trip data analysis (previously discussed in Section 2.2), crossing pedestrians were observed to approach with about the same probability from both the left and right sides of the road. A different PCAM sensing challenge potentially exists based upon the pedestrian's direction of travel versus the striking vehicle. Pedestrians crossing in front of a vehicle traveling on a two-or-more-lane-road from the near-side, for example, enter the roadway at a different angle relative to the vehicle and are potentially in-path relative to the vehicle for a shorter time than a pedestrian entering from the opposite side. Therefore, the preliminary test matrix considered pedestrian test mannequins entering the test vehicle path from both the left and right sides for test cases representing pedestrians crossing the roadway. For similar reasons (i.e., lack of data), pedestrian test mannequins moving toward and away from the test vehicle were considered for test cases that represent pedestrians walking along the side of the roadway.

2.3.2 Ambient Light Conditions

Table 4 provides the number of reported crashes and fatalities occurring in daylight versus darkness conditions for each of the PCAM S1 – S4 scenario classifications. In this analysis, darkness includes all conditions listed in GES that are not daylight, including "Darkness," "Not Lighted + Darkness," "Lighted + Darkness," and "Lighting Unknown." Appendix D contains additional detail for these conditions for each of the 20 pre-crash maneuvers which resulted in the highest FYL.

As shown in Table 4, a majority of the overall pedestrian crashes occurred in daylight. However, a few specific pedestrian crash scenarios occurred frequently in dark conditions. First, the only PCAM scenario (of the 4 identified) that occurred more frequently in darkness than in daylight was the S4 (i.e., pedestrians walking along the side of the roadway) scenario, under which 61 percent of the cases occurred in darkness. Second, a substantially larger percentage of both the S1 and S4 fatalities occurred in darkness. These findings are consistent with studies performed by the Insurance Institute for Highway Safety (IIHS, 2011; Jermakian & Zuby, 2011). None of the S3 cases in the GES database resulted in a fatality, and no fatalities occurred in darkness occurred for S2 cases. Therefore, the preliminary test matrix considered both daylight and darkness conditions for S1 and S4 test scenarios, and only daylight tests for the S2 and S3 test scenarios.

Table 4: Comparison of Pedestrian Crashes by Lighting Condition

		Daylight		Darkness - All Conditions	
PCAM Scenario Classification	No. of Crashes by Scenario	No. of Crashes	Row Percent	No. of Crashes	Row Percent
S1	115,339	65,196	57	43,727	38
S2	1,966	1,170	59	528	27
S3	8,787	5,617	64	2,604	30
S4	12,510	4,250	34	7,622	61

		Daylight		Darkness - All Conditions	
PCAM Scenario Classification	No. of Fatalities by Scenario	No. of Fatalities	Row Percent	No. of Fatalities	Row Percent
S1	7,233	1,338	18	5,810	80
S2	16	16	100	0	0
S3	0	0	0	0	0
S4	1,003	153	15	783	78

Note: Darkness - All Conditions includes Darkness, Not Lighted + Darkness, Lighted + Darkness, Lighting Unknown

2.3.3 Obstructions

The information available in the GES database relative to obscuration of pedestrians involved in vehicle-pedestrian crashes can be organized into a few simplified categories. Table 5 provides a summary of this data. Additional details are provided in Appendix D. "No Obstruction Noted" corresponded to cases in which the reporting police agency did not indicate obscuration as a factor in the crash and, thus, can be represented in PCAM test scenarios where no artificial obstruction is used to block the view of the pedestrian test mannequin. The first group of available obstruction categories from GES cannot be practically or easily represented by PCAM test conditions. These include factors such as design features on the striking vehicle or conditions of the striking vehicle such as the A-pillar, windshield fog, frost, people, etc., or weather and/or light conditions that are difficult or impossible to readily control in a test environment. The remaining types of obstructions observed in GES were conditions which are external to the striking vehicle, are reasonably controllable as test parameters, and are likely to affect the potential performance of a PCAM system. Examples of this type of obstruction included parked cars, buildings and signs.

Table 5: Comparison of Pedestrian Crashes With and Without Obstructions

		Obstructions Which Cannot Be Represented in PCAM Testing		Obstructed by Outside Obstacle		No Obstruction Noted	
PCAM Scenario Classification	No. of Crashes by Scenario	No. of Crashes	Row Percent	No. of Crashes	Row Percent	No. of Crashes	Row Percent
S1	115,339	25,955	23%	18,642	16%	70,742	61%
S2	1,965	356	18%	105	5%	1,504	77%
S3	8,787	1,615	18%	843	10%	6,329	72%
S4	12,510	6,644	53%	170	1%	5,697	46%

As shown in Table 5, the majority of the PCAM pedestrian crash scenarios involved no obstructions obscuring the view of the pedestrian. In addition, when obstructions were present in the GES database, they often included situations which cannot be reasonably represented in PCAM testing. For example, 23 percent of the crashes for S1 and 53 percent of the crashes for S4 involved obstructions of this type, as described earlier. Examples of these types of obstructions included host-vehicle related obstructions such as a fogged or cracked windshield, or A-pillar or other body parts obscuring the view of the pedestrians. Since these obstructions affect the driver's view of the pedestrians and not necessarily the view of the PCAM sensors, these types of obstructions were considered outside the scope of testing activities for this project. Since S1 is the PCAM scenario with the largest number of obstructions that may be reasonably represented in test methods, the preliminary test matrix considered tests with obscured and unobscured pedestrian test mannequins for the S1 scenarios only. All other scenarios considered only unobscured pedestrian test mannequins.

2.3.4 Test Vehicle Speeds

Figure 2 provides a summary of estimated vehicle travel speeds obtained from the GES database with respect to each pedestrian crash scenario. For the turning vehicle cases, S2 and S3, most of the crash cases occurred with estimated vehicle speeds below 10 mph. The S1 cases, which involve vehicles traveling straight with pedestrians crossing the roadway in front of the vehicle, display a relatively normal distribution, peaking in the 21-25 mph speed range. The majority of these crashes occur at speeds less than 25 mph. The S4 cases, however, which involved vehicles traveling straight and striking pedestrians traveling along the side of the roadway, display more of a bi-modal distribution. In these cases, the numbers of crashes appeared to peak at both the 6 – 10 mph speed range and again around the 26 to 40 mph speed range. Additional detailed GES analysis data is available in Appendix D.

As a result of this analysis, tests at lower speeds (approximately 10 mph) and higher speeds (approximately 25 mph) were conducted for S1 and S4 scenarios. This approach also provided an assessment of the potential boundaries between pedestrian crash avoidance and crash mitigation capabilities. All tests conducted for the vehicle turning scenarios, S2 and S3, were conducted at approximately 10 mph.

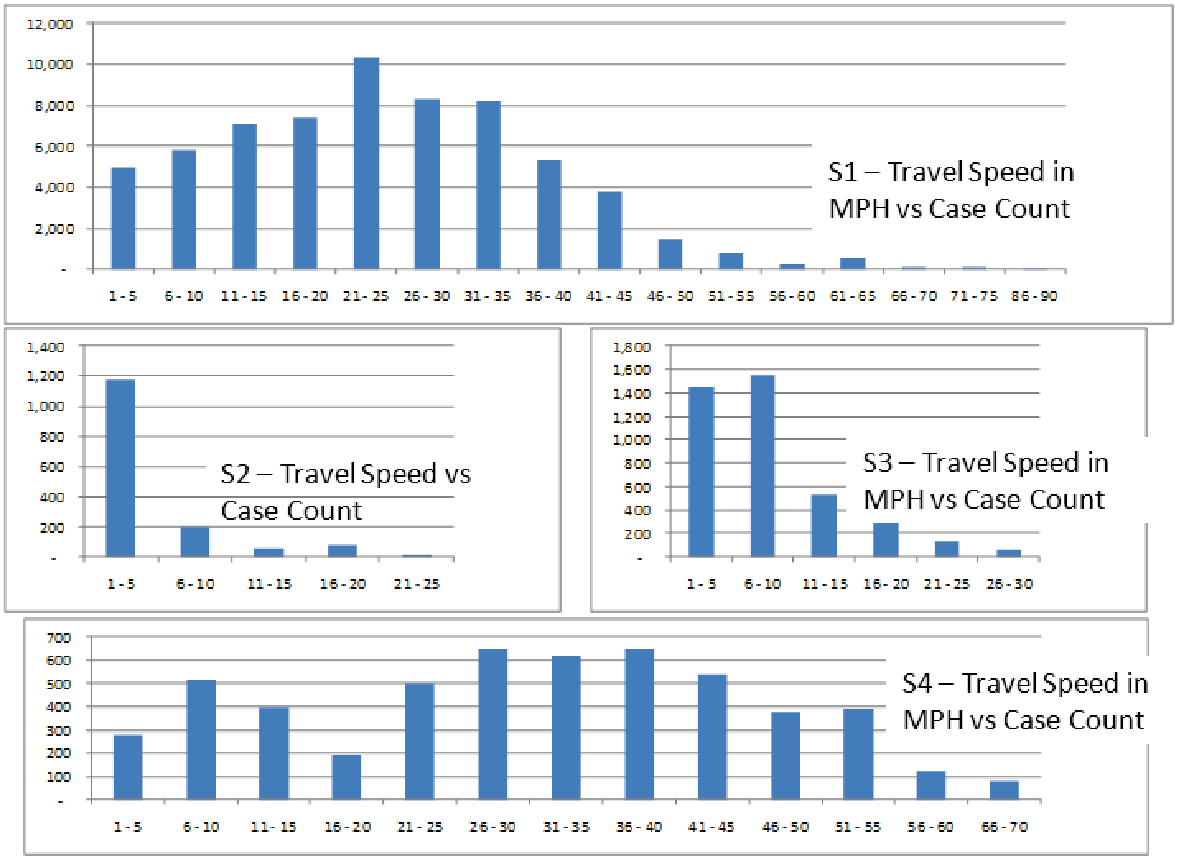

Figure 2: Estimated Vehicle Travel Speeds

2.3.5 Pedestrian Test Mannequin Speeds

Due to the organization of the GES database, very little information was available regarding the travel speeds of the pedestrians involved in crashes. This information could only be obtained by dissecting the cases individually based on the description of the pre-crash maneuver. Instead, it was decided to use typical pedestrian walking speeds for all scenarios. Additional mannequin speeds would then be considered for the S1 and S4 tests since those scenarios represent the highest percentage of both FYL and pedestrian fatalities in the United States. For S1 tests, mannequin speeds representing both walking and darting pedestrian actions were considered in the preliminary matrix. Actual travel speed requirements for the pedestrian test mannequins during testing were further defined based upon observations recorded from the CIB ROAD Trip described in Section 2.2. Test data from the initial project baseline tests could then be assessed to determine whether significant differences were detected in PCAM system performances as a result of the different mannequin travel speeds. For S4 tests, the preliminary test matrix for the baseline tests considered pedestrian test mannequins in stationary positions facing toward and away from the test vehicle as well as at a walking speed. These conditions allowed an evaluation of whether pedestrians moving parallel to the vehicle's path could be reasonably represented using a stationary pedestrian test. This approach could potentially simplify the test method for the S4 scenario and the overall test equipment design.

2.3.6 Driver Action Attempted

Table 6 presents the driver's "corrective" action attempted in the scenarios examined. This information is contained in the GES data and is reported by the police during the accident investigation. "Braking with Lockup" cases only represented approximately 2 percent of the PCAM cases identified in the GES, and were assumed to include crashes in which the driver applied as much brake force as the vehicle dynamics and road surface conditions could support. Therefore, minimal additional benefit would be expected from a PCAM system.

Table 6: Driver "Corrective" Action Attempted

Braking Condition	PCAM Test Factor	Percent of Cases Analyzed
Braking with lockup	No additional benefit expected from PCAM systems	~2%
Braking with no known lockup	Dynamic brake support	~10% of S1 cases but ≤3% for S2 – S4 cases
No known braking	Autonomous braking	>70% in each scenario type
Note: This approach does not account for potential changes in driver reaction as a result of pedestrian warnings that may precede PCAM system activations		

"Braking with No Known Lockup" cases were assumed to include crashes in which the driver did react to a pedestrian, but did not apply sufficient braking to avoid a crash. These conditions correspond with the generally intended purpose of dynamic brake support (DBS) functionality. DBS supplements driver-initiated braking based upon CIB sensor input and calculations comparing driver-applied braking levels versus the estimated deceleration required to avoid impact with the pedestrian or other objects. This braking category was identified in approximately 10 percent of the S1 scenarios but less than 3 percent of the S2 through S4 cases.

"No known braking" cases were assumed to include crashes in which the driver did not react to a pedestrian to avoid a crash. These conditions correspond with the generally intended purpose of autonomous CIB functionality. CIB autonomously applies the vehicle's brakes once the system predicts that a crash is likely to occur when the driver has not taken avoidance actions. Depending upon the PCAM system configuration, sensing and algorithm capabilities, vehicle speeds, environment and other factors, the system may attempt to avoid or mitigate the severity of a potential crash. "No known braking" was identified in greater than 70 percent of the PCAM crashes in each of the four PCAM crash scenarios.

Based on the above assessment, the preliminary test matrix for the project baseline tests considered assessments of potential DBS functionality for pedestrian mannequins during the S1 test scenario only. Tests assessing potential autonomous CIB functionality were considered for all four PCAM scenarios.

It should be stressed that the scope of the PCAM Project does not allow addressing or accounting for the potential benefits of pedestrian warnings (when implemented in conjunction with a PCAM system) that may elicit driver maneuvers (such as braking) prior to a PCAM system activation.

2.3.7 Preliminary Pedestrian Test Mannequin Sizes

The PCAM Project scope was defined to include test methods developed using male, 50th percentile mannequins. This scoping limitation enabled use of PCAM sensor correlation data collected with these adult mannequins in the previous CAMP CIB Project (Carpenter et al., 2011b), which was particularly important given that no PCAM sensor response data was available to correlate a child-size mannequin to actual human children. Project timing and resource constraints prevented further mannequin development. However, in order to demonstrate that the test methods and test equipment developed within this project are adaptable to a variety of potential mannequin sizes, a limited number of tests using uncorrelated child-size mannequins were incorporated into the PCAM Project for demonstration purposes only.

To define preliminary requirements for the adult pedestrian mannequin, measurements from a number of sources were compared. These included specifications for the Hybrid III anthropomorphic test device crash test dummy (Humanetics Innovative Solutions, 2012), human growth charts from the U.S. Centers for Disease Control and Prevention (CDC, 2000), pedestrian size information from the NASS Crashworthiness Data System crash database, as well as typical clothing industry mannequins such as those used in the CIB Project (Carpenter et al., 2011b). Table 7 provides a summary of the test mannequin measurements (which are further described in Section 3.3). Data in this table suggests that a pedestrian test mannequin 65 to 70 inches tall would reasonably represent a typical adult.

Additionally, the following criteria were used to define shape of the dummy such that it was proportioned similarly to a typical human. These criteria use the head height and width as the basic measurement units:

- The total height of the dummy should be 7 or 8 times the head height when standing straight with the legs together.
- The shoulders should be 2 or 3 times the head width. The waist should also be 2 to 3 times the head width. For men, the shoulders are three times the head width and the waist is two times the head width. For women, this is reversed: The shoulders are two times the head width and the waist is three times the head width.

- For the legs, the outseam is four times the head height, while the inseam is three times the head height.
- The length of the arms is typically three times the head height.

Table 7: Summary of Adult Human Measurements

Dimension	Hybrid III	CDC – Male 20 Years	CDC – Female 20 Years	CDS – Average Male 20 Years	CDS – Average Female 20 Years
Height	69 in.	69.5 in.	64.5 in.	70 in.	65 in.
Weight	172.3 lbs.	156 lbs.	128 lbs.	172 lbs.	142 lbs.

Two factors were considered in developing the mannequin to simulate a child pedestrian. First, a mannequin size that could reasonably approximate a child walking alone in in-traffic conditions was desired. Second, a child size that was significantly different from the selected adult mannequin was also desired in order to demonstrate that the test methods and test equipment could be used with different mannequin attributes. Given these considerations, an 8-year-old child's size was selected for the demonstration tests. Based on CDC data, a typical 8-year-old is approximately 50 inches tall with a chest measuring 25 inches, waist of 26 inches and hips of 30.5 inches. Additional test mannequin requirements are presented in Section 3.3.1.

From the above assessment of potential parameters associated with pedestrian crashes, Table 8 presents a summary of the preliminary test factors considered when developing the test scenarios for baseline testing.

Table 8: Preliminary Baseline Test Factors

Test Scenarios	Pedestrian Direction				Light Condition		Obstructions		Test Vehicle Speeds			Mannequin Speeds			PCAM Functions	
	Left	Right	Toward	Away	Day	Night	No	Yes	5 mph	10 mph	25 mph	0 mph	Walk	Dart	CIB	DBS
S1	X	X			X	X	X	X		X	X		X	X	X	X
S2	X	X			X		X		X				X		X	
S3	X	X			X		X		X				X		X	
S4			X	X	X	X	X			X	or 30	X	X		X	

3 Test Equipment

3.1 Baseline Test Vehicles

The NHTSA Vehicle Research and Test Center was responsible for procuring the production vehicles required for baseline testing. Production vehicles were selected for this phase in order to provide early assessment of the test methods and equipment and to establish baseline PCAM system performance. To support NHTSA, candidate vehicles were initially recommended by the PCAM TMT.

The selected baseline test vehicles included the following:

- Baseline 1 – This is a current production vehicle available in the United States with pedestrian detection and full auto braking capability. The system includes lidar, radar, and monovision sensors and can avoid impacts with pedestrians at speeds up to 22 mph in daylight, according to information available from the manufacturer.
- Baseline 2 – This is a United States-specification vehicle with a stereo-vision based active safety system which has been in production in Japan and Australia.

3.2 PCAM Project Test Vehicles

After a review of pedestrian detection sensors and active braking technologies, the PCAM TMT and NHTSA jointly agreed on using existing test vehicles that were provided by the PCAM Project participants for testing and developing test procedures. Three different test vehicles were used for evaluating the PCAM test apparatus and test methods with different potential PCAM technologies (e.g., monocular camera, stereo camera, and long/mid–range radar sensors).

As Table 9 shows, all test vehicles were equipped with both automatic braking capabilities and dynamic brake support systems. The autonomous CIB braking functions are designed to automatically apply emergency braking in cases where the driver does not react to any warnings. The system is designed to prepare the brake system for an emergency stop (i.e., pre-fill or precharge) and to warn the driver of an imminent crash. The specific driver warnings used in each vehicle varied. The types of driver warnings included a haptic force feedback accelerator pedal, an auditory alert and a visual warning. If the driver does not apply the brakes, the system can provide high brake intervention levels up to full autonomous emergency braking. Deceleration levels for the CIB function (as well as the DBS function below) also varied by vehicle. These were set by the respective vehicle providers.

The DBS function is designed to act to reduce the stopping distance when a driver responds to an emergency situation. The system actuators will apply full braking, typically, faster than a driver could perform during a panic situation. As in the CIB function, the DBS system is designed to pre-fill and pre-brake to prepare for an emergency stop and to warn the driver of an imminent crash.

Table 9 further illustrates that a wide variety of sensing systems and sensing combinations were chosen to exercise the test apparatus and methods. Two of the project vehicles included fusion systems. One fusion system (Vehicle 1) used a combination of stereo camera and long-/mid-range radar sensors, whereas the other fusion system (Vehicle 2) used a combination of mono camera and long-/mid-range radar sensors . The third project vehicle used a pure vision system with stereo camera sensors.

Table 9: Test Vehicles With Pedestrian Detection Sensors and Active Braking Technology

Test Vehicle	Sensor Technology	FCW: Forward Collision Warning	DBS: Dynamic Brake Support	CIB: Crash Imminent Braking
Vehicle 1	Fusion of radar and stereo camera	Visual and audible	Up to full braking	Up to 0.6 g of braking
Vehicle 2	Fusion of radar and mono camera	Visual and audible	Up to full braking	Up to full braking
Vehicle 3	Stereo-vision	Haptic and audible	Up to full braking	Up to full braking

3.2.1 Project Vehicle 1

Table 10 gives an overview of sensor parameters in project Vehicle 1. This vehicle was equipped with stereo camera and 76 GHz long-/mid-range combination radar.

Table 10: Project Vehicle 1 Sensor Parameters

Parameter	Stereo-Vision	Long-Range Radar	Mid-Range Radar	Units
Field of View	46 x 24 (h x v)	18	56	Degree
Cycle Time	60	15	15	Hz
Sensor	CMOS – Color sensor	76 GHz Electronically scanned radar	76 GHz Electronically scanned radar	
Resolution	1024 x 400 Pixels (stereo processing region of interest)	-	-	
Distance Range	2 – 40	0.25 – 200	0.25 – 60	m
Distance Accuracy	< 4%	±0.25 m	±0.25 m	

3.2.2 Project Vehicle 2

Table 11 gives an overview of Project Vehicle 2 sensor parameters. This vehicle was equipped with a monochrome vision sensor and 76 GHz long-/mid-range combination radar.

Table 11: Project Vehicle 2 Sensor Parameters

Parameter	Mono-Vision	Long-Range Radar	Mid-Range Radar	Units
Field of View	45 x 30 (h x v)	20	60	Degree
Cycle Time	30	20	20	Hz
Sensor	CMOS – Monochrome sensor	76 GHz Electronically scanned Radar	76 GHz Electronically scanned Radar	
Resolution	640 x 480 pixels	-	-	
Distance Range	2 – 40	2 – 150	2 – 50	m
Distance Accuracy	< 4	< 4	< 4	%

3.2.3 Project Vehicle 3

This project vehicle used stereo-vision as an environmental sensor for object classification (see Table 12).

Table 12: Project Vehicle 3 Sensor Parameters

Parameter	Stereo-Vision	Unit
Field of View	46 x 24 (h x v)	Degree
Cycle Time	60	Hz
Image Sensor	CMOS – Color sensor	
Resolution	1024 x 400 pixels (stereo processing region of interest)	
Distance Range	2 – 40	m
Distance Accuracy	< 4	%

3.3 Mannequins

3.3.1 Baseline Pedestrian Mannequin Targets

The design requirements for the test mannequins were finalized and were provided to the test mannequin supplier. These design requirements served as the basis for mannequin construction. The following points summarize the requirements and features developed for the pedestrian mannequins:

- Mannequins were required to be “strikeable” to maintain target presence up to the point of impact with the test vehicle. This requirement allowed the mannequin to remain within the PCAM sensors’ field of view up to the point of impact with the test vehicle. This eliminated the potential for the PCAM system activation to change as the result of the mannequin suddenly disappearing from the sensor view prior to impact, such as may happen with test equipment designed to extract the mannequin from the test vehicle path to prevent vehicle damage. The mannequins must remain functional and not damage test vehicles after impacts up to 60 km/h (about 37 mph). To enable these capabilities, the mannequin mass must be less than 25 lbs. using low-density, soft construction with no hard points of contact. In order to achieve this requirement, the mannequins were fabricated of laminated layers of low-density closed-cell polyethylene foam which were then hand-carved to achieve the desired three-dimensional shapes. The masses of the adult and child mannequins are 6 lbs. and 3 lbs., respectively (without clothing and mannequin support structures).
- Closed-cell foam was also used in order to reduce the likelihood that the mannequins would absorb moisture while testing outdoors in varying weather conditions.
- A quick reset time (less than 5 minutes) was required after the mannequin was struck.

- Two mannequin sizes were selected. All PCAM test method development was to be conducted using a mannequin representative of a 50th percentile adult male. A smaller mannequin representative of an 8-year-old child was to be used for demonstration purposes to show that the test methods and equipment could be potentially used with various size mannequins.

- Mannequins were required to be physically representative of a 3-D human and follow human relative proportions. Although mannequin articulation could be used by some sensor systems to enhance pedestrian detection and classification, it was not identified as a requirement for this project. The mannequins shall include a head, a torso, two arms and two legs, be easily clothed appropriate for the mannequin size, and should allow a mask, wig, or hat to be affixed to the head. The surface of the mannequin should not be highly reflective or shiny and should be a neutral color. General mannequin dimensions are presented in Table 13. The dimensions of the adult mannequin are also very similar to the mannequins developed by project groups working with the Federal Highway Research Institute of Germany.

Table 13: Selected PCAM Mannequin Measurements

Adult Male Dimensions			Male Child Dimensions	8 Years
Height	65” – 70”		Height	50.5”
Chest	36”		Chest	25”
Waist	31”		Waist	26”
Hips	36”		Hips	30.5”

- Since PCAM systems could include radar sensors (often in a sensor-fusion arrangement with vision-based sensors), the pedestrian test mannequins were required to have radar reflective characteristics which were similar to those of humans. Radar response measurements (i.e., radar cross section, or RCS, measurements) were made on adult humans as part of the previous CIB Project (Carpenter et al., 2011b, p. H-2) in order to define radar measurement acceptance bands for characterizing surrogate pedestrian test mannequins. These radar measurement acceptance bands were defined orientations using two 77 GHz radars from two different suppliers. The acceptance bands represent ±1 standard deviations from the mean response at each distance (see Figure 3). Only side and backward mannequin orientations are presented in the appendix based on the CIB Project finding that the adult human radar response measurements provided relatively symmetric results side-to-side and front-to-back. The radar reflectivity of the adult PCAM pedestrian test mannequin was required to fall within the limits presented in Figure 3. Any radar reflective material applied to the mannequins to achieve the specified performance was required to be proportionally distributed throughout the mannequin and accessible for easy modification and tuning during development and during use at the testing site. Verification of these measurements for the PCAM pedestrian test mannequins was conducted using the same radar models as used in the prior CIB study.

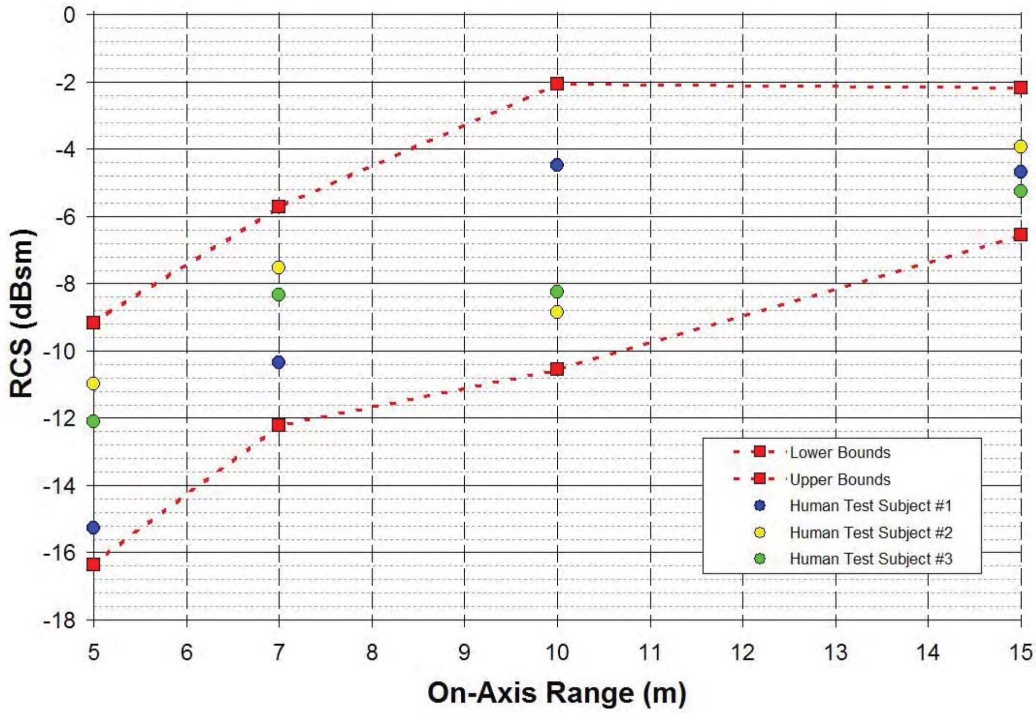

Figure 3: Example of Radar Reflectivity Data for an Adult Pedestrian in Backward Orientation Using a 76/77 GHz Radar

- During the test method development, the potential effects of mannequin position relative to PCAM system performance needed to be studied. Therefore, the limbs of the mannequin were designed such that both shoulders and both hips could be posed and held in the posed position until impact with the test vehicle. The initial PCAM mannequin samples included moveable primary joints at the limbs, as shown in Figure 4. The joints were held together using elastic ropes which passed from the limb on one side, through the torso, to the limb on the opposite side. Industrial hook-and-loop fasteners were then used to secure the position of each limb individually. This allowed each limb to be posed independently with a range of positions of 360 degrees for each arm and approximately 180 degrees for each leg. The torso structure in the pelvic region and the placement of the hook-and-loop fasteners maintained lateral separation of the legs such that the outer edges of the feet approximate the shoulder width. These features were expected to provide the required abilities to pose the mannequin positions while maintaining flexibility at the joints for better durability while also ensuring that the mannequin components remained connected together during impacts with the test vehicles.

Figure 4: PCAM Mannequin Shoulder Joint Construction

- The final feature of the PCAM test mannequins was the attachment method used between the mannequins and test apparatus. A harness assembly allowed connection of the support lines from the mannequins to the test apparatus. A pair of vertical lines connected the shoulders of the mannequins to the center of the corresponding legs of the carriage assembly on the test apparatus. Pairs of angled support lines were then connected from the center of gravity of the mannequin, at approximately the hip area, to the forward and rearward ends of the corresponding legs of the test apparatus carriage assembly. Low tensile-strength plastic clips were used to connect each support line to the mannequin. This configuration allowed a flexible and easily detachable connection between the mannequin and the mannequin carriage to minimize impact forces with test vehicles. Under acceleration and deceleration of the mannequin during preliminary testing, the forward or rearward angled lines appeared to provide sufficient reaction forces in the opposite direction to maintain the mannequin's vertical orientation and avoid swinging motions. This configuration also allowed flexibility to accommodate virtually any desired size of pedestrian mannequin during testing.

Figures 5 through 7 illustrate the mannequins developed for the project.

Figure 5: Illustrations of Pedestrian Mannequins: Adult Mannequin (Left and Center Photos) and Child Mannequin (Right Photo)

Figure 6: Adult Mannequin in Obstructed Test Configuration

Figure 7: Baseline PCAM Child Mannequin

3.3.2 PCAM Test Mannequins for Validation Testing

During baseline testing, the functionality of the production PCAM systems could not be used to assess the characteristics of the test mannequin relative to the various sensing systems used. Since the baseline tests were conducted with production vehicles that were not manufactured by the PCAM Project participant companies, the output from the sensing systems could not be accessed. Therefore, it was not possible to determine why each system did or did not respond to a given test scenario or mannequin combination. During the validation test phase, however, the detailed sensing data was available from the PCAM sensing systems in the test vehicles. Therefore, a series of tests was conducted with each of the three project vehicles to evaluate various potential mannequin characteristics. This was done to determine which characteristics were critical to the available sensing technologies in detecting and classifying the test mannequin as a pedestrian within a similar range and confidence level relative to an actual person.

The three PCAM Project vehicles included various combinations of vision and radar sensing systems. Therefore, the mannequin characteristics evaluated focused on features relevant to these sensors. The mannequin features contained within the test matrix are shown in Table 14. The leg spread angles were set and held through use of modified indexing hip joints as shown in Figure 8. Placement of reflective material placed between the mannequin and clothing was also tuned to achieve comparable radar response characteristics from the mannequin as compared to a real human. These characteristics were assessed with the mannequin facing different directions relative to the vehicle as well as when the mannequin was moving versus stationary. Various outdoor lighting conditions were also considered during these tests. These combinations of factors were assessed under two mannequin mounting methods, including a platform and an overhead pole, which will be discussed later in the report.

Table 14: Mannequin Attributes and Configurations Examined During Characterization Tests

Mannequin Attributes	Configurations Tested
Mannequin Shirt and Pant Colors	The following nine color combinations were evaluated (shirt/pants): 1. Dark Red/Blue 2. Dark Red/Beige 3. Dark Red/Black 4. White/Blue 5. White/Beige 6. White/Black 7. Yellow/Blue 8. Yellow/Beige 9. Yellow/Black
Arm Orientation	1. Both straight down 2. Both arms angled
Leg Orientation	1. Both Legs Straight (no spread) 2. Legs with Small Spread 3. Legs With Medium Spread 4. Legs with Large Spread
Mannequin Direction	1. Mannequin facing Left 2. Mannequin facing Right 3. Mannequin facing Toward 4. Mannequin facing Away
Mannequin Type	1. Adult mannequins, PCAM #1 through #3 2. Adult mannequin, NHTSA #1 3. European clothing display mannequin 4. Real human (close to 50% adult male)
Test Apparatus Mounting	1. PCAM apparatus with pole attachment 2. NHTSA platform base

Figure 8: Indexing Hip Joints

The test procedure used for the mannequin characterization study consisted of the following steps:

1. A four-meter test lane was marked with Botts' dots within 10 m of the mannequin.
2. The mannequin was moved to the center of the test lane and kept stationary throughout test.
3. The mannequin position was adjusted according to appropriate direction, and arm and leg spread.
4. From approximately 35 m, the test vehicle began approaching the mannequin at 10 mph (±1 mph).
5. Sensor performance, system warnings, and brake reactions are recorded.
6. Tests were repeated five times for each configuration.

Appendix F provides photographs of the test configurations.

The results from each vehicle were analyzed to select the characteristics that were most consistently detected as similar to real human subjects. As shown in Figure 9, the following feature combinations were selected for the remainder of the PCAM validation test phase:

- Mannequin Type: Closed-cell foam 50th percentile adult male mannequin developed for the PCAM Project.
- Clothing: White shirt with dark pants.

- Arm Spread: Arm angled and approximately 13 inches from center of hand to center of mannequin.
- The leading arm and leading leg will be on opposite sides of the torso (right arm and left leg forward).
- Leg Spread: Medium leg spread approximately 20 inches from heel-to-heel.
- One piece of reflective quilted material added to the outside of each thigh plus one piece of the same material on each side of the torso plus front and back of the torso. The dimensions of the various pieces of reflective material added to the mannequin were 7 inches wide and 12 inches tall.

Figure 9: Mannequin Configuration Selected for PCAM Validation Test Phase

These mannequin characteristics were monitored throughout the validation test phase to determine if any of the above settings required adjustment, particularly in the event of changing background environment (e.g., snow cover, lighting conditions, etc.).

3.4 Test Apparatus

3.4.1 Concept Development and Selection

Once preliminary test scenarios were developed (see Section 2), three general apparatus concepts were identified for transporting the pedestrian mannequins in a test run. These included two overhead, gantry-style designs and one moving sled arrangement. Several adaptations of each concept were also considered. The apparatus concepts were characterized in sketches and compared by the TMT to aid in selecting one concept to ultimately design and construct. The concept comparisons focused on comparing costs, development time, and expected functional benefits and limitations. Figures 10, 11, and 12 present sketches of the three general concepts considered, and Table 15 presents a summary of the TMT's comparison of the advantages and disadvantages of these concepts.

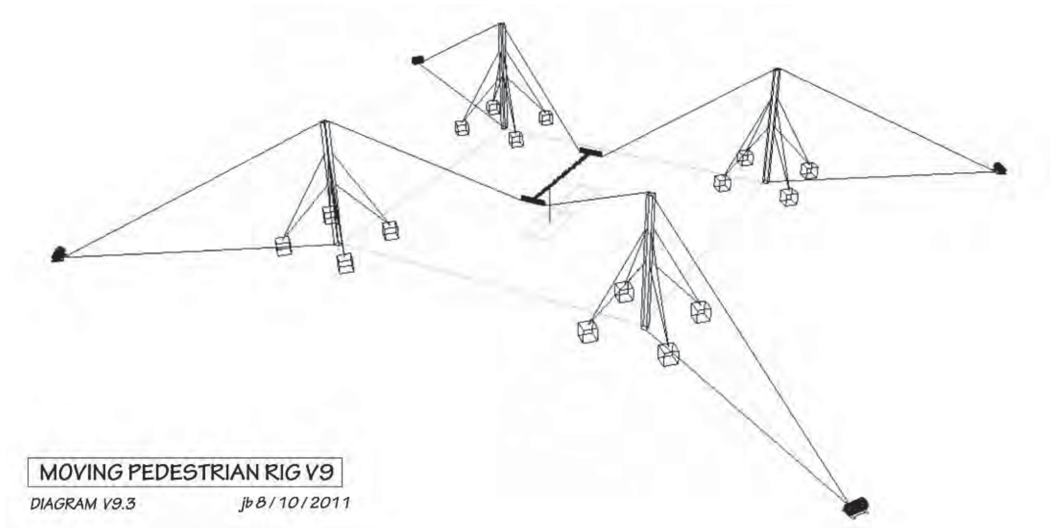

Figure 10: Sky Truss Concept

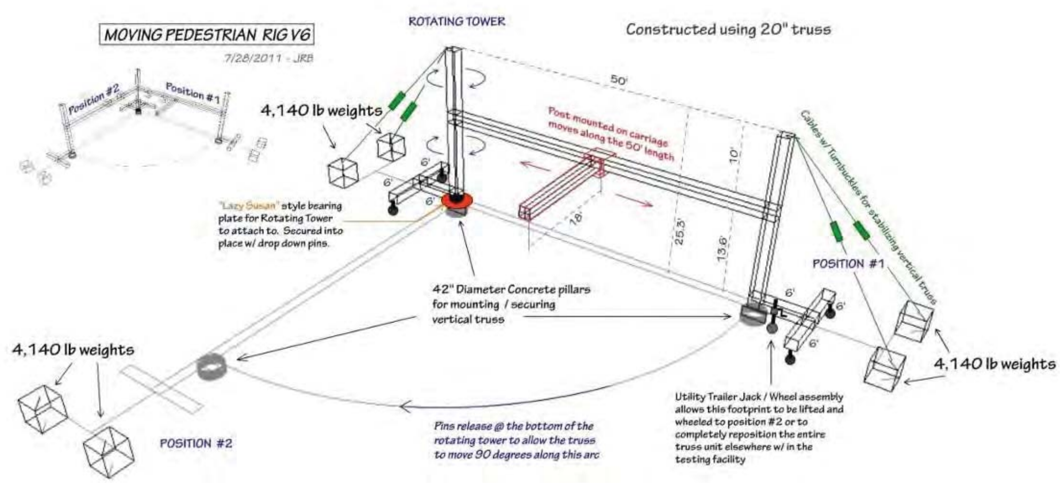

Figure 11: Swing Bridge Concept

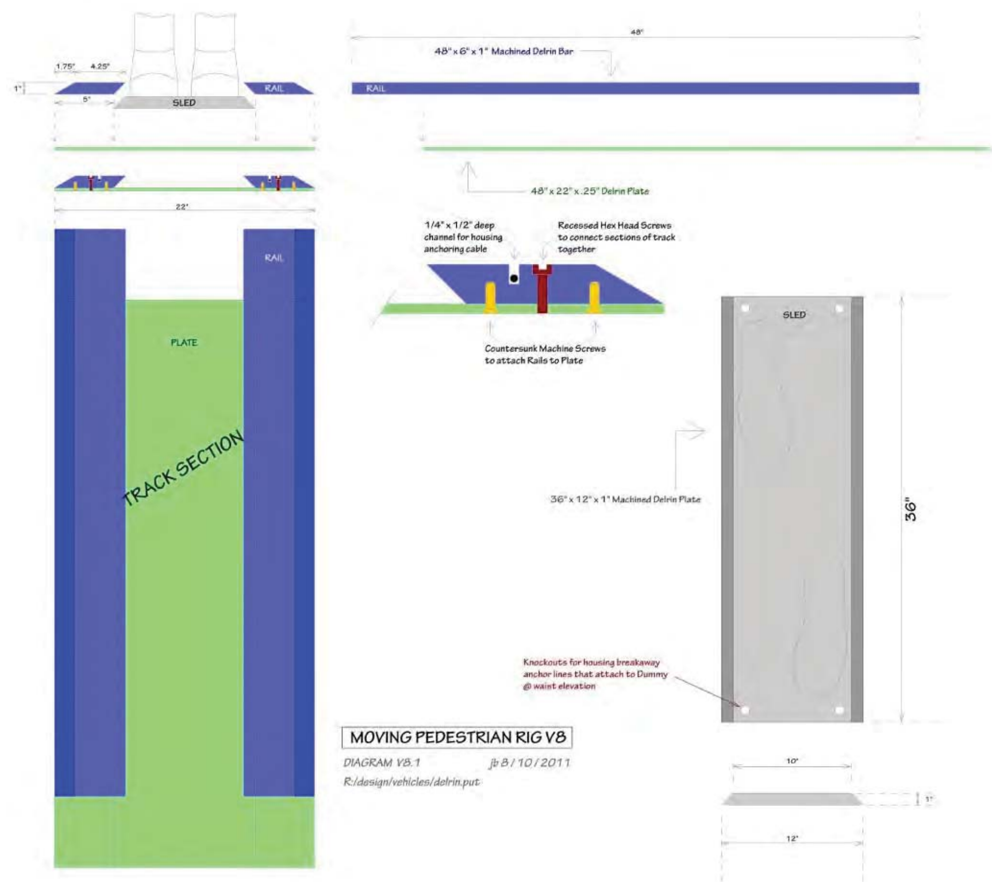

Figure 12: Ground Sled Concept

Table 15: Summary of Subjective Comparisons of Initial Apparatus Design Concepts

Apparatus Concept	Relative Advantages	Relative Disadvantages
Sky Truss	High overall confidence in concept – overhead truss concept shares similarities to equipment used elsewhere to simulate pedestrian crashes Mannequin articulation feasible Could be left in place when not testing provided sufficient clearance is provided vertically between the track surface and overhead structure as well as horizontally between the edges of the track and any apparatus support structures Quick reset time between trials	Highest expected total cost Long production time expected More logistical issues related to transportation of apparatus Large crew and long time needed for setup and tear-down No adjustment on deflection to accommodate roadway crown Requires installation of concrete foundation Bucket lift needed for installation No synchronization on winches Complexity high - more moving parts Potentially complex to repair Complexity in moving swing arm from perpendicular to parallel
Swing Bridge	Mannequin articulation feasible Deflection adjustable to accommodate roadway crown Quick reset time between trials	High expected total cost Long production time expected Would require movement to side of roadway every night Complexity in moving swing arm from perpendicular to parallel More logistical issues related to transportation of apparatus Large crew and long time needed for setup and tear-down Requires concrete foundations and tall support towers to keep tension in cables within practical limits High complexity - more moving parts, potentially complex to repair, bucket lift needed for installation

Apparatus Concept	Relative Advantages	Relative Disadvantages
Ground Sled	Lowest expected total cost Shortest expected production time Easiest installation and tear-down Easiest to operate; fewest moving parts Most portable concept; few logistical issues related to equipment transportation Realism (no structure over roadway)	Requires guide channel to be installed and removed from roadway on a daily basis Low overall confidence in this concept; little world-wide pedestrian crash simulation experience using this approach Mannequin articulation probably not feasible Guide channel must be kept clean Potential for damage to equipment from vehicles traveling on roadway High potential for a radar return from equipment components

The apparatus concepts were reviewed and the Ground Sled Concept was eliminated from further consideration based largely on the following assessments:

- The guide track used in this concept could not be permanently installed at the test facility and would require significant time to set up and remove for each testing session.
- There was lower confidence overall in meeting the operational requirements for the project (and, consequently, a higher development risk) for the Ground Sled Concept, especially given the lack of facilities world-wide using this approach for simulating pedestrian crash situations.

After reviewing the remaining two concepts, an overhead suspended truss design was selected. This concept was essentially an adaptation of the Sky Truss Concept in which an H-shaped truss, shown in Figure 13, would be suspended over the test track. For initial testing, two boom-type hydraulic equipment lifts positioned at each end of the truss and off the roadway surface supported the truss while providing more flexibility to evaluate various test scenario options and test locations. This approach also eliminated the need for additional support structure during the baseline tests. As a result, substantial complexity could be eliminated from the apparatus design and site construction work could be avoided at least until the design could be more fully evaluated through the baseline tests. The primary advantages of the Sky Truss Concept, as compared to either of the initial truss concepts, are reduced development cost, shorter production time and simplified equipment setup and removal procedures.

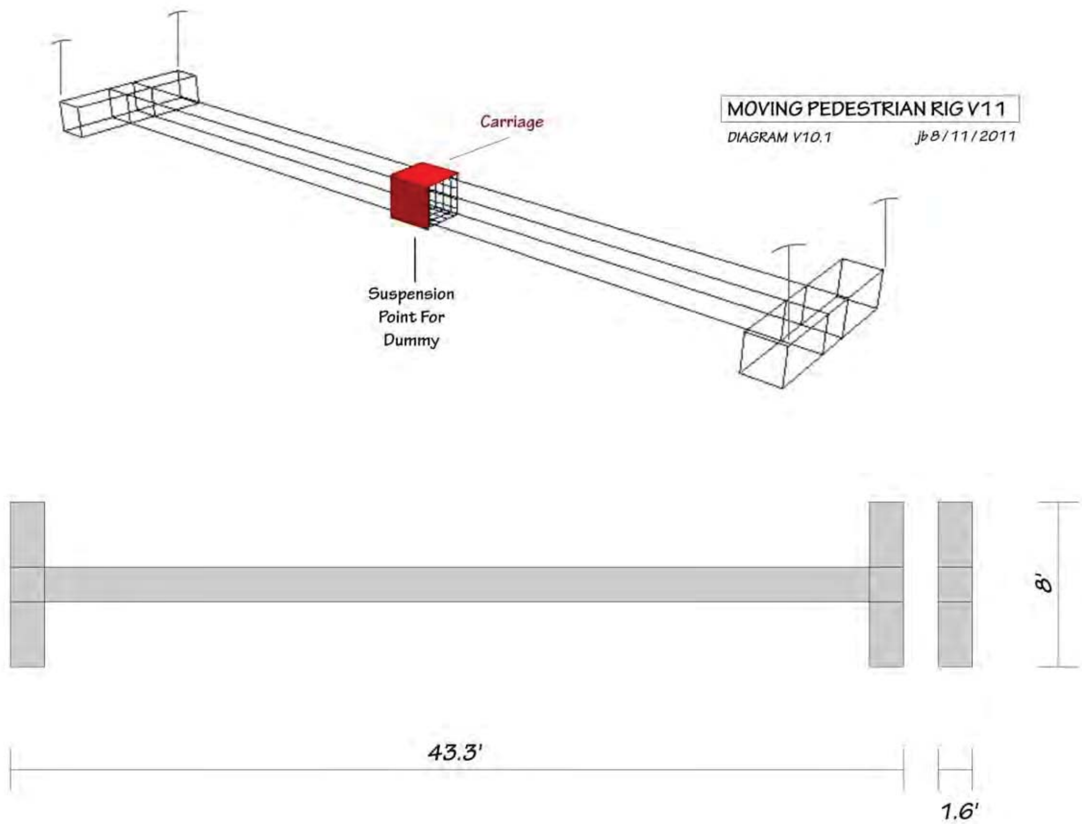

Figure 13: Overhead Truss Concept

3.4.2 General Apparatus Requirements

Following the selection of the overhead suspended truss concept, the design requirements for the test apparatus were finalized. The general requirements developed for the test apparatus included the following items:

- The equipment must be functional in an outdoor test environment, use strikeable mannequins, and must allow set-up and removal of the equipment from test site.
- The apparatus design should prevent interference with vehicle sensors – including visual camouflaging of the apparatus, components which direct radar returns away from the test vehicle, and radar absorbing foams covering exposed apparatus components.
- The test apparatus motion must accommodate the pedestrian crash scenario movements defined for the project including lateral and longitudinal mannequin movement to represent pedestrians crossing the vehicles path and walking in-line with the vehicle path, respectively.

In addition to the above general requirements, the test apparatus must also provide a minimum envelope of 40 feet of linear mannequin movement with a minimum vertical clearance of 14 feet. The apparatus must also incorporate the mannequin position ground truth system which is capable of reporting the mannequin absolute and relative positions with respect to the test vehicle with accuracies up to 2 cm and 3 cm, respectively. The test apparatus should also enable the mannequin “shoe sole” to remain within one inch of the road surface and control mannequin movement in the presence of wind up to 15 mph from any direction.

The test apparatus movement control initially used a 48-volt DC motor integrated into a drive and control system which was capable of storing and executing at least 32 separate mannequin motion profiles. The control system was also capable of receiving a “trigger” command (i.e., a start command) which initiated execution of one of the stored motion profiles. The trigger message was sent to the apparatus control system by the test vehicle based on the output from the onboard DGPS. The movement control also incorporated safety interfaces such as limit switches and manual stop switches which limited the range of motion, requested velocity/acceleration, etc.

3.4.3 Evaluation of Test Apparatus

Appendix E summarizes the design and construction of the apparatus and its major components. Once the initial apparatus was constructed, it was temporarily assembled for system check-out prior to baseline testing. This allowed assessments of the apparatus structure, assembly and disassembly procedures and tools, drive system operations, and control algorithms. Any changes were subsequently communicated to the apparatus supplier and were incorporated in updated system design documentation. Lastly, preliminary mannequin motion profiles were created for baseline testing.

3.4.4 Baseline Tests

Figures 14 through 16 show the test set-up for the baseline tests.

Figure 14: Baseline Test Apparatus

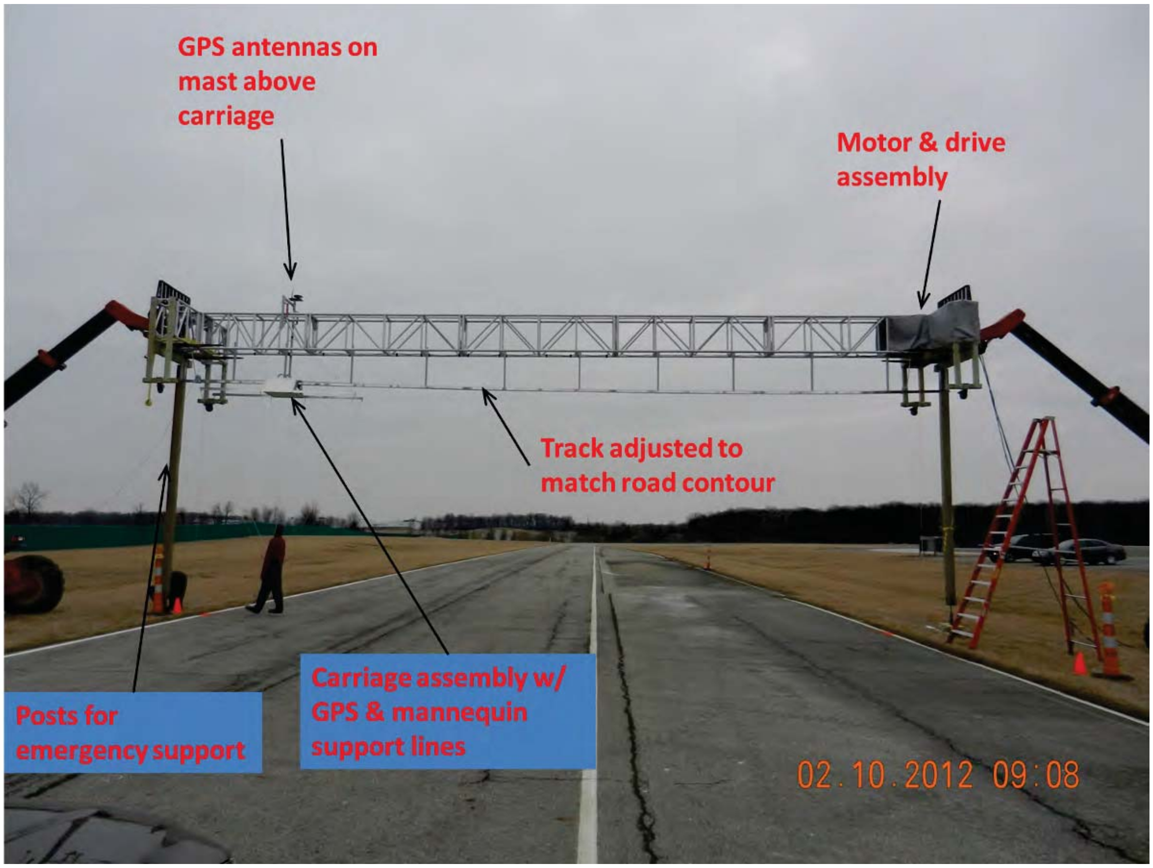

Figure 15: Baseline Test Apparatus Components

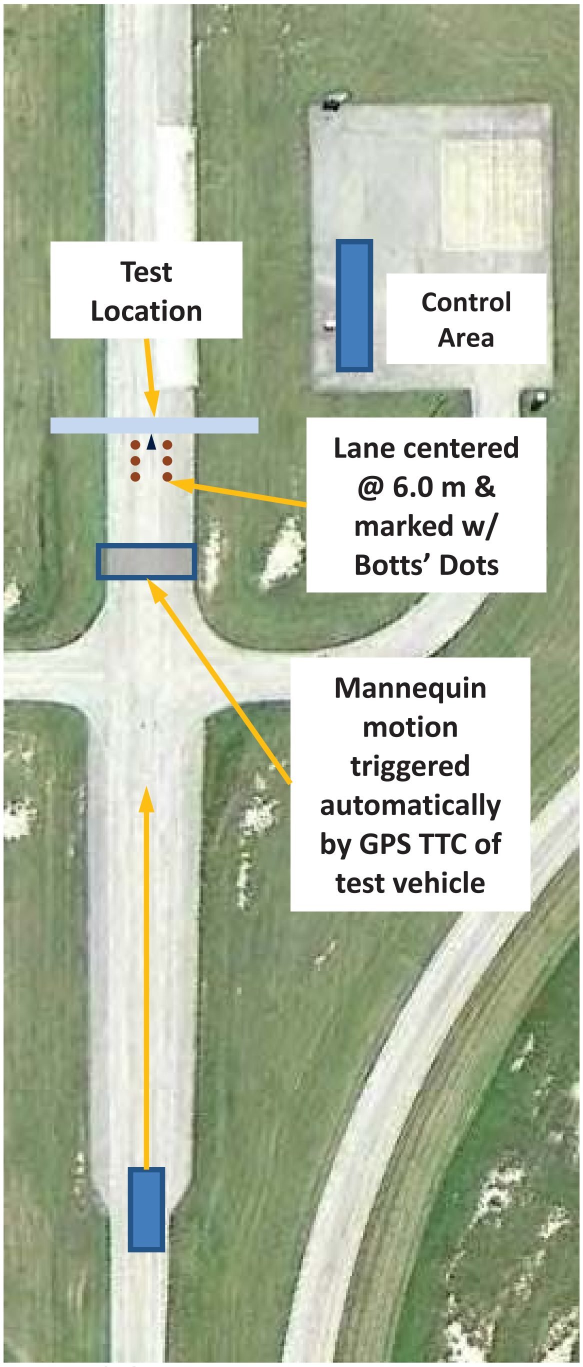

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Figure 16: Schematic of Baseline S1 Scenario Equipment

The baseline testing phase was conducted using two different production vehicles equipped with PCAM systems. This allowed initial review of the candidate test procedures and general assessment of the equipment needed to support testing. During this phase of testing, analyses were focused on assessing test repeatability, particularly as it related to equipment performance. A valid baseline test was defined to include impact between the test vehicle and the mannequin at the center of the vehicle's front bumper when no vehicle braking occurred. The collision point is illustrated in Figure 17.

Figure 17: Baseline S1 Scenario Mannequin Collision Position

This definition required precise control over vehicle speed and lateral position as well as mannequin speed and lateral position. Variation in the test apparatus drive motor speed and wind effects on the mannequin created major test development challenges. On-site modifications were made to the test apparatus and methodology in order to complete the baseline testing. However, further analysis was needed afterwards to determine whether the additional improvements to the current drive system were possible and could resolve remaining control issues, or whether more significant modifications were required.

Figures 18 and 19 provide graphs of the test apparatus carriage speed versus time at various stages throughout the baseline tests. The carriage is the overhead trolley that transports an attached mannequin during a test run. The first few weeks of testing primarily involved initial test apparatus set-up and evaluation plus preliminary lower-speed tests. During Weeks 4 and 5, an increasing number of tests failed to meet the basic acceptance criteria of mannequin impact at the center of the vehicle's front bumper. In many of these tests, the mannequin completely missed the vehicle's front bumper. Assessment of the carriage speed from Weeks 4 and 5 revealed significant variation, especially at the mannequin running speeds. Figure 18 shows the carriage speed variation in Weeks 4 and 5 of the baseline tests.

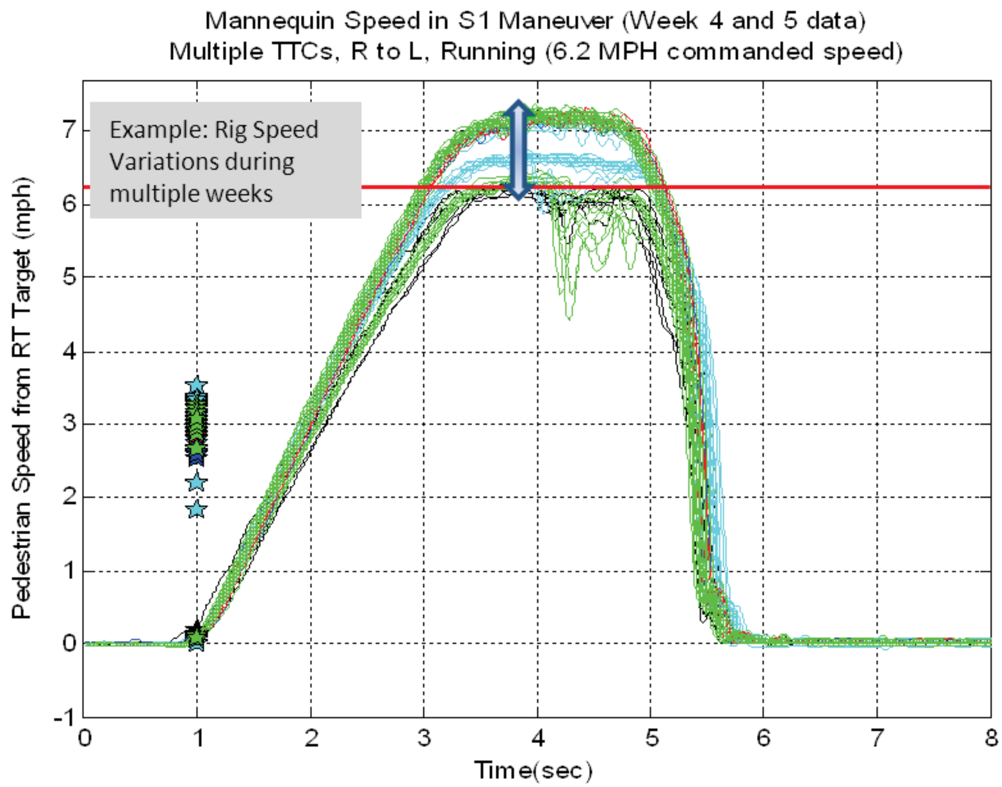
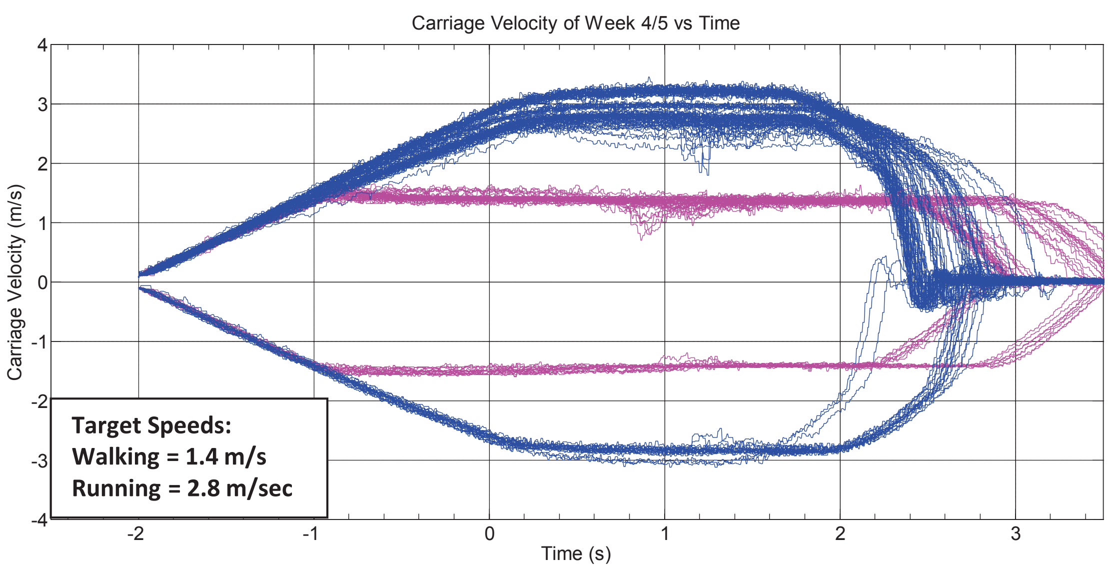


Figure 18: Baseline Testing Mannequin Speed From Multiple Weeks



Note: Positive velocity means mannequin movement away from the drive motor; negative velocity means movement toward the drive motor.

Figure 19: Carriage Speed Variation in Weeks 4 and 5 of Baseline Testing

The analysis of lateral position errors during this limited sample of Weeks 4 and 5 yielded the following general conclusions:

- Carriage speed control contributed up to 24 inches in either direction.
- Wind effects contributed up to 18 inches in either direction.
- Vehicle lateral position contributed up to six inches in either direction.
- Vehicle speed control contributed up to one inch in either direction.

Field improvements, including revised mounting of the shaft encoder and modified encoder cables, provided significant improvement to the carriage speed variation. However, these improvements did not completely resolve the missed impact conditions between the test vehicle and mannequin in a large number of tests.

As a result of the above assessments and additional testing throughout the baseline test phase, additional modifications to the test apparatus drive system were deemed necessary. Details of these changes are provided in the next section of this report.

3.4.5 Preparations for Validation Testing

Several issues were identified which required refinements to the test equipment to reduce the sources of unwanted variation in the tests. The most significant of the issues were related to the variability of mannequin travel speed and position during a test run, resulting from factors such as:

- Propulsion system speed and position variability.
- Equipment triggering timing.
- Mounting and attachment of the mannequin to the overhead trolley, especially as it relates to mannequin stability in windy conditions.
- Permanent test equipment mounting at site.

To improve control over the speed and position of the mannequin during test runs, the test apparatus propulsion system was changed from a DC drive motor to a 208-volt, 3-phase AC servomotor. The new drive system is shown in Figures 20 and 21.

Figure 20: Servo Drive and Gearbox

Figure 21: Servo Drive, Gearbox, and Drive Pulley With Improved Mounting System

The wireless communication system used to trigger the carriage motion was also analyzed. It was determined that although the error contributions associated with this system were a small percentage of the overall error experienced during the baseline testing this error could be further reduced by installing an improved wireless router and antenna system.

The mannequin position errors associated with the temporary apparatus lifting method (boom-type equipment lifts on either side of the test track) were also determined to be significant. This was due to variations in the position of the apparatus caused by adjustments to these equipment. It was determined that a more permanent mounting arrangement was necessary in order to address this source of mannequin position error. The resulting apparatus mounting system is shown in Figure 22.

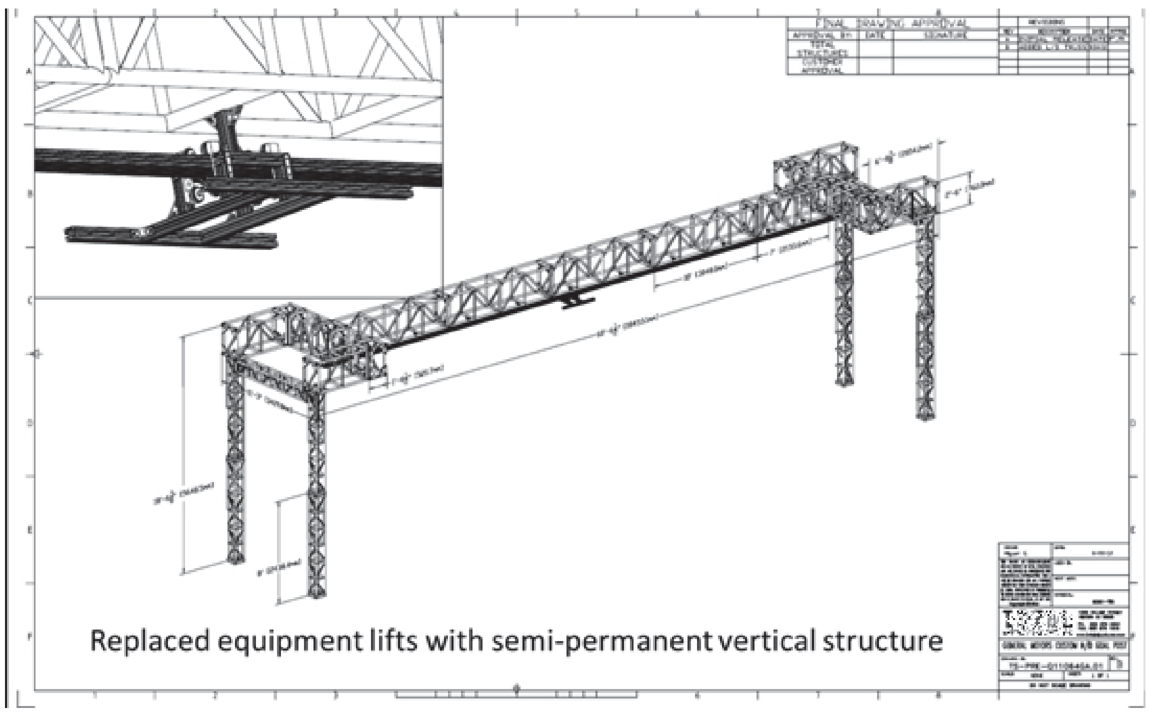


Figure 22: Illustration of Improved Apparatus Support System

A redesign of the mannequin support mechanism was completed and implemented (Pedestrian Detection Test Equipment With Mannequin Stabilizer, 2013). The new design used a fiberglass tubular pole connected through a ball-joint to the bottom of the carriage assembly and extending down through the top of the mannequin's head. The new support method is illustrated in Figure 23. A quick-release mechanism above the mannequin's head allowed removal of the mannequin and vertical adjustment of the mannequin. A collar with adjustable snap-ring arrangement connected by wires to the carriage arms provided quick-release of the mannequin once it was struck by the test vehicle. This allowed the mannequin support pole to pivot on the ball-joint attachment away from the vehicle. The quick-release mechanism is shown in Figures 24 and 25. This arrangement also allowed faster reset between tests and eliminated the need to reattach and readjust the mannequin between tests. The rigid pole (shown in Figures 25 and 26) also minimized the effects of wind on the mannequin and kept it positioned below the carriage assembly as required for accurate position control and measurement.

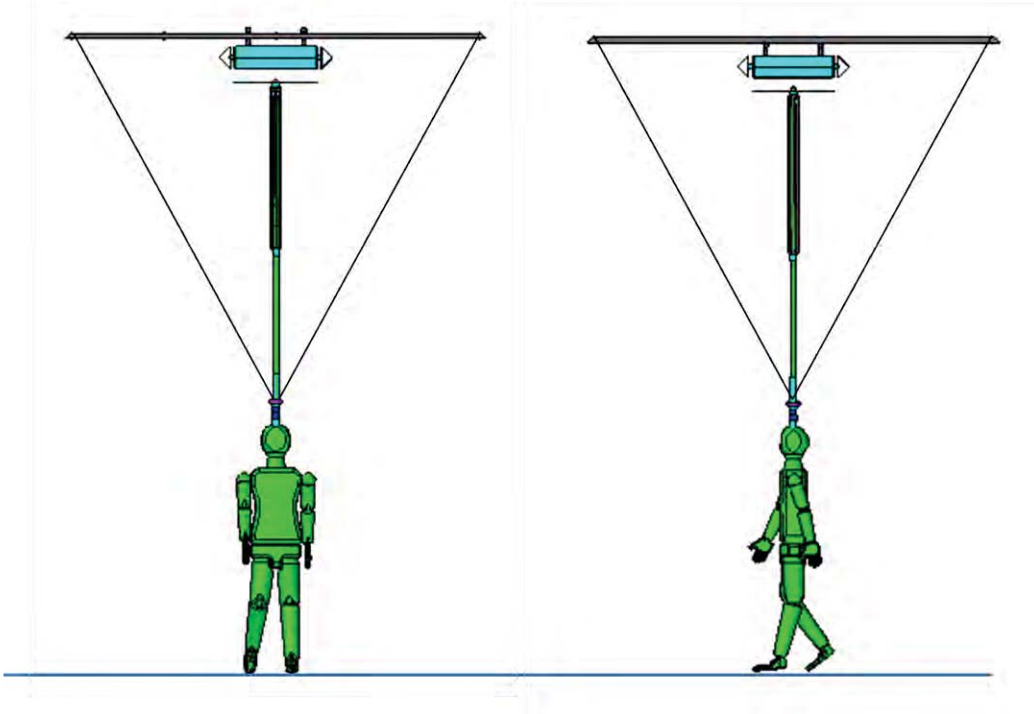


Figure 23: Illustration of New Method for Mannequin Attachment to Overhead Carriage

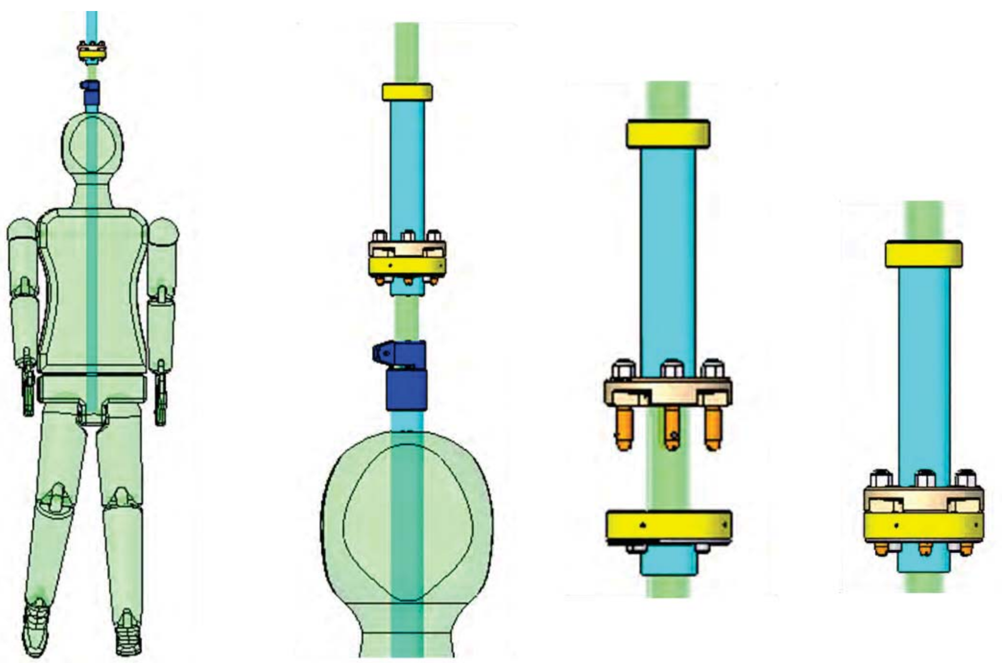


Figure 24: Illustration of Quick-Release Mechanism for Mannequin Attachment to Support Pole

Figure 25: Illustration of Quick-Release Mechanism for Mannequin Attachment to Support Pole

Figure 26: Illustration of Mannequin Support Pole

3.4.6 Validation Testing

The validation test phase began with verification of the repeatability of the modified test apparatus with respect to reducing the mannequin speed and position variability. These tests are referred to as “verification tests’ in the following discussion.

The verification tests indicated that servo motor speed and position control variability, including both intra-run and inter-run variation, was substantially improved as a result of refinements. Response latency (i.e., internal to the equipment control and drive system) was also analyzed and was reduced from approximately 0.96 s during baseline testing to about 0.15 s with the modified controls.

Figure 27 presents data collected directly from the servo motor encoder during the verification tests conducted following the modifications to the test apparatus. These data indicate there is substantially less inter-run variability (as indicated by overlapping plots on the graph) and improved speed stability during the period when the mannequin reached its final speed for the remainder of the trial. This latter point is shown in Figure 27 in the period between two and 4.5 seconds after the trial starts.

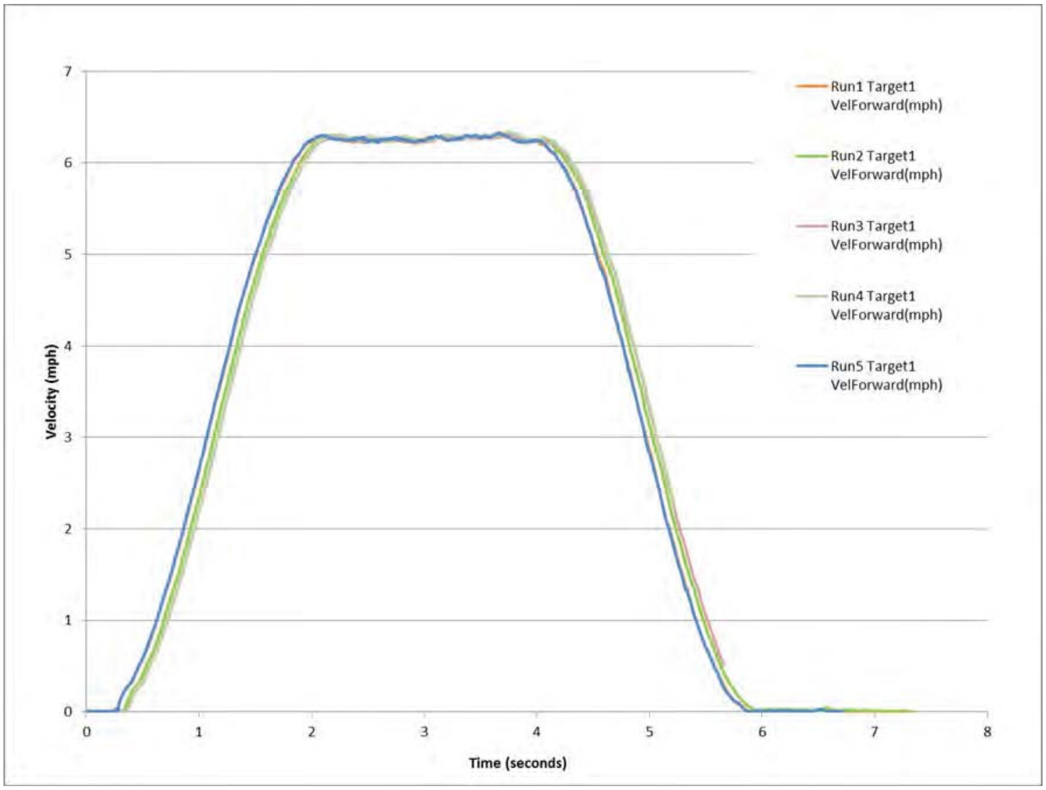


Figure 27: Mannequin Speed After Test Apparatus Improvements

The mannequin position error of the improved system was also analyzed during the validation test phase of the project. During this testing, a much larger sample size was analyzed including various test scenarios. The mannequin and vehicle position and speed information for this analysis was collected from DGPS ground-truthing and mannequin motion triggering system. The following factors that contributed to this mannequin position variation were identified:

- Motion trigger variation.
- Mannequin position/speed control variation.
- Mannequin ground-truth accuracy.
- Mannequin position variation relative to carriage.
- Test vehicle ground-truth accuracy.
- Test vehicle lateral position variation.
- Test vehicle longitudinal speed variation after trigger.

As shown in Figure 28, the position of the mannequin when the vehicle and the mannequin would have collided (assuming that the test vehicle did not initiate any autonomous braking) was improved relative to the initial baseline testing. Throughout the S1 validation testing, the typical observed intended collision position was within a range of ± 0.30 m on either side of the vehicle centerline.

Figure 28: Mannequin Position Variation During S1 Validation Testing

3.4.7 VRTC Ground-Based Apparatus

3.4.7.1 Alternative Apparatus Development

For the validation test phase, NHTSA VRTC built an alternative test apparatus based on the original Ground Sled proof of concept designs. It was determined that this alternative apparatus would prove useful in evaluating any sensitivity of the test methods relative to the apparatus used to convey the mannequin.

The apparatus (Figure 29) uses a servo drive motor and spring tensioner (Figure 30) to drive a low-stretch rope which then drives the mannequin sled (Figure 31). This sled is pulled along a track which is mounted to the test lane surface. The rope runs in a loop around the drive unit on one end of the track and a return pulley arrangement on the opposite end of the track (Figure 32). The apparatus uses a mannequin (also shown in Figure 31) of similar construction to that used for the PCAM test apparatus. This ground-based apparatus does not require the stabilizer pole and guy lines which extend from the overhead carriage to the mannequin. However, it does use internal stabilizer poles and guy lines in order to maintain the mannequin in a rigid upright position. This system can be used in a crossing orientation for S1, S2, and S3 scenarios (Figure 33) or it can use an additional right-angle pulley mechanism to orient it parallel to the length of the test lane for S4 test scenarios (Figure 34 and Figure 35).

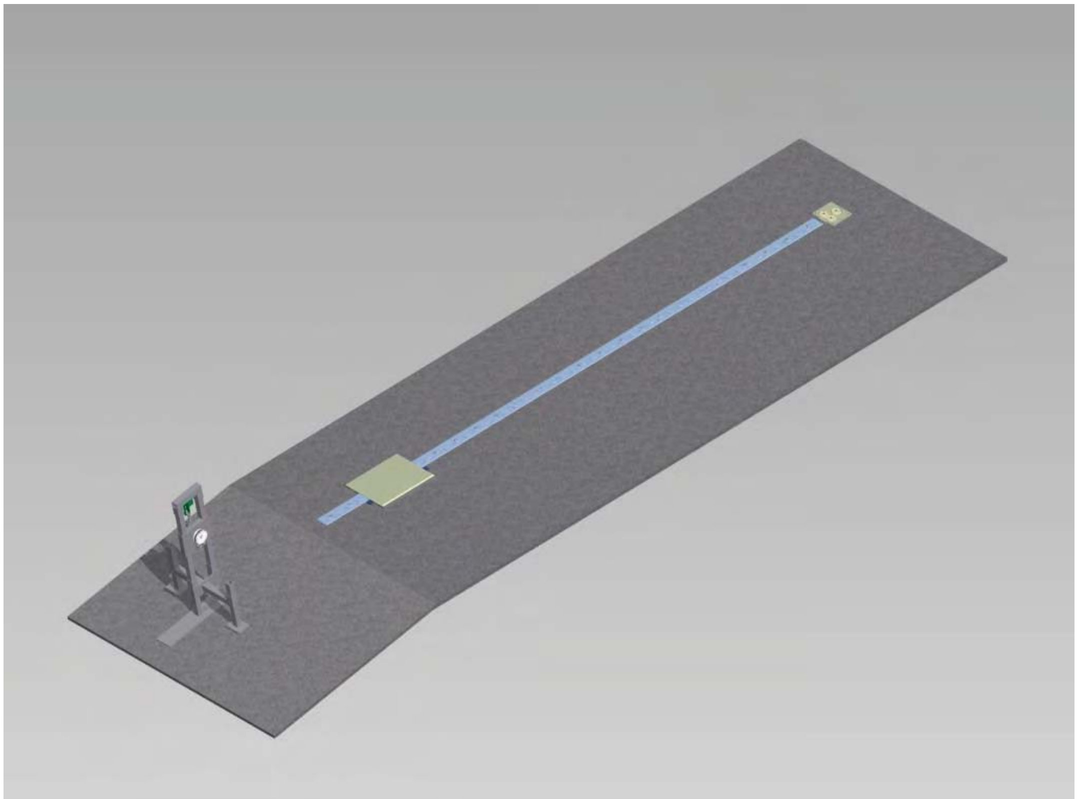


Figure 29: VRTC Ground-Based Apparatus in Crossing Configuration

Figure 30: VRTC Ground-Based Apparatus in Crossing Configuration

Figure 31: VRTC Ground-Based Apparatus Track, Sled, and Mannequin in Crossing Configuration

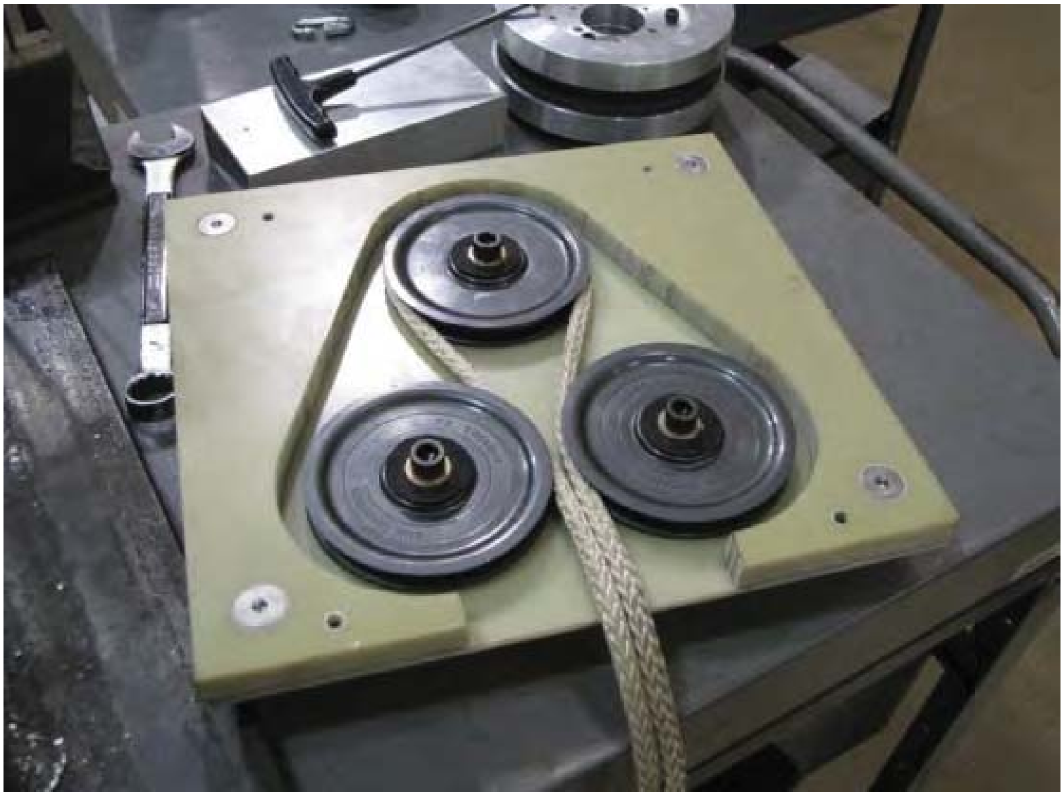


Figure 32: VRTC Ground-Based Apparatus Return Pulley

Figure 33: VRTC Ground-Based Apparatus in S1 Crossing Configuration

Figure 34: VRTC Ground-Based Apparatus in S4 Configuration

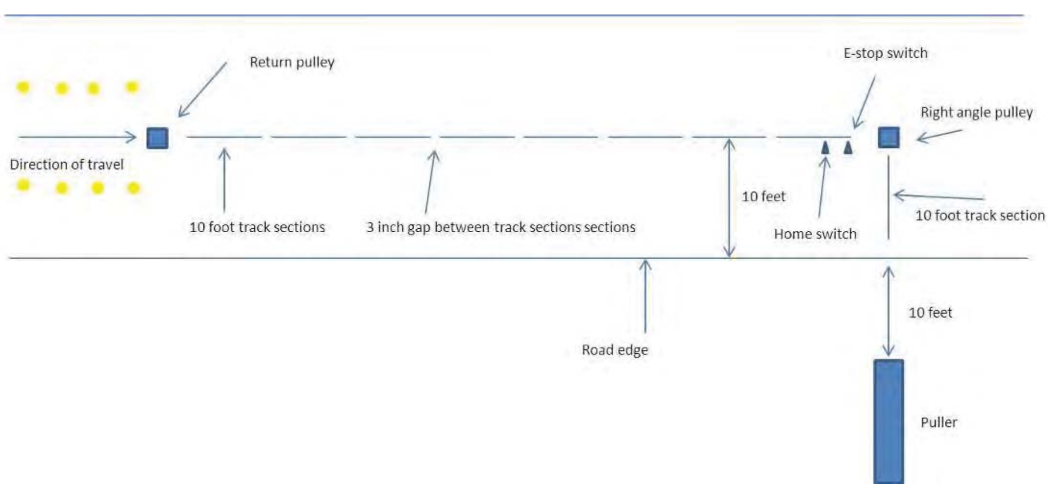


Figure 35: VRTC Ground-Based Apparatus in S4 Configuration

One additional difference between the overhead PCAM apparatus and this alternative ground-based apparatus is the type of mannequin triggering and ground-truthing solution employed. Instead of using a GPS system, the VRTC ground-based system used a scanning laser system (Figure 36) which tracked the positions of the mannequin and the test vehicle in order to perform similar ground-truthing and triggering functions.

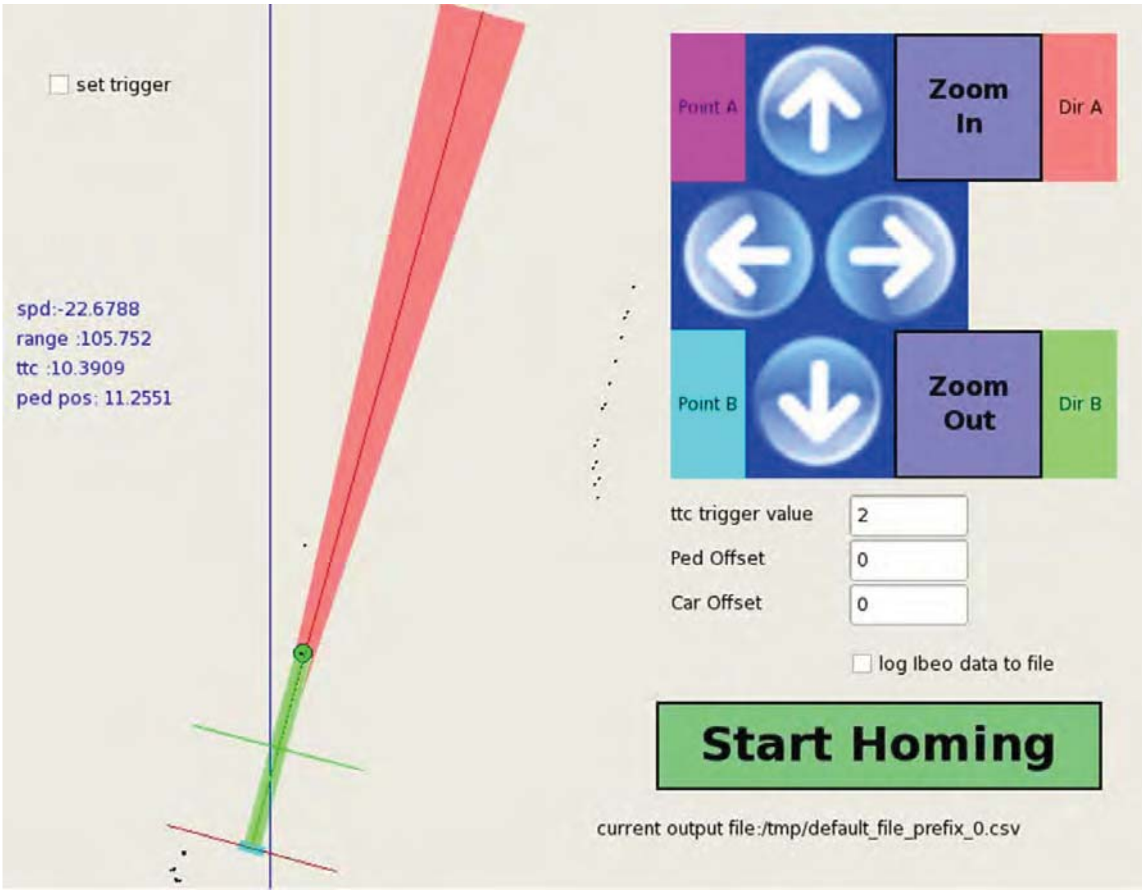


Figure 36: VRTC Ground-Based Apparatus Laser Triggering and Tracking

3.4.7.2 Alternative Apparatus Validation Testing

During the validation test phase, this alternative test apparatus was used along with the PCAM apparatus in order to evaluate the effects of a ground-based mannequin conveyance system on the performance of the project vehicles. This information was used to compare the performance of the project vehicles when tested using the overhead PCAM apparatus and the ground-based VRTC apparatus. Results from this comparison can be found in Section 4.5.4 of this report.

4 Development, Validation and Finalization of Test Methods

Tests for evaluating PCAM system performance were developed to:

- Measure the systems' capabilities to avoid or mitigate the severity of pedestrian crashes (functional tests); and
- Examine the propensity of the systems to falsely activate (operational tests).

The process used to develop, validate, and finalize the functional tests is documented in the following Sections 4.1, 4.2 and 4.4. The process for gathering real-world data and establishing related operational tests is described in Section 4.3. This latter activity involved the collection of six weeks of operational data in three areas of the United States where pedestrian traffic was known to be high or where a high rate of pedestrian crashes had been observed. Analysis of the data from these trips was used to identify driving conditions where the PCAM system configurations and sensors were potentially prone to false activations.

4.1 Functional Test Method Development Process

As described in Section 2.1, pedestrian crash scenarios were identified based on the number of fatalities and the functional years lost associated with pedestrian crashes occurring in traffic. As shown earlier in Figure 1, this analysis yielded four scenarios which accounted for 98 percent of the functional years lost. These scenarios were:

S1 - Pedestrian crossing straight across the roadway in front of the car either from right to left or from left to right

S2 - Pedestrian crossing an intersecting roadway while the car was making a left turn

S3 - Pedestrian crossing an intersecting roadway while the car was making a right turn

S4 - Pedestrian walking in the same roadway as the car either in the same or opposite direction as the car

Figure 37 illustrates these four scenarios.

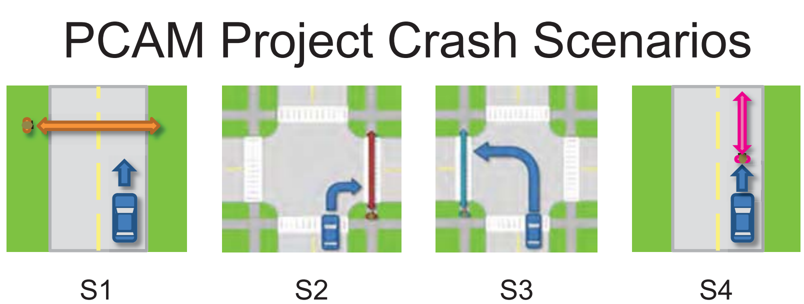


Figure 37: Four Pedestrian Crash Scenarios Examined in PCAM Project

Test methods were developed to emulate these four scenarios. One important objective in this effort was to develop methods that were capable of differentiating the functional performance of the various PCAM systems used. To address this objective, the development of test methods was divided into two phases: baseline testing (described in Section 4.1.1) and validation testing (described in Section 4.1.2).

4.1.1 Initial Prove-out Tests using Representative Baseline PCAM Systems

The baseline tests were performed by NHTSA with support from the PCAM project. The support provided to NHTSA included the test equipment and mannequin target, recommended specified performance characteristics to be tested, and specific test procedures. NHTSA collaborated and agreed to the testing approach, and selected and obtained the vehicles to perform this test series. Project representatives attended these tests and assisted with the testing. Results of the testing were provided to the project with the vehicle brand information masked. The goals of this activity were to:

- Evaluate the performance of the test equipment and mannequin target. Testing of a PCAM system requires the ability of the test equipment to accurately control the position and speed of the mannequin target. Much of this testing involved measurement and quantification of these parameters. Also required is a mannequin target that is recognizable by the PCAM systems and durable enough to withstand impacts with the vehicle. These characteristics were also evaluated during this test phase.
- Assess and develop the preliminary test methods selected to analyze the practicality of the procedures, verify that the instrumentation and ground truth measurement method is acceptable, and determine if the maneuvers are executable.

4.1.2 Validation of the Test Methods and Mannequin Targets

During this phase, an extensive test matrix was used which included variations in both vehicle and mannequin speed, mannequin position, mannequin line-of-sight obstructions, and lighting conditions. Variations in mannequin pose and clothing were also evaluated. The goals of this testing phase included:

- Further develop and refine the functional test methods.
- Evaluate the variation and performance characteristics associated with the modified test equipment and mannequin.
- Evaluate the test equipment requirements for the S4 scenarios. The test equipment developed for moving the mannequin would require repositioning to move the mannequin parallel to the road. Test equipment developed by VRTC was used for these tests. The effects of a moving mannequin versus a stationary one were evaluated.
- Incorporate the collection of PCAM sensor data and vehicle controller area network data from the project test vehicles into the test method development and mannequin characteristics. Since this information could not be obtained from the baseline systems, the project test vehicles were able to provide

enhanced insight into mannequin target and test parameters which influenced the PCAM system performance and test methods.

- Develop the data necessary for validating the final PCAM test methods and selected mannequin target.
- Confirm the ability of the test methods to measure performance differences among PCAM systems.

At the conclusion of the validation test phase, each test method was categorized as follows:

Test Methods Recommended – This category included the scenarios for which repeated test runs resulted in similar PCAM system performance, the test data distinguished the performance levels between the various PCAM systems evaluated, and sufficient system activations were recorded to enable the measurement of the system performance. The test methods recommended were sensitive to performance differences across PCAM systems under various test conditions. The data collected showed that the recommended test methods were capable of differentiating specific measureable PCAM performance.

Test Methods Not Recommended – This category included the scenarios for which the test method was initiated but was not sufficiently validated. Test methods in this category included scenarios which were not compatible with the capabilities of the near-term deployable systems, were difficult to execute in a repeatable manner, or would require significant changes in the test equipment.

The test method recommendations are presented in Section 6.

4.2 Functional Test Method Validation

4.2.1 General Test Conditions

- As described in Section 3, two sets of equipment were used during the validation test phase:
  - Overhead test apparatus developed by the PCAM Project was used for S1, S2, S3 and some S4 (static mannequin only) testing at Test Area 1 location shown in Figure 38.
  - Ground-based apparatus developed by NHTSA VRTC was used for S4 static and moving mannequin testing at Test Area 2 location shown in Figure 38.

Figure 38: Illustration of the Winding Road Course

- Tests were conducted when wind speeds were below to 24 km/h (15 mph) to prevent unwanted mannequin movement.
- Tests were not performed during periods of inclement weather. This includes rain, snow, hail, and fog.
- Visual references were used to keep test driver within the defined paths. Botts' dots were placed 20 cm from outside of tire to inside of cone on each side.
- Differentially-corrected DGPS equipment was used to measure ground truth of vehicle to mannequin.
  - DGPS units with inertial corrections were installed in both the test vehicle and on the platform moving with the mannequin target.
  - Real-time kinematic accuracy was obtained using onsite base station.
  - Vehicle position, velocity and acceleration accuracy was obtained using differential and inertial corrections with accuracy shown in Table 16.

Table 16: Specified DGPS Equipment Accuracy for Position, Velocity, and Acceleration

Measurement	Vehicle/Target	Accuracy	Update Rate
Longitudinal position	Test vehicle	2 cm	100 Hz
	Mannequin target system	2 cm	100 Hz
Lateral position	Test vehicle	2 cm	100 Hz
	Mannequin target system	2 cm	100 Hz
Longitudinal speed	Test vehicle	0.15 m/s	100 Hz
	Mannequin target system	0.15 m/s	100 Hz
Longitudinal acceleration	System vehicle	0.10 m/s²	100 Hz
	Mannequin target system	0.10 m/s²	100 Hz

- The trigger to initiate mannequin target for the correct timing was achieved by sending out Time-to-collision values from the test vehicle's DGPS setup. The signal was transferred via Wi-Fi and a laptop at the apparatus control station would initiate the mannequin motion once the pre-defined TTC was reached by the test vehicle.

Table 17 presents the data channels that were collected and used for analysis.

Table 17: Data Channels Acquired During Testing

Variable Name	Description	Source	Units
Forward_Vel_H	Vehicle speed	DGPS	m/s
Forward_Accel_H	Vehicle acceleration	DGPS	m/s^2
Long_Range_T1	Longitudinal distance to target	DGPS	m
Lat_Range_T1	Lateral distance to target	DGPS	m
_Distance	Lateral distance traveled by mannequin	DGPS	m
_Speed	Mannequin speed	DGPS	m/s
_Calc_TTC	TTC calculation used to trigger the mannequin motion	DGPS	s
Forward collision warnings & autonomous braking requests	System response to evaluate performance	CAN signals from test vehicles	--
Driver brake request	Driver brake input (i.e., brake switch signal)	CAN signals from test vehicles	--

4.2.2 Primary Scenarios (S1, S2, S3 and S4)

For all the test figures used to illustrate the test setup for functional and operational test scenarios, the diagrams shown in Figure 39 are used to depict how the mannequin was facing to indicate if the sensor system was detecting the front, rear, left or right side of the mannequin.

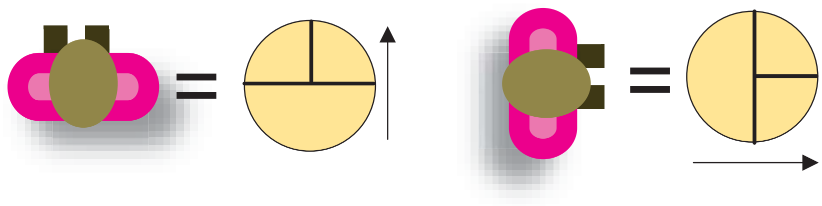


Figure 39: Mannequin Direction Description for Scenario Diagrams

4.2.3 Setup Method for Ground Truth

Prior to actual data collection for testing on the PCAM test apparatus, the test vehicles needed to be configured so accurate ground truth was possible. Before any tests were conducted, a local coordinate system was created within the DGPS systems as illustrated in Figure 40. The origin of the coordinate system was set up so zero of the y-axis was at the center line of the lane and the zero of the x-axis was where the bumper of the test vehicle just made contact with the mannequin. This required a unique configuration for each test vehicle since the offset of the bumper to RT inertia systems were all different. Once these coordinates were set up, no changes were made within each vehicle's DGPS configuration.

Before each test series, the individual test vehicles were parked directly in front of the static mannequin target such that the centerline of the vehicle was in the center of the test lane and the bumper just contacted the mannequin (same as original setup). The mannequin was also placed directly in the center lane. Once this was achieved, the test driver would ensure that the pre-defined coordinates were correct.

Two virtual targets were defined in the DGPS configuration during the setup. Target 1 was a static target located at the centerline of the lane and used to set up the automatic trigger software to ensure the mannequin would move to the proper location at the appropriate time. For most cases, the timing was defined so the mannequin would contact the center of the vehicle if no braking intervention occurred. The test vehicle would broadcast the TTC calculation via a Wi-Fi connection between DGPS units located in the test vehicle and a personal laptop computer located at the test apparatus control panel. The laptop sent a digital signal to the motor controller to start the mannequin motion. System delays caused by Wi-Fi latency, motor controller latency and actual apparatus motion were compensated for in the trigger software so the appropriate timing was achieved. DGPS Target 2 was a dynamic target used to determine the actual speed and distance traveled by the mannequin.

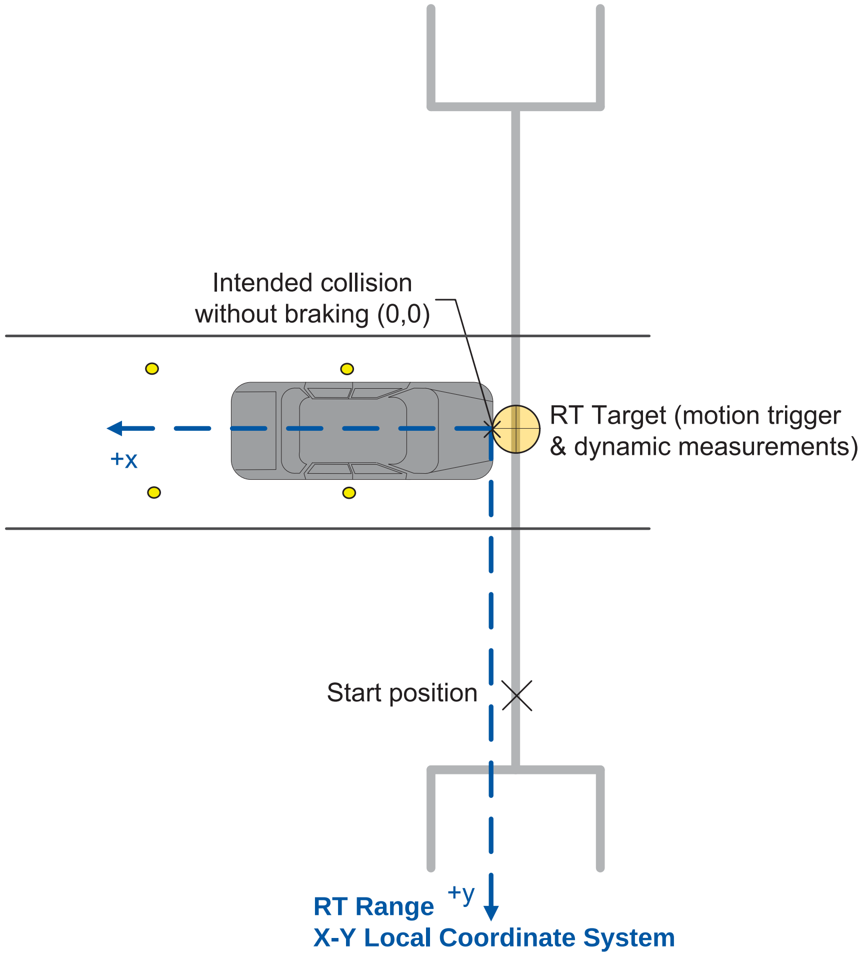


Figure 40: Ground Truth and Mannequin Trigger Setup

4.2.4 S1: Crossing Mannequin Perpendicular to Vehicle Path

Several variations of the S1 scenario were conducted during the validation test phase. The S1 scenario is where the vehicle approaches the moving mannequin perpendicular to the mannequin motion. These are shown in Figures 41 through 44. The tests were conducted with and without obstructions between the mannequin and approaching test vehicle. Tests were conducted with the mannequin moving from left to right of the test vehicle (designated as toward motor) and from right to left of the test vehicle (designated as away from motor).

The following test speeds were conducted during the S1 procedures:

- Vehicle Speeds: 10, 15 and 25 mph (16, 24, and 40 km/h).
- Mannequin Speeds: 3 mph (5 km/h, walking) and 6 mph (10 km/h, running).

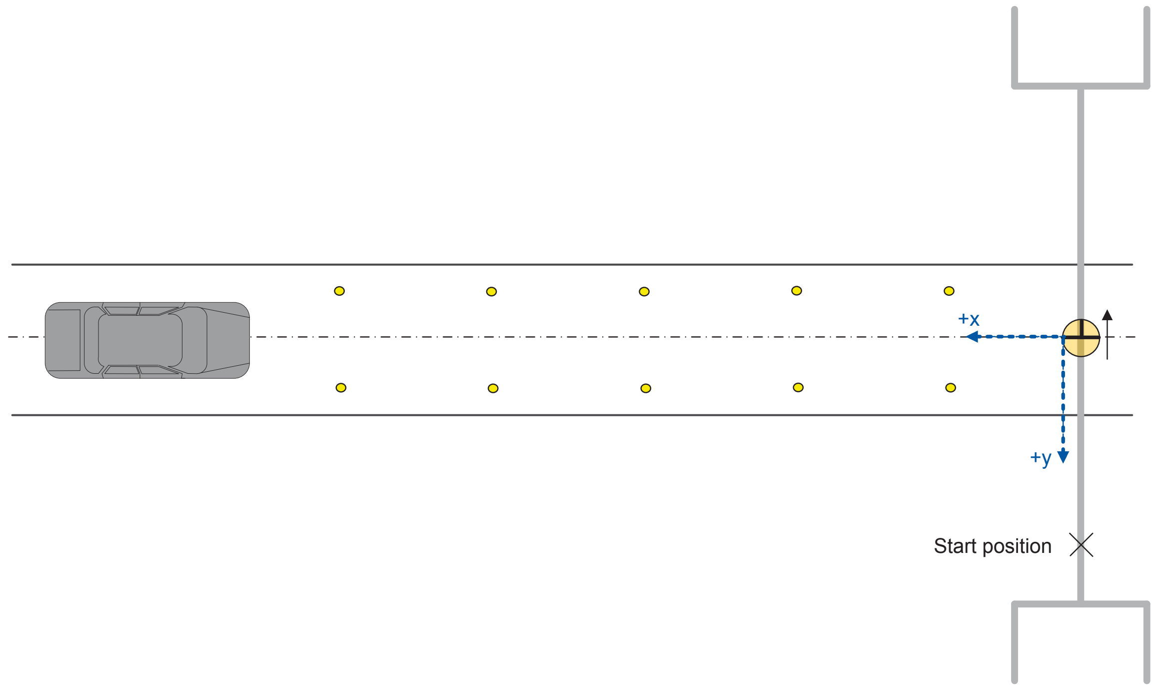


Figure 41: S1 – Vehicle Heading Straight With Mannequin Crossing Path (No Obstruction)

The basic test procedure described below was used throughout the project. This basic procedure was also applicable to other scenarios with minor changes required for the specific scenario. These exceptions will be noted in the material which follows this section of the report.

<u>Basic Procedure</u>

1. A test lane about 20 cm from the vehicle tires was marked with Botts' dots within 20 m of the mannequin.
2. Test vehicle accelerated to the desired test speed (±1.6 km/h tolerance) and, before reaching the mannequin motion trigger, the vehicle pitching behavior was allowed to settle.
3. After the test vehicle reached the mannequin motion trigger, where the timing was designed to get the mannequin to the desired location, the mannequin started its motion (either walking or running).
4. After passing the mannequin motion trigger, the test vehicle maintained the speed at the trigger point within a tolerance of ±1.6 km/h and lateral position within a tolerance of ±20 cm.
5. After the motion trigger, no test driver braking was allowed during the remainder of the event until after the vehicle passed the impact zone (x=0).
6. Tests were repeated five times for each combination of test conditions. If no system reaction occurred for three straight events, then testing was stopped to prevent mannequin damage.

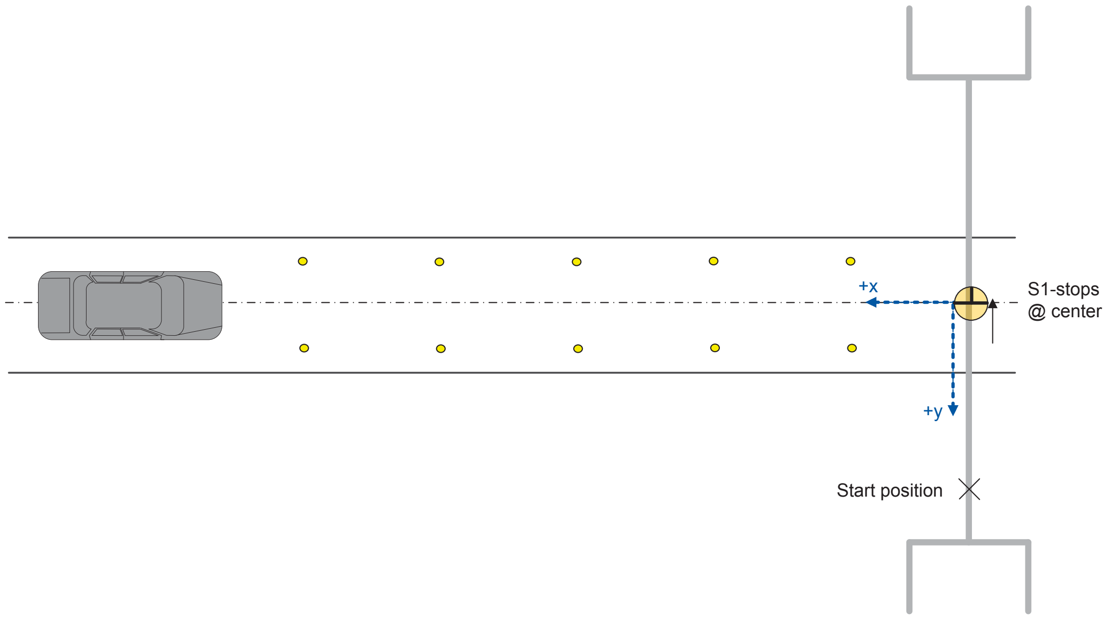


Figure 42: S1 – Alternate Test: Vehicle Heading Straight With or Without Mannequin Stops at Center of Path (No Obstruction)

Since there were cases where a test vehicle was unable to react to the previous scenario setup, an alternative test was designed to trigger the motion of mannequin earlier to ensure system reaction. The tests were also repeated with the mannequin stopping at the center of the lane. This extra step was taken to assess whether adjustments to the test procedures were needed based on the performance capabilities and limitations of the PCAM systems tested.

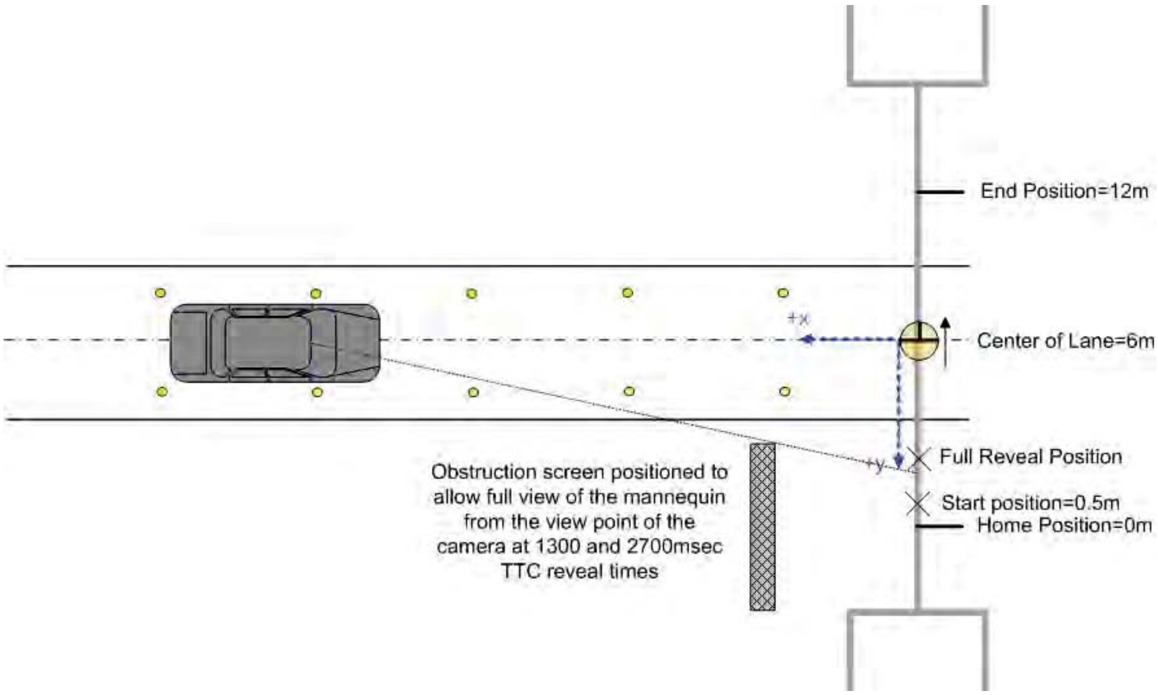


Figure 43: S1 – Vehicle Heading Straight With Mannequin Crossing Path (With Obstruction for 1,300 and 2,700 ms TTC Reveal Times)

For obstruction testing, a large screen was used to block the view of the approaching mannequin until the desired TTC reveal times were reached. The test vehicles used within the PCAM project incorporated camera-only or radar-camera fused sensing systems. These systems used the camera as the primary means of pedestrian detection. The radar sensor input (where used) provided a secondary detection for increased confidence level and reduction of false detections. For this reason, it was not necessary to screen the mannequin from the radar sensor. The obstruction screen used obstructed the primary (vision) sensor, but did allow the secondary (radar) sensor to detect the mannequin prior to the point at which the camera was able to detect the mannequin.

Alternatively, an obstruction screen could be developed which would not allow the radar to sense the mannequin when it is also visually obscured by the screen. This could be accomplished via a radar-absorbing obstruction screen or a radar-reflective obstruction screen. The implications discussed below should be considered when either of these radar obstruction screens is considered for use in future testing. For these reasons, a more realistic suggested obstruction for future testing would be a large radar-reflective box or L-shaped target. This type of obstruction would block visibility of the pedestrian with a surface that would provide a radar reflection that is separated longitudinally by two or more meters from the path of the pedestrian target.

4.2.4.1 Implication of Radar-Absorbing Obstruction Screen

An obstruction screen that uses radar-absorbing materials could require different “tuned” materials for each radar wave length tested. In addition, radar-absorbing materials are typically constructed of coated foam materials which tend to be susceptible to damage when subjected to outdoor environmental conditions (i.e., high humidity or rain).

4.2.4.2 Implications of Radar-Reflective Obstruction Screen

An obstruction screen that is significantly radar-reflective can cause problems associated with mannequin detection. If the mannequin and the screen are at approximately the same longitudinal distance from the test vehicle, these two reflective radar targets can be “blended’ and detected as one target. The radar can sense that the center of this “blended” target is in a significantly different lateral location than the mannequin. This occurs as the mannequin moves from behind the screen because the reflective screen radar target is very large in comparison to the mannequin’s radar return. The center of this blended target can differ significantly from the lateral location of the vision target identified as the mannequin. This target “blending’ can occur until there is sufficient separation distance to allow the mannequin and the radar-reflective screen to be acquired as separate radar targets. However, this concern could be effectively addressed by separating the radar-reflective screen and the mannequin path by some significant distance (as depicted in Figure 43). In this manner, the radar can use the significantly different longitudinal ranges of these two reflective targets to effectively separate the screen and mannequin targets. This can allow the radar to confirm the mannequin target’s position much sooner when the mannequin moves from behind the obstruction screen.

This obstruction screen configuration used in the PCAM Project validation testing is shown in Figure 44.

Figure 44: Illustration of Mannequin Obstruction Screen

Table 18 provides the vehicle and mannequin positions used to determine the appropriate obstruction screen location such that the mannequin became fully visible at the reveal time of 1,300 or 2,700 ms.

Table 18: Vehicle and Mannequin Locations Used to Establish Obstruction Screen Positions

For Reveal TTC of:	Vehicle Test Speed	Mannequin Profile	Vehicle Position from Intended Impact Point w/ Mannequin	Absolute Mannequin Position (See Figure 43)
1.3 s	10 mph (16.1 km/h)	walking away	5.81 m	4.2 m
1.3 s	10 mph (16.1 km/h)	running away	5.81 m	2.7 m
1.3 s	10 mph (16.1 km/h)	walking toward	5.81 m	7.8 m
1.3 s	10 mph (16.1 km/h)	running toward	5.81 m	8.9 m
1.3 s	25 mph (40.2 km/h)	walking away	14.53 m	4.2 m
1.3 s	25 mph (40.2 km/h)	running away	14.53 m	2.7 m
1.3 s	25 mph (40.2 km/h)	walking toward	14.53 m	7.8 m
1.3 s	25 mph (40.2 km/h)	running toward	14.53 m	8.9 m
2.7 s	10 mph (16.1 km/h)	walking away	12.07 m	2.2 m
2.7 s	10 mph (16.1 km/h)	running away	12.07 m	profile start
2.7 s	10 mph (16.1 km/h)	walking toward	12.07 m	9.8 m
2.7 s	10 mph (16.1 km/h)	running toward	12.07 m	profile start
2.7 s	25 mph (40.2 km/h)	walking away	30.18 m	2.2 m
2.7 s	25 mph (40.2 km/h)	running away	30.18 m	profile start
2.7 s	25 mph (40.2 km/h)	walking toward	30.18 m	9.8 m
2.7 s	25 mph (40.2 km/h)	running toward	30.18 m	profile start

<u>Obstruction Set-Up Procedure</u>

1. “Reveal TTC,” “Vehicle Speed,” and “Mannequin Profile” settings were identified from the validation test matrix.
2. The GPS position data was used to place the vehicle within the test lane at the range from the mannequin shown the table above.
3. The read-out on the test control panel was used to position the mannequin at the absolute position shown in the table above.
4. The obstruction screen was positioned parallel to the mannequin path between the test vehicle and the mannequin.
5. With the driver sighting through the camera sensor location to the mannequin, the screen was moved parallel to the mannequin path until the entire mannequin just became fully visible. If the mannequin was within the camera’s field-of-view and an on-board display was available, the video display from the sensor was used for this step.
6. This set-up was verified and adjusted, as needed, for each test vehicle.

Method Used for Determining Set-Up

1. For each reveal TTC time (1.3 s and 2.7 s), the distance of the test vehicle from the intended impact point was calculated for each intended test speed (16.1 and 40.2 km/h).
2. The position versus time data from the test apparatus drive motor encoder was reviewed to determine the location of the mannequin from each movement profile at the reveal TTC times (1.3 s and 2.7 s). For profiles which resulted in the mannequin reaching the intended impact point in less time than the reveal TTC value, the mannequin was placed at its starting location of the profile.
3. Since the project test vehicles all rely on camera sensors in the windshield for pedestrian detection and classification, it was judged to be more realistic to base obstruction screen placement on the locations at which the mannequin would become fully visible to the camera sensors rather than the front bumper. See Figure 43.
4. In some cases, the combination of vehicle position and mannequin location at the reveal TTC might not place the mannequin within the camera sensors field of view. Under these conditions, the test driver sighted through the camera location to the mannequin. The obstruction screen was then moved until the entire mannequin first became visible to the driver with this reference orientation.
5. For test configurations that result in the mannequin being visible within the camera sensor field of view, an on-board video display of the sensor output was used to adjust the obstruction screen position until the mannequin first became fully visible within the display.

4.2.5 S1: Crossing Mannequin Perpendicular to Vehicle Path Procedures for Dynamic Brake Support (DBS) Systems

Several variations of the S1 scenario were also used to evaluate their suitability for use with DBS systems. The latest release (at time of testing) of the NHTSA proposed DBS vehicle-to-vehicle tests (NHTSA, 2012) was used as the basis for these tests. Specifically, the “Subject Vehicle Encounters a Stopped Principal Other Vehicle on a Straight Road” test was used, with the modification of a laterally moving mannequin (S1 Scenario) as the target. This is shown in Figure 45. The tests were conducted without obstructing the mannequin from the sensor systems. Tests were conducted with the mannequin moving from right to left of the test vehicle (designated as away from motor).

To ensure test repeatability, a GPS-enabled braking robot was implemented that was capable of applying the required braking force in the manner prescribed in the draft NHTSA DBS test procedure. As prescribed in the draft NHTSA DBS procedure, the braking robot application and rate of apply were calibrated to provide a nominal deceleration of 0.3 g. The braking robot used the GPS ground-truth equipment to trigger onset of braking at the specified distance of 12 m (1.1 s TTC at 40.2 km/h).

The following test speeds were conducted during the DBS S1 procedures:

- Vehicle Speeds: 25 mph (40 km/h)
- Mannequin Speeds: stationary at collision point, 3 mph (5 km/h, walking), and 6 mph (10 km/h, running)

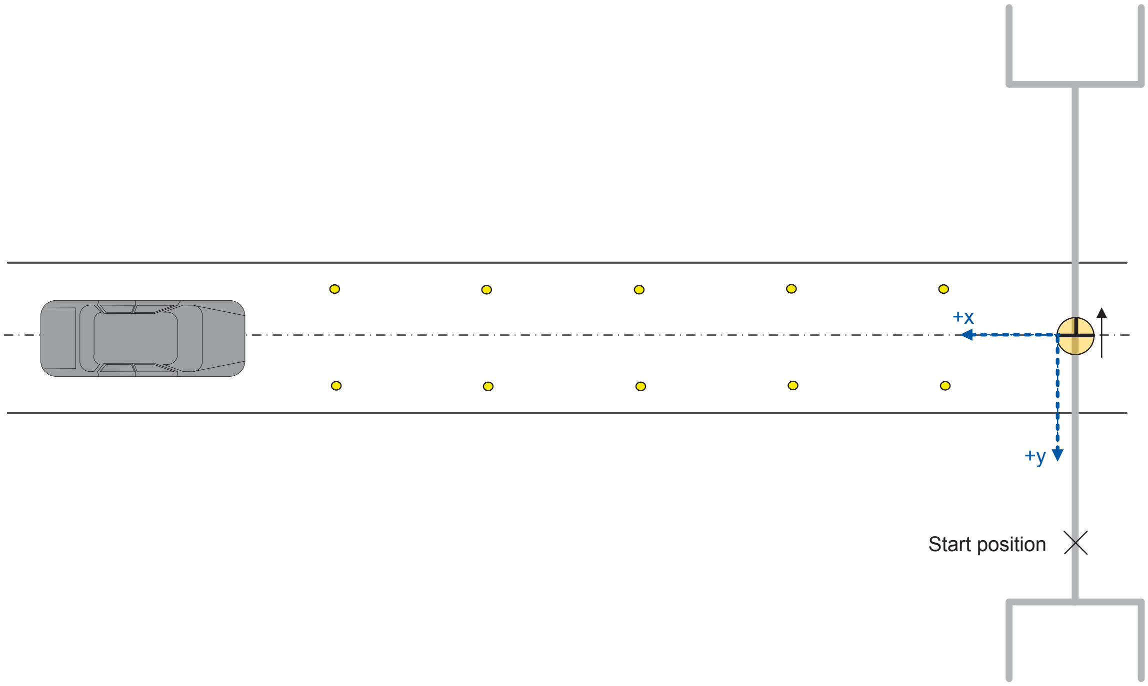


Figure 45: S1 – Vehicle Heading Straight With Mannequin Crossing Path (No Obstruction)

The basic test procedure described in Section 4.2.4 was used for this scenario with the following changes:

1. After passing the mannequin motion trigger, the test vehicle maintained the speed to within ±0.8 km/h of the specified value and lateral position was maintained to a tolerance of ±20 cm until a range of 23.5 m (2.1 s TTC) to the collision point was reached. At that time the throttle was released.
2. When the test vehicle reached a range of 12.2 m (1.1 s TTC) to the collision point, the braking robot applied brake pedal displacement to achieve a nominal 0.3 g of deceleration, consistent with the 2012 NHTSA DBS test procedure proposal.

Since there were cases where a test vehicle was unable to react to the previous scenario setup, an alternative test was designed to trigger the motion of mannequin earlier and stop at the center of the lane to ensure system reaction. This test is depicted in Figure 46.

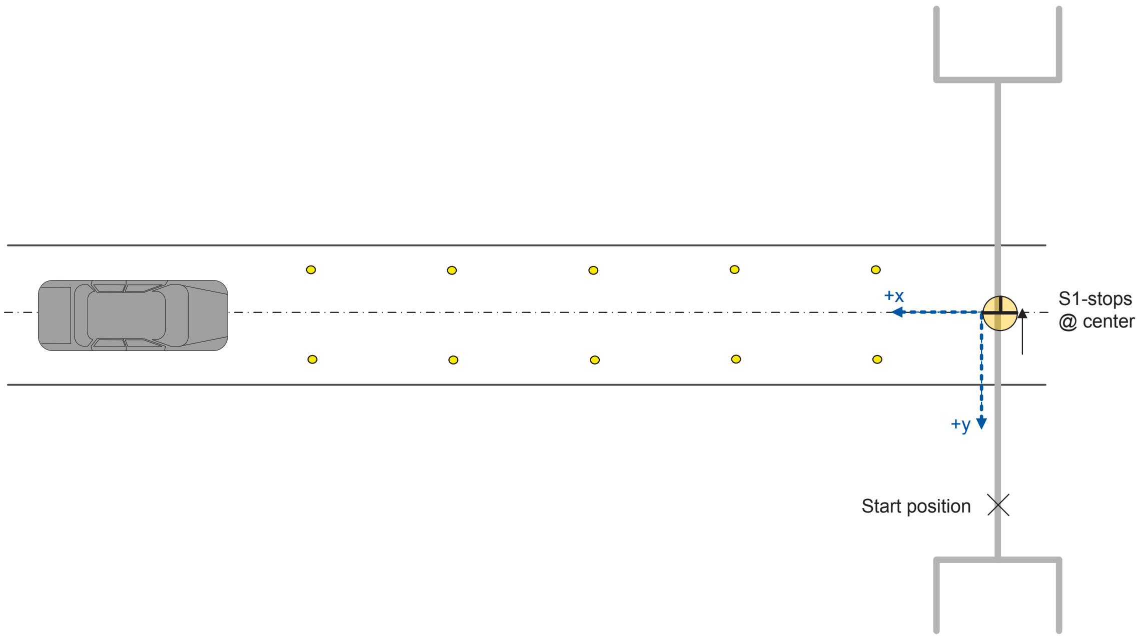


Figure 46: S1 Alternate Test – Vehicle Heading Straight With Mannequin Stopping at Center of Path (No Obstruction)

4.2.6 S2: Vehicle Turning Right into Mannequin Crossing Path

Figure 47 illustrates the method used to conduct the S2 scenario tests. The basic test procedure described in Section 4.2.4 was used for this scenario except that Botts' dots were placed to mark the curve for the entire radius.

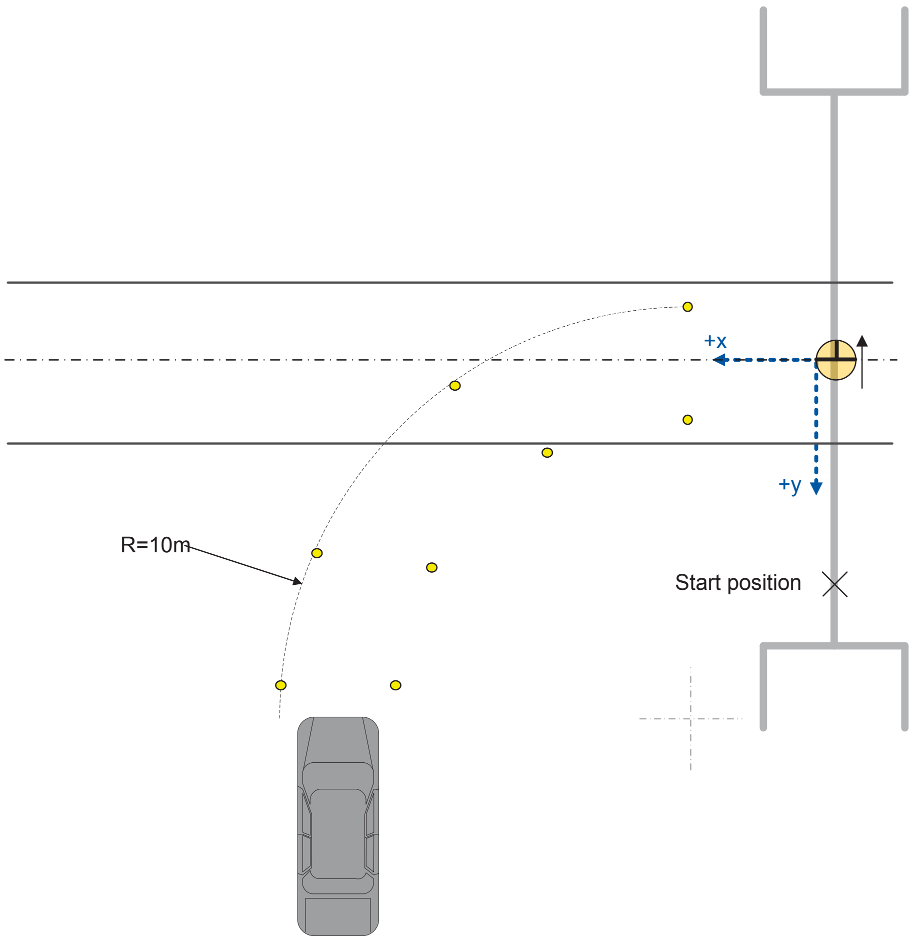


Figure 47: S2 – Vehicle Turning Right With Mannequin Crossing Path

4.2.7 S3: Vehicle Turning Left into Mannequin Crossing Path

The procedure used to conduct the S3 scenario tests is illustrated in Figure 48. The basic test procedure described in Section 4.2.4 was used for this scenario except that Botts' dots were placed to mark the curve for the entire radius.

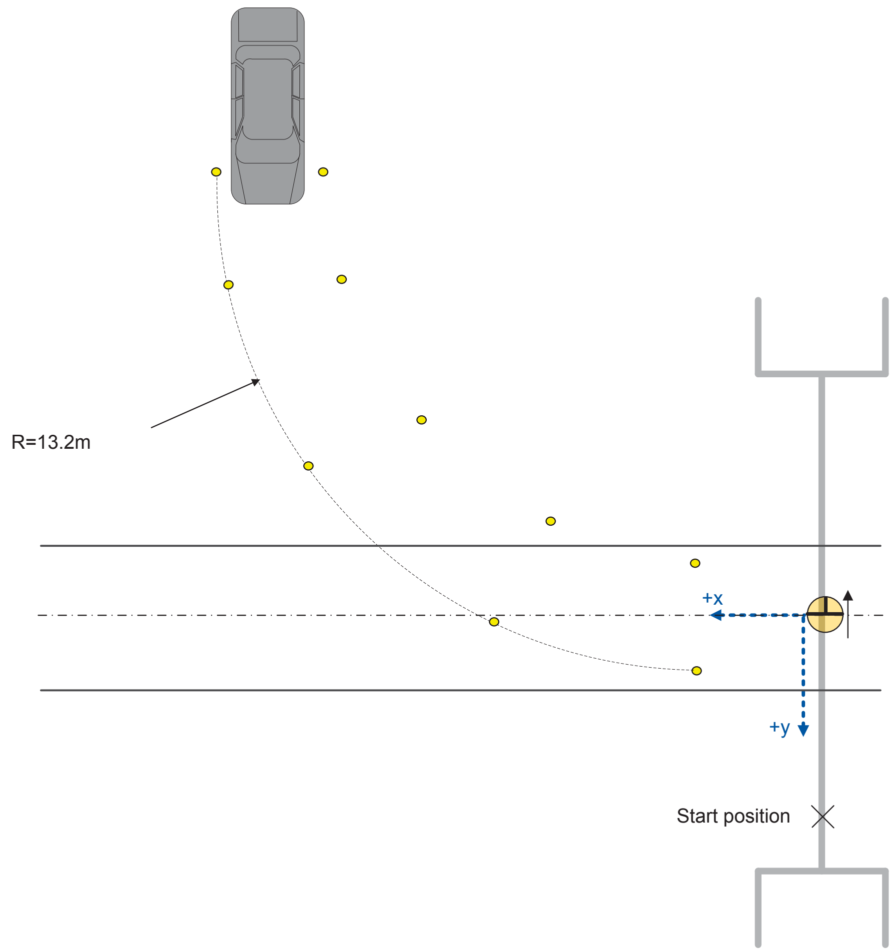


Figure 48: S3 – Vehicle Turning Left With Mannequin Crossing Path

4.2.8 S4: Mannequin Moving Parallel to Vehicle Path

Figures 49 and 50 present the procedures used to conduct the S4 tests. The basic test procedure described in Section 4.2.4 was used for these two scenarios with the following changes:

1. For the S4 scenario with the moving mannequin (shown in Figure 49), a test lane about 20 cm from the vehicle tires was marked with Botts' dots within 10 m of the mannequin starting position.
2. For the S4 scenario with the static mannequin (shown in Figure 50), a test lane about 20 cm from the vehicle tires was marked with Botts' dots within 20 m of the mannequin.

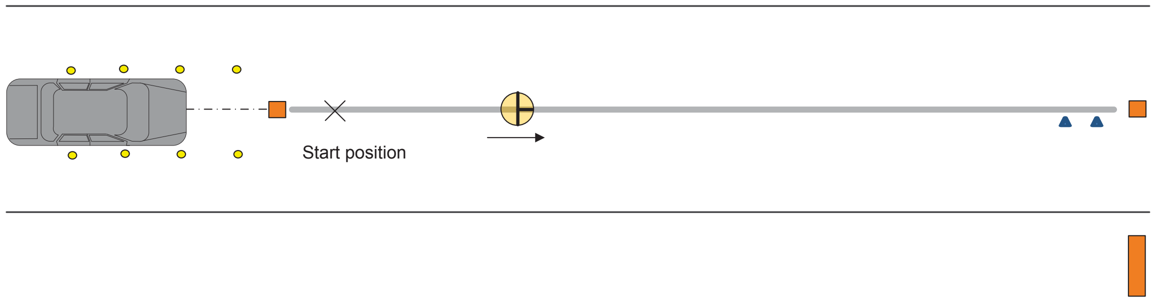


Figure 49: S4 – Vehicle Straight With Mannequin Moving Along Path

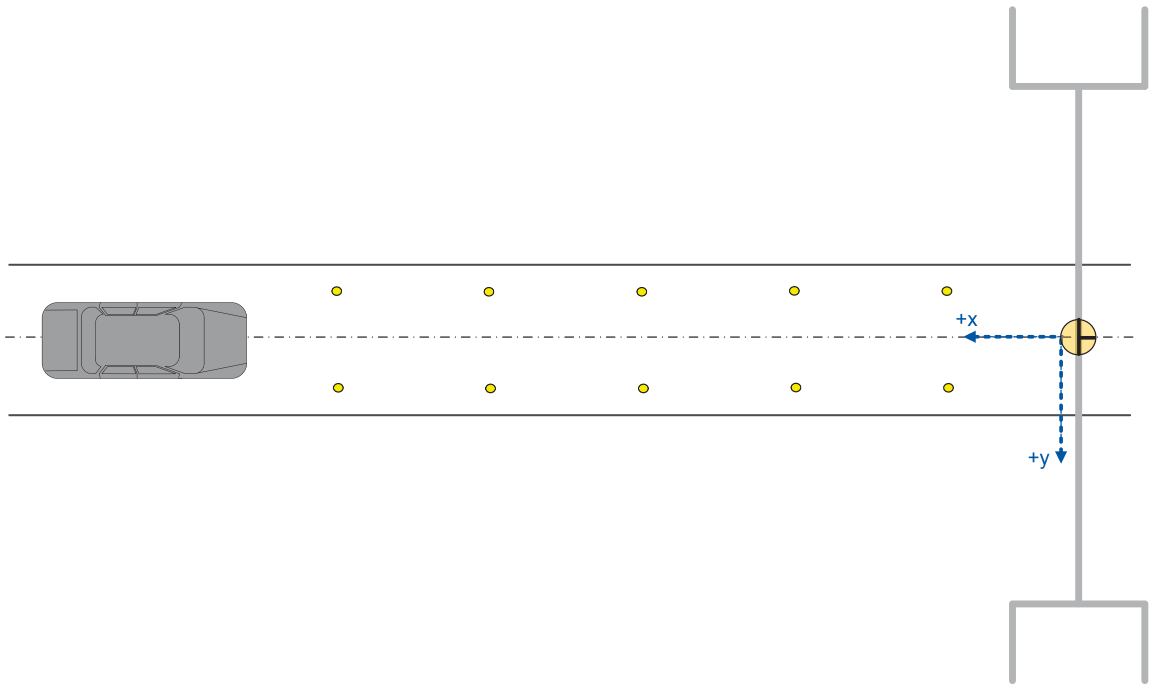


Figure 50: S4 – Vehicle Straight With Mannequin Static at Center of Path

4.3 Real-World Operational Assessment Data (ROAD) Trip

The PCAM ROAD Trip was a Task 4 data collection activity conducted from June 2012 to August 2012. The purpose of the ROAD Trip was to obtain information from pedestrian encounters during actual driving which could provide a basis for potential operational test scenarios. The PCAM ROAD Trip design and findings are described in the following sections.

4.3.1 Overview of PCAM ROAD Trip Design

The PCAM ROAD Trip was designed as three separate trips concentrating on urban areas likely to result in pedestrian encounters. These included cities with widely varied pedestrian environments, cities that were considered “pedestrian-friendly,” and cities that were considered “pedestrian unfriendly.” “Pedestrian friendly” and “pedestrian un-friendly” refer to the general roadway infrastructures in an area and whether design elements are generally in place to separate and protect pedestrians from vehicle traffic. Data from this trip was used to assess PCAM system reliability. Positive performance tests show only one aspect of a PCAM system's performance. Understanding the potential unintended consequences in real-world operation of PCAM systems is important to assess, as well. In order to have a balanced assessment of PCAM system performance, test methods are required that can assess system performance with regard to false events.

The PCAM ROAD Trip segments included cities along the East Coast, Florida, and the West Coast. The East Coast segment was conducted June 17 to 28, 2012, and included Boston, New York, and Washington, DC. These cities were generally selected based on their high rates of pedestrian traffic and relative proximity. Figure 51 contains a diagram of the overall segment route. Detailed routes driven within each city are presented later in this report.

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Figure 51: Overall Route of East Coast Trip

The Florida segment included Jacksonville, Orlando, Tampa, and Miami. These cities were designated by Transportation for America (2011) as the four most dangerous metropolitan areas for pedestrians in the United States. This segment was completed July 15 to 27, 2012. Figure 52 contains a diagram of the overall segment route.

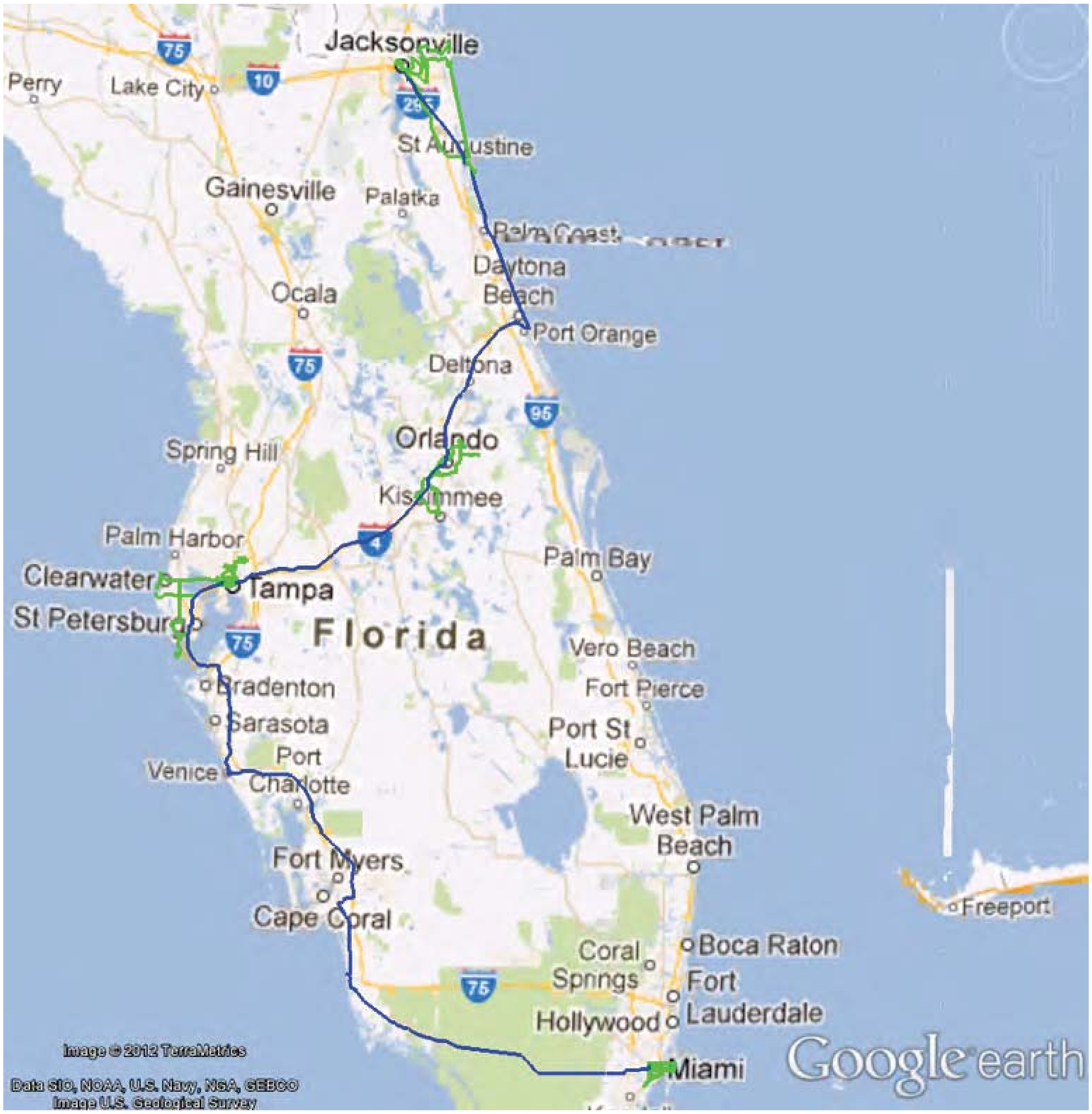

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Figure 52: Overall Route of Florida Trip

The West Coast segment was conducted August 5 to 18, 2012, and included Las Vegas, San Diego, Los Angeles, and San Francisco. These cities were generally selected based on their high rates of pedestrian traffic and relative proximity. Figure 53 contains a diagram of the overall segment route.

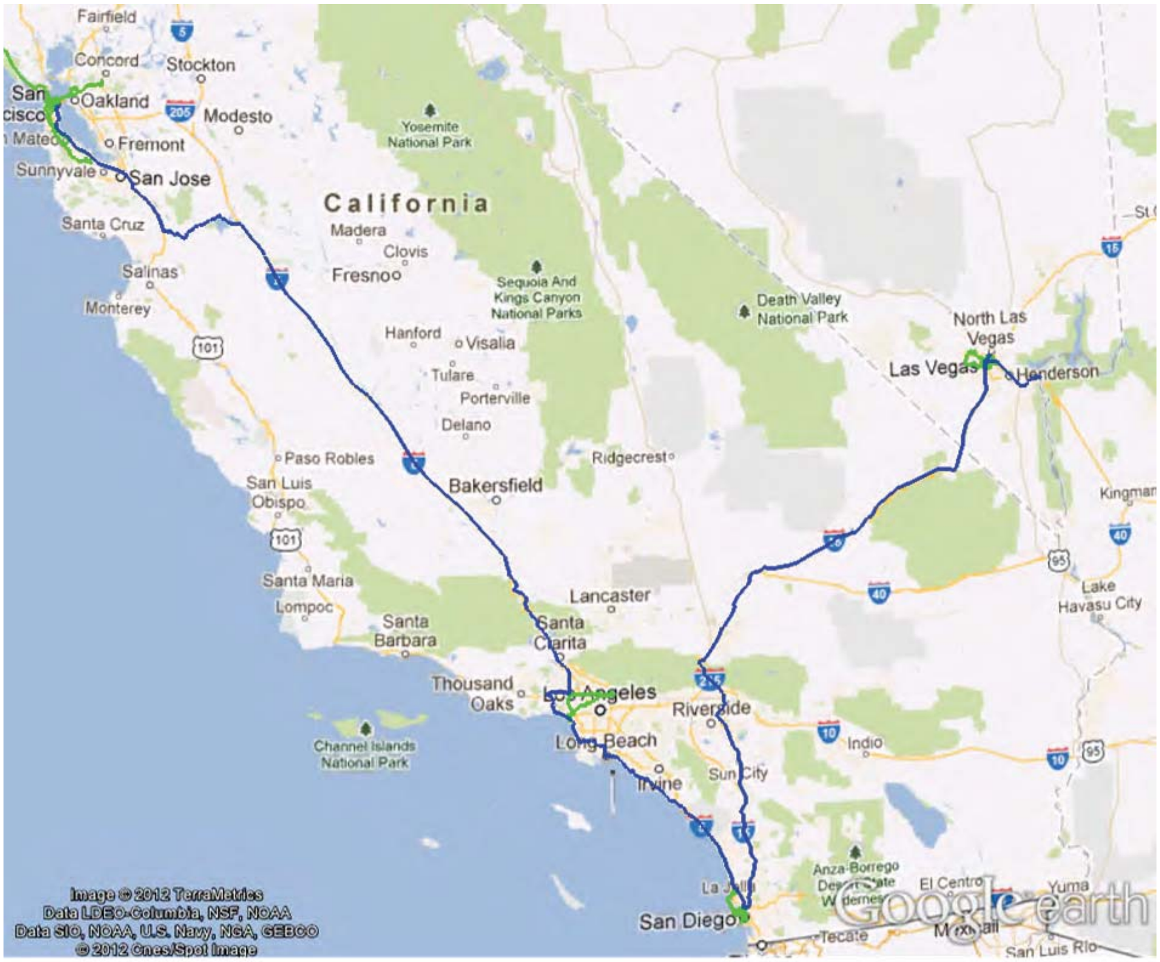

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Figure 53: Overall Route of West Coast Trip

4.3.2 Overview of PCAM ROAD Trip Vehicles

Two PCAM test vehicles were used for the ROAD Trip data collection. Vehicle 1 contained a fusion sensing system with radar and stereo camera. Due to the large file sizes associated with collecting raw stereo video, this vehicle used an event-based triggering system to collect vehicle, sensing, and PCAM system information. A manual trigger button was also present for the driver to use to record additional events of interest.

Vehicle 2 contained a fusion sensing system with radar and mono camera. The data acquisition system in this vehicle was capable of recording vehicle, sensing, and PCAM system data continuously. This vehicle's continuous data collection allowed post-drive analysis of system performance with different algorithm thresholds.

4.3.3 ROAD Trip Summary

This section describes the overall data collection strategies, overviews of selected driving routes within each city, and high-level vehicle driving data.

Figure 54 presents a map showing the vehicle travel route in Boston prepared using the GPS data recorded during testing. Similar maps were constructed for each test vehicle for each of the 11 major cities visited during the ROAD Trip. The maps showing the driving routes for both vehicles are presented in Appendix G to the report. Examples of the criteria used in selecting driving areas within each city include:

- Areas unique for the region of the specific ROAD Trip;
- Areas with high pedestrian traffic;
- Areas with traffic speeds compatible with likely PCAM system operational speeds; and
- Areas with subjectively higher risk for pedestrians.

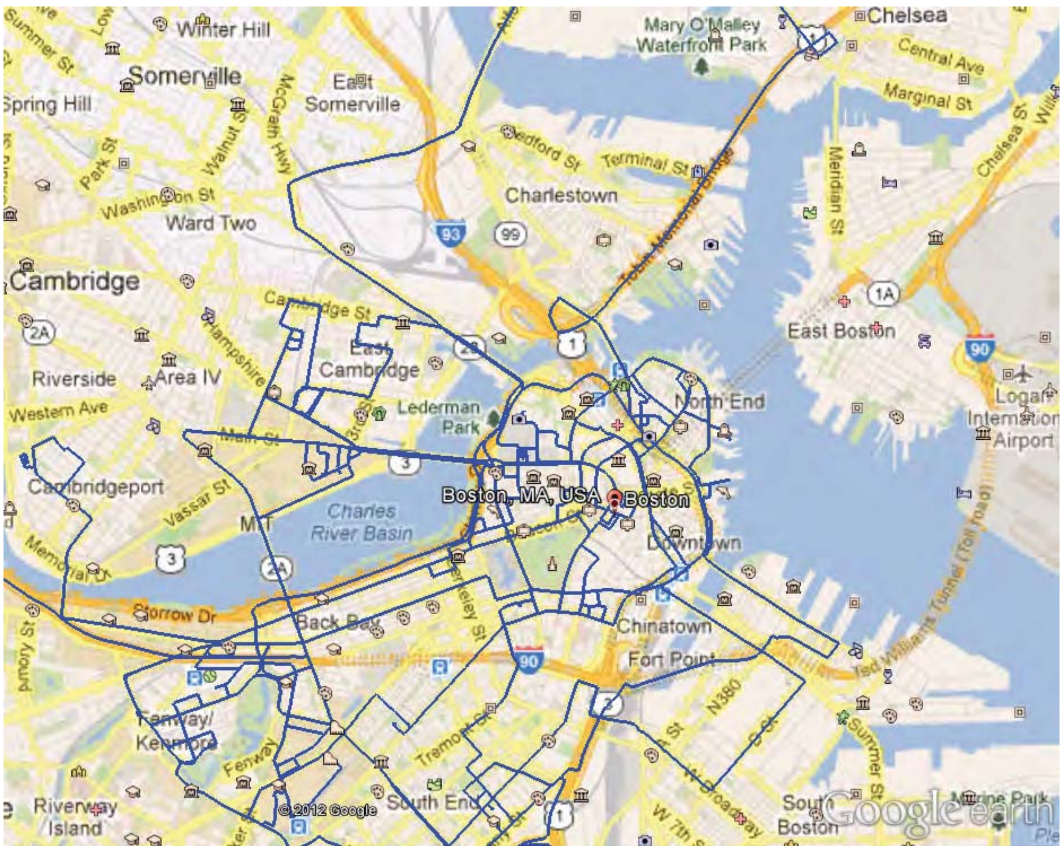


Figure 54: Example Map of Vehicle 1 Driving Routes for Boston

Both PCAM test cars were generally driven in the same areas. However, specific routes for the individual vehicles and hours of driving could differ due to varying downtimes for maintenance, parking, high traffic density, etc., and the need to cover as wide a range of pedestrian conditions as possible. The cars were driven about seven hours a day excluding downtimes. The number of miles driven per day ranged from as few as 34 to more than 500 miles. On average, the number of miles driven each day was about 140 miles.

Figures 55 to 57 show the Vehicle 1 percentage of hours driven in the cities within various speed bins. Standing times and transfers between the cities are excluded. The distribution is similar across the three East Coast cities (Figure 55), whereas there is more variability between cities in the Florida and West Coast trips (Figures 56 and 57, respectively). These distributions are consistent with what would be expected in an urban environment and consistent with pedestrian crash data analyzed by Volpe in Task 2 of the project.

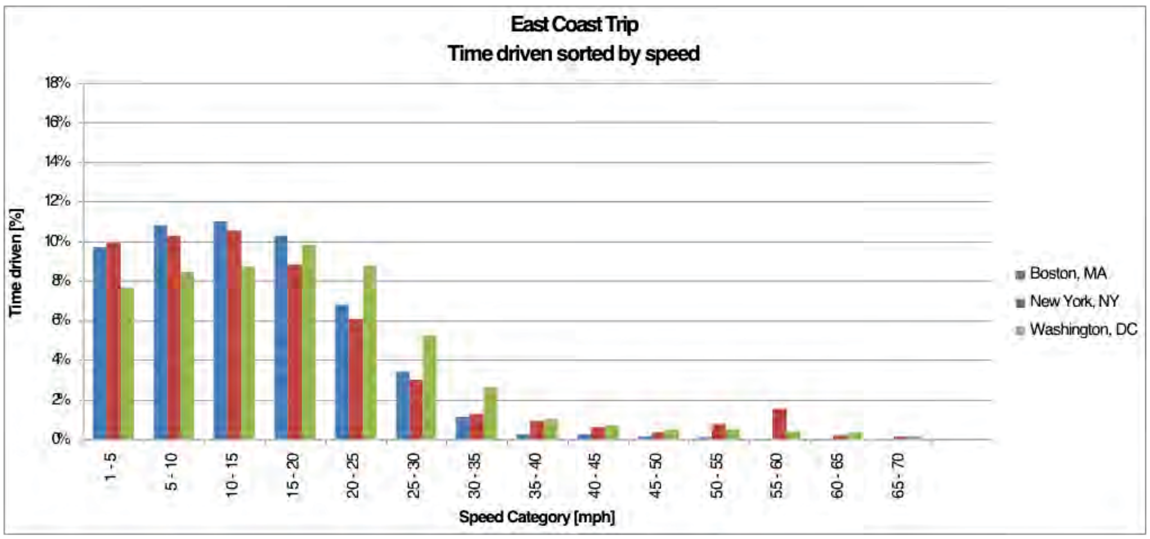


Figure 55: Percent of Time Driven by Speed Range and City During the East Coast Trip (Vehicle 1)

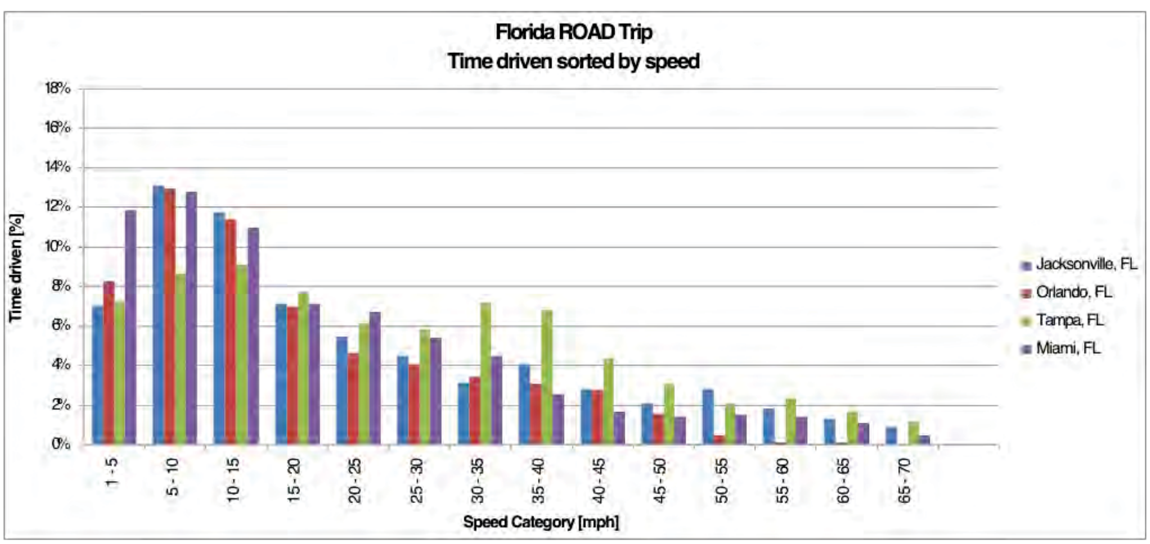


Figure 56: Percent of Time Driven by Speed Range and City During Florida Trip (Vehicle 1)

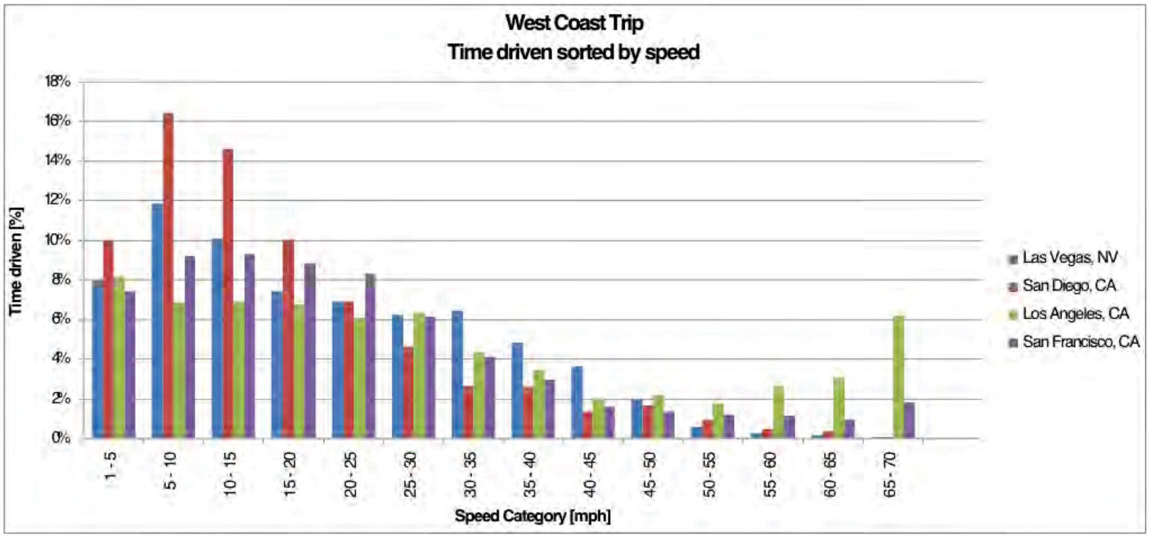


Figure 57: Percent of Time Driven by Speed Range and City During West Coast Trip (Vehicle 1)

Table 19 presents the number of driving hours and miles driven by city for Vehicle 2 during the ROAD Trip. Overall during the ROAD Trip, Vehicle 2 was involved with nearly 160 hours of in-city driving which covered approximately 3,660 miles in 11 major cities. On average, this vehicle was driven about 333 miles in each metropolitan area and an average of a little over 14 hours of driving in each location.

Table 19: Typical Hours and Distances Travelled

East Coast Trip	(excludes transit miles)		
City	Hours	Miles	Avg Speed (mph)
Boston	14.75	253	17
New York	19	274	14
Washington, DC	18.4	366	20
Total	52.15	893	

Florida Trip	(excludes transit miles)		
City	Hours	Miles	Avg Speed (mph)
Jacksonville	11.75	361	31
Orlando	15.4	431	28
Tampa	13.6	369	27
Miami	8.1	172	21
Total	48.85	1333	

West Coast Trip	(excludes transit miles)		
City	Hours	Miles	Avg Speed (mph)
Las Vegas	8.75	226	26
San Diego	12.8	275	21
Los Angeles	13.5	428	32
San Francisco	22.6	508	22
Total	57.65	1437	

Figures 58 through 60 present the percent of time driven by speed category for Vehicle 2 during the three segments of the ROAD Trip. Similar to Vehicle 1, standing times and transit times between cities have been excluded. Although there are some differences in the distributions of percent of time driven between Vehicle 2 and Vehicle 1, these differences can be attributed to the differing routes driven and times of day driving was conducted by the two vehicles. As was with Vehicle 1, all distributions are reflective of driving in urban environments.

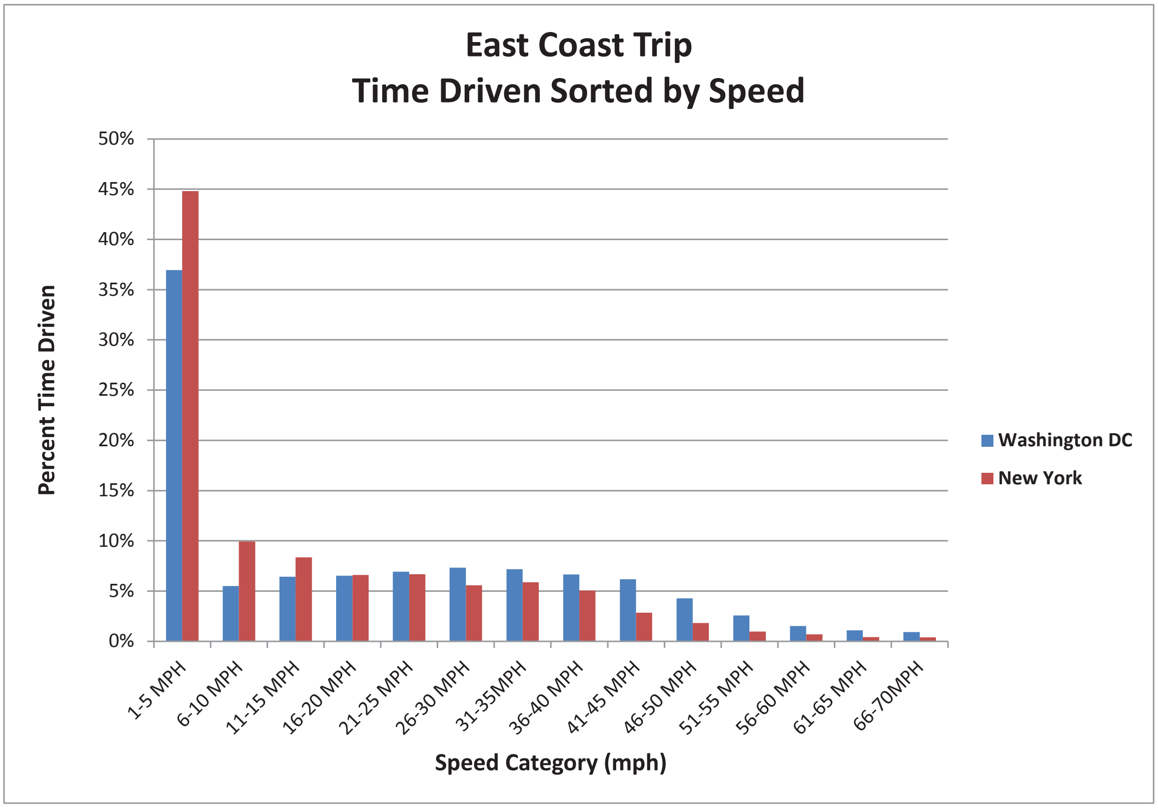


Figure 58: Percentage of Time Driven by Speed Range and City During the East Coast Trip (Vehicle 2)

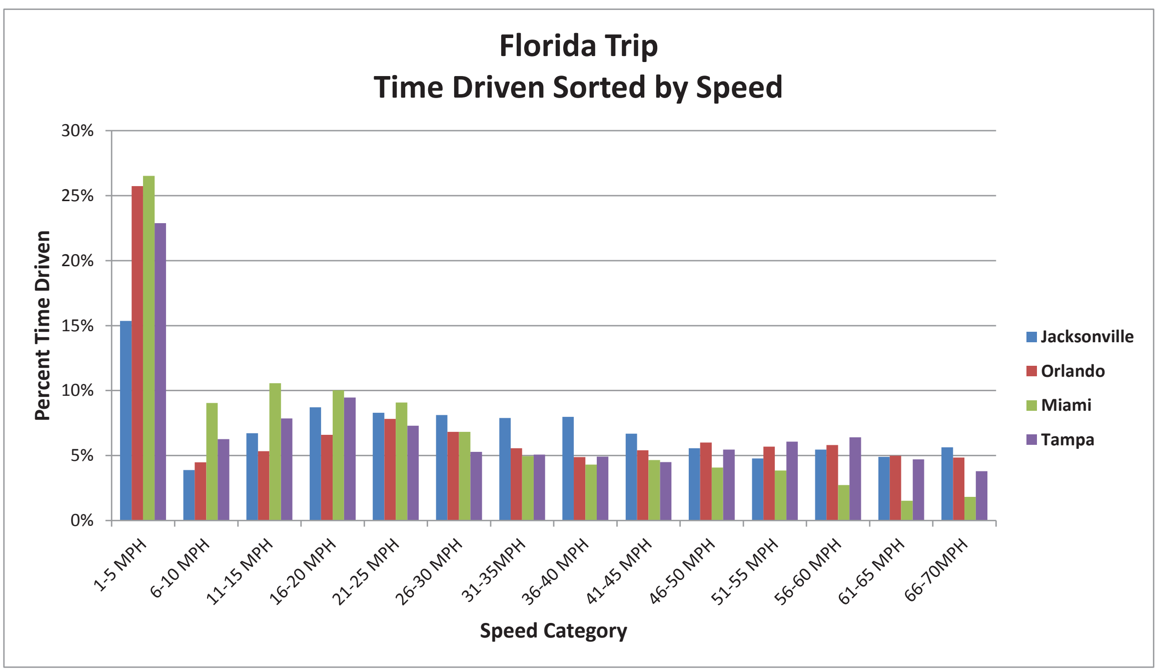


Figure 59: Percentage of Time Driven by Speed Range and City During Florida Trip (Vehicle 2)

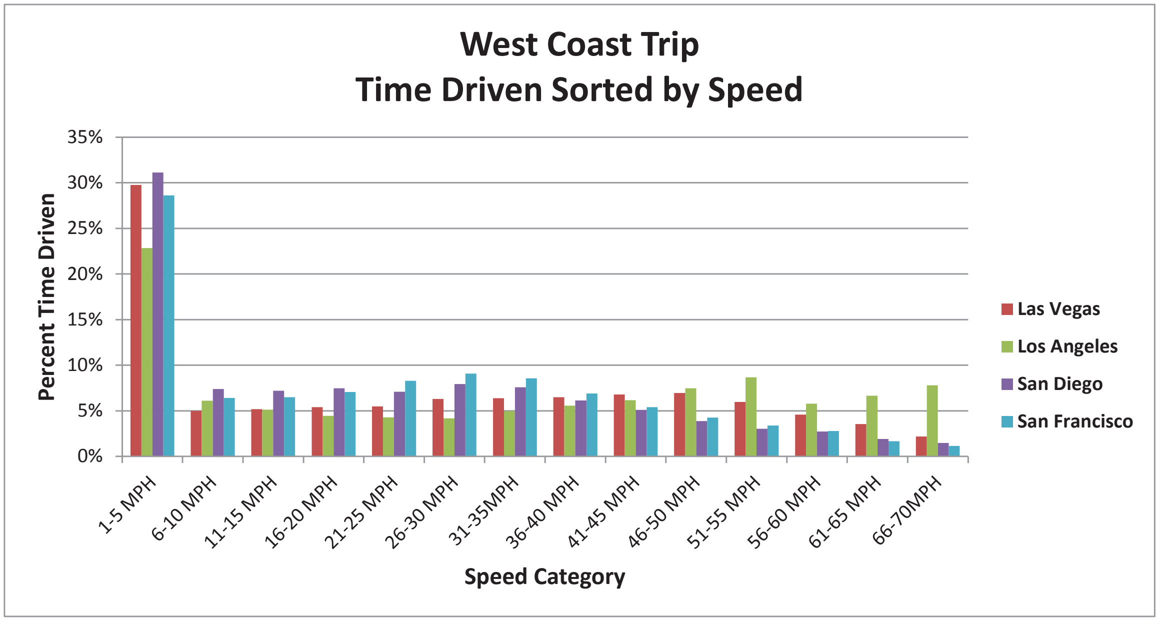


Figure 60: Percent of Time Driven by Speed Range and City During West Coast Trip (Vehicle 2)

4.3.4 PCAM System Operational Observations

Due to a different maturity of the two PCAM systems represented in this ROAD Trip, the analysis of Vehicles 1 and 2 could not be done in the exact same way. Thus, the results from the two vehicles are not directly comparable. Vehicle 1 was equipped with a measurement computer triggered to record data when a pedestrian was detected within specific zones in front of the vehicle. The dimension of the zones was chosen to allow triggering both in critical and non-critical situations which happened close to the vehicle. All events recorded during the ROAD Trip were then analyzed and grouped according to their criticality (warnings or detections in uncritical situations within vehicle or lane width). Table 20 presents the data obtained from Vehicle 1.

The counts in Table 20 are based on the event-triggered data collection system. Within all 25 warnings that occurred, there was only one situation which was caused by something other than a pedestrian. This event involved signs placed along the outside of a curve in a tunnel and is illustrated later in this report.

Table 20: Data Collection from Vehicle 1

	Automatic Pedestrian Triggers	Real Pedestrians	Other Vulnerable Road Users (i.e., Bicycles, Bikes, Wheel-Chairs)	Non-Pedestrians
Pedestrian Collision Warnings	25	20	4	1
Pedestrian Detections Approx. Within Vehicle Width	215	189	24	2
Pedestrian Detections Approx. Within Lane Width	745	630	102	13
Total	985	839	130	16

The scenarios observed during the ROAD Trip data analysis generally fell into three broad categories denoted as follows:

- Events involving actual pedestrians
- Events involving other vulnerable road users
- Events in which no pedestrian was present

Information about these three event categories is presented pictorially in the following sections of the report.

4.3.4.1 Events Involving Actual Pedestrians

Figures 61 to 63 show typical samples of events in which real pedestrians were present.

Figure 61: S1 Pedestrian Crossing Scenario Moving Right-to-Left, Unobstructed

Figure 62: S4 Pedestrian In-Path Scenario Moving Away From the Vehicle

Figure 63: S1 Pedestrian Crossing Scenario Moving Left-to-Right, Obstructed by a Truck

4.3.4.2 Events Involving Other Vulnerable Road Users

Other vulnerable road users are people typically using all kinds of two- or three-wheeled vehicles such as bicycles, tricycles, motorcycles, wheel-chairs, Segways, etc. As the users of those vehicles often appear like persons for the sensor systems, they were detected several times and classified as pedestrians.

Figures 64 through 67 show samples of events in which other vulnerable road users were present. These events typically involved tricycles, bicycles, motorcycles and similar vehicles whose rider is detected by the sensing system.

Figure 64: Tricycle Example

Figure 65: PCAM Vehicle Driving Toward Bicyclist

Figure 66: S1 Configuration With Person in Wheel Chair, Vehicle Stationary

Figure 67: Bicyclist Stopped Along the Roadway on the Outside of a Left Curve

4.3.4.3 Events in Which No Pedestrian Was Present

Figures 68 through 71 show examples of the events in which objects were classified as pedestrians.

Figure 68: Left Curve Inside a Tunnel

Figure 69: Print of a Person on a Bus Outside of the Vehicle's Travel Lane

Figure 70: Steering Toward a Mailbox or Garbage Can While Turning

Figure 71: Steering Toward a Sign Outside of the Vehicle Path

4.3.5 Detailed Analysis of ROAD Trip Data from Vehicle 2

Vehicle 2 contained a continuous data collection system which allows analysis of performance with different algorithm thresholds. In order to evaluate the data collected during the PCAM ROAD trip on a single mono-vision typology, the ability to distinguish vision-only targets from fused radar plus vision targets is a necessity. While performing a re-simulation of the ROAD trip data, all PCAM alerts recorded on the ROAD trip were still based on the fused target output. While it was possible to perform a vision-only re-simulation of the data, the resulting vision performance would not have been optimized for standalone performance, and would have suffered from range rate issues that would normally have been addressed in a standalone application. Therefore, vision-only performance was simulated for the purposes of this study by using fused data, but with a relaxed radar target matching requirement. This should give an approximation of vision-only performance while alleviating the inherent range rate issues associated with a non-optimized standalone vision system.

Therefore, it became necessary to create a rudimentary threat assessment algorithm for the vision-only target data based on the TTC with the closest in-path stationary, moving, or moveable pedestrian target.

The equation used for the TTC calculation when the pedestrian is stationary is as follows:

$$TTC = \frac{R}{V_o}$$ **Equation 1**

Where:

R = Range to the closest, in-path pedestrian
V_o = Range Rate to the closest, in-path pedestrian

While in theory, the following equation should be used when the primary pedestrian is moving or moveable (longitudinally):

$$TTC = \frac{-V_o - \sqrt{V_o^{\,2} + 2(a_t + a_h)R}}{a_t - a_h}$$ **Equation 2**

Where:

V_o = Range Rate to the closest, in-path moving target
R = Range to the closest, in-path moving target
a_t = Longitudinal acceleration of the target
a_h = Longitudinal acceleration of the host vehicle

The ability to directly extract the acceleration of the pedestrian from the collected data did not exist within our dataset, and thus Equation 1 was used for all detected pedestrians.

In the final analysis, the majority of events detected for this sensor combination involved stationary and slowly-moving pedestrians, so the effect of not using the target acceleration in the TTC calculation was minimal.

Since the goal of a PCAM system is likely to be collision avoidance when possible, threshold TTC values used to determine where PCAM autobraking (i.e., autonomous braking) would have occurred become a function of vehicle speed and the braking deceleration performance available:

$$TTC_{avoidance} = \frac{V_{Host}}{2a_{braking}} \quad \textbf{Equation 3}$$

Where:

V_{Host} = Host Vehicle's current speed

$a_{braking}$ = average deceleration available from host vehicle's autobraking system

During testing it was observed that the average deceleration due to braking during the deceleration period decreased somewhat at lower speeds, due to the available rate of braking pressure application. At lower speeds it is possible to bring the vehicle to a stop before the commanded deceleration is reached. This effect was approximated from track data and accounted for in the TTC threshold calculations, as noted in Table 21.

4.3.5.1 Identify Potential Operational Scenarios

An investigation of the driving scenarios in which potential false events occurred was performed for both Vision-Only and Radar-Vision Fusion sensing combinations. Event timings for potential FCW, Precharge and Autobraking events were considered, as outlined in Table 21.

A typical method for mitigating the effects of false autobraking events is to limit the maximum amount of autonomous braking available to the PCAM system. As can be seen from Equation 3, this approach will increase the value needed for TTCavoidance (i.e., increased sensitivity). Thus it is possible to perform a tradeoff analysis between number of potential false events and the severity of those events. For the purposes of this study, sensitivity levels were chosen to represent attempted full avoidance with maximum commanded braking levels of:

10 m/s^2 (baseline sensitivity),
8 m/s^2 (baseline sensitivity +25%), and
6.7 m/s^2 (baseline sensitivity +50%).

Table 21: TTC Settings for FCW, Precharge and Intervention Braking

Alert Type	Sensitivity Setting	Commanded Deceleration (m/s^2)	$a_{braking}$* (m/s^2)	Time to Collision (TTC) Criteria s
Forward Collision Warning	Baseline	10	6.4	$TTC_{avoidance}$ +1000 ms
	+25% sensitivity	8	5.1	$TTC_{avoidance}$ +1000 ms
	+50% sensitivity	6.7	4.3	$TTC_{avoidance}$ +1000 ms
Precharge	Baseline	10	6.4	$TTC_{avoidance}$ +400 ms
	+25% sensitivity	8	5.1	$TTC_{avoidance}$ +400 ms
	+ 50% sensitivity	6.7	4.3	$TTC_{avoidance}$ +400 ms
Intervention Braking	Baseline	10	6.4	$TTC_{avoidance}$
	+25% sensitivity	8	5.1	$TTC_{avoidance}$
	+50% sensitivity	6.7	4.3	$TTC_{avoidance}$

*This value is speed dependent – value shown is for 25 mph

Potential events of each type were then tabulated by noting any time where an in-path pedestrian had a TTC value less than or equal to the $TTC_{avoidance}$ threshold associated with the type of event and sensitivity setting. Each of these events were then analyzed and binned as to the type of scenario that caused the event. In all, the events were found to fall into one of the following list of scenario types:

O1: Pedestrian Crossing Laterally in Front of Vehicle. This scenario was similar to the S1 test scenario, except that the pedestrian either stopped short of the vehicle or finished crossing the vehicle's path before a collision could occur.

O2: Vehicle Making Right Turn Toward Pedestrian. This scenario is similar to the S2 test scenario, except that the pedestrian either stopped short of the vehicle or finished crossing the vehicle's path before a collision could occur.

O3: Vehicle Making Left Turn Toward Pedestrian. This scenario is similar to the S3 test scenario, except that the pedestrian either stopped short of the vehicle or finished crossing the vehicle's path before a collision could occur.

O4: Vehicle Approaching Longitudinally Moving Pedestrian. This scenario is similar to the S4 test scenario, except that no collision occurred with the pedestrian.

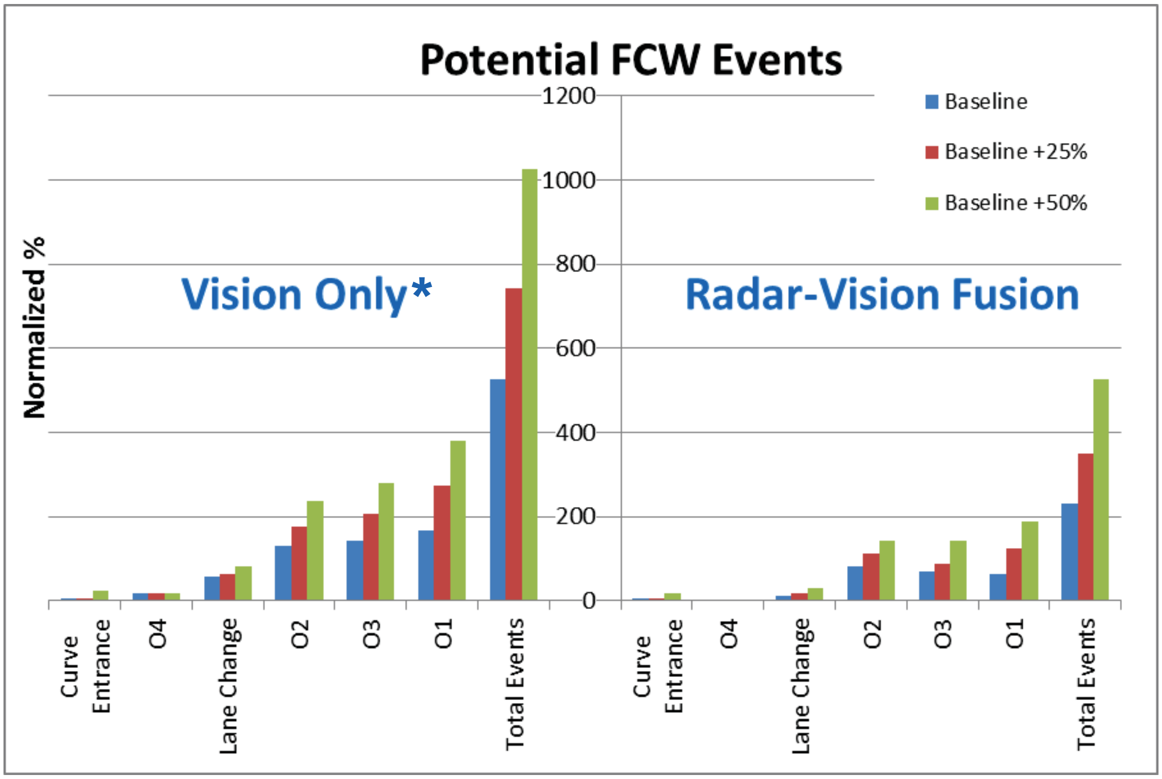
Lane Change: The vehicle is making a routine lane change which results in a pedestrian being in-path long enough to trigger the TTC criteria, Completion of the lane change takes the pedestrian out of the path and no collision occurs.

Curve Entrance: Pedestrian appears to be in path due to upcoming curve in the road.

Figure 72 through Figure 74 show the relative distributions of these scenarios for the various event types and sensitivity settings. *It should be noted that the values shown are normalized percentages. The total number of Potential False Precharge events at the Baseline sensitivity setting was used as the normalization factor.*

It should also be noted that the algorithms used for this study were not production algorithms and did not have many of the false event countermeasures that are normally used in production. This was intentionally done in order to get a better assessment of what types of scenarios are capable of initiating a false event in the field, and to have a large enough population of potential false events to glean useful data as to the kinematics of these scenarios.

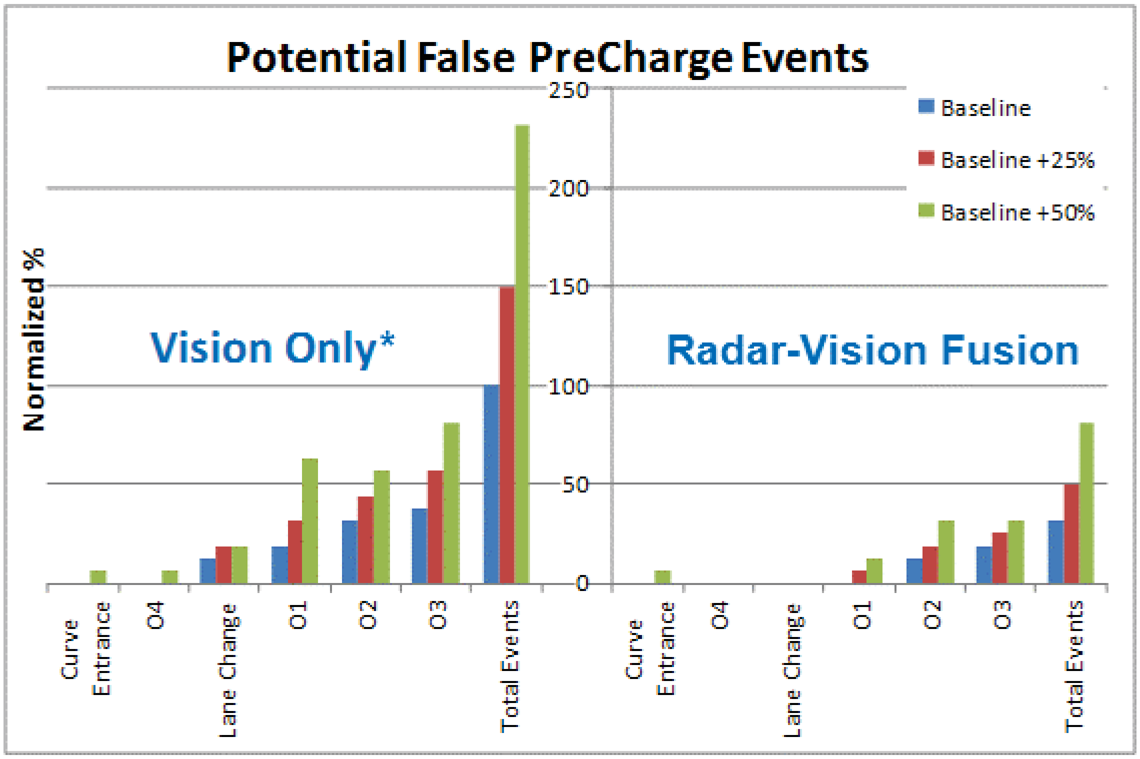
As illustrated in Figure 72, the majority of the potential FCW events occurred during scenarios where the pedestrian was crossing laterally in front of the vehicle (O1), the vehicle was making a right or left turn into the pedestrian (O2, O3), and where the vehicle was performing a routine Lane Change toward a nearby pedestrian. There were also a small number of events where the vehicle was approaching a pedestrian moving longitudinally down the road, both in a straight section of road (O4), or at a Curve Entrance. It should also be noted that the number of potential FCW events was cut roughly in half by fusing radar information with the vision system (requiring radar confirmation of the pedestrian target identified by the camera).



* Note: Vision-only performance was simulated from fused data system.

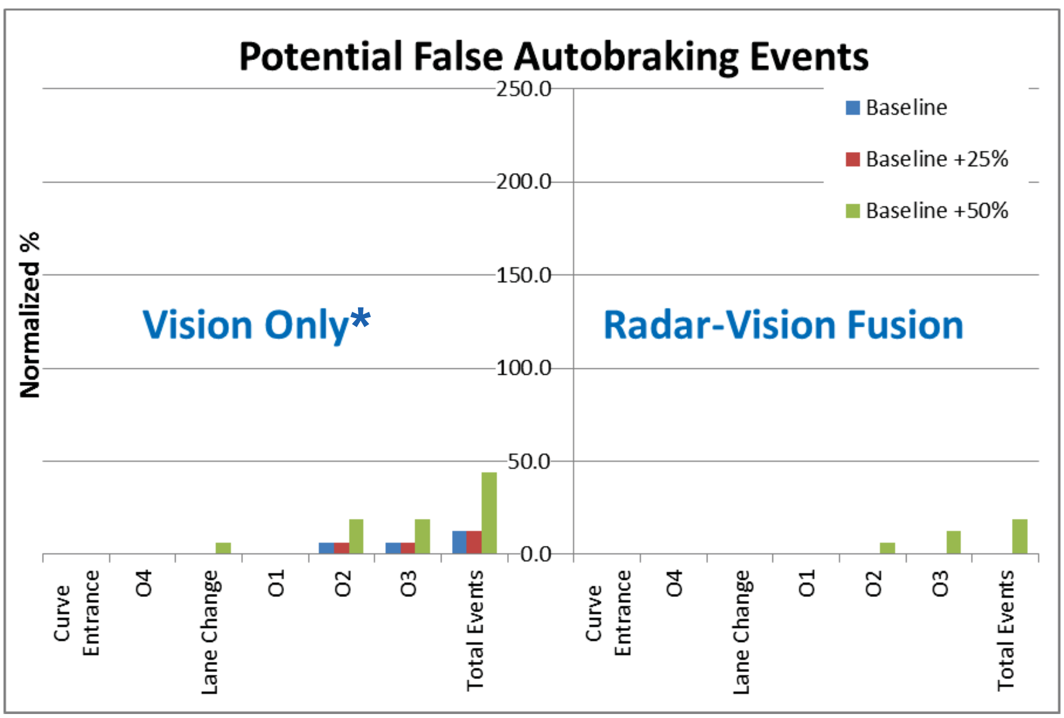
Figure 72: PCAM ROAD Trip Potential FCW Event Distribution

Figures 73 and 74 show the majority of the Potential False Precharge and Autobraking events occurred during scenarios where the pedestrian was crossing laterally in front of the vehicle (O1), the vehicle was making a right or left turn into the pedestrian (O2, O3), and where the vehicle was performing a routine Lane Change toward a nearby pedestrian. There were also a small number of events where the vehicle was approaching a pedestrian moving longitudinally down the road, both in a straight section of road (O4), or at a Curve Entrance. It should also be noted that the number of potential FCW events were cut roughly by a factor of three by fusing radar information with the vision system, and potential false autobraking events were eliminated in all but a very small number of O2 and O3 scenarios at the highest sensitivity setting.



* Note: Vision-only performance was simulated from fused data system.

Figure 73: PCAM ROAD Trip Potential False Precharge Events



* Note: Vision-only performance was simulated from fused data system.

Figure 74: PCAM ROAD Trip Potential Autobraking Events

4.3.5.2 Analysis of ROAD Trip Operational Scenarios

From the above ROAD Trip data analysis, a number of potential operational test scenarios can be identified. The following scenarios represent plausible conditions that should be considered for assessing PCAM system operational robustness. Figure 75 contains illustrations of four scenario types, which are consistent with the preliminary functional test method scenario descriptions developed within the project. For the operational scenarios, however, the PCAM systems should not activate autonomous braking functions, except as noted for individual tests.

While not a substitute for extensive real-world evaluation, these tests are designed to expose the systems to situations that have been observed to result in false events in a track test environment.

The physical requirements of the tests are suggested to replicate the range of values observed in the field, but in real-world situations false activations should be rarely observed and are not always repeatable. To address this, it is recommended that these tests be run as a series of repeated tests, run with randomly distributed physical characteristics that are within purposely wide ranges.

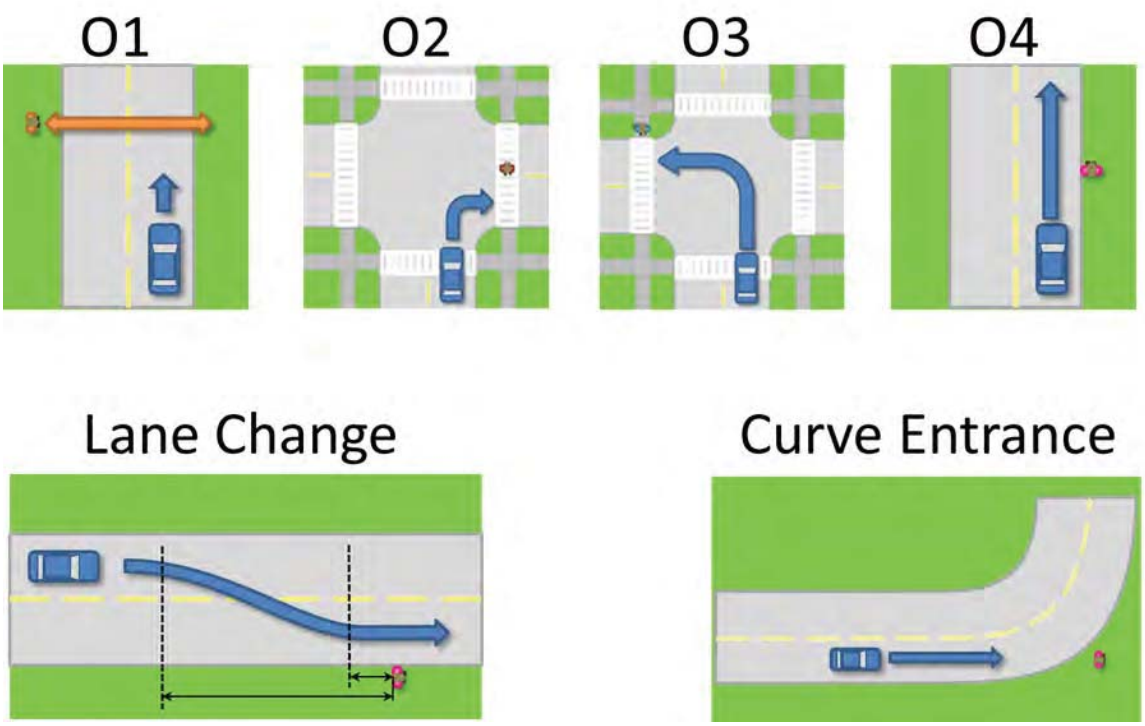


Figure 75: Operational Test Scenario Types

The proposed operational scenarios include:

- O1 scenario with the mannequin stopping short of vehicle path. This scenario is similar to the functional S1 test in which a mannequin crosses perpendicular to a vehicle traveling straight, however, the operational scenario would stop the mannequin target short of the test lane such that the vehicle would not contact the mannequin.

- O1 scenario with the mannequin clearing vehicle path before vehicle arrives. This scenario is similar to the previous test. However, this operational test would move the pedestrian mannequin completely across the test vehicle's path such that the vehicle would not contact the mannequin.
- O2 and O3 scenarios with a stationary mannequin located on outside of curved vehicle path. For these tests, the pedestrian mannequin would be placed along the outside of the test vehicle's intended path such that the vehicle would turn away from and not contact the mannequin.
- O4 scenario with the mannequin outside of vehicle path, similar to the functional S4 test in which a mannequin moves parallel to the vehicle's path. For the operational scenario, the pedestrian mannequin is positioned alongside the test lane such that the vehicle passes by without contacting the mannequin.
- O4 scenario with a stationary mannequin outside of test lane and vehicle changing lanes. This scenario is similar to the functional S4 test in which the test vehicle drives toward a stationary mannequin. For this operational scenario, the pedestrian mannequin is positioned alongside the test lane such that the vehicle passes by without contacting the mannequin. The test vehicle starts in the lane to the left of the test lane then changes lanes into the test lane such that the vehicle momentarily heads toward the mannequin before straightening into the test lane.
- O4 Scenario with a stationary mannequin outside of the test lane at the entrance to a curve. This scenario is similar to the functional S4 test in which the test vehicle drives toward a stationary mannequin. For this operational scenario, the pedestrian mannequin is positioned alongside the test lane just past the entrance to a curve, such that the vehicle passes by without contacting the mannequin.

4.3.5.3 Pedestrian Crossing Laterally (O1) False Event Scenario

Figure 76 shows an example of the O1 Scenario, where the pedestrian crosses laterally across the vehicle's path, and either stops before entering the vehicles path, or clears the path before the vehicle reaches the collision point. In this dataset, this scenario tended to occur mostly for potential FCW and Precharge events. The scenario generally resolves itself before the vehicle is close enough to warrant brake application. In this dataset, no potential false brake applications were observed for the O1 scenario at any sensitivity level.

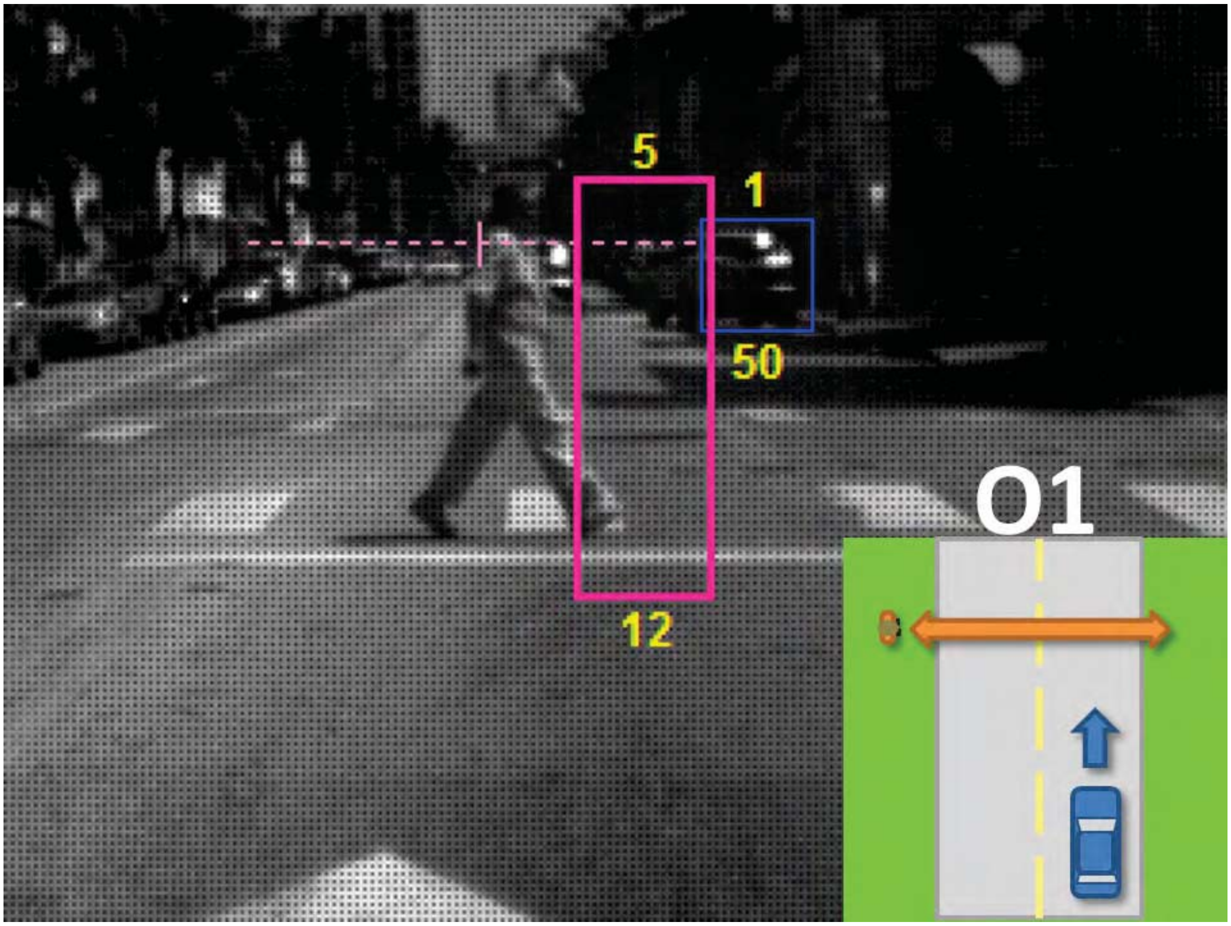


Figure 76: Example of Pedestrian Crossing Laterally (O1)

4.3.5.3.1 Pedestrian Crossing Laterally (O1) Kinematics

A kinematic analysis of the O1 false event scenario illustrated in Figure 76 shows that the speed of the host vehicle during this alert was typically between 5 and 20 mph for all alert sensitivity settings (see Figure 77). Examination of the vehicle's inertial measurements for the O1 Scenario (Figure 78, 79, and 80) show that the vehicle was typically traveling in a relatively straight path and relatively constant speed.

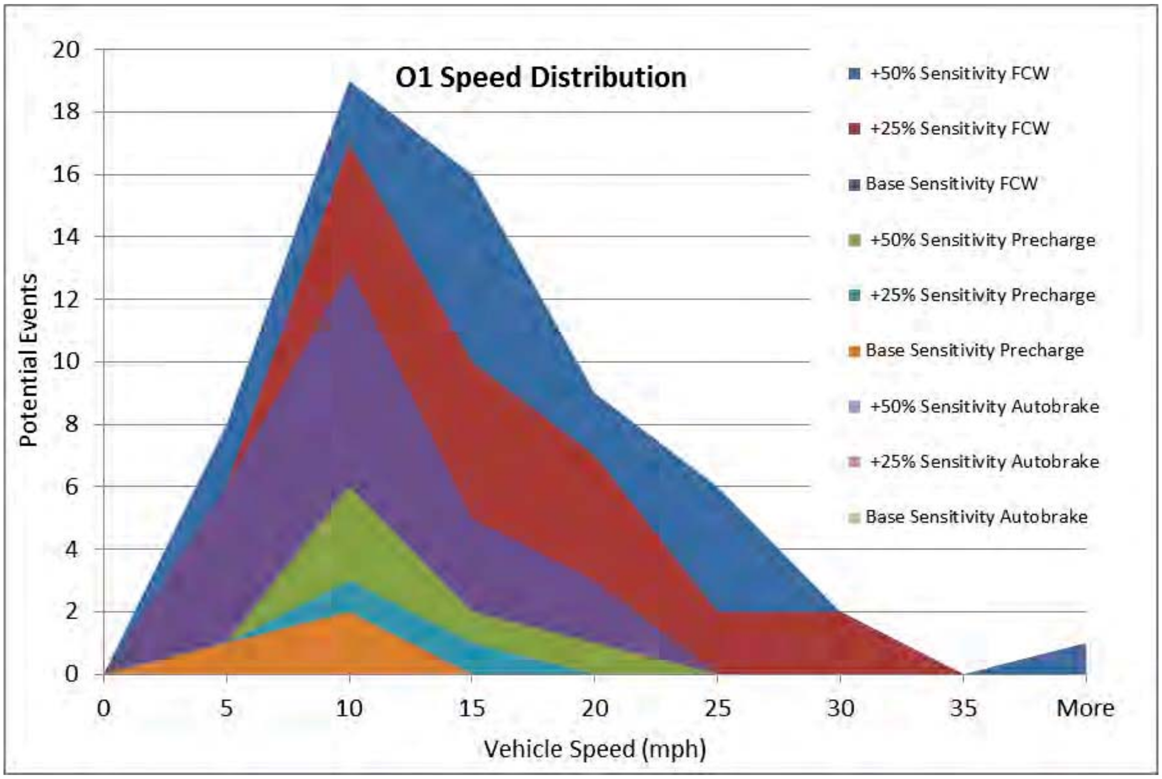


Figure 77: Speed Distribution for O1 Scenario

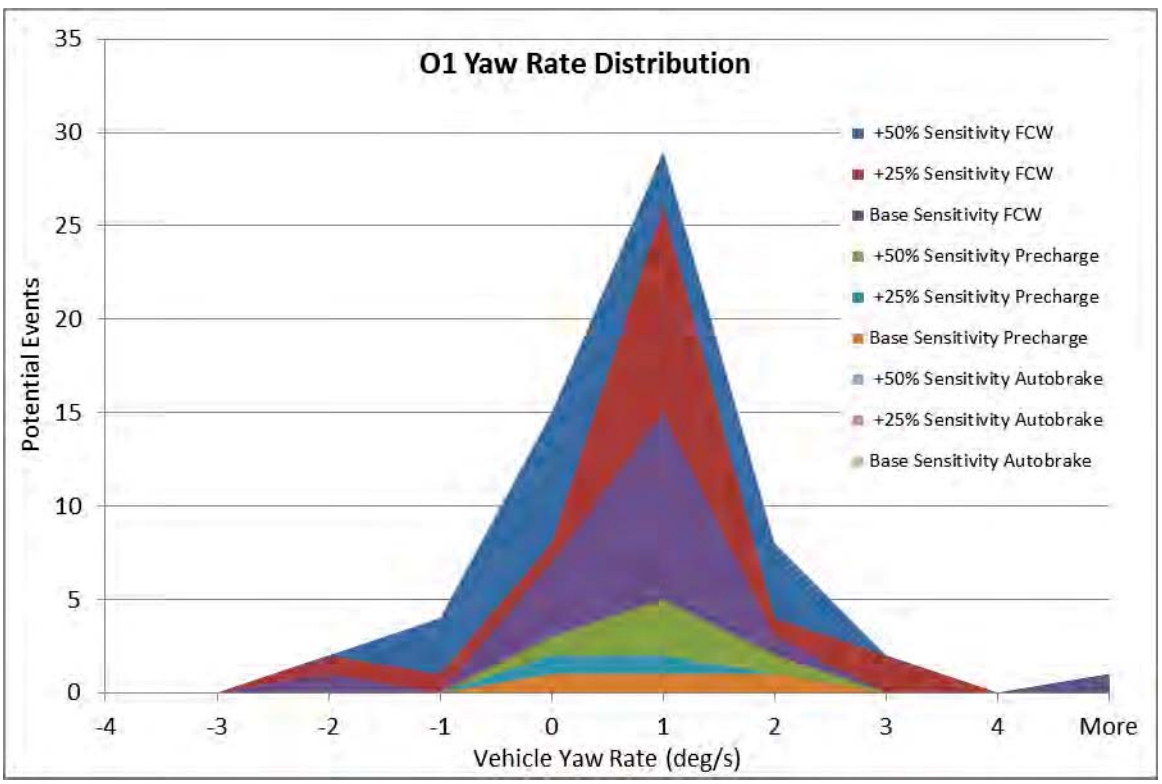


Figure 78: Yaw Rate Distribution for O1 Scenario

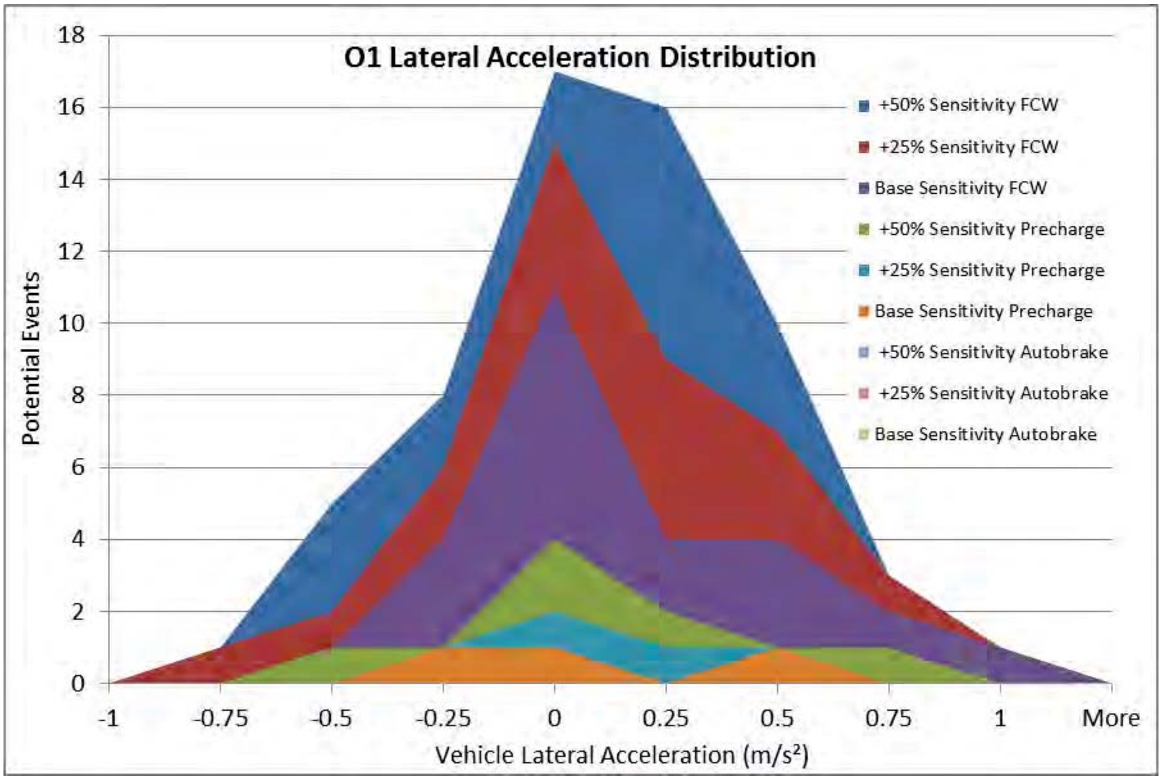


Figure 79: Lateral Acceleration Distribution for O1 Scenario

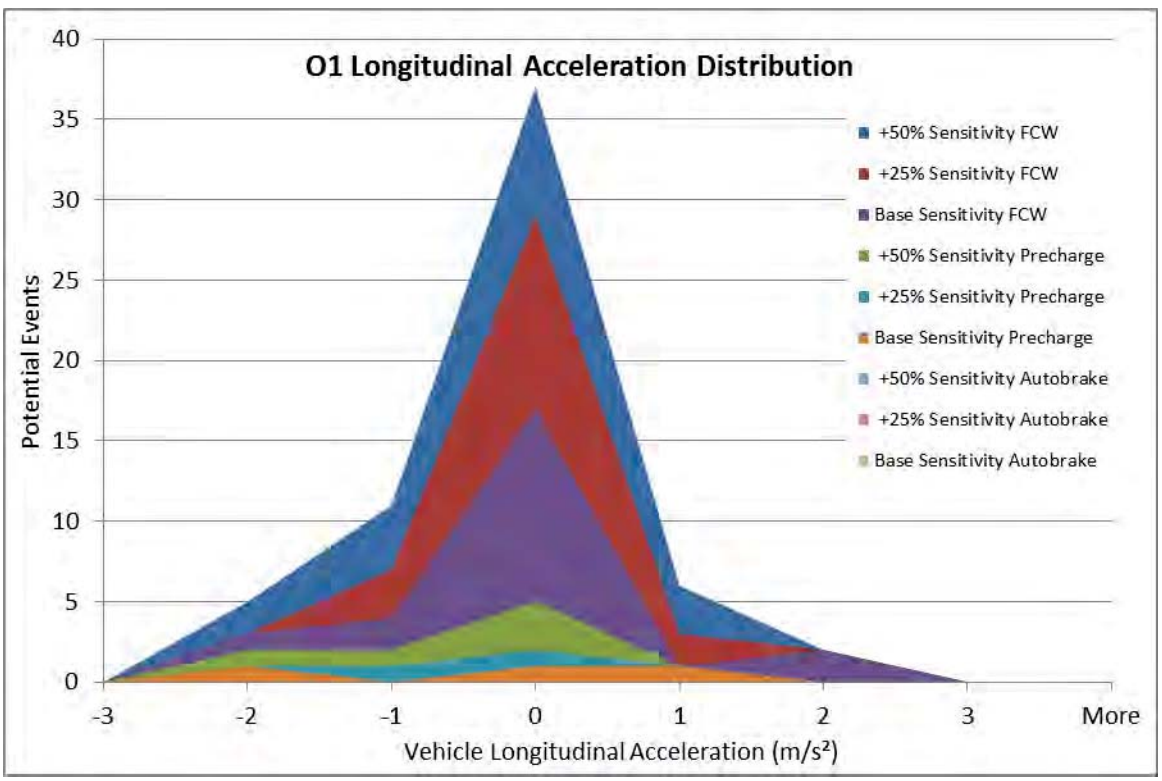


Figure 80: Longitudinal Acceleration Distribution for O1 Scenario

As previously noted, the O1 scenario typically unfolds in one of two ways. The pedestrian either stops short of the vehicle's path before actually crossing, or the pedestrian crosses the vehicle's path and clears the path before a collision can happen. The algorithm in the vehicle used to create this dataset was configured not to react to pedestrians before entering its path, so the O1 scenarios observed were all of the type where the pedestrian crosses and then clears the path. Figure 81 shows the distribution of TTC values at which the pedestrian was observed to leave the vehicle's path. While higher TTC values were observed, the bulk of the TTC values for clear path were observed to be between one and three seconds.

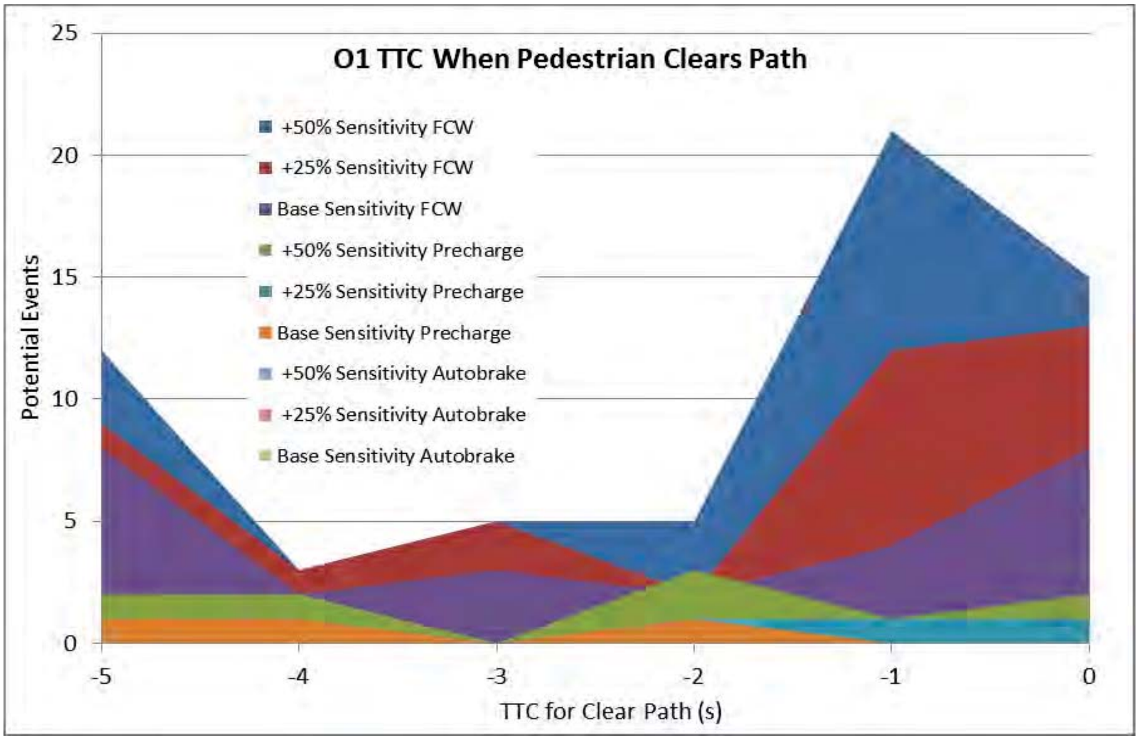


Figure 81: TTC When Pedestrian Clears Path for O1 Scenario

Given these observations, testing parameters for an O1 Operational Test could be specified as illustrated in Table 22.

Table 22: Test Parameters for O1 Where Pedestrian Clears Path

Host Vehicle Parameters	
Speed	5 - 20 mph
Yaw rate	±1 deg/s
Lateral acceleration	±0.5 m/s²
Longitudinal acceleration	±1.0 m/s²
Pedestrian Parameters	
Speed	3.1 mph
TTC at which pedestrian clears path	1 - 2 s

Similar parameters could also be used to configure an O1 scenario where the pedestrian stops short of the path.

When preliminary O1 tests were performed during the track testing phase, it was noted that for the cases where the pedestrian cleared the path that some warnings and braking events occurred. Due to the nature of this event some amount of braking could be deemed acceptable, so long as it ceases when the pedestrian leaves the vehicle's path.

4.3.5.4 Right Turn Toward Pedestrian (O2) False Event Scenario

Figure 82 shows an example of the O2 Scenario, where the vehicle encounters a pedestrian while making a right turn, typically at an intersection with crosswalks. In this dataset, this scenario was observed to occur for potential FCW, precharge and brake intervention events.

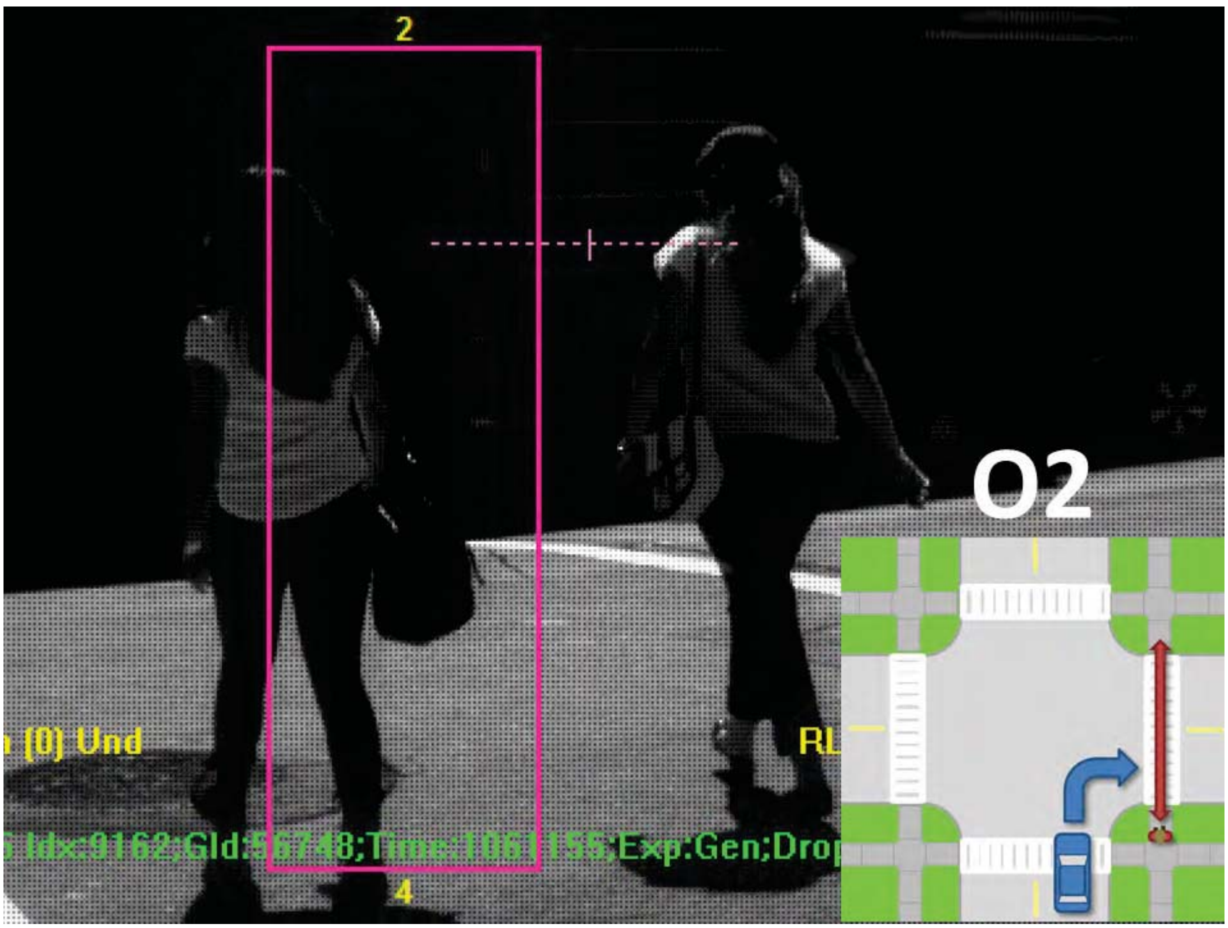


Figure 82: Example of Right Turn Toward Pedestrian (O2)

4.3.5.4.1 Right Turn Toward Pedestrian (O2) Kinematics

A kinematic analysis of the O2 false event scenario illustrated in Figure 82 shows that the speed of the host vehicle during this alert was typically between 10 and 15 mph for all alert sensitivity settings (see Figure 83). Examination of the vehicle's inertial measurements for the O2 Scenario (Figure 84, Figure 85 and Figure 86) show that the vehicle was typically traveling at a relatively constant speed and radius of curvature. The vertical bars on the graphs in this section represent the speeds and radius of curvature that were chosen for the validation tests prior to completion of this analysis.

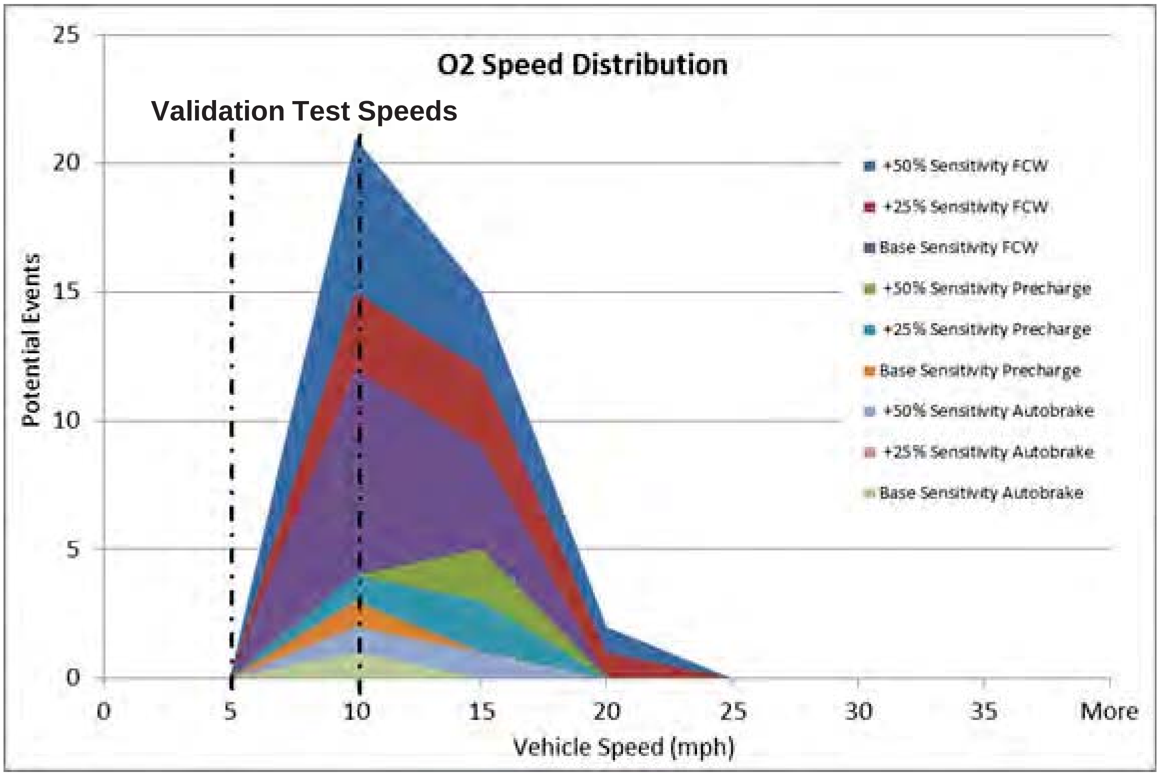


Figure 83: Speed Distribution for O2 Scenario

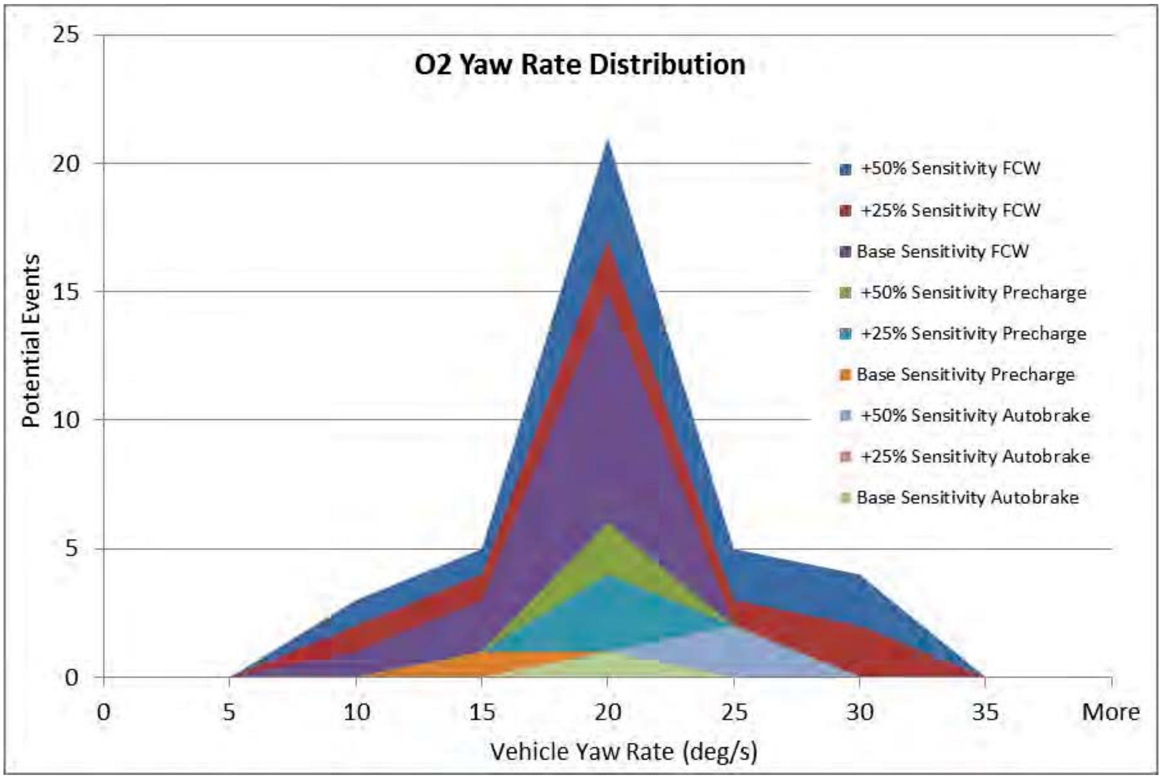


Figure 84: Yaw Rate Distribution for O2 Scenario

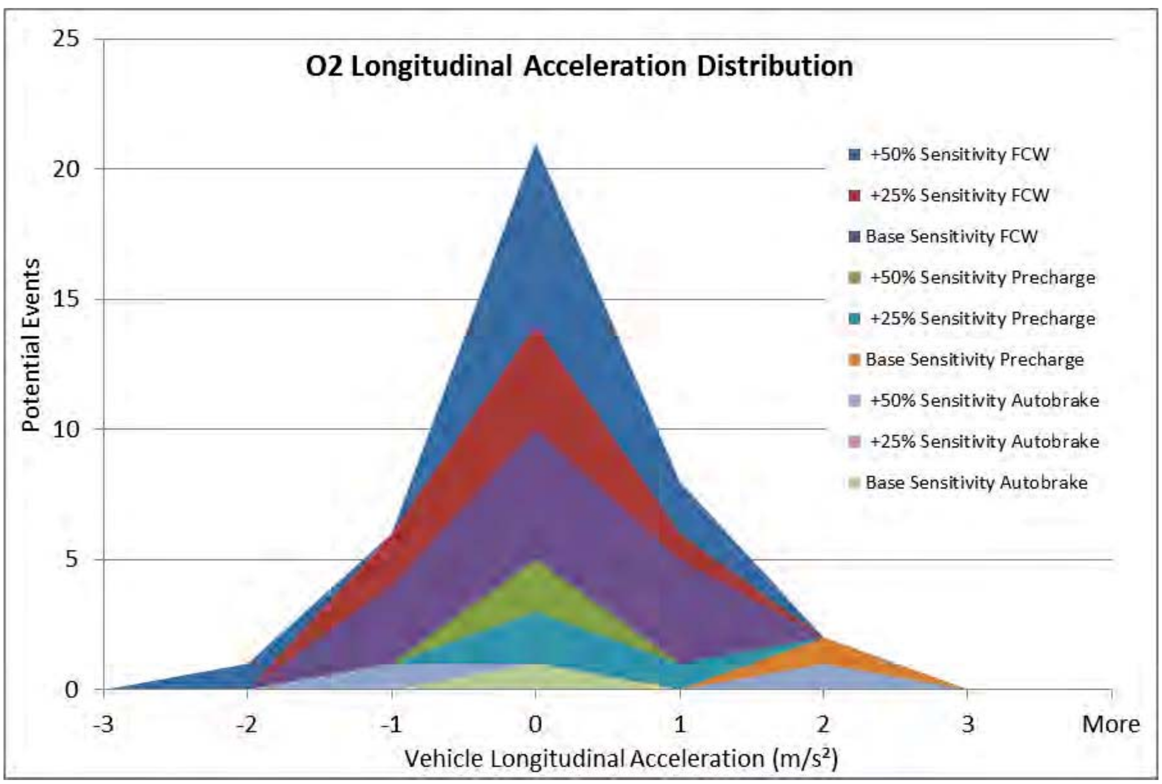


Figure 85: Longitudinal Acceleration Distribution for O2 Scenario

The field of view for currently available sensor systems typically does not make detection of S2/O2 scenarios likely when the pedestrian is approaching from the inside of the turn. As a result, the O2 scenarios observed in this dataset all involved the pedestrian approaching from the outside of the curve, where it was possible for the sensors to detect the pedestrian for a period of time as the vehicle approached.

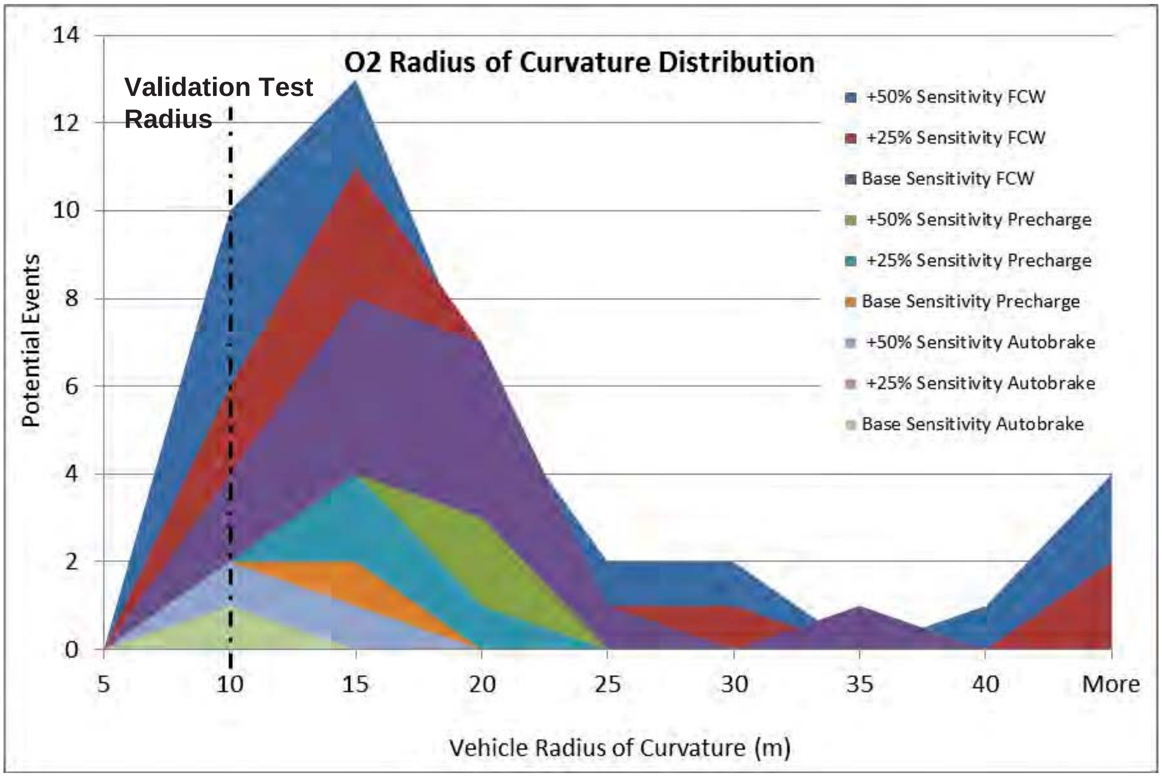


Figure 86: Radius of Curvature Distribution for O2 Scenario

Given these observations, testing parameters for an O2 Operational Test could be specified as illustrated in Table 23.

Table 23: Test Parameters for O2

Host Vehicle Parameters	
Speed	10 - 15 mph
Longitudinal acceleration	±1.0 m/s²
Radius of curvature	15 m
Pedestrian Parameters	
Speed	0 mph
Distance from vehicle path (outside)	1 m

Due to the above noted sensing characteristics, it is suggested to use a stationary pedestrian just outside of the vehicle's path to create a realistic Operational test for this scenario.

When preliminary O2 tests were performed during the track testing phase, a smaller radius of curvature was used, with lower speeds than recommended here. The preliminary radius of curvature for the O2 scenario is illustrated by the dotted line in Figure 86. When these tests were performed using the preliminary test parameters, the vehicle motion was observed to feel "unnatural" for this type of event. Subsequent independent testing of this scenario with the values based in real world observations and shown in Table 23 resulted in a much more realistic test.

4.3.5.5 Left Turn Toward Pedestrian (O3) False Event Scenario

Figure 87 shows an example of the O3 Scenario, where the vehicle encounters a pedestrian while making a left turn, typically at an intersection with crosswalks. In this dataset, this scenario was observed to occur for potential FCW, precharge and brake intervention events.

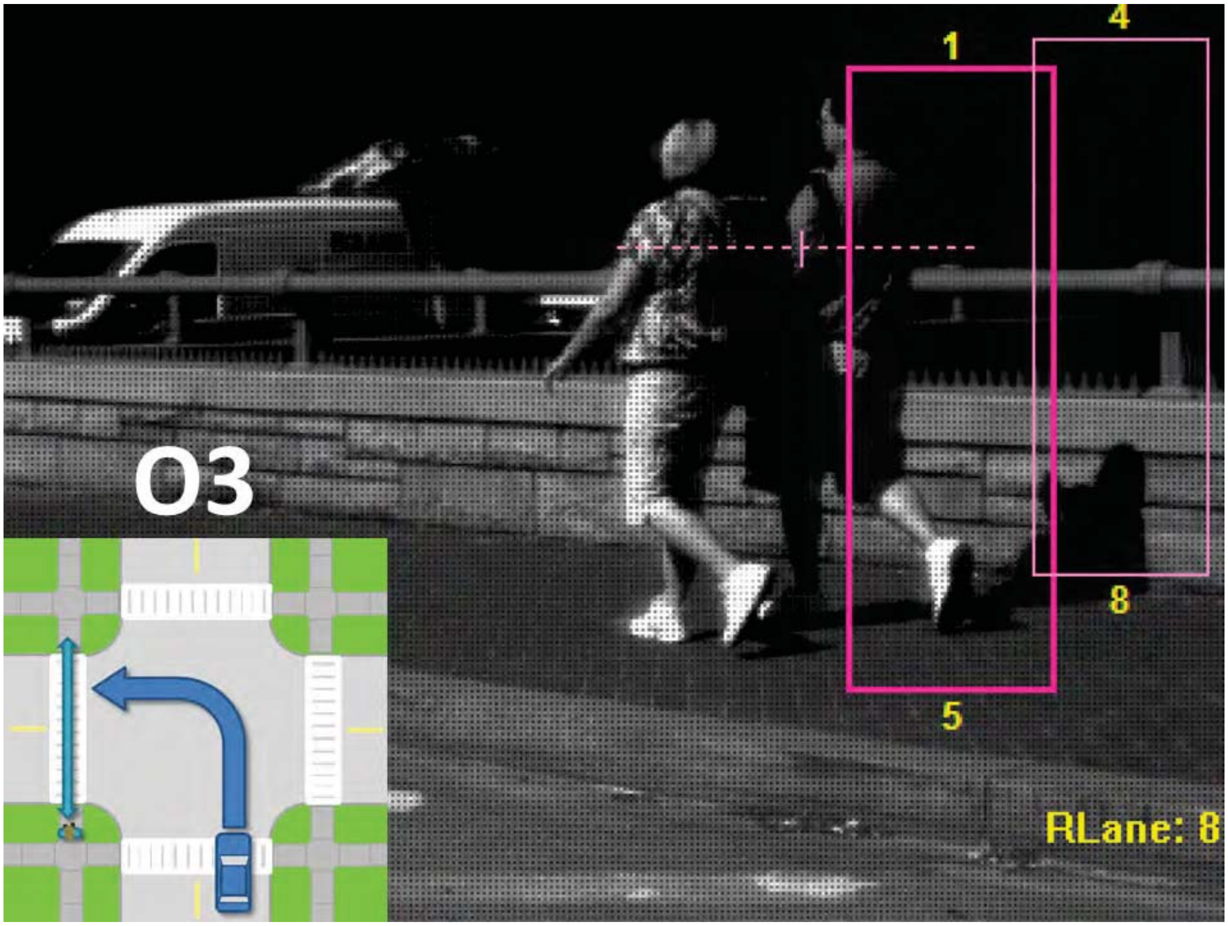


Figure 87: Example of Left Turn Toward Pedestrian (O3)

4.3.5.5.1 Right Turn Toward Pedestrian (O3) Kinematics

A kinematic analysis of the O3 false event scenario illustrated in Figure 87 shows that the speed of the host vehicle during this alert was typically between 10 and 15 mph for all alert sensitivity settings (see Figure 88). Examination of the vehicle's inertial measurements for the O3 Scenario (Figure 89, Figure 90 and Figure 91) show that the vehicle was typically traveling at a relatively constant speed and radius of curvature. The vertical bars on the graphs in this section represent the speeds and radius of curvature that were chosen for the validation tests prior to completion of this analysis.

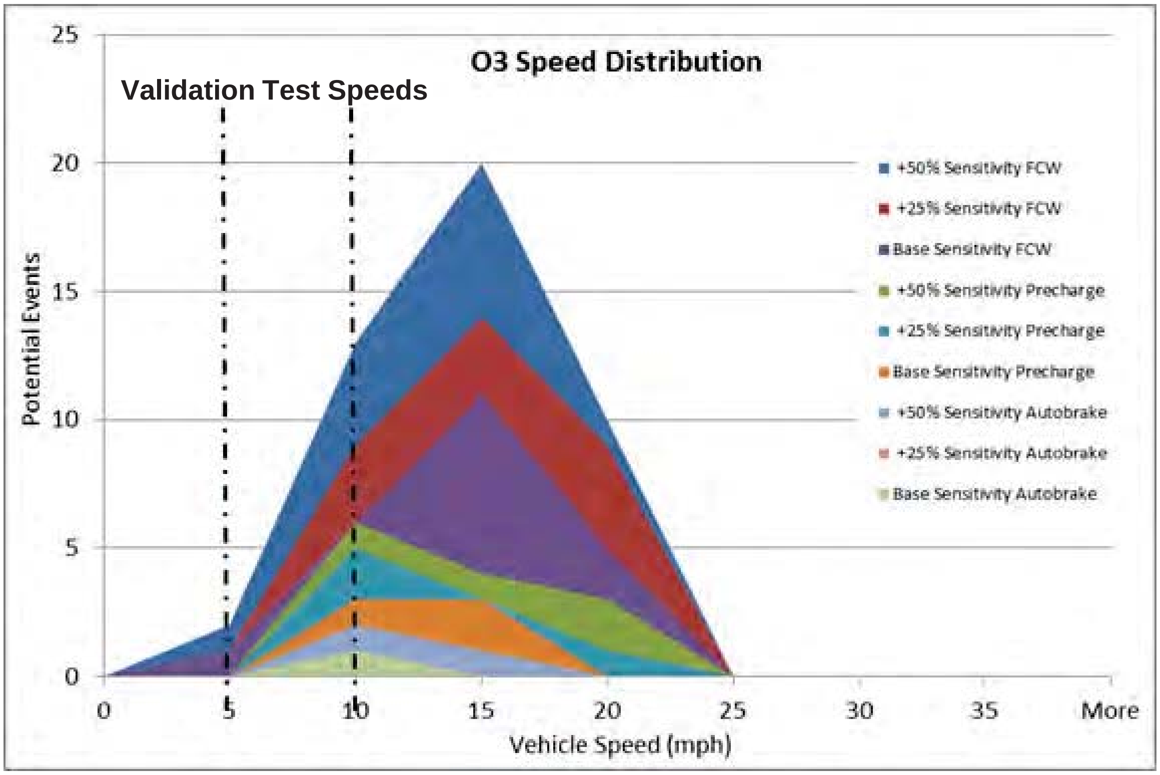


Figure 88: Speed Distribution for O3

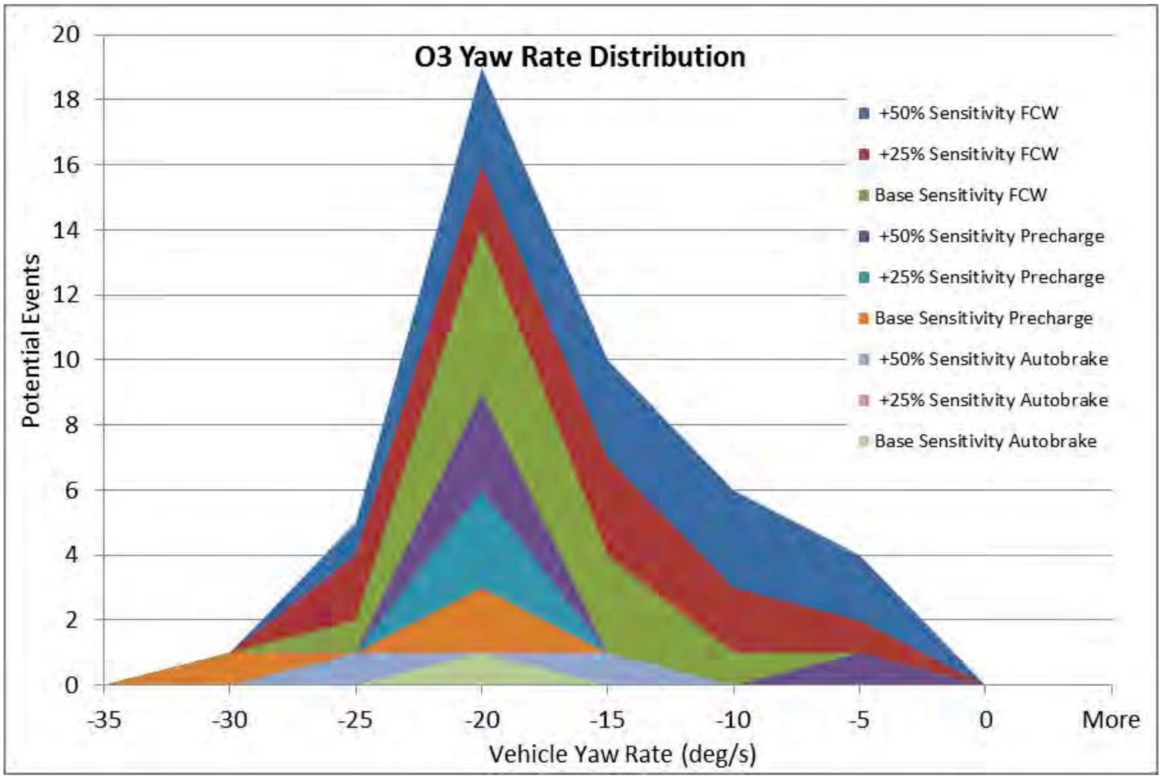


Figure 89: Yaw Rate Distribution for O3

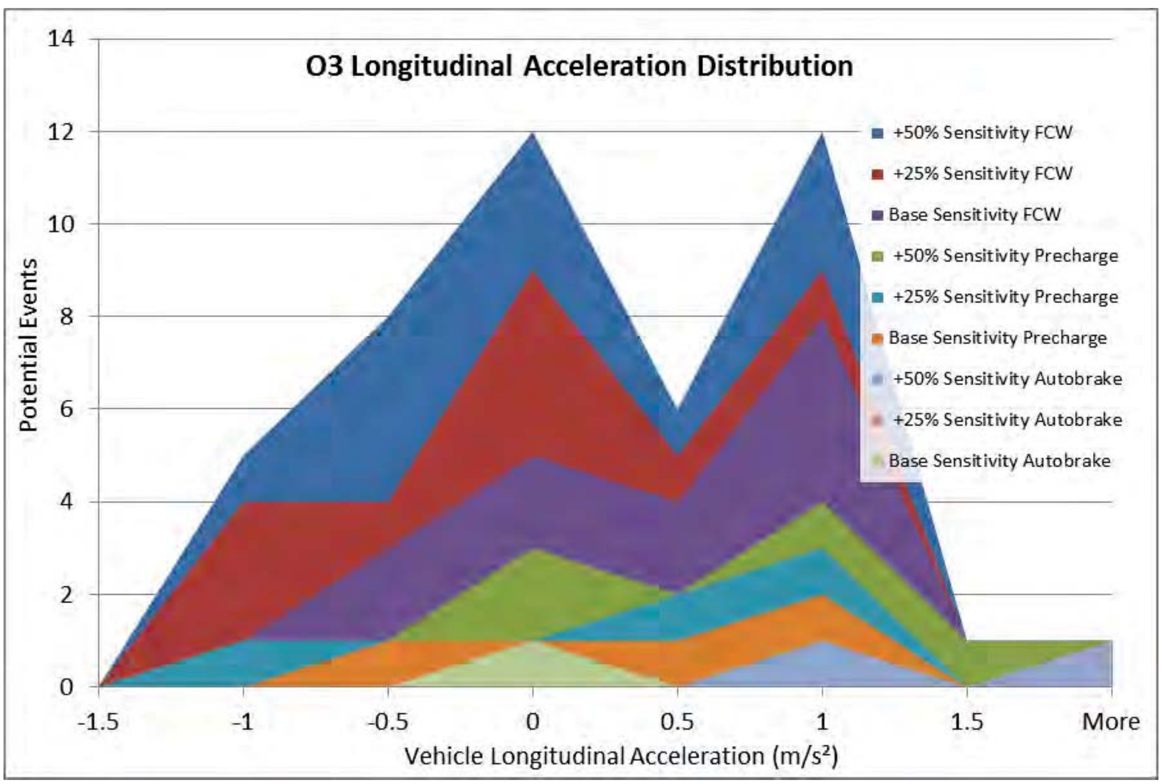


Figure 90: Longitudinal Acceleration Distribution for O3

The field of view for currently available sensor systems typically does not make detection of S3/O3 scenarios likely when the pedestrian is approaching from the inside of the turn. As a result, the O3 scenarios observed in this dataset all involved the pedestrian approaching from the outside of the curve, where it was possible for the sensors to detect the pedestrian for a period of time as the vehicle approached.

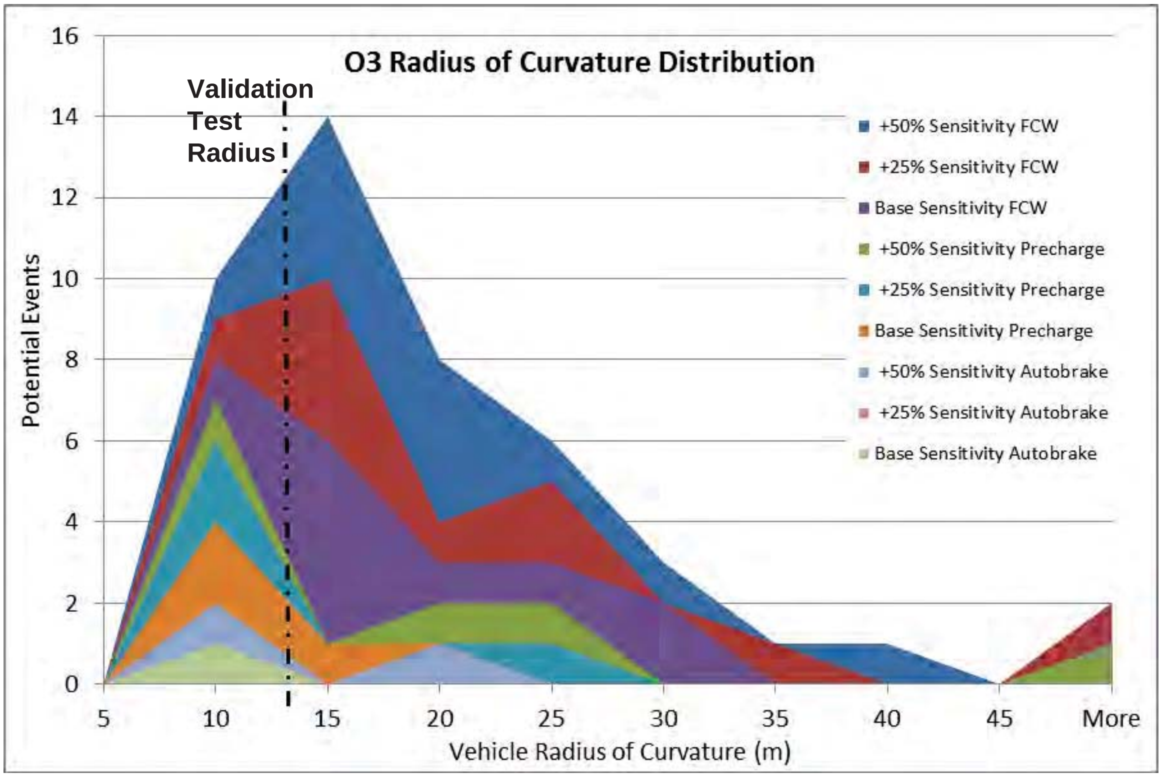


Figure 91: Radius of Curvature Distribution for O3

Given these observations, testing parameters for an O3 Operational Test could be specified as illustrated in Table 24.

Table 24: Test Parameters for O3

Host Vehicle Parameters	
Speed	10 - 15 mph
Longitudinal acceleration	±1.0 m/s²
Radius of curvature	20 m
Pedestrian Parameters	
Speed	0 mph
Distance from vehicle path (outside)	1 m

Due to the above noted sensing characteristics, it is suggested to use a stationary pedestrian just outside of the vehicle's path to create a realistic operational test for this scenario.

When preliminary O3 tests were performed during the track testing phase a smaller radius of curvature was used, with lower speeds than recommended here. The preliminary radius of curvature for the O3 scenario is illustrated by the dotted line in Figure 91. When these tests were performed using the preliminary test parameters, the vehicle motion was observed to feel "unnatural" for this type of event. Subsequent independent testing of this scenario with the values based in real world observations and shown in Table 24 resulted in a much more realistic test.

4.3.5.6 Approaching Longitudinally Moving Pedestrian (O4) False Event Scenario

Figure 92 shows an example of the O4 Scenario, where the vehicle encounters a pedestrian who is moving in a path parallel to the vehicle and just outside of its path. In this dataset, this scenario tended to occur mostly for potential FCW events. The scenario generally resolves itself before the vehicle is close enough to warrant brake application. In this dataset, only a very limited number of potential false precharge applications were observed for the O4 scenario, and these were only observed at the highest sensitivity level without radar-vision fusion. No potential false brake intervention events were observed for O4 at any sensitivity level.

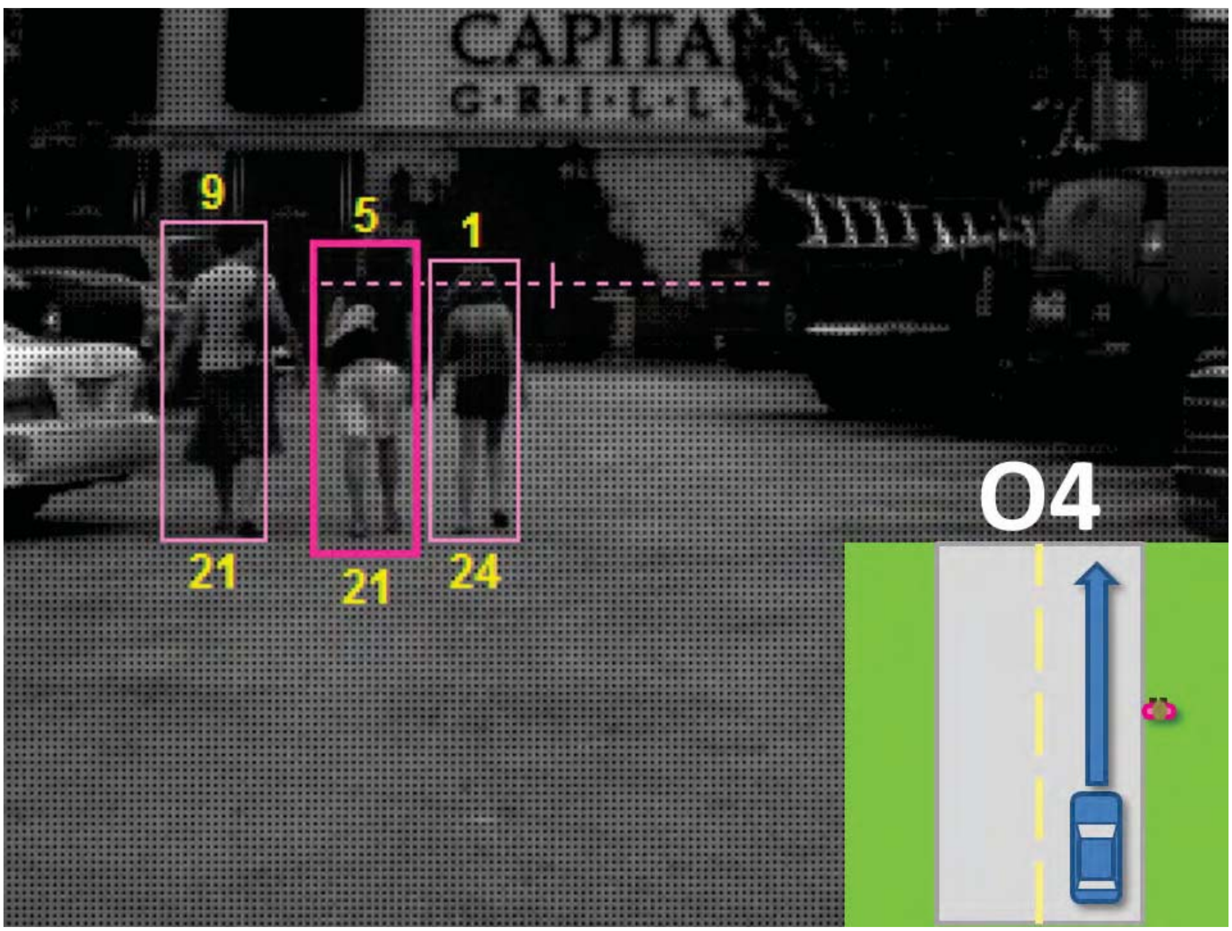


Figure 92: Example of Longitudinally Moving Pedestrian (O4)

4.3.5.6.1 Approaching Longitudinally Moving Pedestrian (O4) Kinematics

A kinematic analysis of the O4 false event scenario illustrated in Figure 92 shows that the speed of the host vehicle during this alert was typically between 5 and 25 mph for all alert sensitivity settings (see Figure 93). Examination of the vehicle's inertial measurements for the O4 Scenario (Figure 94, Figure 95 and Figure 96) show that the vehicle was typically traveling in a relatively straight path and relatively constant speed.

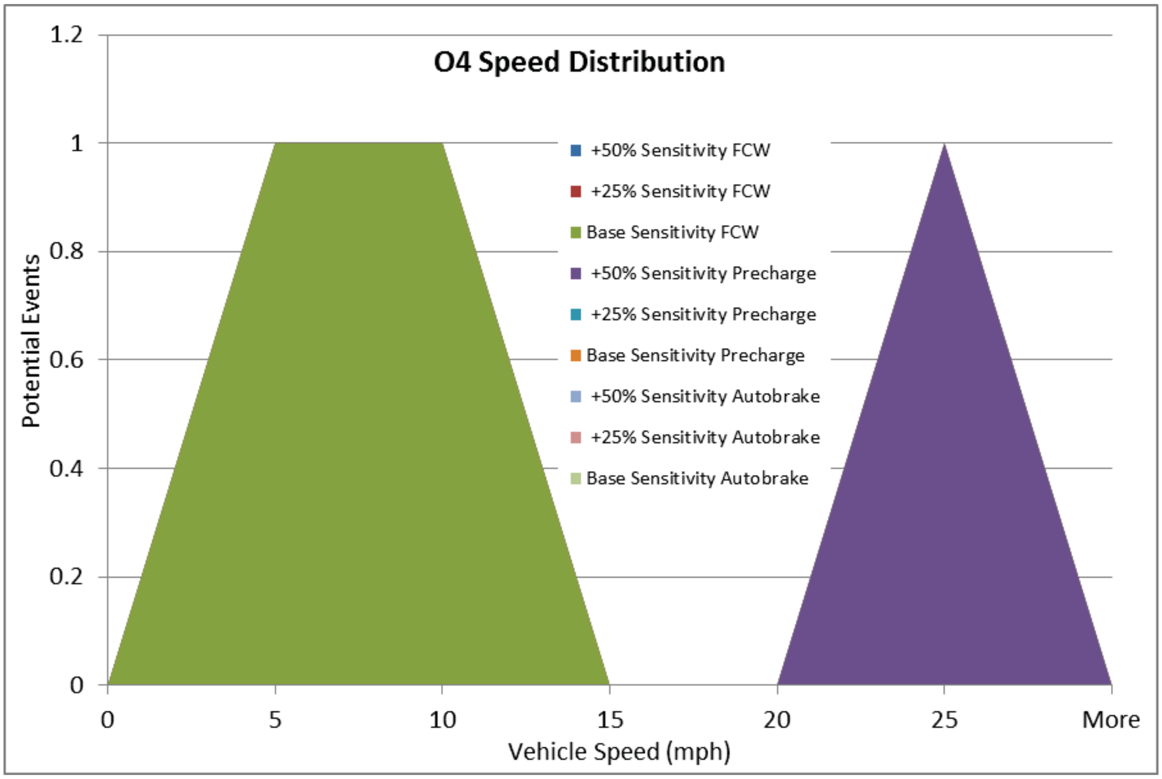


Figure 93: Speed Distribution for O4

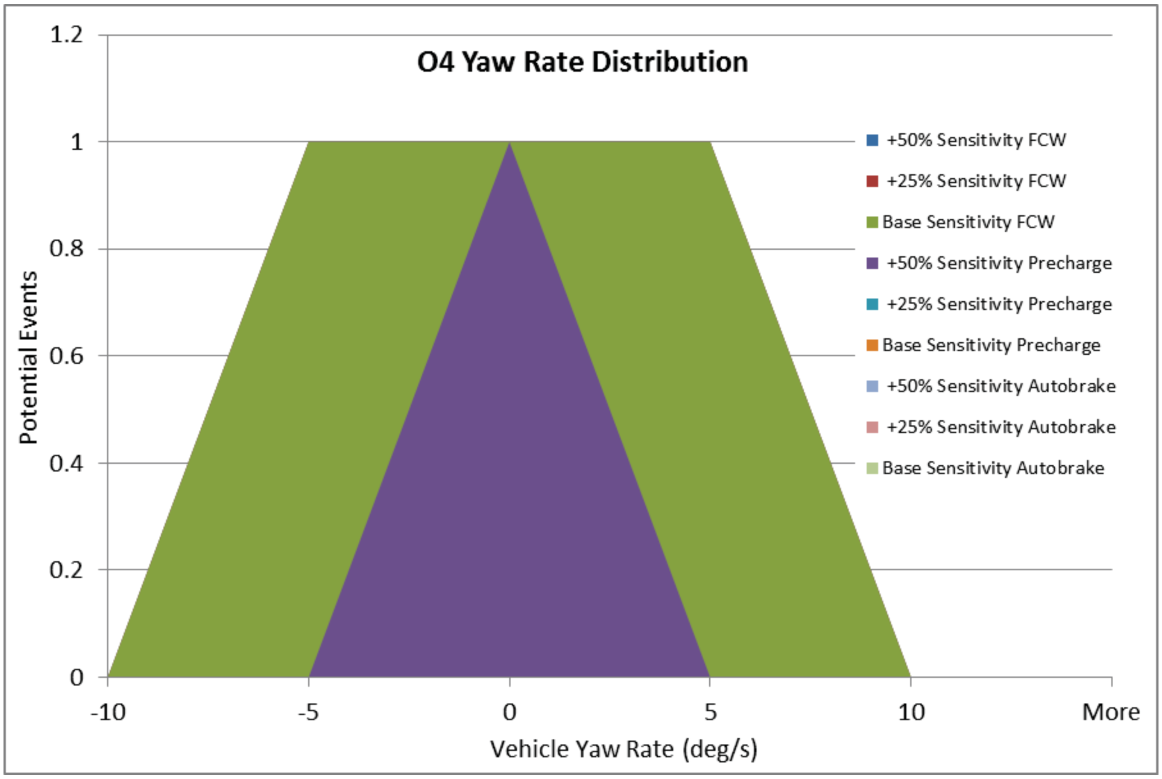


Figure 94: Yaw Rate Distribution for O4

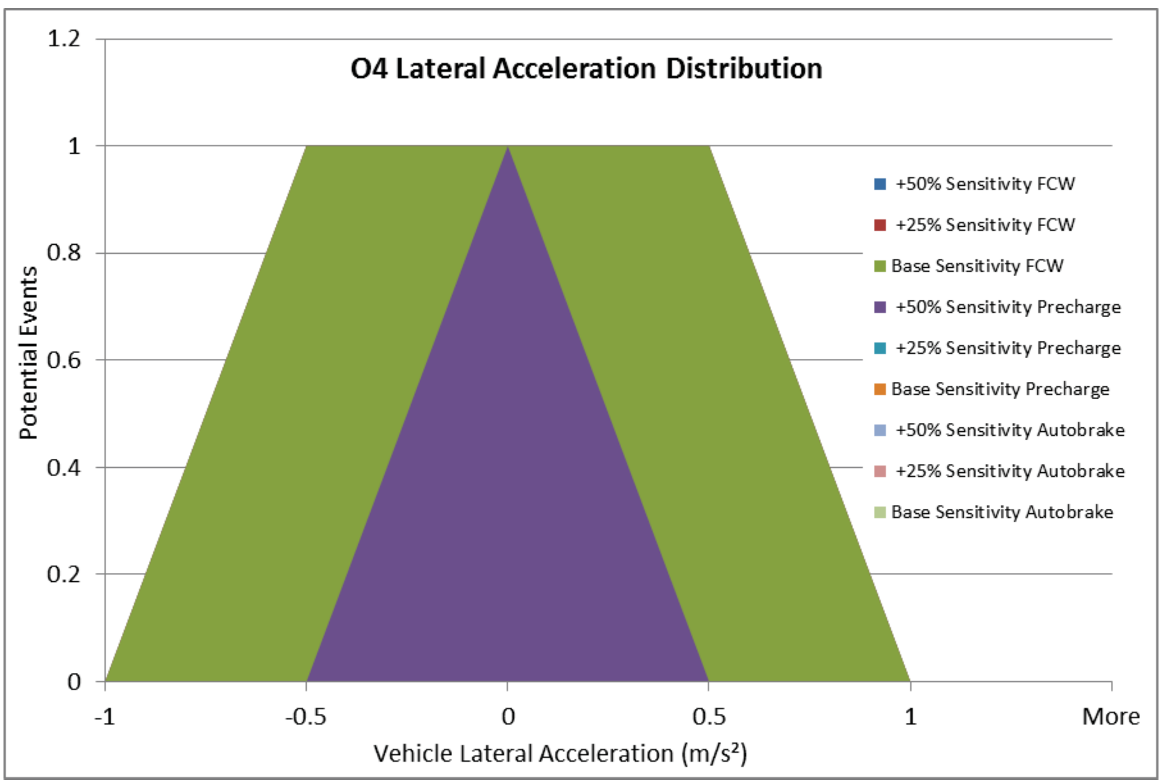


Figure 95: Lateral Acceleration Distribution for O4

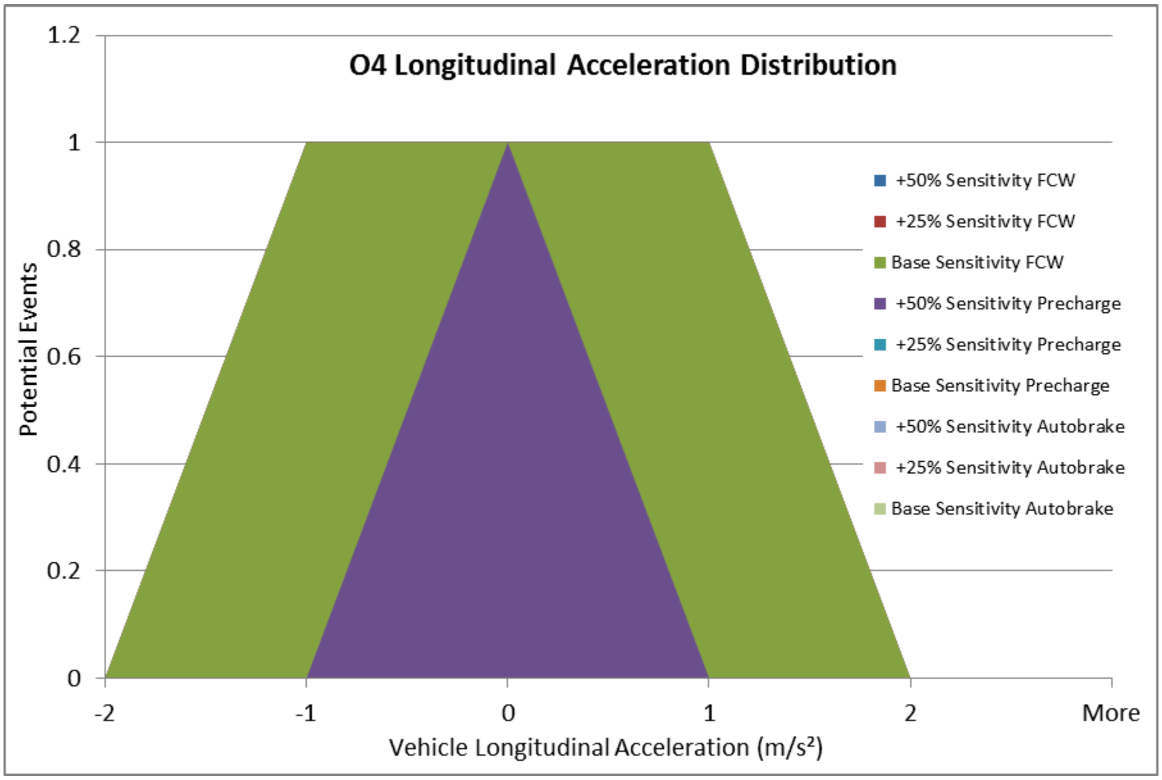


Figure 96: Longitudinal Acceleration Distribution for O4

Given these observations, testing parameters for an O4 Operational Test could be specified as illustrated in Table 25.

Table 25: Test Parameters for O4

Host Vehicle Parameters	
Speed	10 - 25 mph
Yaw rate	±2 deg/s
Lateral acceleration	±0.5 m/s²
Longitudinal acceleration	±1.0 m/s²
Pedestrian Parameters	
Speed	±6.2 mph

Given the limited dataset for this scenario, the ranges for these parameters were chosen to also coincide with those already selected for the functional tests.

4.3.5.7 Lane Change False Event Scenario

Figure 97 shows an example of the Lane Change False Event Scenario, where the vehicle encounters a pedestrian who is moving in a path parallel to the vehicle and just outside of its path, while performing a normal lane change. In this dataset, this scenario tended to occur mostly for potential FCW and Precharge events. The scenario generally resolves itself before the vehicle is close enough to warrant brake application. In this dataset, only a very limited number of potential false brake intervention events were observed for the Lane Change False Event scenario, and these were only observed at the highest sensitivity level without radar-vision fusion.

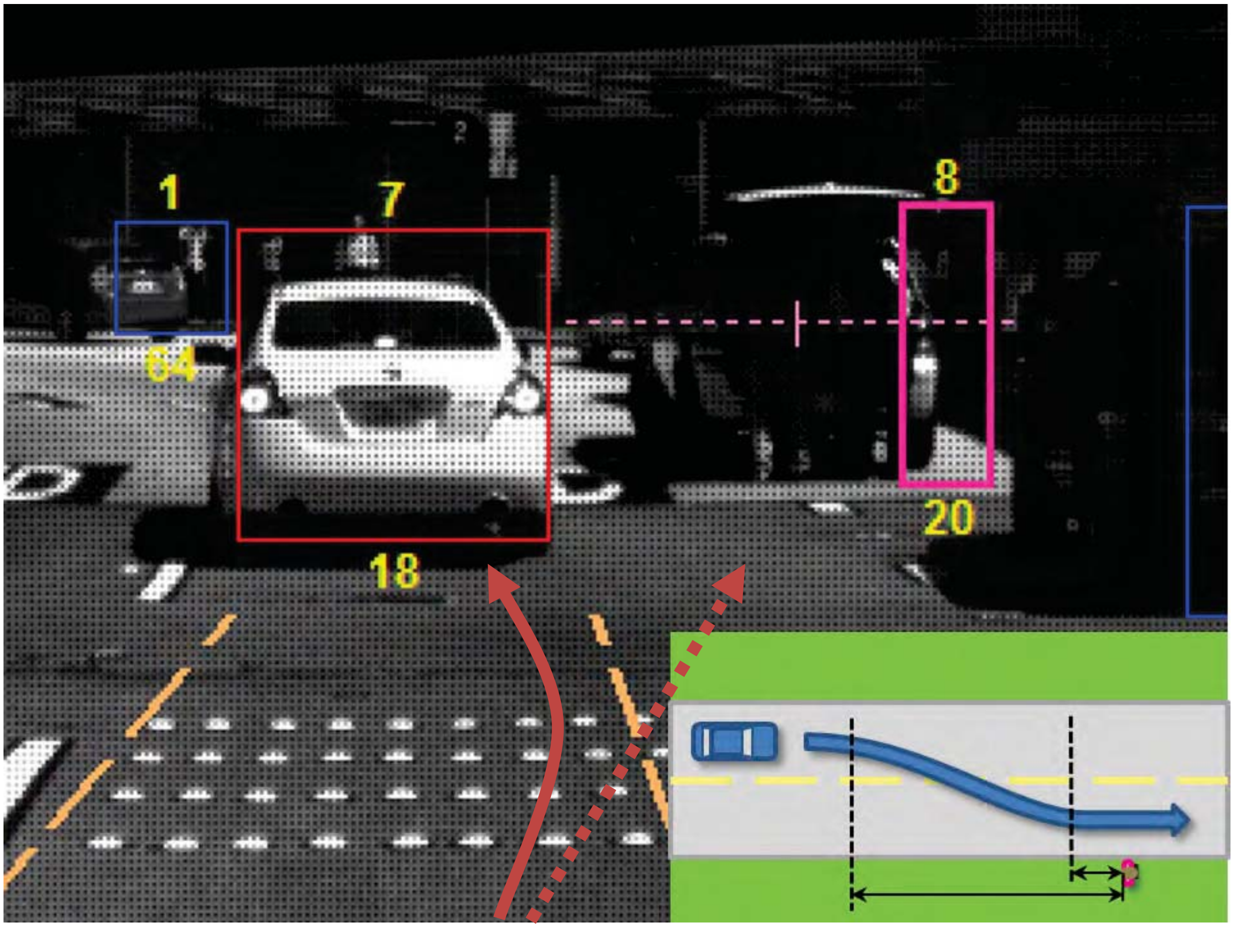


Figure 97: Example of Lane Change

4.3.5.7.1 Lane Change Kinematics

A kinematic analysis of the O4 false event scenario illustrated in Figure 97 shows that the speed of the host vehicle during this alert was typically between 10 and 30 mph for all alert sensitivity settings (see Figure 98). Examination of the vehicle's inertial measurements for the Lane Change Scenario show that the vehicle was typically traveling at a relatively constant speed during the maneuver (see Figure 99).

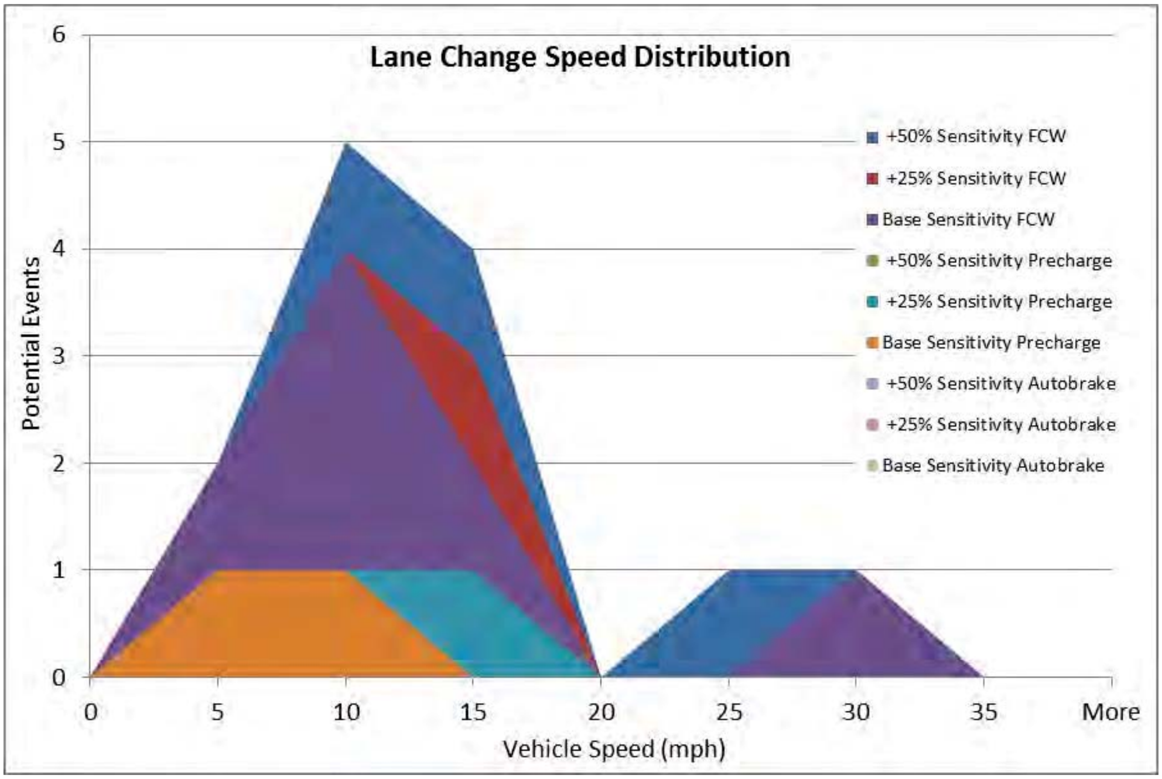


Figure 98: Speed Distribution for Lane Change

The lane change maneuver events observed in this dataset occurred over a fairly wide range of speeds, which can be divided into lane changes that occurred at less than 20 mph (low speed), and those that occurred above 20 mph (high speed).

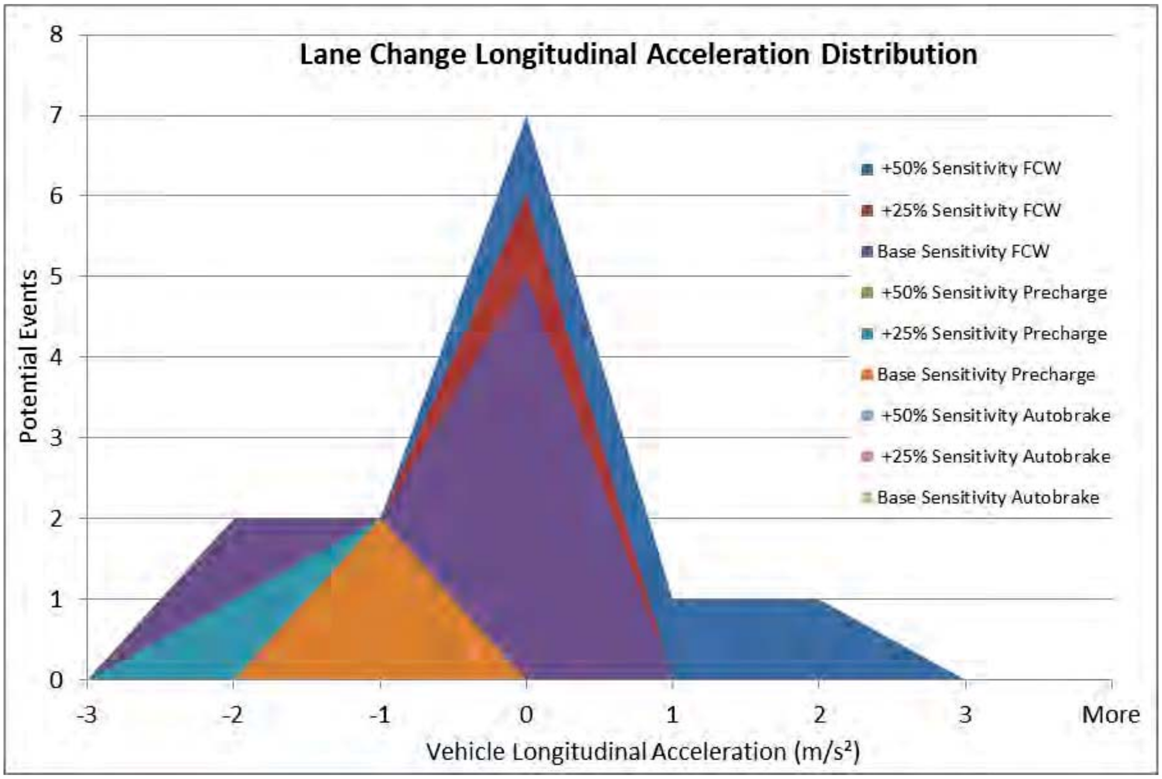


Figure 99: Longitudinal Acceleration Distribution for Lane Change

The low speed lane changes tended to take place over a shorter distance with a closer range to the pedestrian at the time of the event. Typical range to the pedestrian at the time of the event for low speed lane changes ranged from 10 m to 15 m, as shown in Figure 100. The higher speed lane changes tended to take place over a longer distance, with typical range to the pedestrian at the time of event from 20-25 m, as shown in Figure 101.

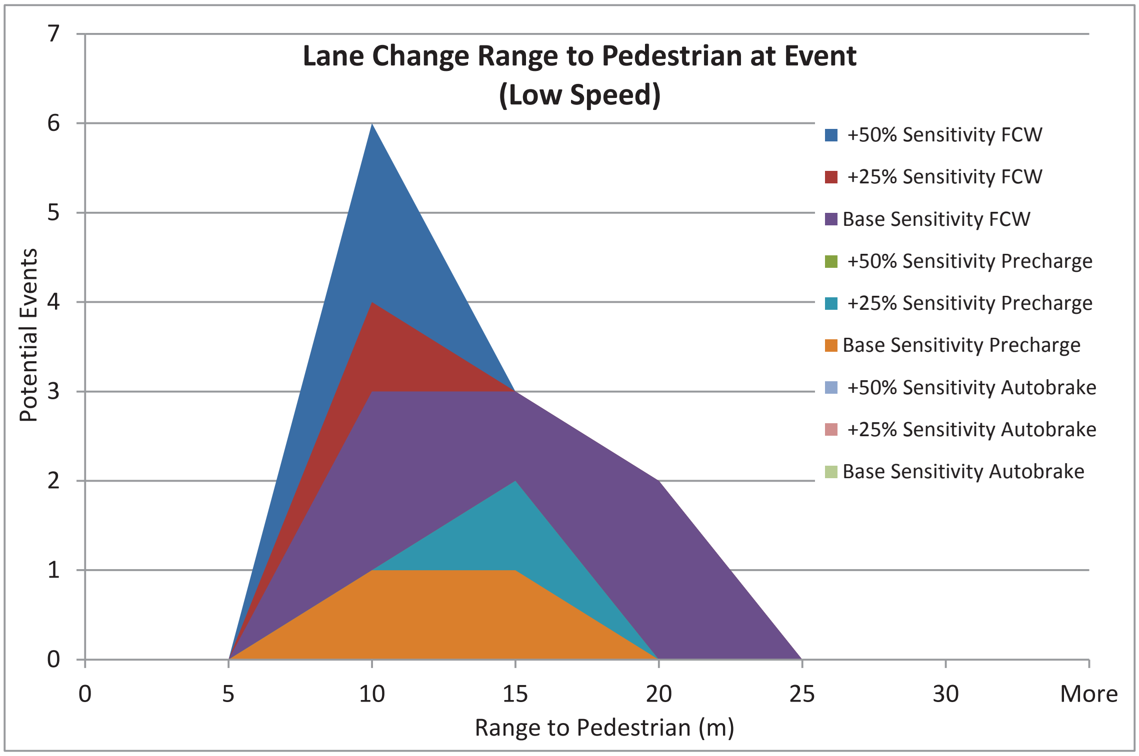


Figure 100: Range to Pedestrian Distribution for Lane Change (Low Speed)

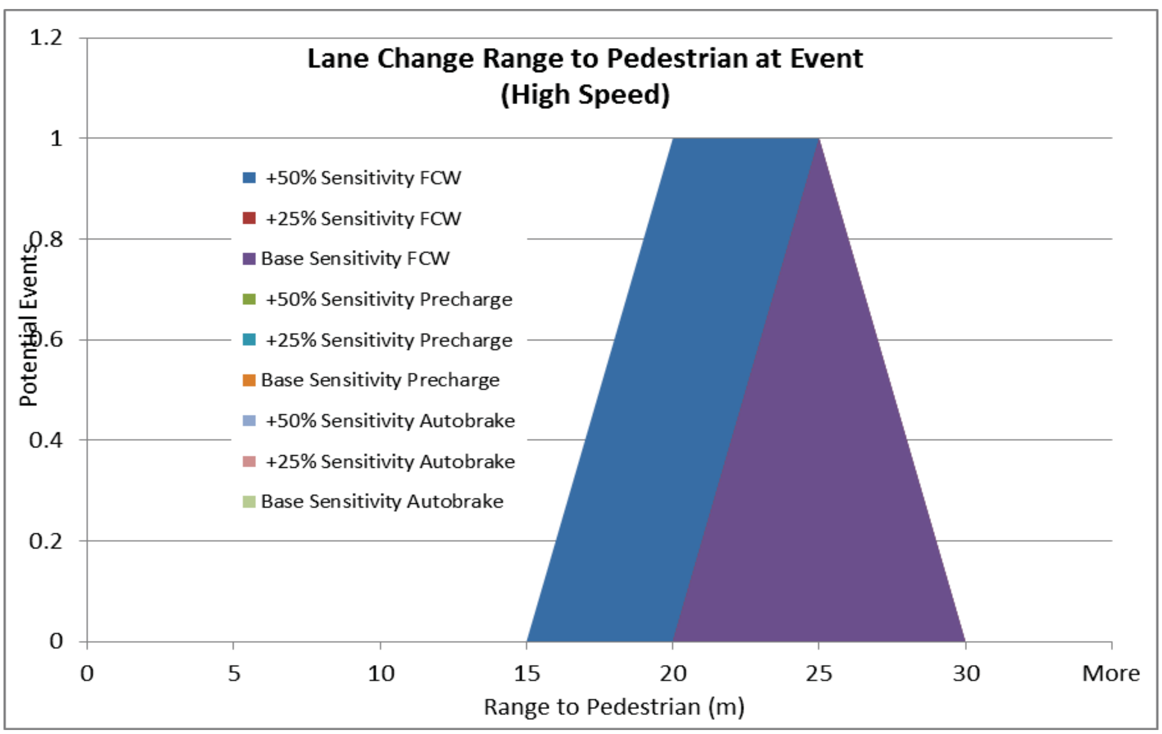


Figure 101: Range to Pedestrian Distribution for Lane Change (High Speed)

Given these observations, testing parameters for a Lane Change Operational Test could be specified as illustrated in Table 26 and Table 27.

Table 26: Test Parameters for Low Speed Lane Change

Host Vehicle Parameters	
Speed	10 - 15 mph
Longitudinal acceleration	±1.0 m/s²
Longitudinal range D1 to midpoint of first turn (m)	20 m
Longitudinal range D2 to midpoint of second turn (m)	10 m
Pedestrian Parameters	
Speed	0 mph
Distance from vehicle ath (outside)	1 m

Table 27: Test Parameters for High Speed Lane Change

Host Vehicle Parameters	
Speed	15 – 25 mph
Longitudinal acceleration	±1.0 m/s²
Longitudinal range D1 to midpoint of first Turn (m)	30 m
Longitudinal range D2 to midpoint of second turn (m)	15 m
Pedestrian Parameters	
Speed	0 mph
Distance From Vehicle Path (Outside)	1 m

Due to the above noted sensing characteristics, it is suggested to use a stationary pedestrian just outside of the vehicle's path to create a realistic operational test for this scenario.

4.3.5.8 Curve Entrance False Event Scenario

Figure 102 shows an example of the Curve Entrance False Event Scenario, where the vehicle encounters a pedestrian who is just past the beginning of a curved section of roadway, such that the pedestrian appears to be in the path of the vehicle. In this dataset, this scenario tended to occur mostly for potential FCW events. The scenario generally resolves itself before the vehicle is close enough to warrant brake application. In this dataset, only a very limited number of potential false precharge applications were observed for the Curve Entrance False Event scenario, and these were only observed at the highest sensitivity level. No potential false brake intervention events were observed for the Curve Entrance scenario at any sensitivity level.

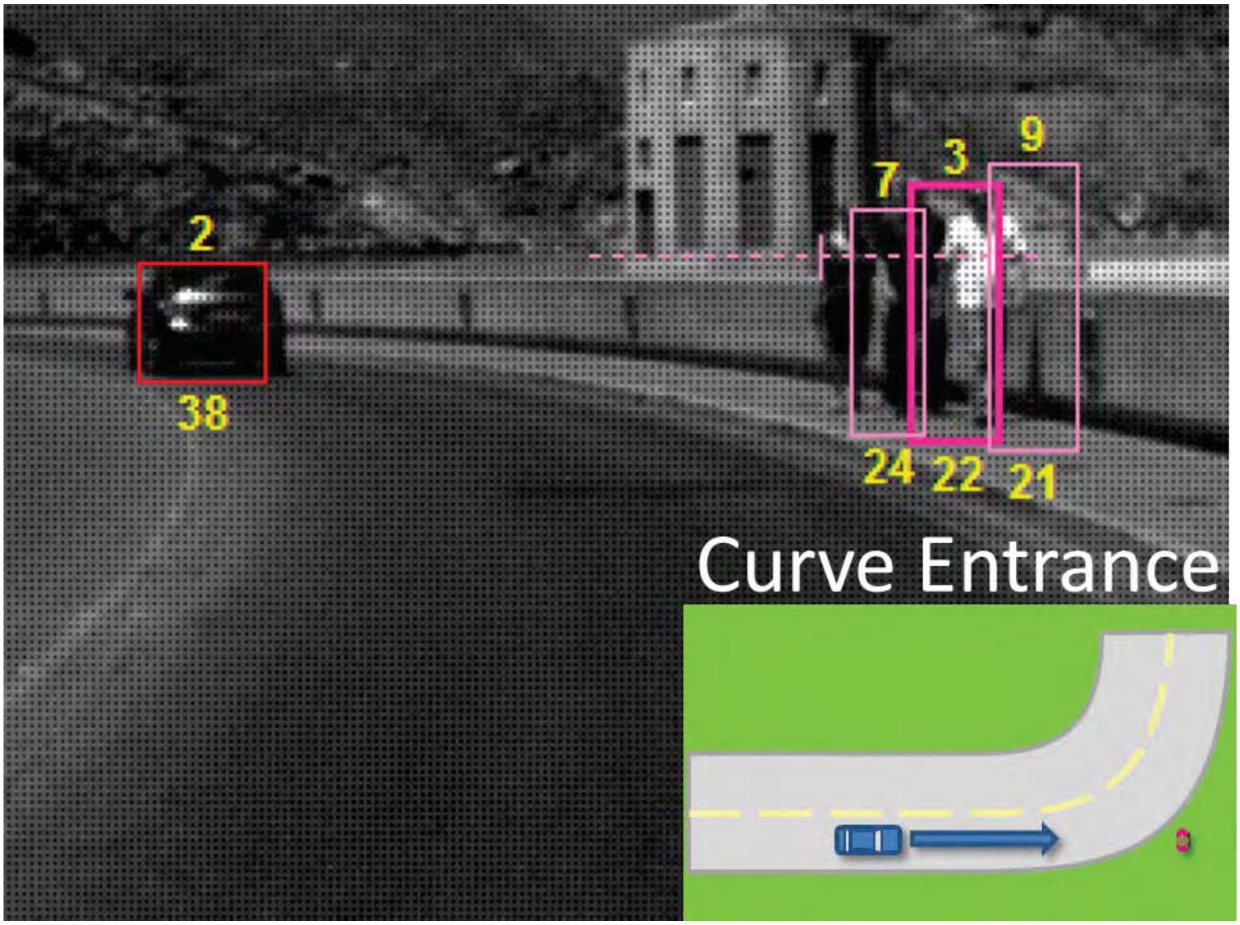


Figure 102: Example of Curve Entrance

4.3.5.8.1 Curve Entrance Kinematics

A kinematic analysis of the Curve Entrance false event scenario illustrated in Figure 102 shows that the speed of the host vehicle during this alert was typically between 20 and 30 mph for all alert sensitivity settings (see Figure 103). Examination of the vehicle's inertial measurements for the O4 Scenario (Figure 104 and Figure 105) show that the vehicle was typically traveling in a relatively straight path before entering the curve and at a relatively constant speed.

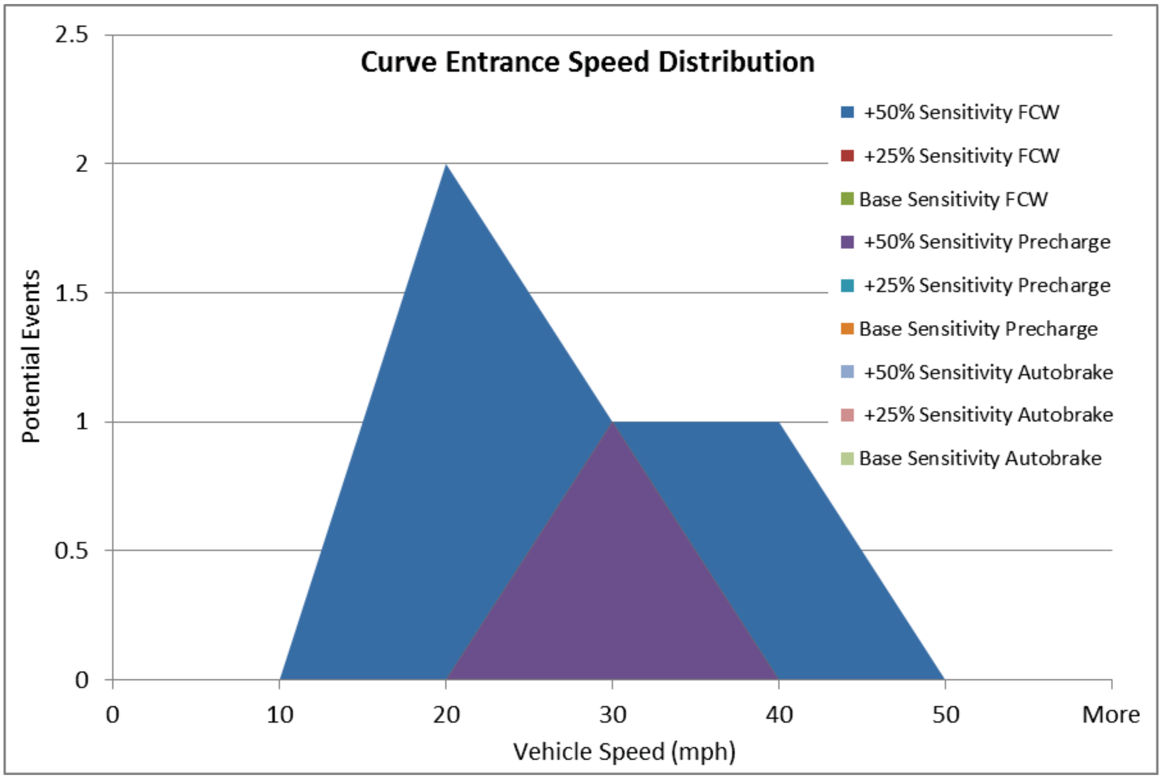


Figure 103: Speed Distribution for Curve Entrance

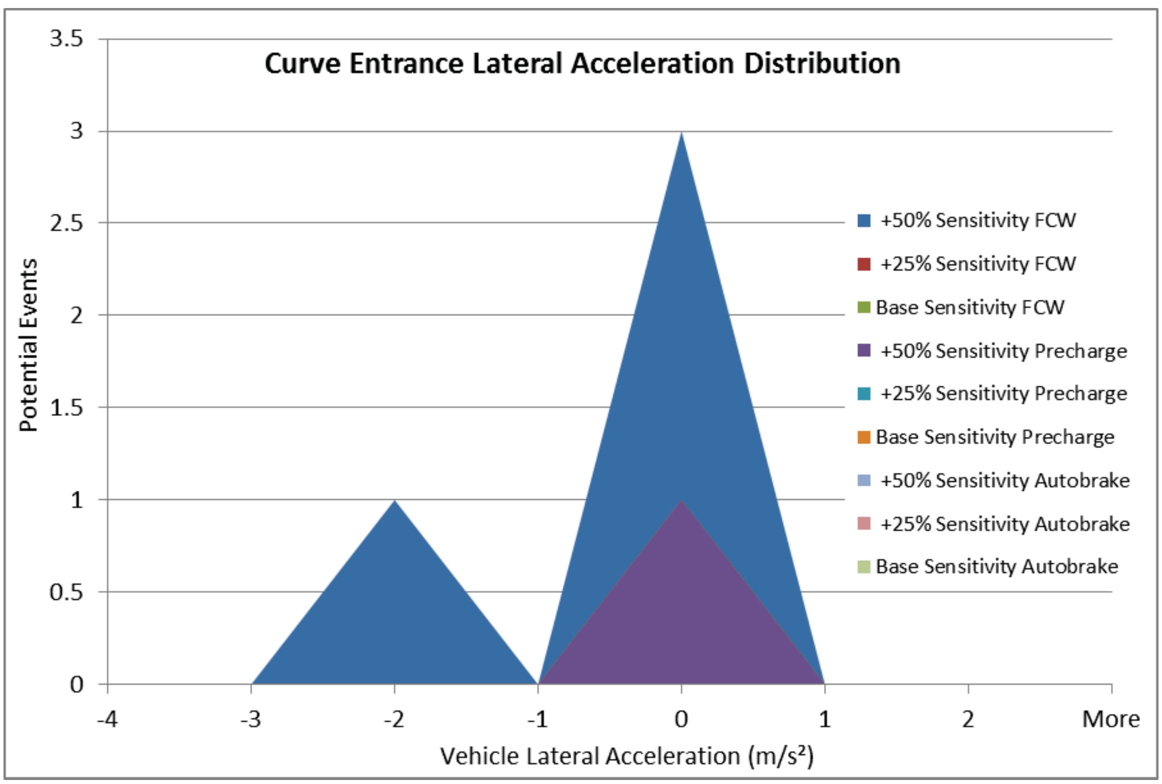


Figure 104: Lateral Acceleration Distribution for Curve Entrance

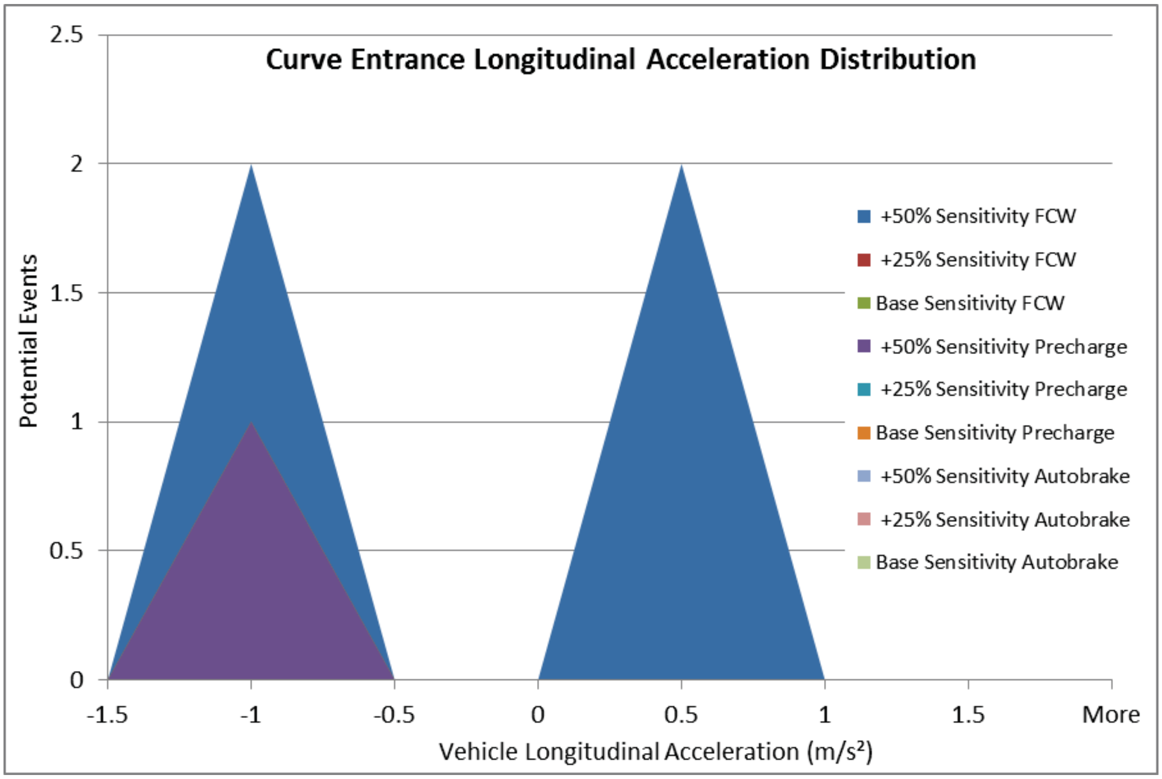


Figure 105: Longitudinal Acceleration Distribution for Curve Entrance

Given these observations, testing parameters for a Curve Entrance Operational Test could be specified as illustrated in Table 28.

Table 28: Test Parameters for Curve Entrance

Host Vehicle Parameters	
Speed	20 - 30 mph
Longitudinal acceleration	±1.0 m/s²
Radius of curvature	20 m
Pedestrian Parameters	
Speed	0 mph
Distance from vehicle path (outside)	1 m

Due to the above noted sensing characteristics, it is suggested to use a stationary pedestrian just outside of the vehicle's path to create a realistic operational test for this scenario.

4.3.5.9 Potential Events from False Pedestrian Detection

During the course of this data collection exercise, a few false pedestrian detections were observed, and some examples of the types of things that were observed to be false detections are shown in Figures 106 through 109. The false detections observed in this data all resolved themselves before an FCW, precharge or brake intervention was requested. There were no false events of any kind caused by false pedestrian identifications in the dataset.

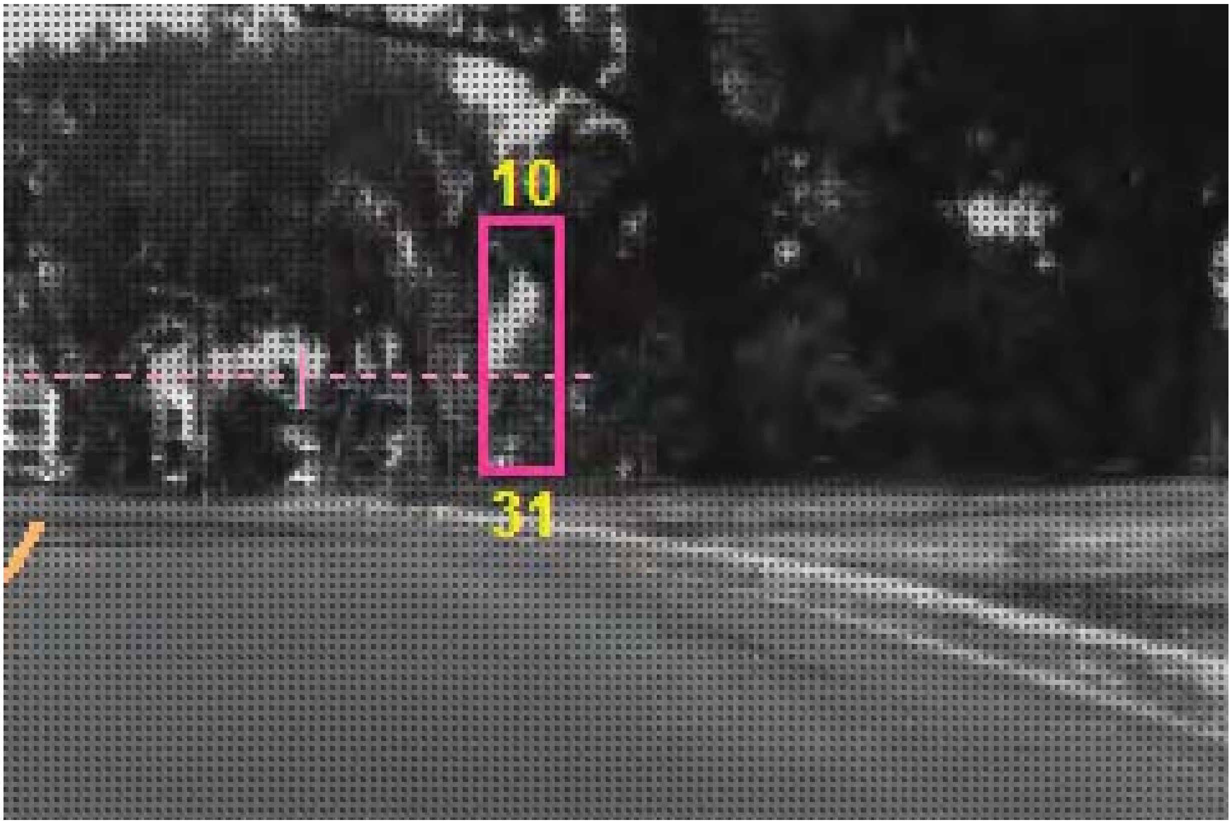


Figure 106: False Pedestrian ID From Sign/Fire Hydrant

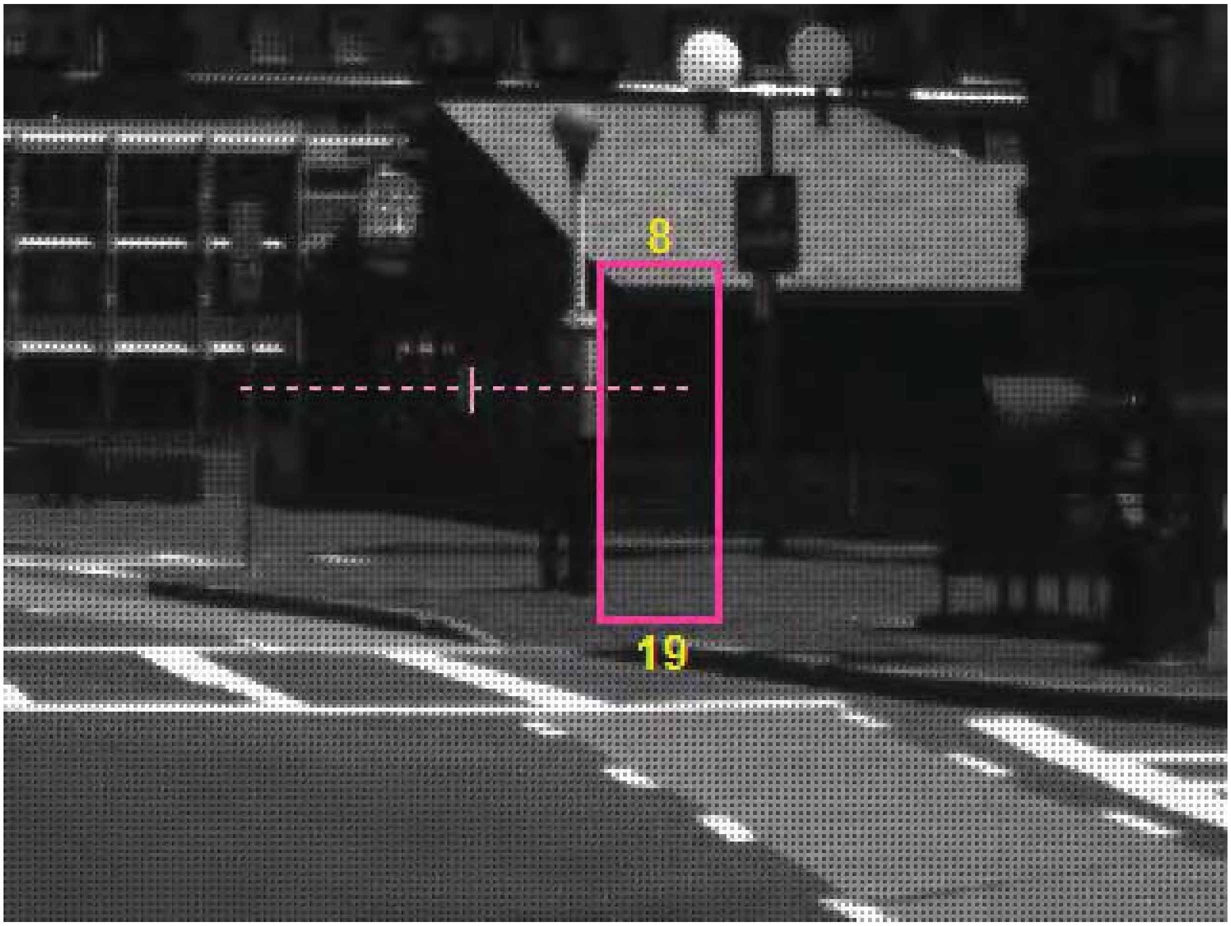


Figure 107: False Pedestrian ID From Pole

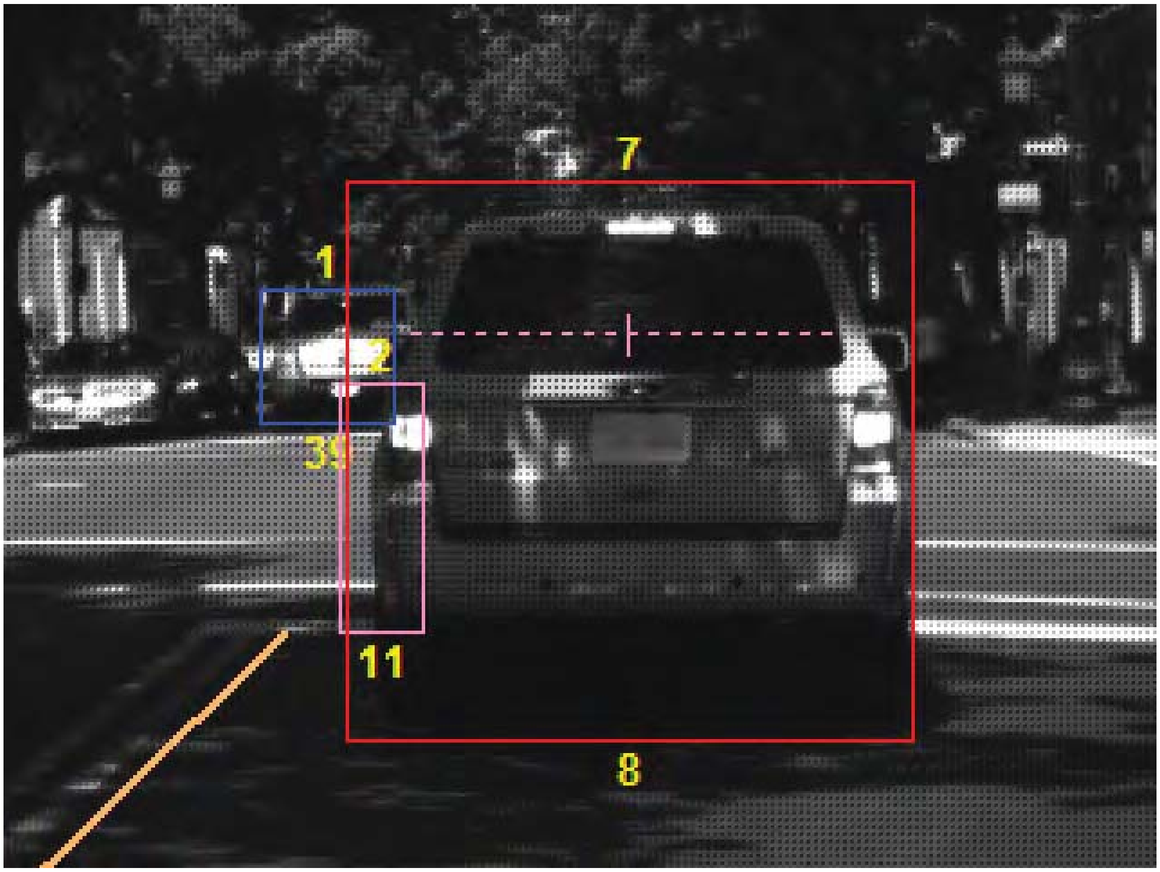


Figure 108: False Pedestrian ID From Vehicle Features/Shadows

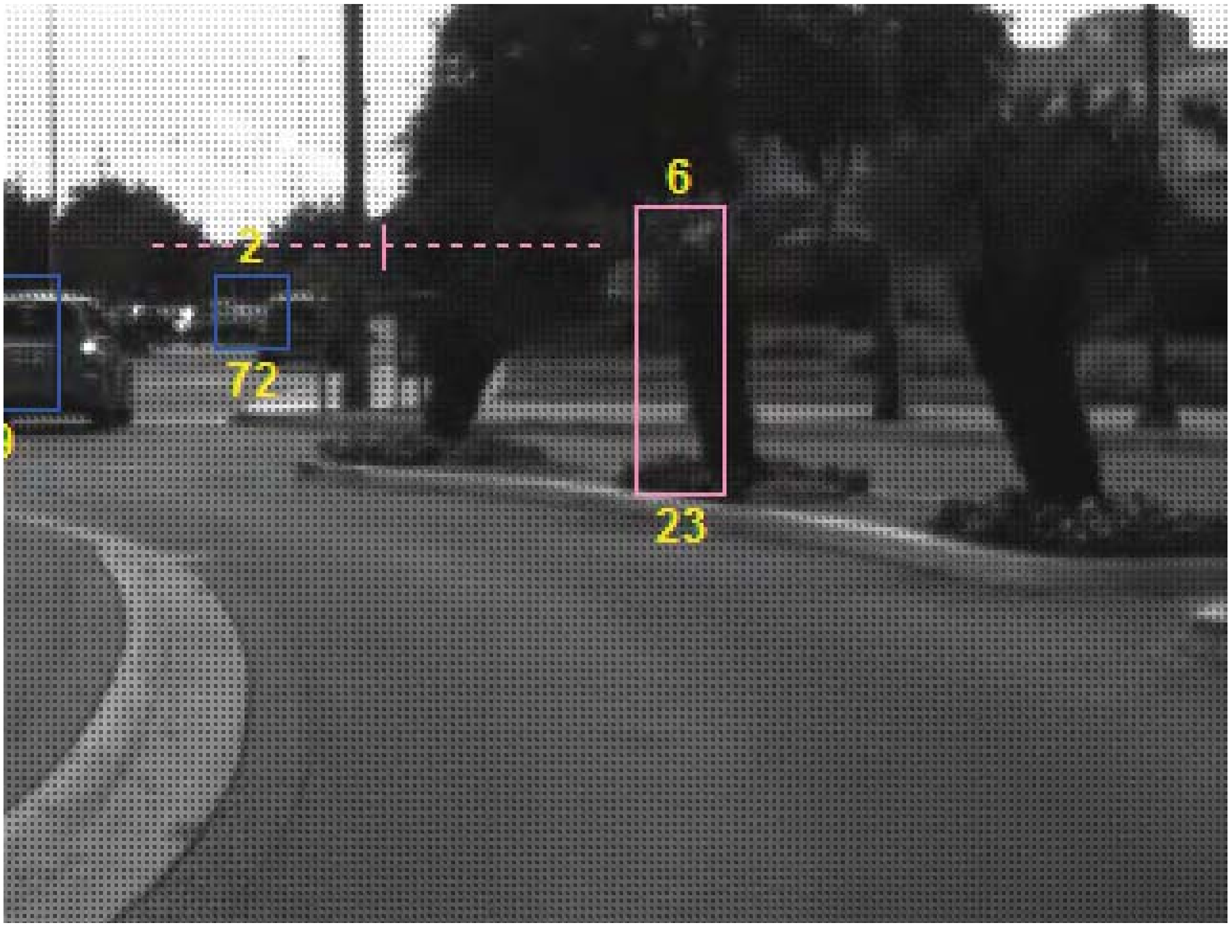


Figure 109: False Pedestrian ID From Tree

4.3.6 Environmental Conditions Not Assessed by ROAD Trip

The sensing system employed in the vehicle used to generate this dataset did not have full nighttime pedestrian detection capability. This system had the capability to function well into dusk conditions, but true nighttime pedestrian situations were not assessed.

Due to program timing limitations, it was not possible to expose the vehicles driven on the ROAD Trip to winter driving conditions. Therefore, it seems likely that there may be winter driving scenarios that could cause false events that were not captured on this trip. One such scenario that has been observed by an OEM consortium member has been caused by formation of icicles in front of a radar range sensor, as shown in Figure 110 and Figure 111.

Figure 110: No Evidence of Obstruction on the Outside of the Fascia

Figure 111: One Icicle on the Inside of the Foam Block

Formation of an icicle in front of the radar aperture can have the effect of distorting the perceived direction of the returned radar signal without attenuating it appreciably. When this happens the reported angles to targets can be altered such that an out of path target can be reported as in path, or an in path target can be reported as out of path. An actual occurrence of this phenomenon is shown in Figure 112.

Figure 112: False Targets Are Circled in Red

As can be seen in Figure 112, multiple “sidelobe” false tracks (circled in the plan view above) appear throughout the scene while the icicle is present. These tracks can appear next to real objects and can be aliased into the host’s path (for adjacent lane real objects) or out of the host's path when the real object is in the host's lane. The false tracks are eliminated when the icicle is removed.

This type of event could potentially cause false events in fused vision and radar PCAM systems if a decelerating vehicle in the adjacent lane is incorrectly fused with a non-threat pedestrian in the host's path during a lane change or curve entrance type of scenario. Additionally, because ice represents a phase shift in the radio frequency rather than an attenuator, it can be difficult for the radar to detect as a fault condition.

It has been found that partial blockage due to ice can be emulated with plastic strips placed in front of the antenna aperture (either on the radome of the antenna or the fascia), as illustrated in Figure 113. This has been verified by correlating antenna patterns from a radar blocked with ice with antenna patterns from a radar blocked with plastic sheets.

Figure 113: Plastic Strips Used to Emulate Partial Ice Blockage

4.3.6.1 PCAM ROAD Trip Summary

Through the use of on-road data collection with vehicles equipped with PCAM sensor systems, a number of potential scenarios were identified in which pedestrians or other objects that appear as pedestrians may be present but do not pose a risk of collision with the vehicle. In these cases, the PCAM system should not activate autonomous braking functions, unless otherwise noted for the individual scenario. Data from multiple cities and regions of the United States were collected to identify both common and unique conditions that may influence these scenarios. From this data, a set of potential test cases have been identified which may be used to assess PCAM system robustness against false activations in these scenarios.

4.4 Operational Test Method Validation

Due to project timing, complete analysis of the ROAD Trip data was not possible before validation testing was initiated. Therefore, a set of prototype Operational Tests were identified based on preliminary analysis of the ROAD Trip data. These scenarios were:

- O1: Mannequin Crossing Laterally in Front of Vehicle.
- O2: Vehicle Making Right Turn Toward Mannequin.
- O3: Vehicle Making Left Turn Toward Mannequin.
- O4: Vehicle Approaching Longitudinally Moving Mannequin.
- Lane Change toward a Mannequin.

Figure 114 illustrates these five scenarios.

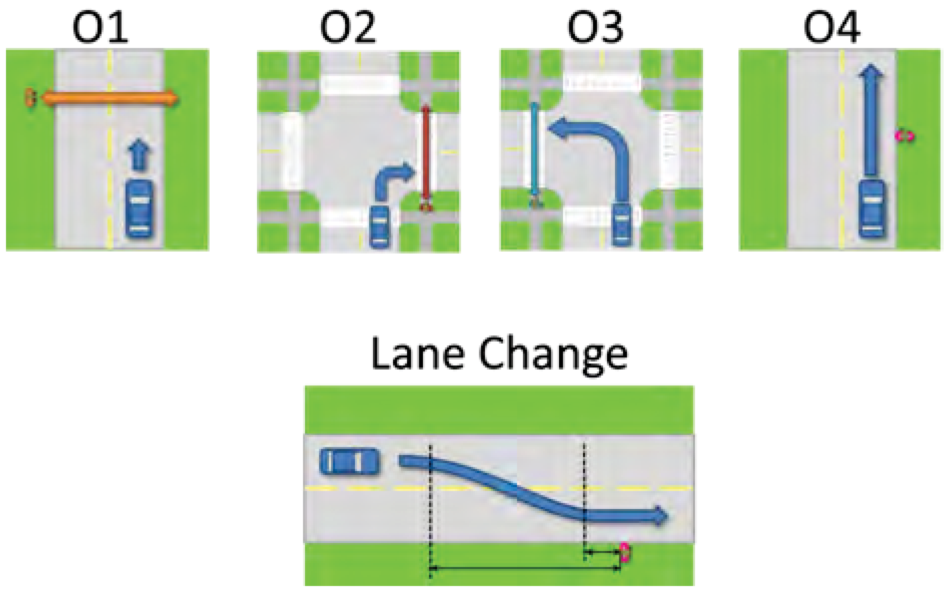


Figure 114: Five Mannequin Operational Test Scenarios Examined in PCAM Validation Testing

Test methods were developed to emulate these five scenarios. One important objective in this effort was to develop methods that were representative of operational scenarios that had been observed during the ROAD trip. Since the final detailed analysis of the ROAD Trip was not yet available, engineering estimates of reasonable test parameters were then chosen to evaluate the feasibility of the prototype operational test methods. The validation test phase was therefore used primarily to validate the operational test method layout, and recommendations for final operational testing parameters were made after the detailed analysis was completed. These recommendations can be found in Section 6.

4.4.1 General Test Conditions

For Operational validation testing, the same general test conditions, ground truth measurement system and mannequin characterization methods used for development of Functional Tests were applied.

4.4.2 O1: Operation Test Procedure for Crossing Mannequin Perpendicular to Vehicle Path

In the O1 scenario, the test vehicle approached the moving mannequin perpendicular to the mannequin motion. The mannequin movement was controlled so that no collision would occur. Two variations of this scenario were conducted during the validation test phase. These are shown in Figures 115 and 116. The tests were conducted without obstructions between the mannequin and approaching test vehicle. Tests were conducted with the mannequin moving from right to left of the test vehicle (designated as away from motor).

The following test speeds were conducted during the O1 procedures:

- Vehicle Speeds: 10 and 25 mph (16 and 40 km/h).
- Mannequin Speed: 3.1 mph (5 km/h), walking.

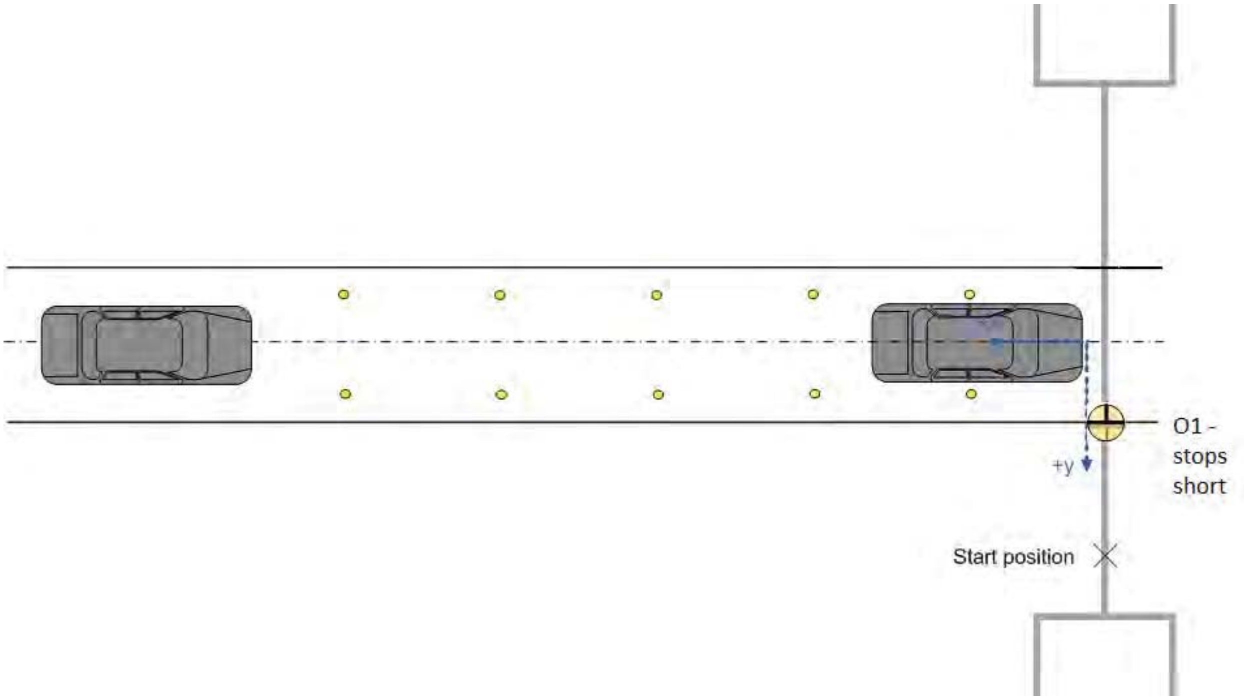


Figure 115: O1 – Vehicle Heading Straight With Mannequin Stopping Short of Vehicle Path (No Collision)

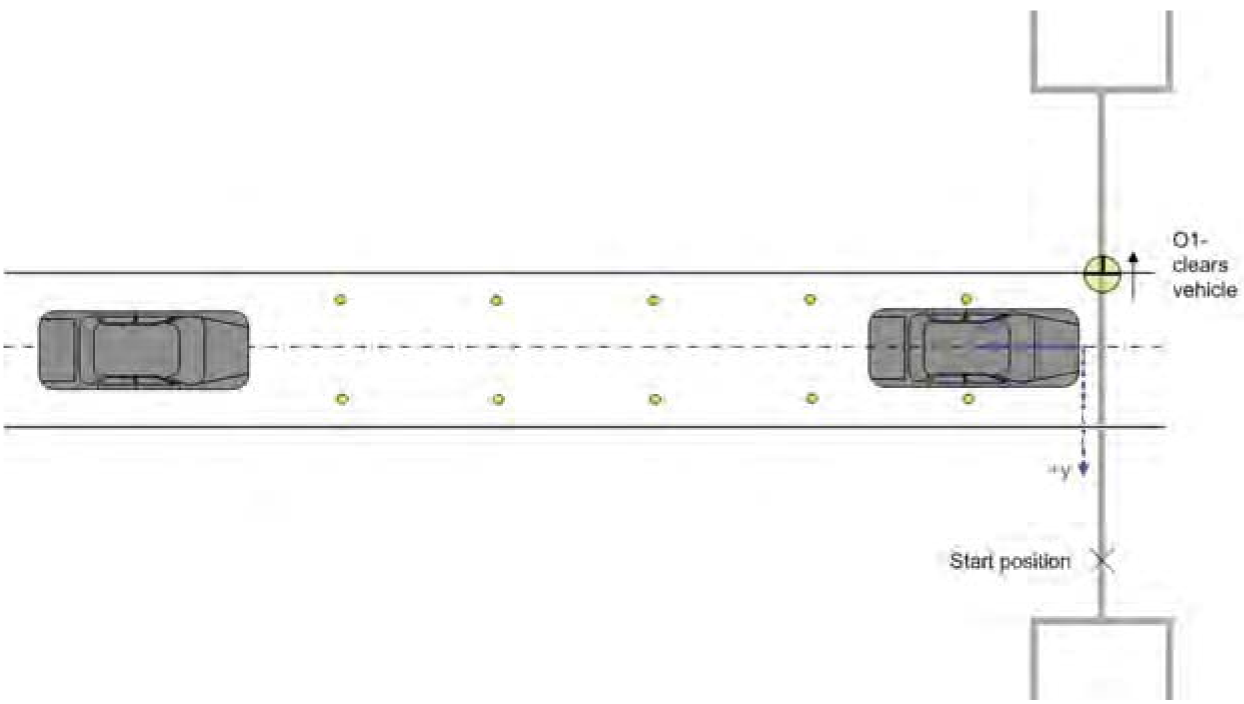


Figure 116: O1 – Vehicle Heading Straight With Mannequin Clearing Path of Vehicle (No Collision)

The basic test procedure described in Section 4.2.4 was used for both of these scenarios with the following changes:

1. After the test vehicle reached the mannequin motion trigger, the mannequin started its motion. The mannequin's motion profile was designed to move the mannequin at the desired speed toward the path of the vehicle, and then decelerate until it stopped at a point 1 m before entering the path of the vehicle. The trigger point was designed to have the mannequin reach this point at a longitudinal TTC of 1 second.
2. The tests were repeated five times for each combination of test conditions.

4.4.3 O2: Operation Test Procedure for Vehicle Turning Right Toward Mannequin Outside of Path

The O2 scenario involved a vehicle approaching a stationary mannequin while in a constant radius right-hand turn with no collision intended. The mannequin was positioned 1 m outside the vehicle path on the outside of the turn as if intending to cross the test lane. The mannequin was positioned so that no collision would occur. The tests were conducted without obstructions between the mannequin and approaching test vehicle.

The following test speeds were conducted during the O2 procedures:

- Vehicle Speeds: 5 and 10 mph (8 and 16 km/h).
- Mannequin Speed: stationary.

Figure 117 illustrates the method used to conduct the O2 scenario tests. The basic test procedure described in Section 4.2.4 was used for this scenario with the following changes:

1. A set of Botts' dots were placed to mark the curve for the entire radius.
2. Testing was repeated five times for each configuration.

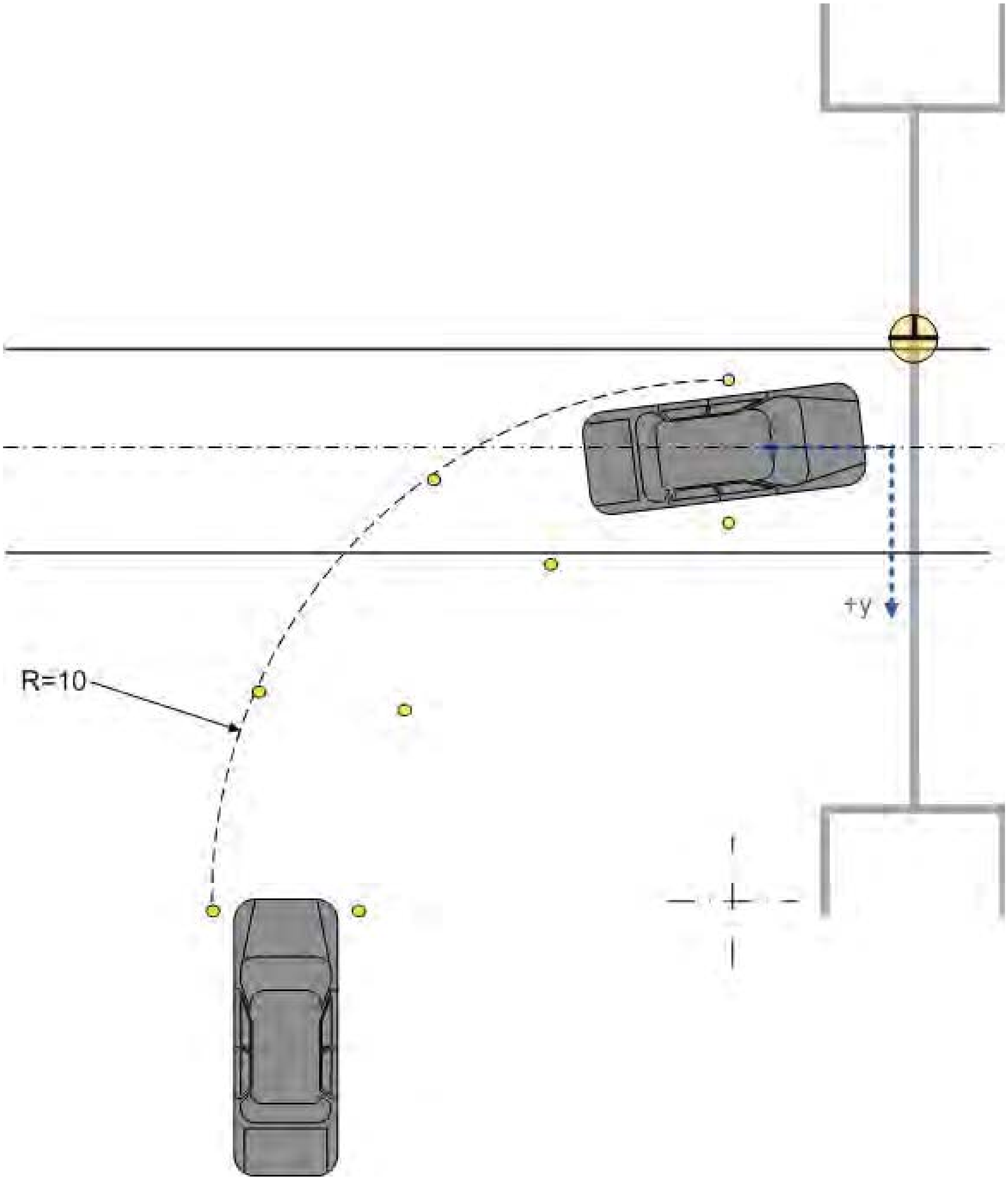


Figure 117: O2 – Vehicle Turning Right Toward Mannequin Outside of Path (No Collision)

4.4.4 O3: Operational Test Procedure for Vehicle Turning Left into Mannequin Outside of Path

The O3 scenario involved a vehicle approaching a stationary mannequin while in a constant radius left-hand turn with no collision intended. The mannequin was positioned 1 m outside the vehicle path on the outside of the turn as if intending to cross the test lane. The mannequin was positioned so that no collision would occur. The tests were conducted without obstructions between the mannequin and approaching test vehicle.

The following test speeds were conducted during the O3 procedures:

- Vehicle Speeds: 5 and 10 mph (8 and 16 km/h).
- Mannequin Speed: stationary.

Figure 118 illustrates the method used to conduct the O3 scenario tests. The basic test procedure described in Section 4.2.4 was used for this scenario with the following changes:

1. A set of Botts' dots were placed to mark the curve for the entire radius.
2. Testing was repeated five times for each configuration.

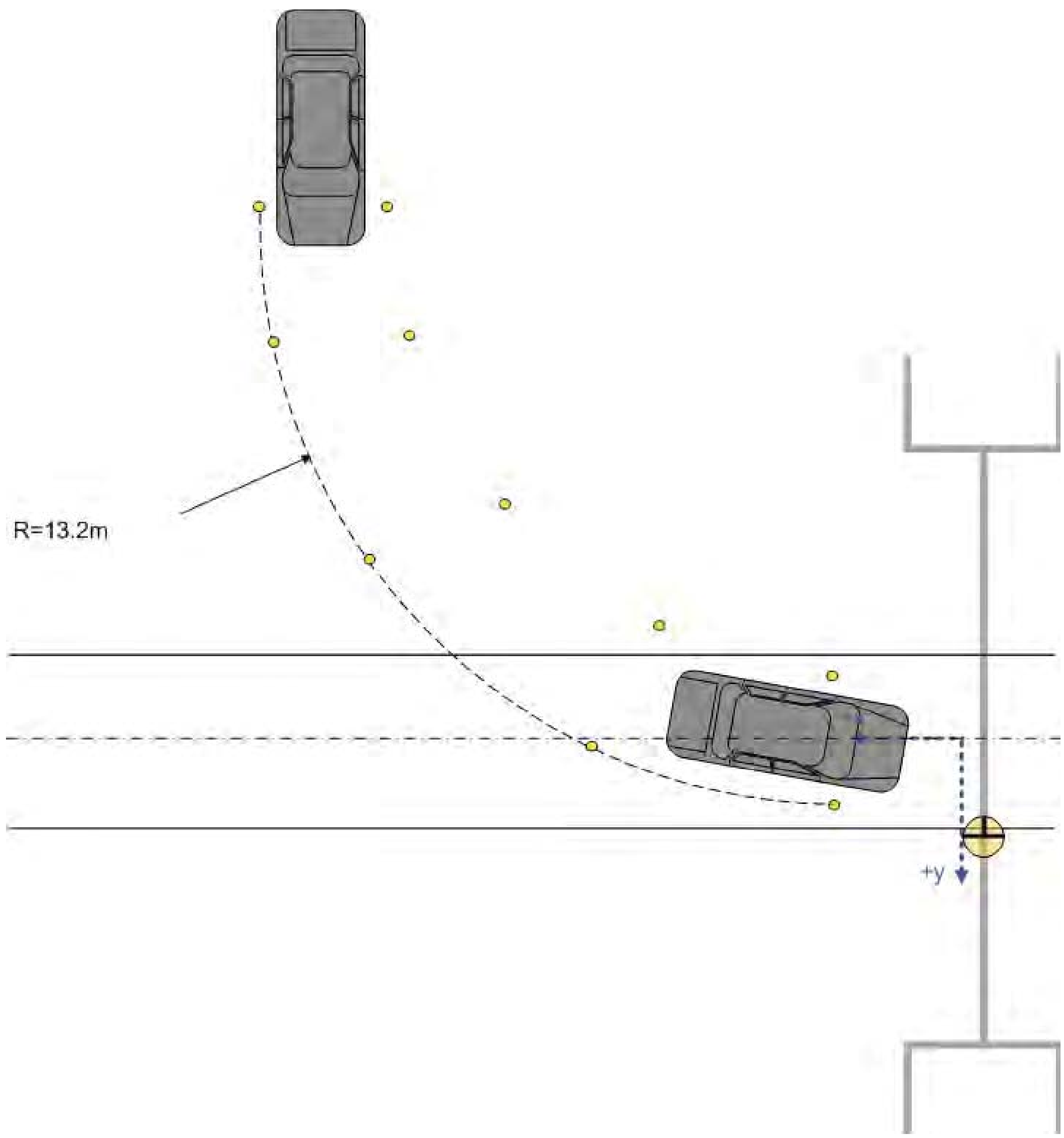


Figure 118: O3 – Vehicle Turning Left With Mannequin Outside of Path (No Collision)

4.4.5 O4: Operational Test Procedure for Mannequin Moving Parallel to Vehicle Path

The O4 scenario involved a vehicle passing by a stationary mannequin or a mannequin moving parallel to the vehicle path so that no collision would occur. The tests were conducted without obstructions between the mannequin and approaching test vehicle. The mannequin was oriented facing away from the vehicle.

The following test speeds were conducted during the O4 procedures:

- Vehicle Speeds: constant speeds ranging between 10 and 25 mph (16 to 40 km/h)
- Mannequin Speeds: stationary, 3.1 mph (5 km/h, walking), and 6.2 mph (10 km/h, running)

Figures 119 and 120 present the procedures used to conduct the O4 tests. The basic test procedure described in Section 4.2.4 was used for these scenarios with the following changes:

1. After the test vehicle passed the mannequin motion trigger, the test driver could not initiate any braking during the remainder of the event until after the vehicle passed the mannequin.
2. Testing was repeated at least five times for each configuration.

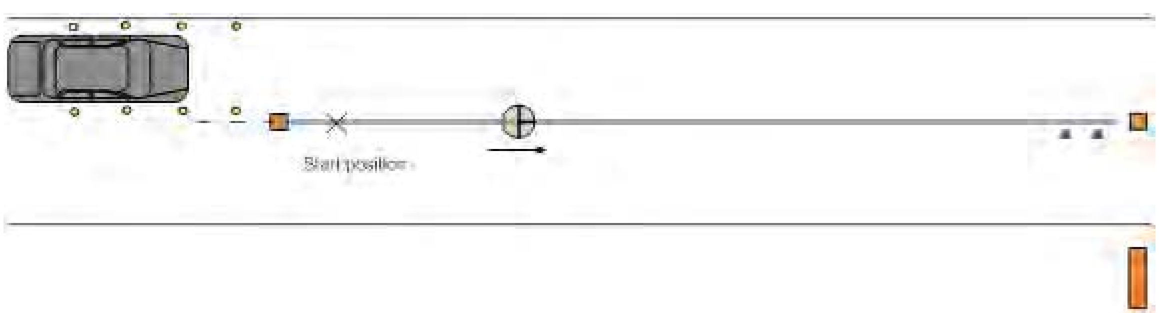


Figure 119: O4 – Vehicle Straight With Pedestrian Moving to Right of Path (No Collision)

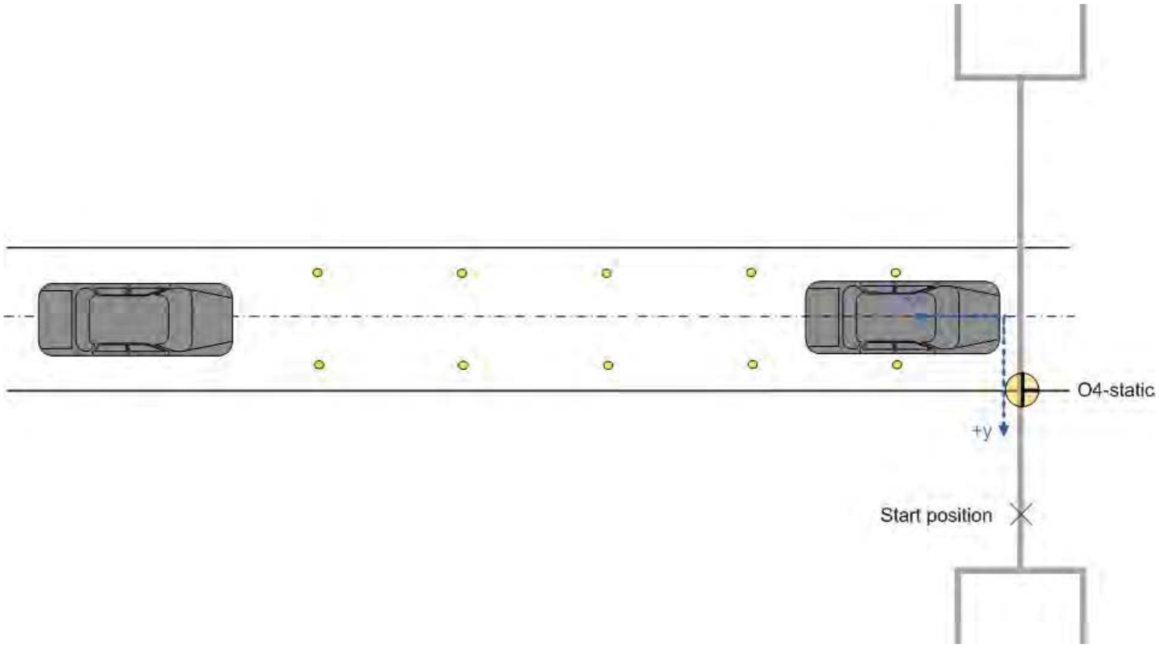


Figure 120: O4 – Vehicle Straight With Mannequin Static to Right of Path (No Collision)

4.4.6 Operational Test Procedure for Vehicle Changing Lanes Toward Mannequin Outside of Path

The Lane Change operational scenario involved a vehicle approaching a stationary mannequin while executing a lane change in the direction of the mannequin. The mannequin was positioned outside of the vehicle path so that no collision would occur. Tests were conducted with long and short lane changes. The tests were conducted without obstructions between the mannequin and approaching test vehicle.

The following test configurations were used during the Short Lane Change procedures:

- Longitudinal Range to Mannequin for First Turn of Lane Change: approximately 20 m
- Longitudinal Range to Mannequin for Second Turn of Lane Change: approximately 10 m
- Vehicle Speeds: Ranging from 10 to 25 mph (16.1 to 40.2 km/h)
- Mannequin Speed: Stationary

The following test configurations were used during the Long Lane Change procedures:

- Longitudinal Range to Mannequin for First Turn of Lane Change: approximately 50 m
- Longitudinal Range to Mannequin for Second Turn of Lane Change: approximately 25 m
- Vehicle Speeds: Ranging from 10 to 25 mph (16 to 40 km/h)
- Mannequin Speed: Stationary

Figure 121 illustrates the method used to conduct the described scenario. The test procedure used for this scenario was as follows:

1. A four-meter test lane was marked with Botts' dots within 10 m of the mannequin position, such that the mannequin was 1 m to the right of the vehicle's path.
2. Turn-in points for the lane change were marked with small traffic cones.
3. The test vehicle accelerated to the defined test speed with a tolerance of ±1.6 km/h and, before reaching the lane change entrance, the vehicle pitching behavior was allowed to settle.
4. After the lane change entrance, no test driver initiated braking was allowed during the remainder of the event until after the vehicle passed the mannequin (x=0).
5. Testing was repeated five times for each configuration.

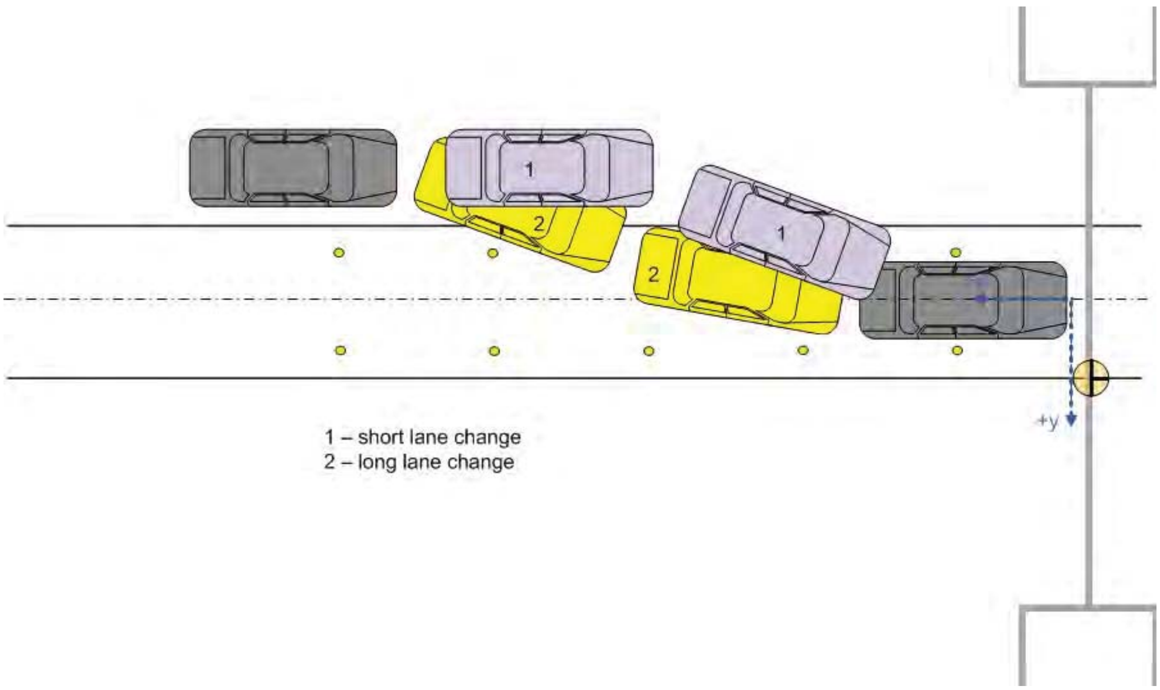


Figure 121: Vehicle Changing Lanes Toward Mannequin Outside of Path (No Collision)

4.5 Functional Test Results from Validation Testing

This section describes the results of the validation tests described earlier. Validation tests were conducted to refine and finalize the test procedures and performance specifications. Access to the mannequin's radar and vision characteristics and a broad knowledge of the underlying baseline system performance helped to characterize the project vehicle sensor responses to mannequin and PCAM test configurations. Finally, each test's functionality, repeatability and limitations were further assessed.

Table 29 presents the test matrix for the validation tests while Table 30 gives an overview of the number of tests that were conducted during the validation test phase. The test results can be found later in the report in Sections 4.5.1 through 4.5.6. Further interpretations along with conclusions from the validation test phase will be presented in Section 6.

Table 29: Validation Test Matrix

	Pedestrian Direction				Light Conditions		Obstructions		Test Vehicle Speeds (mph)			Mannequin Speeds			PCAM Functions	
Test Scenarios	Away from Motor	Toward Motor	Toward Car	Away from Car	Day	Night	No	Yes	5	10	15/ 25	Static	Walk	Run	CIB	DBS
S1	x	x			x	x	x	x		x	x		x	x	x	x
S2		x			x				x	x			x		x	
S3	x	x			x				x	x			x		x	
S4			x	x	x					x	x	x	x	x	x	
S1-VRTC		x			x		x			x	x		x	x	x	
S4-VRTC			x	x		x						x	x	x	x	

Table 30: Number of Runs During Validation Testing

Scenario	Short Description	Vehicle 1	Vehicle 2	Vehicle 3
S1	Crossing	228	75	243
S2/S3	Turning	29	22	13
S4	In Lane	59	34	41

Differences in test counts may be due to availability of equipment and personnel, weather conditions, refinements to test scenarios, and other factors.

To assess the results from the three project vehicles, each of which had its own unique data acquisition system, a common analysis script was developed for automating the analysis process. A common script provided calculations that were equivalent for all test cars with only minimum tailoring for some individual vehicle signals. Figure 122 describes the general concept of the script including the input and the output: The scenario description along with some further setup information was collected in three individual test lists. The corresponding test data files contained the vehicle CAN signals as well as the GPS ground truth and test apparatus channels that were used for the calculations.

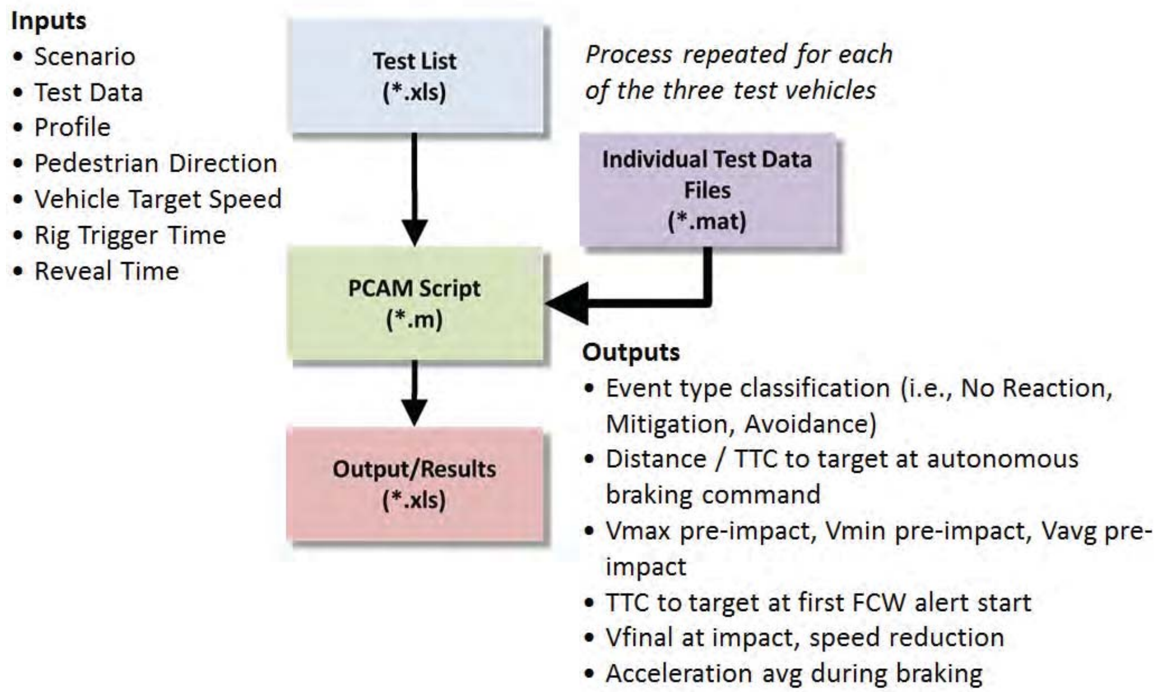


Figure 122: Workflow for Automated Test Assessment

Table 31 explains the naming convention used in this project to describe possible vehicle responses to a PCAM event. “Avoidance I” and “Avoidance II” represent all cases in which autonomous braking was capable of avoiding the impact. In some tests, contact with the mannequin could not be avoided, but the deceleration was still sufficient to reduce the speed and thus mitigate the severity of the impact (“Mitigation”).

If a vehicle did not command any braking in a functional test scenario, the results were flagged with the words “No Reaction.” In many of those cases, autonomous braking was not activated as the mannequin could not be detected. The individual background will be explained in the corresponding paragraphs.

Based on the technical understanding of sensing system capabilities and previously conducted tests, some test configurations were not run based on evidence that the situation could not be detected with that particular PCAM system (i.e., function disabled at certain speed, mannequin never in field of view due to test setup, etc.). For documentation purposes, these configurations are marked with the words “No Reaction Expected.”

Table 31: Classification of Events for Functional Test Scenarios

Event Type Name	Description
Avoidance I	No impact – Autonomous braking results in vehicle coming to complete stop before collision with mannequin
Avoidance II	No impact - Autonomous braking results in collision avoidance due to mannequin clearing vehicle path
Mitigation	Autonomous braking commanded typically resulting in reduced vehicle speed at collision with mannequin
No Reaction	Vehicle does not command autonomous braking
No Reaction Expected	Test was not conducted as there was evidence that vehicle would not react

4.5.1 S1 Centered: Mannequin Crossing Perpendicular to the Vehicle Path

For the main S1 scenario, testing was conducted at vehicle speeds of 10 mph and 25 mph, with a walking and running mannequin (5 km/h and 10 km/h) and with and without obstruction (with reveal times 2.7 s and 1.3 s). The timing for the mannequin was set up in a manner that would lead to an impact at the vehicle centerline if no system activation occurred.

For further analysis, all results were organized using two bar diagrams with a corresponding table underneath. The upper bar diagram shows the average vehicle speed reduction of all tests conducted within each category, including all "avoidance" cases and all "no reaction" cases. This average speed reduction can be used as a performance metric, or "composite average speed reduction," to compare the various vehicle systems.

The lower bar diagram shows the proportion of the event types "Avoidance I," "Avoidance II," "Mitigation," "No Reaction," and "No Reaction Expected" as previously defined in Table 31. A table underneath those two bar diagrams contains the number of test runs which form the basis of the bar diagrams.

The major results for scenario S1 are presented in Figures 123 through 125. Figure 123 presents the results for the unobstructed runs. Figure 124 contains the outcome of tests with a reveal time of 2.7 s while Figure 125 contains the data for a reveal time of 1.3 s TTC.

For the 10 mph vehicle speed with *walking mannequin*, both the *unobstructed test condition* (presented in Figure 123) and the *obstructed test condition with a reveal time of 2.7 s* (presented in Figure 124) show approximately the same results. However, there are differences in the effectiveness of the systems. These differences were:

- Vehicle 1 did not achieve any full avoidance, but started autonomous braking in more than 90 percent of all tests. The average speed reduction was less than 20 percent of the initial speed.
- Vehicle 2 showed autonomous braking in all tests for the unobstructed and obstructed setup with reveal time of 2.7 s. Full avoidance could be reached in about 60-70 percent of all tests. The average percent speed reduction was between 60-70 percent.
- Vehicle 3 had 100 percent avoidance for the unobstructed walking mannequin. With the 2.7 s obstruction, some impacts could only be mitigated so that the average speed reduction turned out to be slightly lower than 100 percent.

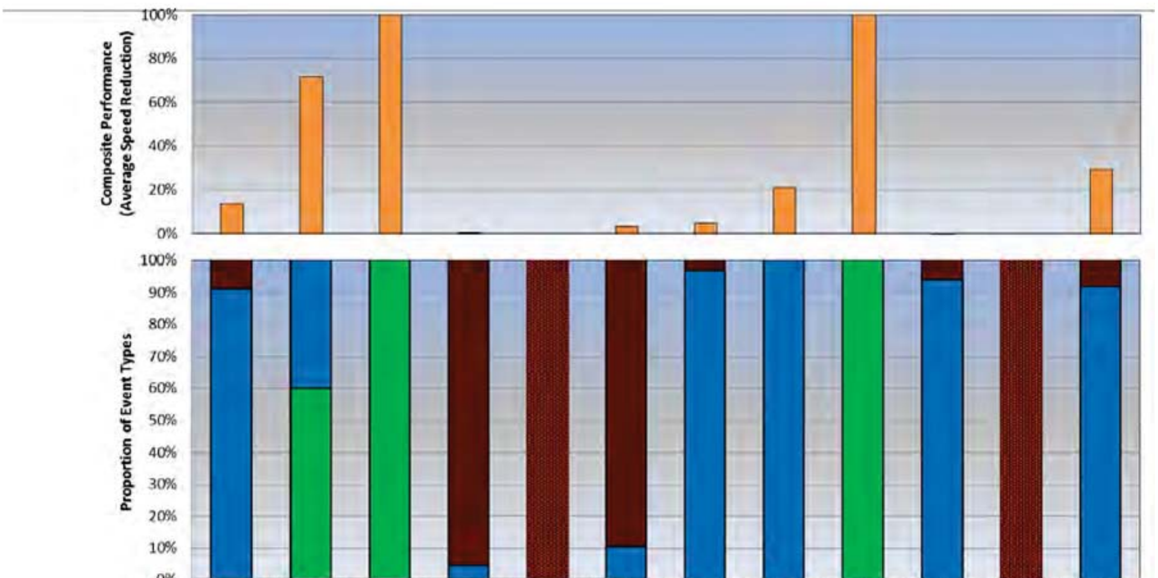


Table: Number of test runs	10mph Walk Veh 1	10mph Walk Veh 2	10mph Walk Veh 3	10mph Run Veh 1	10mph Run Veh 2	10mph Run Veh 3	25mph Walk Veh 1	25mph Walk Veh 2	25mph Walk Veh 3	25mph Run Veh 1	25mph Run Veh 2	25mph Run Veh 3
No Reaction expected					1						1	
No Reaction	3			22		17	1			1		1
Mitigation	31	4		1		2	29	5		15		11
Avoidance II												
Avoidance I		6	19						22			

Figure 123: S1 Test Results Without Obstruction

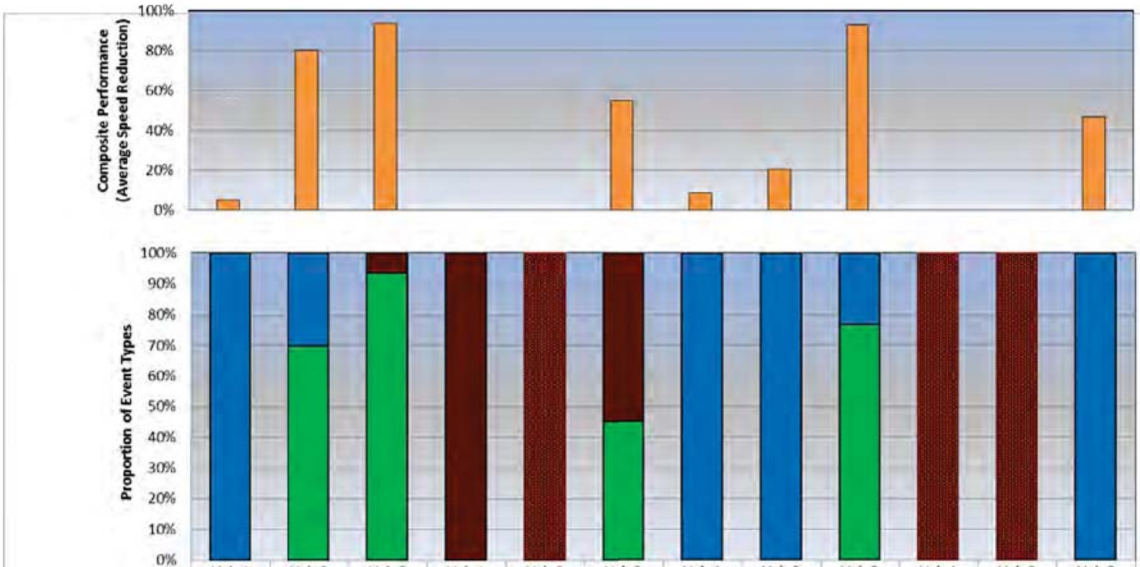


Table: Number of test runs	Veh 1	Veh 2	Veh 3	Veh 1	Veh 2	Veh 3	Veh 1	Veh 2	Veh 3	Veh 1	Veh 2	Veh 3
		Walk			Run			Walk			Run	
			10mph						25mph			
No Reaction expected					1					1	1	
No Reaction			1	8		6						
Mitigation	11	3					4	9	3			9
Avoidance II												
Avoidance I		7	15			5			10			

Figure 124: S1 Test Results Slightly Obstructed (2.7 s Reveal Time)

The results for the *obstructed tests with 1.3 s reveal time,* 10 mph tests with *walking mannequin* showed a totally different picture, as shown in Figure 125:

- Vehicle 1 did not respond to any test configuration.
- Vehicle 2 could still achieve some speed reduction at 10 mph, but stopped responding at higher speeds.
- Vehicle 3 could get more than 40 percent speed reduction for both vehicle speeds.

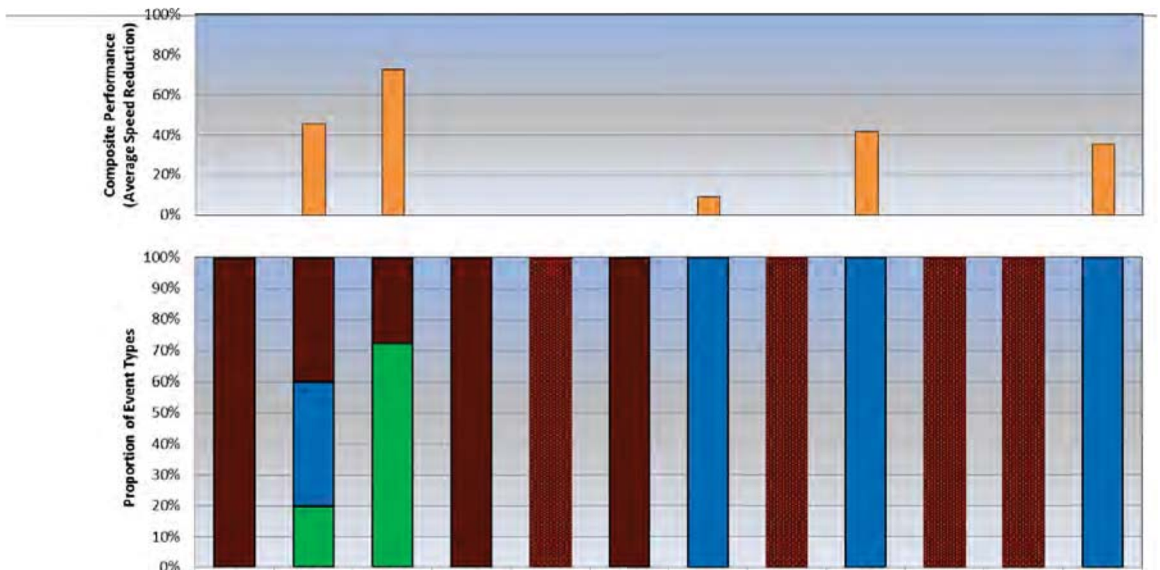


Table: Number of test runs	10mph Walk Veh 1	10mph Walk Veh 2	10mph Walk Veh 3	10mph Run Veh 1	10mph Run Veh 2	10mph Run Veh 3	25mph Walk Veh 1	25mph Walk Veh 2	25mph Walk Veh 3	25mph Run Veh 1	25mph Run Veh 2	25mph Run Veh 3
No Reaction expected					1			1		1	1	
No Reaction	7	2	5	6		6						
Mitigation		2					3		14			10
Avoidance II												
Avoidance I		1	13									

Figure 125: S1 Test Results Obstructed (1.3 s Reveal Time)

Running scenario results with both unobstructed and obstructed configurations are depicted in Figures 123 through 125:

- Vehicle 1 could not effectively reduce the impact speed even though there was braking commanded in some unobstructed 25 mph tests shortly before the impact. Due to the timing of the mannequin, the sensor system was unable to consistently detect the mannequin and react accordingly.
- Vehicle 2 did not respond at all to the running mannequin. The analysis of the raw data revealed that the mannequin using the PCAM timing will never show up in the field of view of the camera. Therefore, the test series was stopped and the test outcome was documented as "No Reaction Expected."
- For Vehicle 3, the maximum speed reduction for the unobstructed case was approximately 30 percent, for the reveal time 2.7 s about 50 percent and for the obstruction screen at a time to collision of 1.3 s less than 40 percent. The reason for this difference in performance was a combined variation of the mannequin arm setup with tolerances in the vehicle lateral position. In other words, the mannequin moves just at the edge of the field of view of the vehicle. More findings will be discussed later in Section 6.

4.5.2 S1 Far Side: Mannequin Crossing Perpendicular to the Vehicle Path With Alternate Timing

Based on some of the differences identified between each of the PCAM systems tested, some additional test configurations were devised to examine the effects of adjusting the mannequin timing for the S1 scenario. Two alternative S1 scenarios were developed. In the first alternative, the mannequin timing was adjusted such that the target impact point moved to the far edge of the vehicle if no autonomous braking occurred. The second alternative scenario, discussed in Section 4.5.3, involved the mannequin stopping in the center of the travel lane.

Figure 126 presents the results for the Far Edge Test Scenario. The figure demonstrates the significantly higher performance of all vehicles compared to primary S1 scenario with the centered impact (shown in Figure 123). In this configuration, the impact could be avoided by just autonomously reducing the vehicle speed without coming to a complete stop. The corresponding speed reductions for “Avoidance II” are lower than 100 percent and, thus, they reduce the average speed reduction bars although there was no impact.

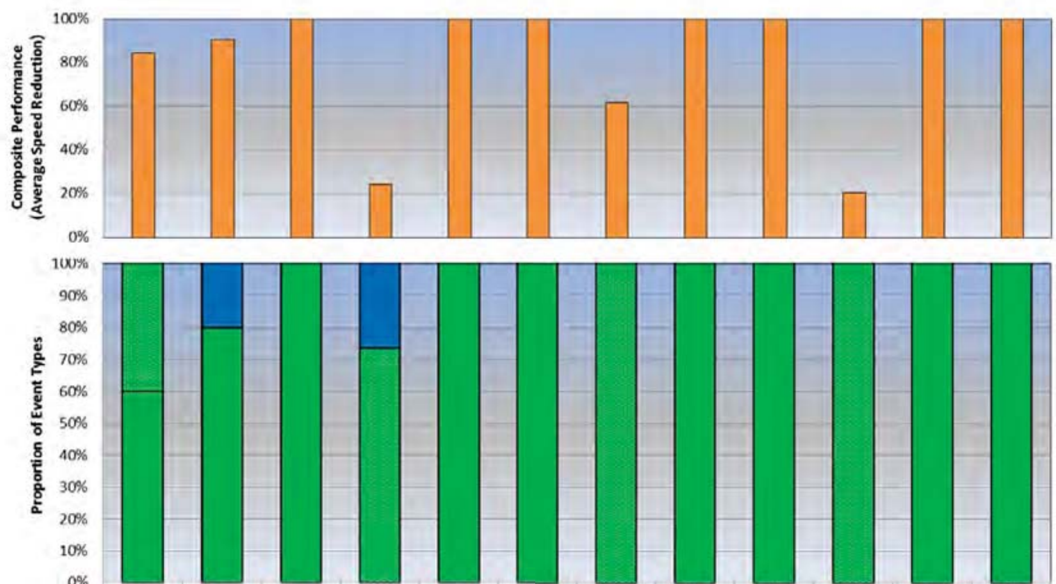


Table: Number of test runs	Veh 1	Veh 2	Veh 3	Veh 1	Veh 2	Veh 3	Veh 1	Veh 2	Veh 3	Veh 1	Veh 2	Veh 3
	Walk			Run			Walk			Run		
	10mph						15mph					
No Reaction expected												
No Reaction												
Mitigation		1		5								
Avoidance II	2			14			5			16		
Avoidance I	3	4	5		5	5		5	5		5	5

Figure 126: S1 Far Edge Results

4.5.3 S1 Far Side With Stop in Lane Center

The second alternative method developed for the S1 scenarios was conducted as follows: The mannequin started with a walking speed equivalent to the S1 Far Side Test, but was then stopped as soon as it reached the centerline of the vehicle. This configuration does not allow any Avoidance II results as the mannequin never leaves the vehicle's path.

Figure 127 presents the results of testing with this scenario. All three vehicles responded to this scenario. When the vehicles drove at the lower 10 mph speed, the impact could generally be avoided. At a higher vehicle speed, there were some Mitigation cases.

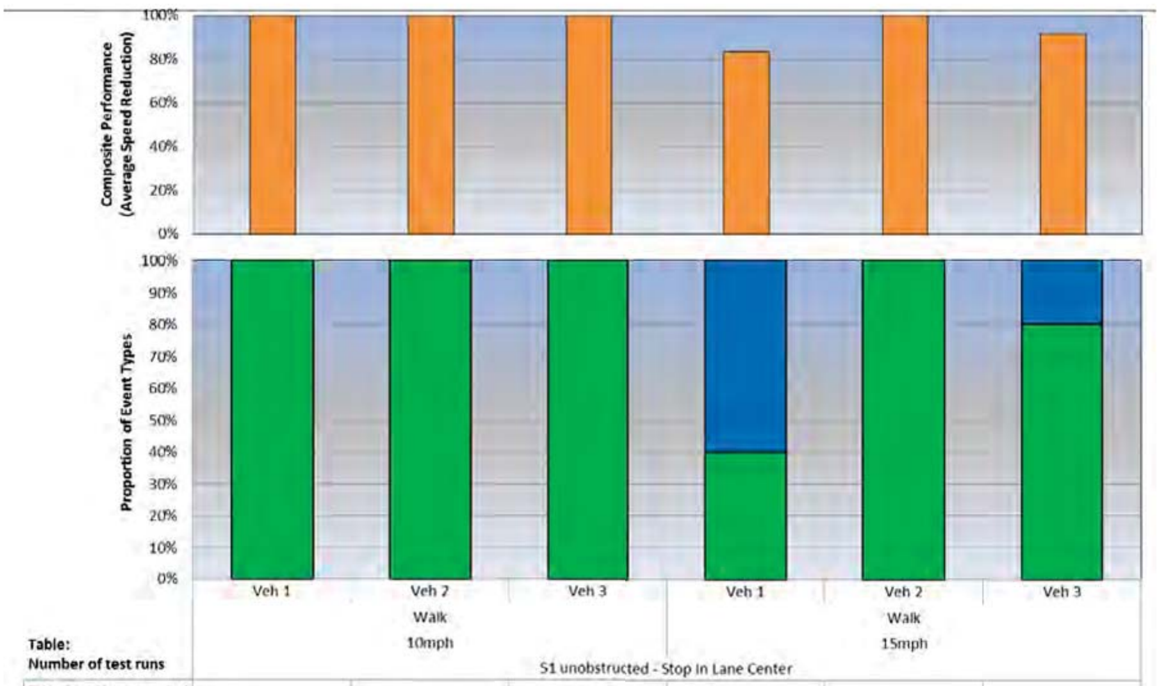


Table: Number of test runs	Veh 1 (Walk 10mph)	Veh 2 (Walk 10mph)	Veh 3 (Walk 10mph)	Veh 1 (Walk 15mph)	Veh 2 (Walk 15mph)	Veh 3 (Walk 15mph)
No Reaction expected						
No Reaction						
Mitigation				3		1
Avoidance II						
Avoidance I	5	6	5	2	4	4

Figure 127: S1 Stop in Lane Center

4.5.4 S1: Comparison PCAM Test Apparatus Versus VRTC Test Apparatus

At the end of the validation testing, there was an opportunity to conduct a small sample of S1 tests with the NHTSA-VRTC platform. This provided limited opportunity to assess whether the choice in test equipment designs would affect the performance of the test methods.

Figure 128 shows that Vehicles 1 and 2 both responded to mannequins presented on either apparatus. Although this figure seems to indicate that the VRTC apparatus elicited better performance from both vehicles, this conclusion is premature. The observed performance differences may be explained by variations in test conditions rather than by differences in equipment design. For example, the ground truth system of the VRTC test apparatus was not fully functional at the time the tests were conducted and the timing of the mannequin was not fully developed. Also, the background of the test area, including light conditions and some glare from the sun, were different. Additional testing under more controlled conditions and acquiring a larger sample size would be needed to further address apparatus design differences.

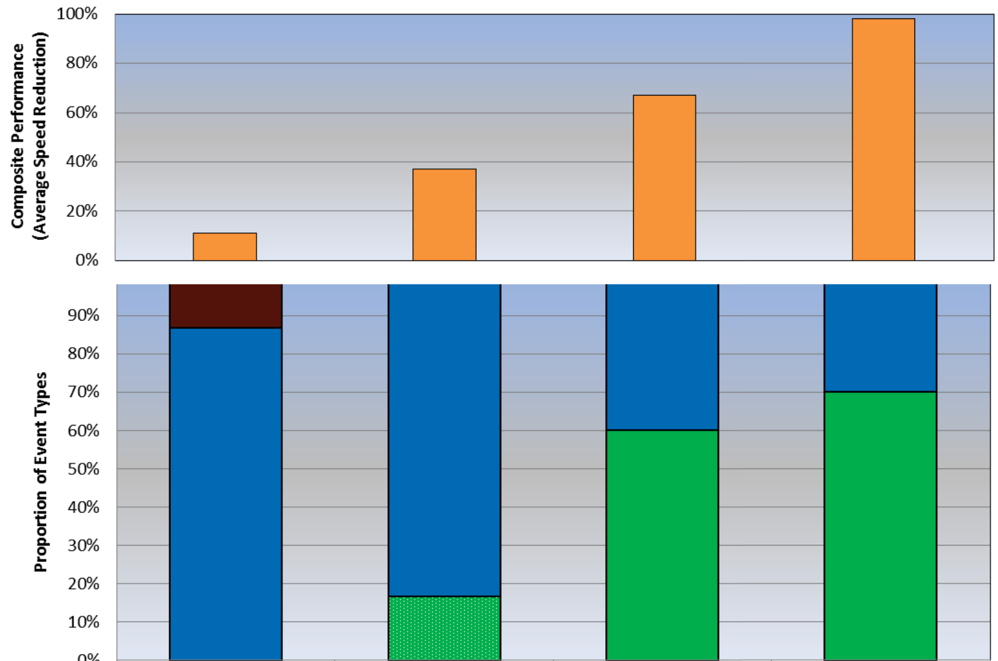


Table: Number of test runs	PCAM Rig S1 veh 10mph ped walk L-R	VRTC Rig S1 veh 10mph ped walk L-R	PCAM Rig S1 veh 10mph ped walk L-R	VRTC Rig S1 veh 10mph ped walk L-R
	Vehicle 1		Vehicle 2	
No Reaction expected				
No Reaction	2			
Mitigation	13	5	2	3
Avoidance II		1		
Avoidance I			3	7

Figure 128: S1 on VRTC Apparatus Compared to S1 on PCAM

4.5.5 S2/S3: Vehicle Turns Right or Left at Crossroads

Figure 129 and Figure 130, respectively, show the results from the S2 (right turn) and S3 (left turn) scenario testing. Vehicle 1 never reacted in any turning case whereas Vehicle 2 and Vehicle 3 reacted in some cases where the mannequin moved from the outside of the turn radius to the inside.

The test results for Vehicles 1 and 3 show no reaction to mannequins moving from the inside of the turn to the outside. This was expected as the sensor systems are unable to detect the mannequin due to the combination of the vehicle and mannequin trajectories and the sensors' field of view. In addition, the Vehicle 3 PCAM system was not enabled at 5 mph.

Another observation from the S2/S3 tests was the difficulty in defining and controlling required test parameters in a repeatable manner. This resulted in a significantly larger number of attempted runs before recording the relatively limited number of valid tests shown in the following figures.

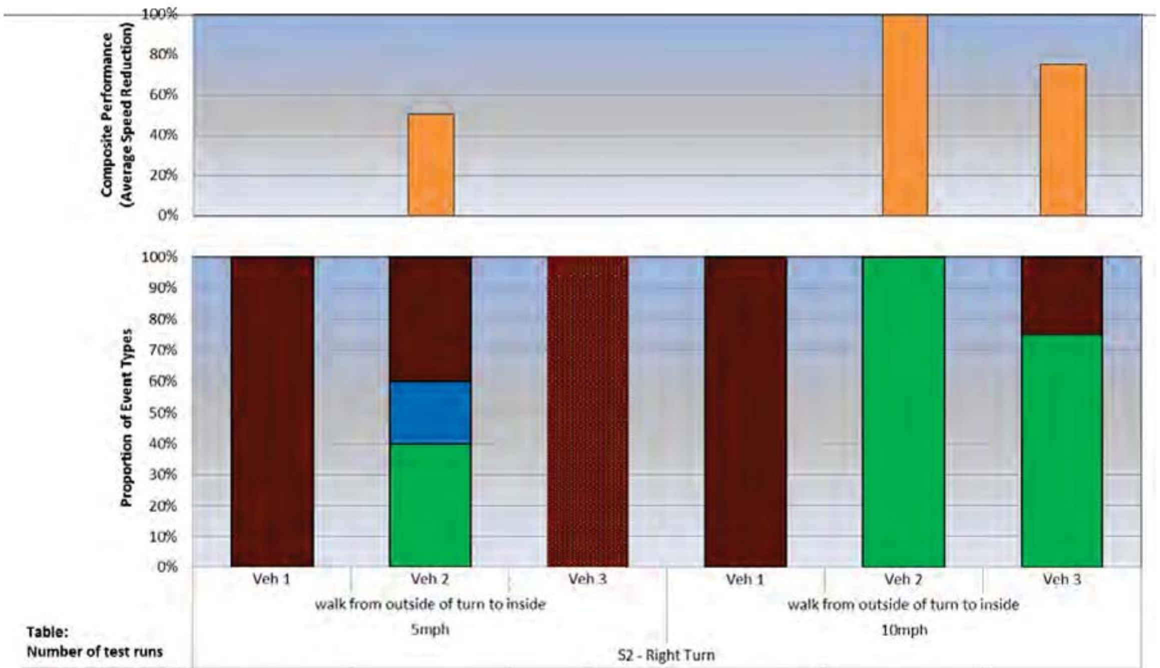


Table: Number of test runs	Veh 1	Veh 2	Veh 3	Veh 1	Veh 2	Veh 3
	walk from outside of turn to inside 5mph			walk from outside of turn to inside 10mph		
	S2 - Right Turn					
No Reaction expected			1			
No Reaction	3	2		5		1
Mitigation		1				
Avoidance II						
Avoidance I		2			5	3

Figure 129: S2: Vehicle Right Turn

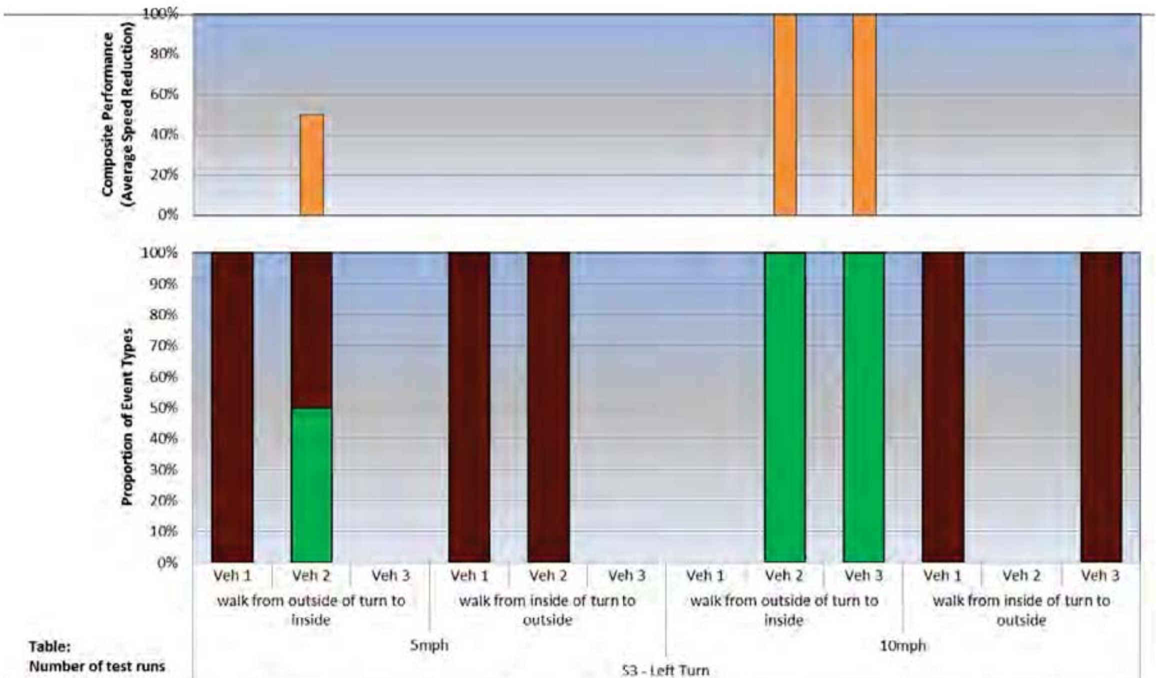


Table: Number of test runs	5mph, walk from outside of turn to inside, Veh 1	Veh 2	Veh 3	5mph, walk from inside of turn to outside, Veh 1	Veh 2	Veh 3	10mph, walk from outside of turn to inside, Veh 1	Veh 2	Veh 3	10mph, walk from inside of turn to outside, Veh 1	Veh 2	Veh 3
No Reaction expected												
No Reaction	7	3		3	1					4		5
Mitigation												
Avoidance II												
Avoidance I		3						5	4			

Figure 130: S3 Vehicle Left Turn

4.5.6 S4: Mannequin in Line With the Vehicle Path Conducted Using PCAM and VRTC-Rigs

As shown previously in Table 29, the validation test matrix included assessments of S4 test methods using a variety of potential conditions. S4 tests conducted with moving mannequins required the use of the NHTSA-VRTC test apparatus since it could be reoriented to operate in either direction. Static mannequin tests were conducted with both sets of test equipment.

The results of these tests are organized in bar diagrams and tables similar to the other configurations, but this time they are organized in one figure per vehicle (Figure 132, Figure 133 and Figure 134). The horizontal axis describes the test setup as follows:

- Relative speed difference between vehicle and mannequin.
- Test
- Dummy speed
- Dummy direction
- Vehicle speed

Vehicle 1 and Vehicle 3 were first tested using a *static mannequin* in an S4 configuration facing away from the car. As shown in Figure 131, no major differences were observed for either vehicle attributable to the test that was used.

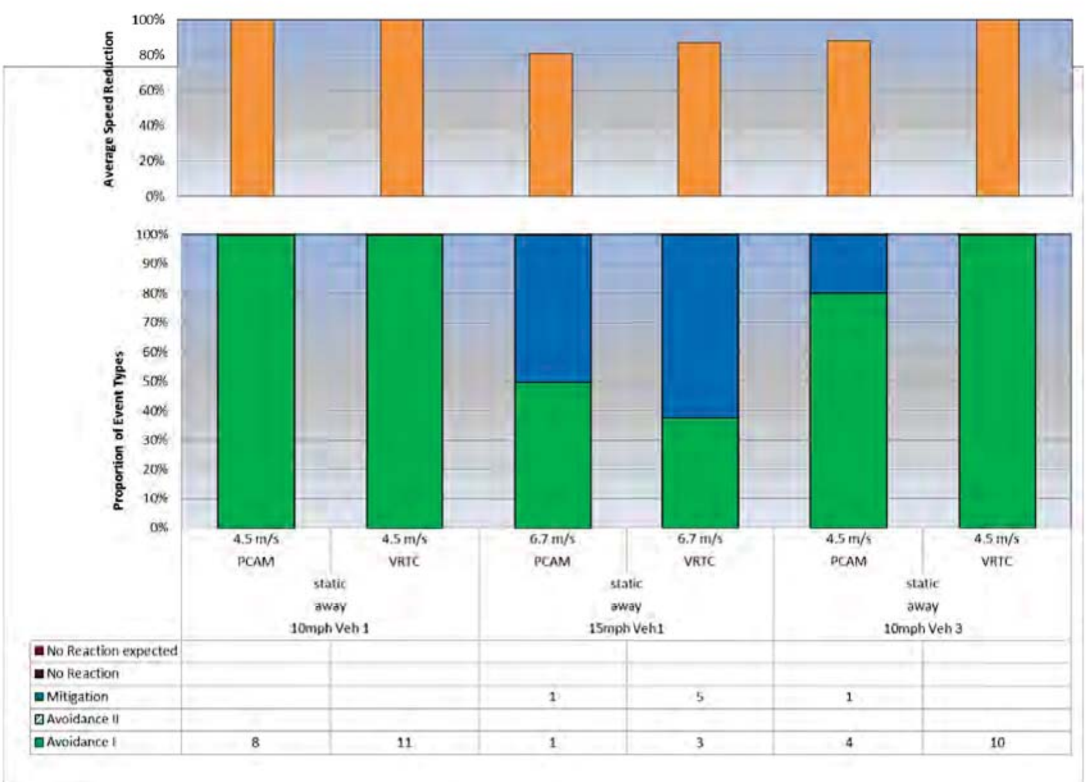


Figure 131: S4 Static, Vehicle 1 and Vehicle 3

The S4 test results using a moving mannequin are presented in Figures 132 through 134. Figure 132 contains the results for Vehicle 1, Figure 133 the results for Vehicle 2, and Figure 134 the results for Vehicle 3**.** The static test results have been included in each figure to enable the comparison between the moving and the static mannequin. The following are the key points observed in this data:

- ***Vehicle 1*** responded to all configurations, but did not avoid any impact with the moving dummy. The average speed reduction for the cases with mannequin moving away from car is between approximately 50 percent and 80 percent. The performance decreases when the mannequin is moving toward the vehicle. Note that the average speed reduction is generally smaller compared to the static tests even in cases with a smaller relative speed difference (3.1 m/s moving versus 4.5 m/s static).
- ***Vehicle 2*** does not offer any static tests to compare with. It is highly responsive to the moving mannequin enabling the high average speed reduction of more than 80 percent in most cases with one exception: No reaction was noted for the 10 mph running toward case. This was later

determined to be caused by system algorithm settings used on that particular vehicle.

- ***Vehicle 3*** showed 100 percent response to all setups where the mannequin moved away from the vehicle. The average speed reduction in the tested configurations was above 90 percent. With a mannequin walking toward the vehicle, the response rate goes down and the average speed reduction decreases to 30-40 percent of the initial vehicle speed.

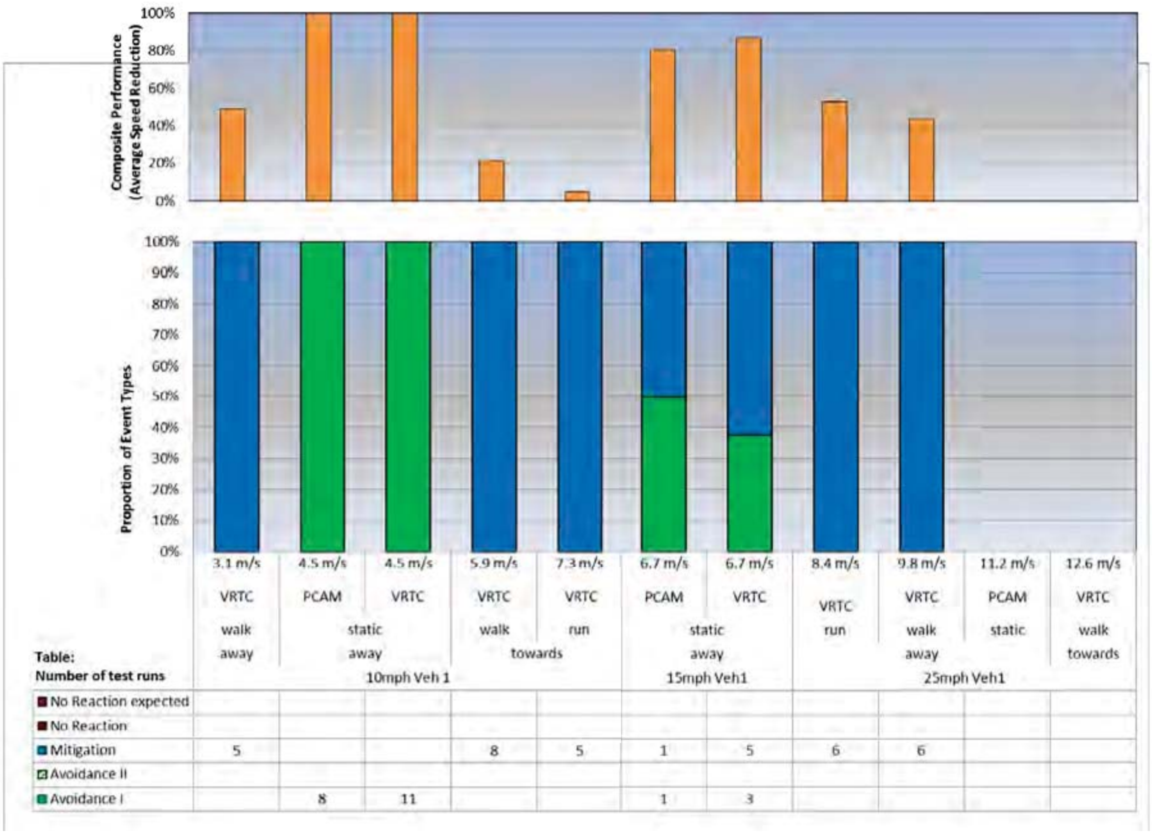


Figure 132: S4 Test Results for Vehicle 1

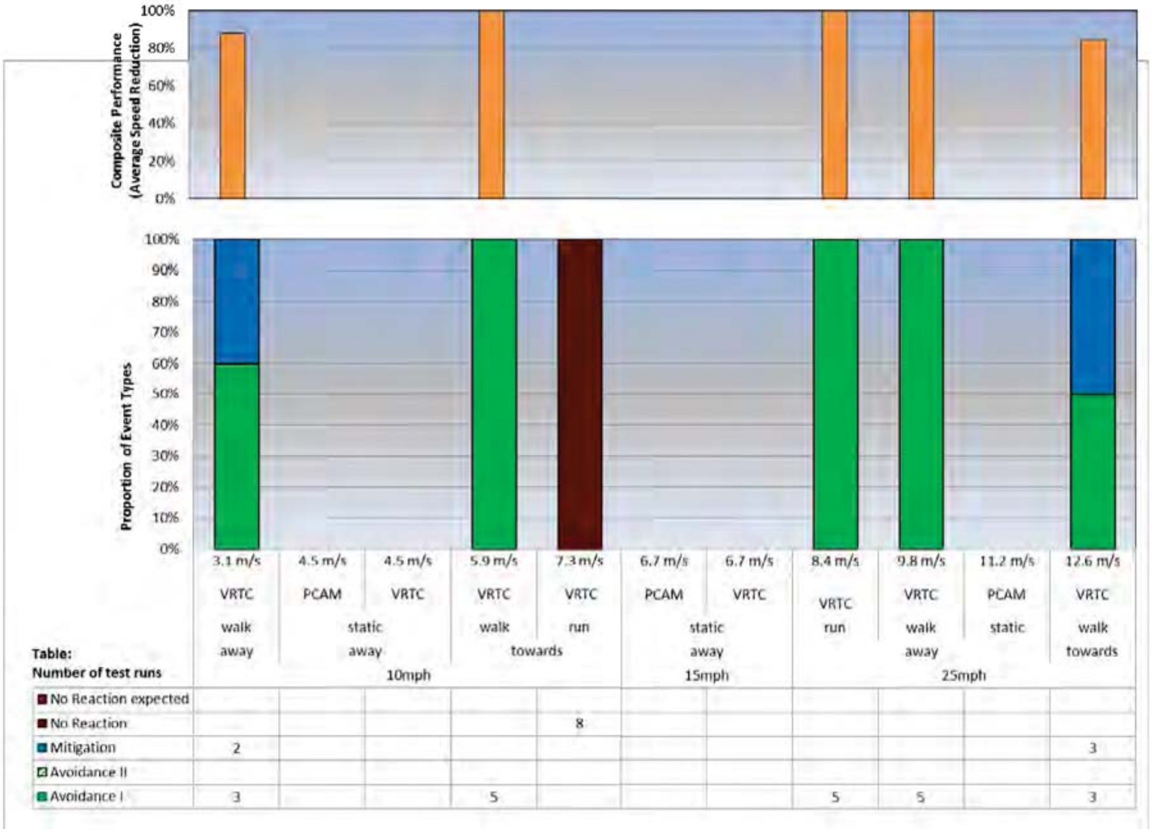


Figure 133: S4 Test Results for Vehicle 2

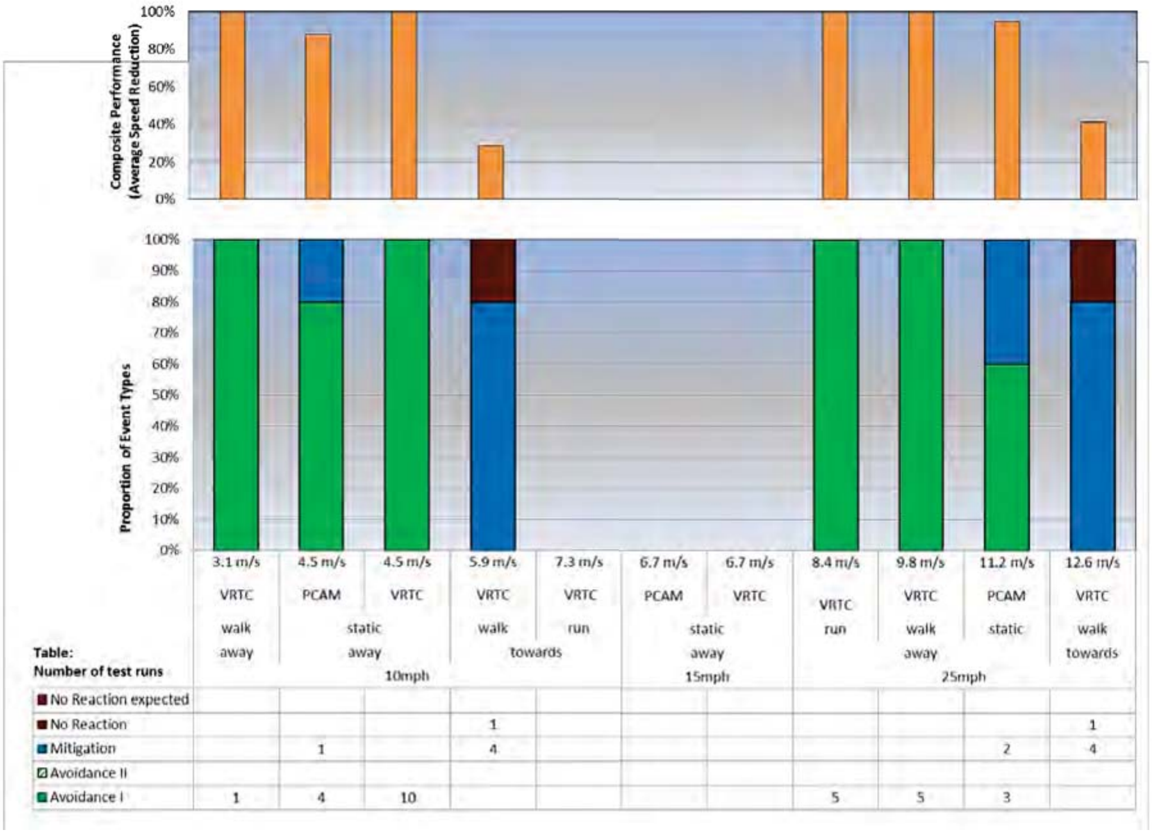


Figure 134: S4 Test Results for Vehicle 3

4.5.7 Influence of Lighting Conditions

Vision-based systems require light to operate and consequently detect fewer objects at night when less light is available. Vision systems can also be adversely affected by, but not limited to, the following conditions:

- Glare from the sun, oncoming traffic lights during darkness, etc.
- Wet road surface leading to reflections
- Poor visibility due to adverse weather conditions
- Poor contrast between pedestrian and background

As described in Table 4 of Section 2.3.2 of the report, most crashes involving pedestrians happen during daylight. However, a significant portion of fatal pedestrian accidents occur during darkness. Available crash databases provide qualitative information but little quantitative information regarding the specific lighting conditions under which these crashes occur. More detailed qualitative information would be needed to develop repeatable and reproducible test procedures for nighttime test procedures. Nonetheless, some tests were conducted during the project in the transition time from daylight to night to understand potential performance capabilities and limitations with the systems tested.

Shown in Figure 135 is the light measurements taken from a light meter during the transition of daylight to night. Measurements were taken at the test site during a test series involving all three vehicles in November 2012. The measured light (in lux) dropped quickly within less than an hour giving limited time to test all scenarios. Consequently, only the S1 walking scenario at driving speed of 10 mph was used to evaluate the influence of the decreasing sunlight. The low beams of the test vehicles were turned on during testing. The vehicle speed reduction is also shown in the figure.

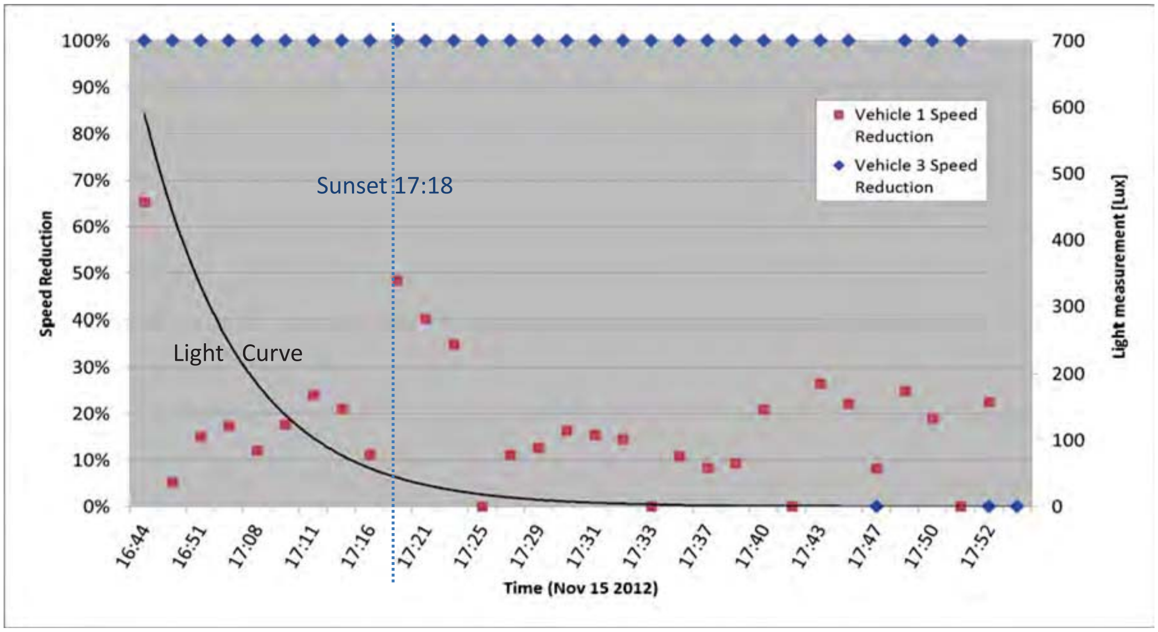


Figure 135: Light Measurement Plots

Figure 136 shows the comparison between the daylight and the transition series. Performance for Vehicle 1 did not change significantly through the transition test period and provided similar results as compared to daylight testing. The observed performance of Vehicle 2 showed PCAM availability became disabled at night (which occurred at about 17:30 on this test date). When light conditions became very dark (less than 1 lux), Vehicle 3 activated less consistently. However, in tests with activations in the lower light conditions, Vehicle 3 provided the same speed reductions as in daylight tests.

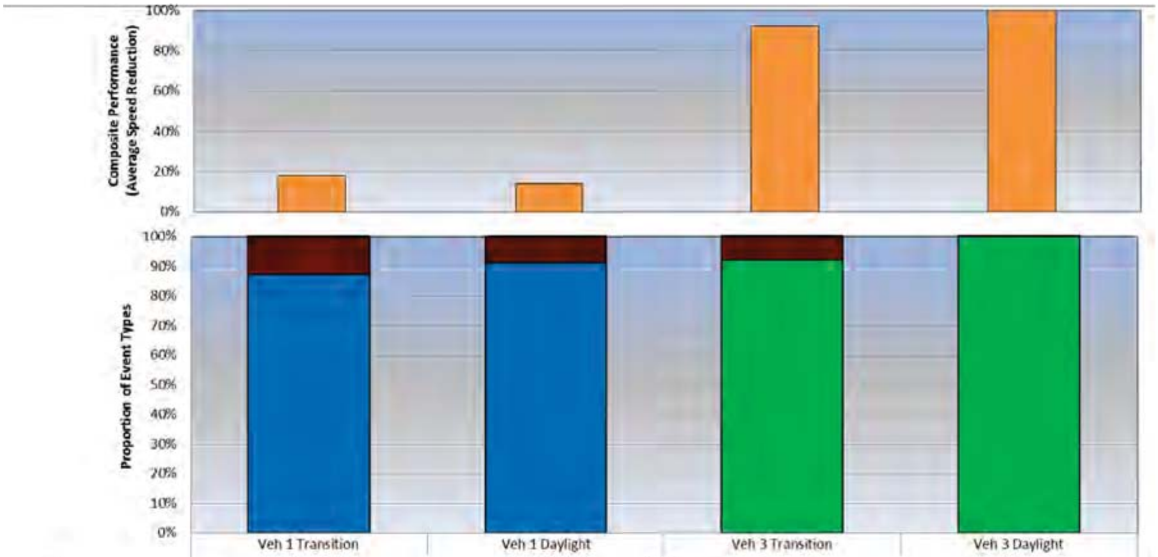


Table: Number of test runs	Veh 1 Transition	Veh 1 Daylight	Veh 3 Transition	Veh 3 Daylight
	Walk 10mph			
No Reaction expected				
No Reaction	4	3	3	
Mitigation	27	31		
Avoidance II				
Avoidance I			34	19

Figure 136: Transition Test Results Compared to Daylight Testing

4.5.8 Dynamic Brake Support Testing

One of the three project vehicles was prepared for DBS testing which was conducted as previously described in Section 4.2.5 of this report. Figure 137 presents a sample velocity plot for a typical 25 mph test. This figure shows that part of the overall speed reduction resulted from the application of the brake robot and remainder from the DBS system. The DBS portion will be referred to as system braking in the following bar diagrams showing the results.

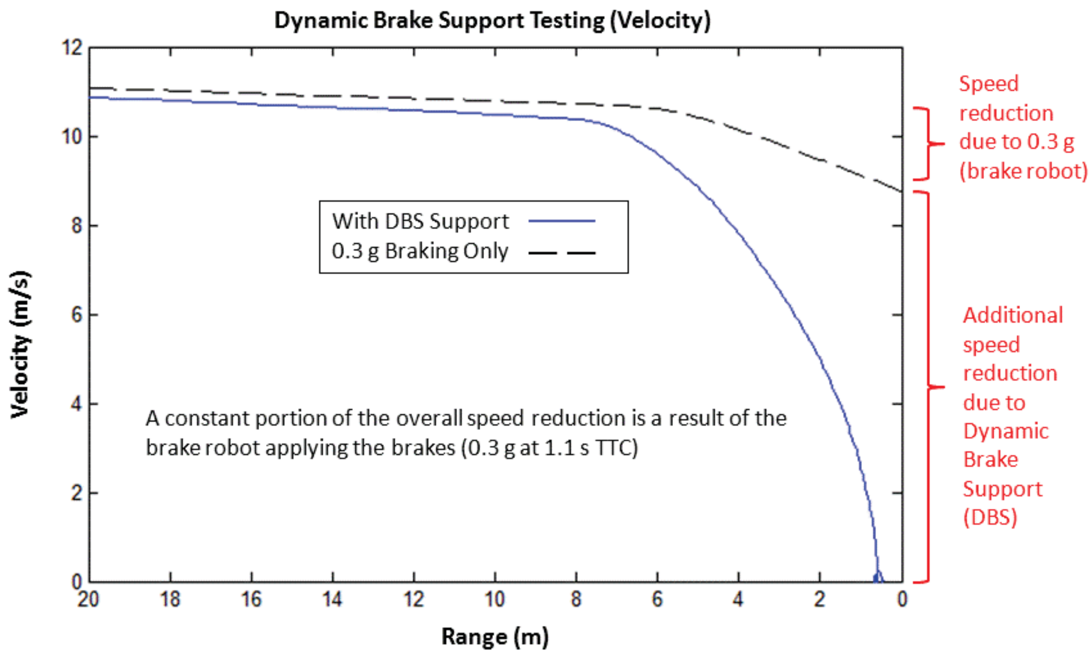


Figure 137: Velocity Curve for DBS Test, 25 mph Vehicle Speed

Figure 138 includes the test results for the walking S1 scenarios with a vehicle approaching at a speed of 25 mph. The grey bars in the composite performance show the portion of brake robot initiated speed reduction whereas the orange bars show the portion of the DBS or the CIB system initiated speed reduction.

The direct comparison for the walking mannequin configuration reveals that the overall composite performance and the system braking portion (orange bar) is higher for DBS than for CIB. *It appears that the 0.3 g pre-braking changes the geometry of the scenario in such a way that the mannequin could be detected earlier and system initiated braking was more effective, leading to a higher performance*.

Unfortunately, there is no direct comparison available for the Far Edge and the Static case. But the trend shows the expected characteristics: For both Far Edge and Static scenario, the mannequin was triggered earlier, so that the earlier and more stable detection led to increased performance.

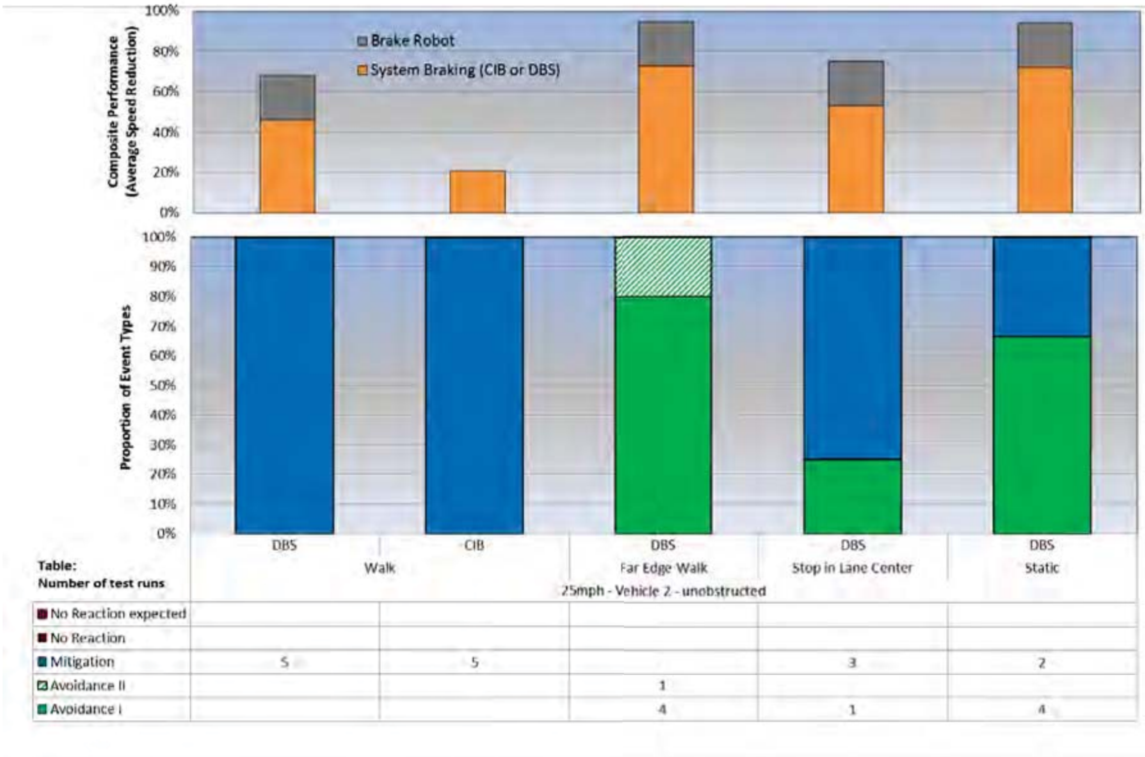


Figure 138: DBS Test Results (S1, Walking, 25 mph Vehicle Speed)

The Running cases were the most challenging S1 scenarios in the CIB test series. The corresponding results of the DBS-tests are displayed in Figure 139. This figure indicates that the vehicle started responding to the running scenario which it did not do with CIB. As described before, it appears that the DBS system benefits from the changed scenario geometry and the earlier detection of the mannequin. For the Far Edge tests, this means that the impact could be avoided as the braking was sufficient to let the mannequin clear the path as the vehicle arrived.

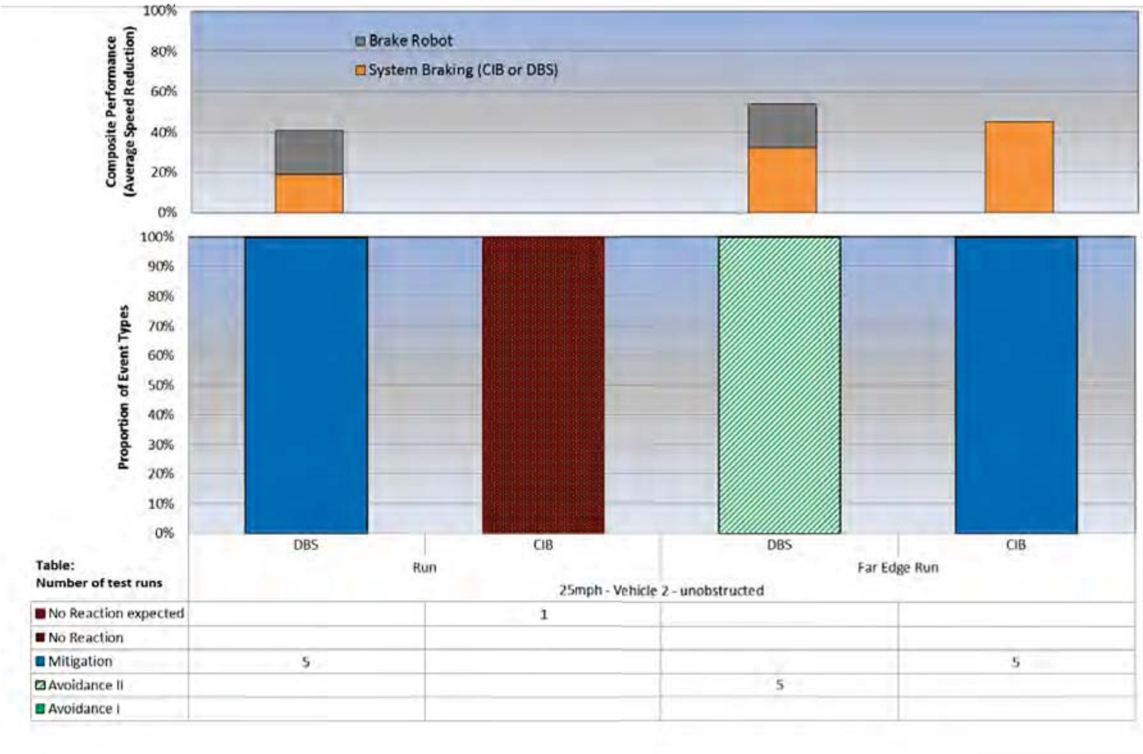


Figure 139: DBS Test Results (S1, Running, 25 mph Vehicle Speed)

Any conclusions that might be drawn out of this test series are based on a relatively small number of runs with only one prototype vehicle (see conclusions in Section 6).

4.6 Operational Test Results From Validation Testing

The operational tests were conducted according to the procedures that were described in Section 4.4. In contrast to the functional tests, the goal of the operational test was to examine a broader spectrum of speeds and more variety in some configurations.

It was initially assumed that there should not be autonomous braking in any of these test setups as they were all designed such that there would not have been any impact. During the course of the test series, it was decided that a limited initiation of autonomous braking might be appropriate in some cases.

Figure 140 shows a situation with a mannequin crossing directly in front of the car and the vehicle traveling at 10 mph: A normal driver would have likely applied the brakes before the autonomous braking was commanded in this situation. Consequently, system activation would not be deemed undesirable: Autonomous braking during a critical situation with a mannequin within the vehicle's path is acceptable as long as the brakes are released when the situation becomes less critical.

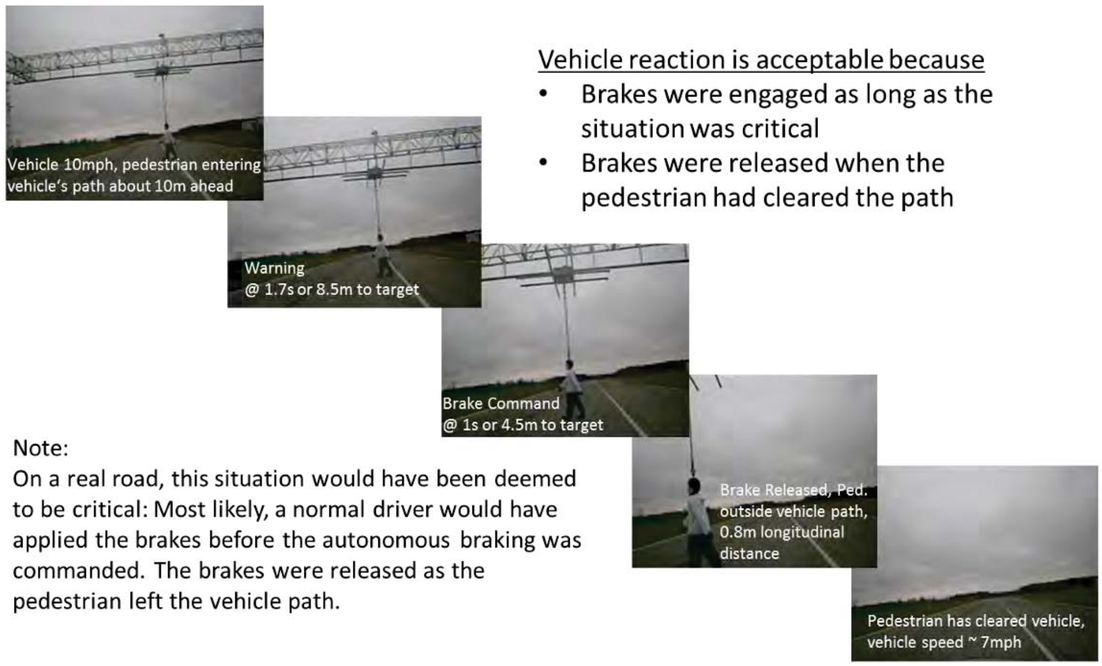


Figure 140: Example of Acceptable Vehicle Reaction From Analysis of O1 Mannequin Clears Path Operational Test

In other cases, autonomous braking would have been objectionable to the driver. Those cases included turning maneuvers with an actively engaged driver (O2, O3) and straight driving with the mannequin sufficiently outside of the vehicle's path such that the situation was not critical.

Based on the criticality of the scenarios, the operational test series were analyzed using the following criteria.

1. Autonomous braking unacceptable:
   - O1 walking mannequin stops 1m short before test lane
   - O2, O3 turning scenarios
   - Static mannequin ≥1m outside of vehicle path
2. Limited autonomous braking potentially acceptable:
   - O1 mannequin clears vehicle
   - Vehicle changing lane, mannequin outside of the vehicle path
   - Static or moving mannequin very close to vehicle (less than 1m from vehicle path)

Table 32 contains the list of tests that were conducted using all three vehicles. The table shows the number of autonomous braking activations along with the number of test runs executed for each vehicle. Also shown is the percentage of test runs that had brake requests. Potentially unacceptable braking activations are highlighted in the table. This analysis demonstrates that the operational test methods are capable of revealing undesireable vehicle reactions. This table also indicates that the PCAM Project vehicles, which were configured to provide higher functional performance, tended to generate more activations in some operational test conditions.

Table 32: Operational Test Results During Validation Testing Phase

Scenario	Description	Vehicle 1	Vehicle 2	Vehicle 3
O1	Mannequin clears vehicle	11 out of 12 (91%)	3 out of 10 (30%)	13 out of 20 (65%)
O1	Walking mannequin stops short before test lane	0 out of 11 (0%)	0 out of 10 (0%)	n/a
O2	Right turn, static mannequin outside vehicle path	0 out of 10 (0%)	6 out of 10 (60%) ✘	n/a
O3	Left turn, static mannequin outside vehicle path	0 out of 12 (0%)	3 out of 10 (30%) ✘	n/a
Lane Change	Vehicle lane change, static mannequin outside the vehicle path	0 out of 12 (0%)	9 out of 15 (60%) ✘	0 out of 6 (0%)
O4 static	Static mannequin outside the vehicle path (1 m outside of vehicle path)	0 out of 12 (0%)	0 out of 10 (0%)	0 out of 12 (0%)
O4 moving	Static mannequin walking away very close (< 1 m) to the right of the vehicle path	0 out of 9 (0%)	0 out of 16 (0%)	3 out of 7 (42%) ✘

✘ = potentially unacceptable braking activation

5 Support to NHTSA for Benefits Estimation Methodology Development and Coordination With Global PCAM Programs

5.1 Support for Benefit Estimation Activities

Under the project agreement, NHTSA's role included determining a methodology for estimating potential safety benefits for PCAM technologies. Within this effort, the PCAM Project:

- Defined target crash scenarios for PCAM systems (Section 2); and
- Provided sample PCAM system data from on-track and road testing conducted during the project for NHTSA/Volpe to use in exercising their proposed methodology.

To facilitate this task, a series of coordination meetings was held between NHTSA, Volpe and the PCAM TMT to review data and discuss benefits estimation methodology questions. Specific meetings were held as follows:

- July 27, 2011 – PCAM Task 2 Milestone Review during which the target pedestrian crash scenarios were finalized for development of test methods
- June 27, 2012 – Baseline test data review for the discussion of preliminary PCAM test results with the first set of exemplary data provided to Volpe and NHTSA
- November 11, 2012 – PCAM ROAD Trip data summary presented to Volpe and NHTSA as supportive information demonstrating the need to balance the functional performance of PCAM systems to mitigate or avoid potential crashes with pedestrians with operational scenarios experienced in regular day-to-day driving during which the systems activation is unwanted
- February 13, 2013 – Validation test data review with Volpe and NHTSA during which the final set of PCAM Project test data was presented and released for use as exemplary data for exercising Volpe's proposed benefits estimation methodology

5.2 PCAM Global Coordination Activities

During the project, NHTSA indicated a desire to harmonize PCAM test methods between the United States and Europe. In April 2010, NHTSA executed a Memorandum of Cooperation with BASt which outlined a framework for conducting the harmonization activities. Guided by this framework, NHTSA coordinated a series of working meetings between PCAM and BASt, including their respective collaborative research project organizations, to discuss harmonization of the pedestrian crash scenarios of interest and the test methods to assess system performance within these scenarios. In this context, the term test methods should be understood to include testing, such as the features of the test apparatus, pedestrian mannequin target characteristics, candidate sensing technologies, required data and the test procedures used for evaluating system performance. These meetings included the following:

- September 24-28, 2010 – Prior to starting the PCAM Project, TMT members visited Stuttgart and Munich, Germany for an Advanced Forward-Looking Safety Systems (vFSS) Project meeting and pedestrian collision avoidance/mitigation test demonstrations at two German OEMs. The information gained during this trip assisted with the development of the PCAM Project scope.
- November 10-11, 2011 – Following kick-off of the PCAM Project, an initial coordination meeting was held in Cologne, Germany at the BASt offices and included participants from BASt-sponsored projects. This meeting focused on comparisons of pedestrian crash data from the United States and Europe as well as a review of the various projects' scopes and test plans.
- January 24, 2012 – A second coordination meeting was held in Washington, DC to review the status of the related projects sponsored by NHTSA and BASt.
- October 16-17, 2012 – A third and final coordination meeting was held at the NHTSA-VRTC test facility in East Liberty, OH. This meeting included demonstrations of PCAM Project equipment and test methods.

6 Conclusions and Recommendations

The following conclusions and recommendations are based on the performance of the three project vehicles, as well as the PCAM system design experience among the project participants. It should be noted that these three vehicles represented varying degrees of system development ranging from near-production to advanced engineering prototypes. As such, the three vehicles provided different levels of performance and showed that the test methods were capable of measuring these performance differences. These vehicles used non-production computing processors and data acquisition equipment that allowed better analysis of the data, but may also have influenced system reaction latencies and their ultimate performance. Further assessment of production PCAM systems from different vehicle manufacturers should be conducted to identify the performance capabilities available in the U. S. market.

6.1 Functional Tests

6.1.1 CIB Tests

6.1.1.1 Scenario S1

S1 test scenarios are recommended for evaluating the functional performance of PCAM systems. These test scenarios represent 84 percent of all FYL and 59 percent of pedestrian fatalities from Volpe's analysis of 2005 to 2009 GES data. Test data shows that even the basic configuration for this test scenario (10 mph vehicle speed with unobstructed walking mannequin) is capable of measuring PCAM system performance differences. Including multiple vehicle test speeds also evaluates upper activation limits and the avoidance versus mitigation capabilities.

Running mannequin tests (10 km/h) proved difficult for eliciting PCAM system response for all three project vehicles. This can be attributed to two major factors. First, the combination of running mannequin speed and 10 mph vehicle speed chosen for testing yields initial movement of the mannequin which follows a path that is just outside or along the edge of the sensors' fields of view. Second, for on-center collisions at any vehicle speed, the running mannequin does not enter vehicle path until approximately 400 ms TTC. This equals the range of response time of conventional brake systems and does not allow for time needed for target detection and classification or system signal processing. For these reasons, running mannequin tests are not recommended at this time. Further assessment with other mannequin and vehicle speed combinations may be needed to refine this test scenario.

For obstructed S1 test cases, PCAM system performance notably degraded with reduced mannequin reveal times. While minimal difference in performance was noted between unobstructed tests and obstruction tests with 2.7 s reveal times, performance for all three vehicles significantly degraded with a reveal time of 1.3 s (less than 20 percent speed reduction). Volpe's analysis of 2005 to 2009 GES crash data showed that approximately 16 percent of S1 cases are obstructed by objects outside the vehicle and approximately 61 percent are unobstructed. However unobstructed tests are simpler tests to set-up, and a 2.7 s TTC reveal time is consistent with current proposals from BASt-sponsored projects. A reveal time of 1.3 s would be the shortest reveal time that should be considered if obstructed tests are included in minimum performance requirements testing and significant reduction in performance should be expected.

Table 33 contains the proposed minimum performance specifications for the S1 tests.

Table 33: Proposed Minimum Performance Specifications for S1 Tests

Vehicle Speed (mph)	Mannequin Speed (m/s)	Obstruction (Unobstructed or TTC Reveal Time in Seconds)	Recommended Performance Metric (% Composite Performance Speed Reduction)
10	1.4	Unobstructed or 2.7	80%
25	1.4	Unobstructed or 2.7	20%
10	1.4	1.3	<20%
25	1.4	1.3	<20%

6.1.1.2 Scenarios S2 and S3

S2 and S3 turning test scenarios are not recommended for evaluating functional performance. Collectively, S2 and S3 represent approximately 2 percent of all FYL and less than 1 percent of pedestrian fatalities from Volpe's analysis of 2005 – 2009 GES data. Test parameters for turning cases are also difficult to define due to the large variety of ways that turning scenarios can unfold and the wide variety of intersection geometries available on the roadways. Additionally, test conditions for turning cases are extremely difficult to control in a repeatable manner. Introducing turning scenarios as functional performance assessments could also lead to increased exposure to potential false activations.

6.1.1.3 Scenario S4

S4 test scenarios are also not recommended for evaluating functional performance of PCAM systems. S4 scenarios represent 10 percent of FYL and 8 percent of pedestrian fatalities, whereas S1 makes up 84 percent (and highest portion) of FYL and 59 percent of pedestrian fatalities from Volpe's analysis of 2005 – 2009 GES data. S4 test results indicated that project vehicles achieved better performance overall than the S1 scenarios, suggesting that S4 scenarios would be less challenging tests from a minimum performance criteria perspective. PCAM systems that address S1 cases should reasonably be expected to also address S4 cases. Based on these findings, it is reasonable to apply S1 test results from an evaluated system as a conservative estimate of the expected functionality of that system in an S4 scenario. Therefore, specific tests simulating S4 scenarios are not needed for estimating benefit in those conditions. Including S4 scenarios with moving mannequins also drives additional complexity to the test equipment with little benefit to system evaluation. This issue could be mitigated by using a stationary mannequin. The results from this study led to the conclusion that either S1 test results or stationary mannequin tests are reasonable predictors of PCAM system performance for S4 scenarios. Since S1 tests are already recommended as described in Section 6.1.1.1, it is more efficient to base estimates of S4 performance on the S1 test results rather than add another set of test conditions using stationary mannequins.

6.1.2 DBS Tests

For the DBS functional tests, the current NHTSA DBS test proposal (NHTSA, 2012) for vehicle-vehicle crashes was adaptable to pedestrian S1 test scenarios. Measureable differences were observed in the test results from DBS versus CIB performance in pedestrian test scenarios. The 0.3 g pre-braking provided by the brake robot changes the geometry of the scenario in such a way that the mannequin could be detected earlier and braking initiated by the PCAM system was more effective.

Proposed minimum performance specifications for DBS tests should be similar to those shown in Table 33. However, these performance levels could not be verified within the project since only one PCAM Project vehicle could be evaluated under these conditions. This may be an area for further research.

6.1.3 Other Important Test Parameters

6.1.3.1 Mannequin Set-up

All mannequin design conclusions are based on the selection of a 50th percentile adult male pedestrian representative. Additional work is needed to define the characteristics required for any other mannequin sizes desired, including children. However, the number of mannequin sizes considered should be minimized.

For the mannequin size evaluated, the mannequin arm spread of 13 inches from hand to center of hip for both arms (one forward, one rearward) and a leg spread of 20 inches (from heel to heel) were found to provide system detection and classification comparative to real humans for all three project vehicles. Mannequin support hardware should blend into the test background and mannequin as much as possible for the sensing systems evaluated. Articulation of the arms and legs may improve detection and classification of the mannequin, but was not required for pedestrian classification in the project vehicles tested. For PCAM systems using radar sensors, the mannequin should have a radar reflection and distribution that is consistent with that of the pedestrian size the mannequin is intended to emulate.

6.1.3.2 Lighting and Background Contrast

For PCAM system using camera sensors, mannequin clothing must contrast with the background at the selected test site. For the testing with the PCAM Project equipment, a white shirt and dark pants were found to provide detection and classification of the mannequin comparative to real humans for all three project vehicles. However, tests conducted on the VRTC equipment, which faced directly into the setting sun, required a different clothing combination to maintain contrast with the late-day background lighting. Another way to potentially address this issue would be to limit testing to avoid direct background sunlight, that is, testing should not be conducted with the test vehicle oriented into the sun during conditions when the sun angle is 15 degrees or less above the horizon.

A full definition of nighttime PCAM test procedures could not be developed within the framework of this project. This could be an area where future research is needed.

6.1.3.3 Mannequin Speed and Position

Accurate control of the mannequin speed and position is essential for repeatable data, and one of the most difficult test parameters to control. A servo drive system that accurately controls the position of the mannequin carrier is recommended. Also the attachment of the mannequin to the carrier is critical to avoid positional errors caused by acceleration, inertia, and wind at the test site. Accurate control and repeatability of the ground truthing equipment is required. In this project a differential GPS system was used both in the test vehicle and the mannequin carrier.

6.1.3.4 Vehicle Speed and Position Variation

Vehicle speed and position are also critical parameters that must be controlled to obtain repeatable data. This requires adequate track length to stabilize the vehicle speed and use of lane markers to guide the driver. On this project, traffic cones were used to mark the lane and Botts' dots were placed on either side of the vehicle to ensure that the vehicle stayed within desired path. The differential GPS system in the test vehicle continuously calculated a time-to-collision and transmitted a signal to the mannequin test equipment to start the mannequin motion at precisely the correct TTC value. In this way, only the variation in vehicle speed after the start of mannequin motion is important.

6.1.3.5 Obstruction Characteristics

For obstructed mannequin tests, a barrier needs to be placed alongside the track to screen the mannequin from the vehicle sensors. The barrier needs to be portable enough to be easily moved yet resistant to unintentional movement from the wind. A portable barrier, such as the one used in this project, needs to be large enough to hide the mannequin from vehicle sensors until the correct TTC value. This includes the time for the test equipment to accelerate the mannequin to the correct speed. The mannequin obstruction should be constructed of a material that hides the mannequin from the vehicle sensors. If radar sensors are used, the barrier should be constructed such that the radar signal is not reflected back at the car at nearly the same longitudinal range as the pedestrian target. The screen material that was used during PCAM performance testing was very effective in blocking vision system detection until the desired TTC reveal time. However, this material was nearly-transparent to the radar-based sensing systems. In the real world, although pedestrians do step out from behind obstructions, these obstructions are rarely screens with little depth as was used in the PCAM project. Therefore, a more realistic suggested obstruction for future testing would be a large radar-reflective box or "L" shaped target. This type of obstruction would block visibility of the pedestrian with a surface that would provide a radar reflection that is separated longitudinally by two or more meters from the path of the pedestrian target.

6.2 Operational Tests

The physical requirements of the tests are suggested to replicate the range of values observed in the field, but it should be noted that in real-world situations, false activations are rare and are often difficult to repeat. To address this, it is recommended that these tests be run as a series of repeated tests, run with randomly distributed physical characteristics that are within the wide ranges observed in real-world situations. However, autonomous braking may in some cases be acceptable as long as the situation is highly critical and there is no evidence that the driver is active. In the project vehicles used here, there was observed a relation between performance and probability for false events, which highlights the need to include *operational* tests in order to have a balanced assessment of PCAM system performance:

- Vehicle 1 showed limited composite performance during the functional tests but high robustness for operational test scenarios.
- Vehicles 2 and 3 showed high performance in the functional tests but also a greater sensitivity to some operational scenarios. Adjustments in the algorithm to prevent false activations might have an influence on the performance in functional configurations.

Table 34 presents the recommended operational test procedures for assessing the false positive potential of PCAM systems. These procedures are finalized versions of the test methods used during the validation phase of the project based on additional detailed analysis of the PCAM ROAD Trip data. The tables include a brief description of the test method, the updated test parameters, and a priority assessment regarding the importance of each scenario in a comprehensive PCAM test methodology.

Table 34: Recommended Operational Test Procedures

Scenario	Description	Vehicle Speed (mph)	Mannequin Speed (mph)	Vehicle Path	Notes:
O1	Similar to S1 but mannequin either stops short or clears the vehicle path 1 to 2 seconds before collision can occur	5 – 20	3.1	straight	High priority operational test since analysis of ROAD trip data indicated there were a significant number of potential False Precharge and FCW events.
O2	Similar to S2 but a static mannequin is positioned outside the vehicle path	10 – 15	Stationary mannequin positioned 1.0 m outside of the radius of vehicle's path	15 m radius curve	High priority operational test since analysis of ROAD trip data indicated there were a significant number of potential False Precharge and FCW events and some potential Autobraking events.
O3	Similar to S3 but a static mannequin is positioned outside the vehicle path	10 – 20	Stationary mannequin positioned 1.0 m outside of the radius of vehicle's path	20 m radius curve	High priority operational test since analysis of ROAD trip data indicated there were a significant number of potential False Precharge and FCW events and some potential Autobraking events.
O4	Similar to S4 but mannequin stays outside of the vehicle path	10 – 20	6.2 along path 1.0 m outside of vehicle path	straight	Low priority operational test since analysis of ROAD trip data indicated there were a small number of potential False Precharge and FCW events.

Scenario	Description	Vehicle Speed (mph)	Mannequin Speed (mph)	Vehicle Path	Notes:
Lane Change (Low Speed)	Vehicle encounters a pedestrian moving in a path parallel to the vehicle and just outside its path while changing lanes	10 – 15	Stationary mannequin positioned 1.0 m outside of vehicle path	1st turn of lane change @ 20 m range 2nd turn of lane change @ 10 m range	Medium priority operational test since analysis of ROAD trip data indicated there were a small number of potential False Precharge, FCW and Autobraking events.
Lane Change (High Speed)	Vehicle encounters a pedestrian moving in a path parallel to the vehicle and just outside its path while changing lanes	15 – 25	Stationary mannequin positioned 1.0 m outside of vehicle path	1st turn of lane change @ 30 m range 2nd turn of lane change @ 15 m range	Medium priority operational test since analysis of ROAD trip data indicated there were a small number of potential False Precharge, FCW and Autobraking events.
Curve Entrance	Vehicle encounters a pedestrian who is just past the beginning of a curved section of roadway such that the pedestrian appears to be in the path of the vehicle	10 – 20	Stationary mannequin positioned 1.0 m outside of vehicle path	20 m radius curve	Low priority operational test since analysis of ROAD trip data indicated there were a small number of potential False Precharge and FCW events.

7 References

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Appendix A Sixty-Seven Pedestrian Crash Scenarios Defined by the Volpe During Analysis of the National Databases

Driving Maneuvers Ranked by Pedestrian Fatalities

Rank	Maneuver	MAIS 2+	MAIS 3+	FYL
1	Going Straight & Improper Crossing Of Roadway Or Intersection	13,544	7,998	237,571
2	Going Straight & Darting or Running Into Road	10,075	4,570	99,661
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	2,639	1,614	48,339
4	Going Straight & Walking With Traffic	2,224	1,278	36,873
5	Going Straight & Inattentive (Talking, Eating, Etc.)	605	359	11,983
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	354	235	7,892
7	Negotiating a curve & Walking With Traffic	249	196	7,744
8	Going Straight & Walking Against Traffic	637	302	7,235
9	Turning left & Improper Crossing Of Roadway Or Intersection	964	334	4,621
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	96	75	2,889
11	Turning right & Improper Crossing Of Roadway Or Intersection	421	174	2,788
12	Passing or overtaking another vehicle & Darting or Running Into Road	135	82	2,733
13	Going Straight & Non-Motorist Pushing A Vehicle	105	76	2,406
14	Decelerating in traffic lane & Darting or Running Into Road	262	122	2,272
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	289	139	1,837
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	149	68	1,673
17	Turning left & Darting or Running Into Road	320	125	1,668
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	301	113	1,519
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	210	83	1,106
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	49	29	984
21	Starting in traffic lane & Improper Crossing Of Roadway Or Intersection	183	73	972
22	Turning left & Walking With Traffic	56	26	827
23	Starting in traffic lane & Darting or Running Into Road	159	58	785
24	Negotiating a curve & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	65	34	750
25	Passing or overtaking another vehicle & Non-Motorist Pushing A Vehicle	16	16	668
26	Leaving a parking position & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	116	48	638
27	Negotiating a curve & Darting or Running Into Road	141	45	636
28	Negotiating a curve & Jogging	20	16	571
29	Changing lanes & Darting or Running Into Road	113	43	570
30	Turning right & Jogging	34	20	560
31	Going Straight & Jogging	97	36	487
32	Changing lanes & Inattentive (Talking, Eating, Etc.)	52	25	326
33	Turning right & Darting or Running Into Road	66	24	321
34	Turning left & Jogging	78	20	307
35	Turning right & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	61	19	274

Driving Maneuvers Ranked by Pedestrian Fatalities (Continued)

Rank	Maneuver	MAIS 2+	MAIS 3+	FYL
36	Accelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	43	21	268
37	Passing or overtaking another vehicle & Improper Crossing Of Roadway Or Intersection	55	17	246
38	Changing lanes & Walking With Traffic	50	16	230
39	Accelerating in traffic lane & Darting or Running Into Road	37	16	212
40	Accelerating in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	32	15	196
41	Turning left & Inattentive (Talking, Eating, Etc.)	44	13	186
42	Turning left & Walking Against Traffic	32	14	184
43	Leaving a parking position & Improper Crossing Of Roadway Or Intersection	38	14	183
44	Leaving a parking position & Darting or Running Into Road	40	11	163
45	Passing or overtaking another vehicle & Inattentive (Talking, Eating, Etc.)	50	9	152
46	Decelerating in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	24	10	139
47	Passing or overtaking another vehicle & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	27	9	127
48	Negotiating a curve & Walking Against Traffic	20	7	96
49	Turning right & Walking With Traffic	21	7	94
50	Leaving a parking position & Walking With Traffic	13	6	83
51	Turning right & Walking Against Traffic	13	6	81
52	Passing or overtaking another vehicle & Jogging	16	4	61
53	Decelerating in traffic lane & Walking With Traffic	10	4	55
54	Turning right & Inattentive (Talking, Eating, Etc.)	10	4	51
55	Merging & Darting or Running Into Road	8	4	49
56	Decelerating in traffic lane & Inattentive (Talking, Eating, Etc.)	6	3	35
57	Making a U-turn & Improper Crossing Of Roadway Or Intersection	9	2	34
58	Changing lanes & Walking Against Traffic	5	1	20
59	Making a U-turn & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	4	1	17
60	Decelerating in traffic lane & Walking Against Traffic	4	1	16
61	Starting in traffic lane & Jogging	3	1	11
62	Entering a parking position & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	2	1	9
63	Starting in traffic lane & Inattentive (Talking, Eating, Etc.)	2	0	7
64	Entering a parking position & Inattentive (Talking, Eating, Etc.)	2	0	6
65	Making a U-turn & Darting or Running Into Road	2	0	6
66	Starting in traffic lane & Walking Against Traffic	2	0	6
67	Passing or overtaking another vehicle & Walking Against Traffic	1	0	3

Appendix B Analysis of CIB ROAD Trip Data

The CIB ROAD Trip was a data collection effort conducted as part of the previously completed CAMP CIB Project (Carpenter et al., 2011a). In this effort, two CIB Project vehicles equipped with video cameras, GPS instrumentation, CIB sensors and data acquisition systems were driven on public roads throughout the United States during a six-week period from July 24 through September 3, 2009. Although the original purpose of this effort was to acquire data for use in developing test methods for CIB systems, it was noted that the pedestrian encounters contained in this data could provide quantifiable details associated with pedestrian and driver actions that do not exist in the GES crash data analysis. Such information could be helpful in defining representative test methods for the PCAM *functional* scenarios. Within the PCAM Project, functional tests evaluate whether a PCAM system correctly activates when system activation is warranted

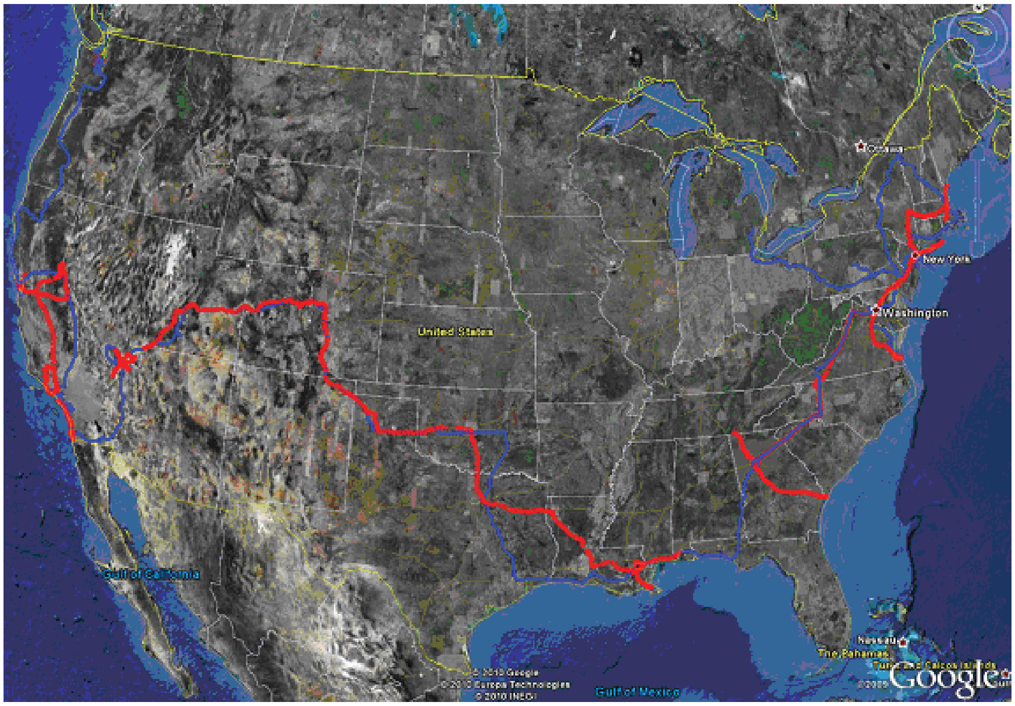
During the PCAM Project, the CIB ROAD Trip data was analyzed to extract specific test parameter information where pedestrians were observed in order to enhance the confidence in the PCAM test methods. This appendix presents the results of the analysis.

The two project vehicles used during the CIB ROAD Trip collected data in significantly different ways. Vehicle E, as designated in the CIB Final Report (Carpenter et al., 2011a), recorded continuous data including full video and GPS locations for the entire trip duration. Real time video data to evaluate pedestrian observations was supplemented by vehicle speed and GPS location to gain further insight. Vehicle E was equipped with environmental sensors from the CIB Project, but was not capable of pedestrian object classification. Therefore, the data was reviewed manually and then sorted and analyzed for various vehicle and pedestrian observations. In all, 4,324 discrete pedestrian scenarios were observed in the data for Vehicle E.

Vehicle H, as designated in the CIB Final Report (Carpenter et al., 2011a), also recorded full video including speed and GPS locations. Unlike Vehicle E, however, this vehicle was capable of pedestrian object classification. Even though the pedestrian object classification was not a production system, this analysis offers helpful insight on potential false positives that also needed to be understood for the PCAM ROAD Trip conducted later in the project. In all, 2,521 objects were identified as pedestrians in the data for Vehicle H.

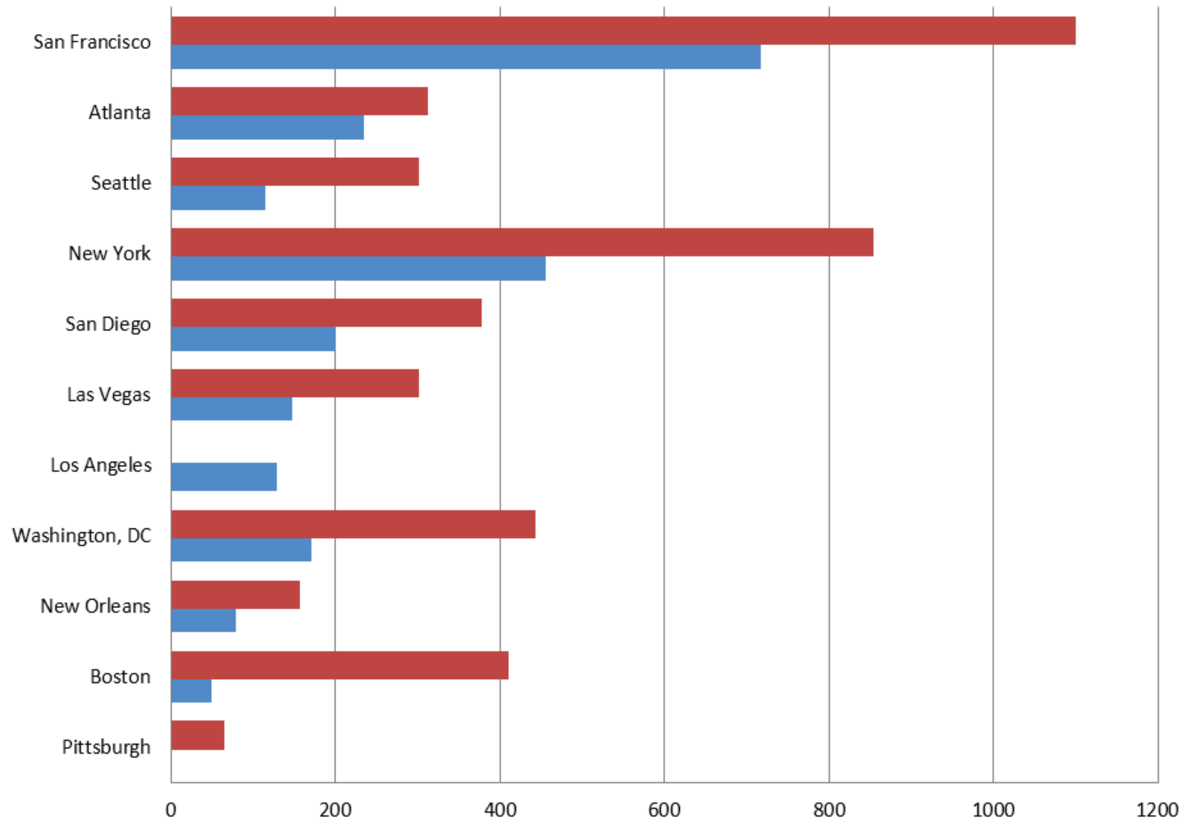
Due to the differences in vehicle setup, Vehicle E was used to understand pedestrian activity and scenario classification, whereas Vehicle H was used to understand potential false positive behavior of future PCAM systems.

Figure 141 illustrates the vehicle routes of both test vehicles during the CIB ROAD Trip. The 11 major U.S. cities visited and analyzed (between both vehicles), as well as the total observations and observation rates, are shown in Figures 142 and 143, respectively. An observation for Vehicle E was a manual classification of pedestrian activity made by a data analyst, while an observation for Vehicle H is when the sensor system classified an object as a pedestrian threat (consequently, Vehicle H had significantly less observations).



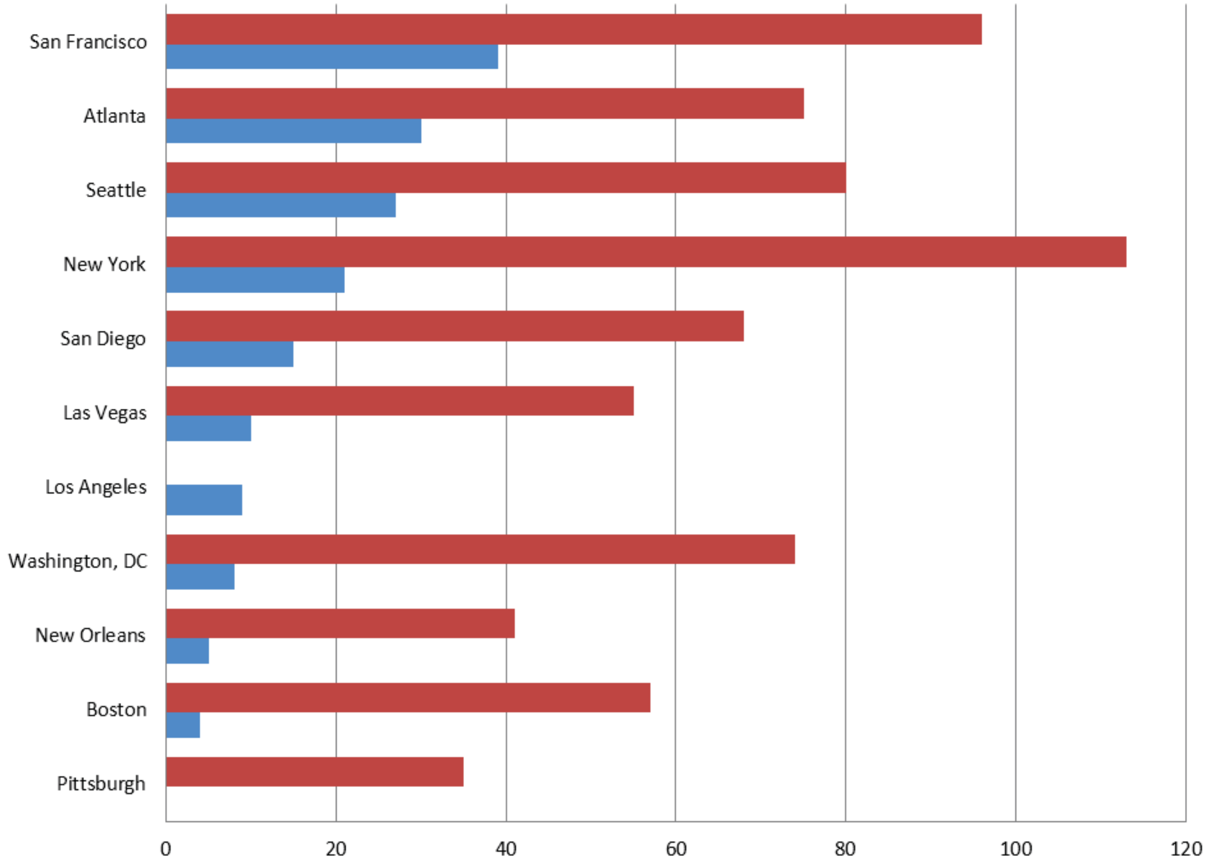
© 2010 Google. © 2010 Europa Technologies. U.S. Dept. of State Geographer. © 2010 Tele Atlas. Used with permission.

Figure 141: CIB ROAD Trip Route for Vehicle E (in Blue) and Vehicle H (in Red)



	Pittsburgh	Boston	New Orleans	Washington, DC	Los Angeles	Las Vegas	San Diego	New York	Seattle	Atlanta	San Francisco
Vehicle "E" Total Observations	65	411	156	443		301	378	855	301	313	1101
Vehicle "H" Total Detections		49	79	171	128	148	201	455	115	234	717

Figure 142: Total Observations for Each City (Vehicle E) and Detections (Vehicle H)



	Pittsburgh	Boston	New Orleans	Washington, DC	Los Angeles	Las Vegas	San Diego	New York	Seattle	Atlanta	San Francisco
Vehicle "E" Observations/hour	35	57	41	74		55	68	113	80	75	96
Vehicle "H" Detections/hour		4	5	8	9	10	15	21	27	30	39

Figure 143: Observations Rate (Observations per Hour) for Each City (Vehicle E and Vehicle H)

Since there were no actual crashes during the CIB ROAD Trip, the purpose of analyzing the ROAD Trip videos was to observe the frequency of potential conflicts with pedestrians. A "potential conflict" is an event in which a pedestrian is deemed to be in the path, or potentially in the path, of the subject vehicle and could be struck. For Vehicle E, the "potential conflict" determination was made subjectively by a data analyst, while for Vehicle H the determination was made by a predefined algorithm that was installed as part of the vehicle's CIB system.

Five scenarios, referred to as S1-S5, were used to classify the ROAD Trip observations in the analysis. Scenarios S1 through S4 are shown in Figure 144. These four scenarios correspond directly with the four PCAM crash scenarios (S1 through S4) defined earlier in Section 2.1 as the pedestrian crash scenarios with the highest FYL. Scenario S5 (with its variations a, b and c) is shown in Figure 145 and was defined for this analysis only to better understand potential conflicts and false positives associated with nearby bystanders that are not in the direct path or projected to be in the path of the approaching vehicle.

This type of information was not available in the analysis of the national crash databases but was deemed important in formulating the initial operational test scenarios for the validation testing planned for Task 4.

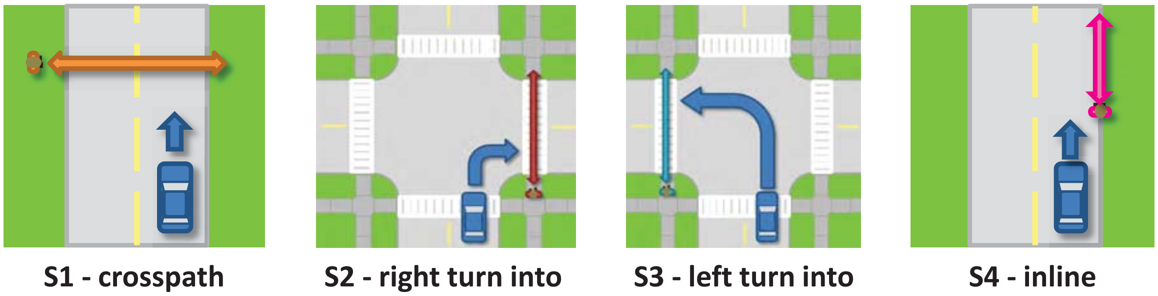


Figure 144: Observations Classified using PCAM Scenarios S1 through S4

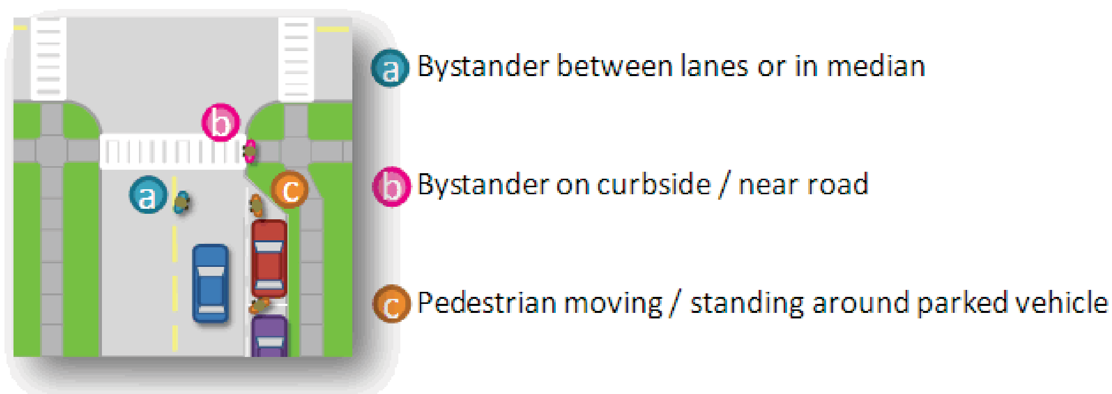


Figure 145: Additional Classification Scenario S5a-c for Bystander and Potential False Positives in Field

B.1 CIB ROAD Trip Analysis for Vehicle E

The vast majority of the data collected during the CAMP CIB ROAD Trip was gathered in daylight conditions on dry roads. Ninety-two percent of the data was collected under daylight conditions. The remaining data included night conditions (5%) and dusk conditions (3%).

The pedestrians observed on the CAMP CIB ROAD Trip were mostly in large cities. Only 2 percent of the observations were children under three feet tall (approximately) as shown in Figure 146. All of the children observed during the ROAD Trip were accompanied by an adult.

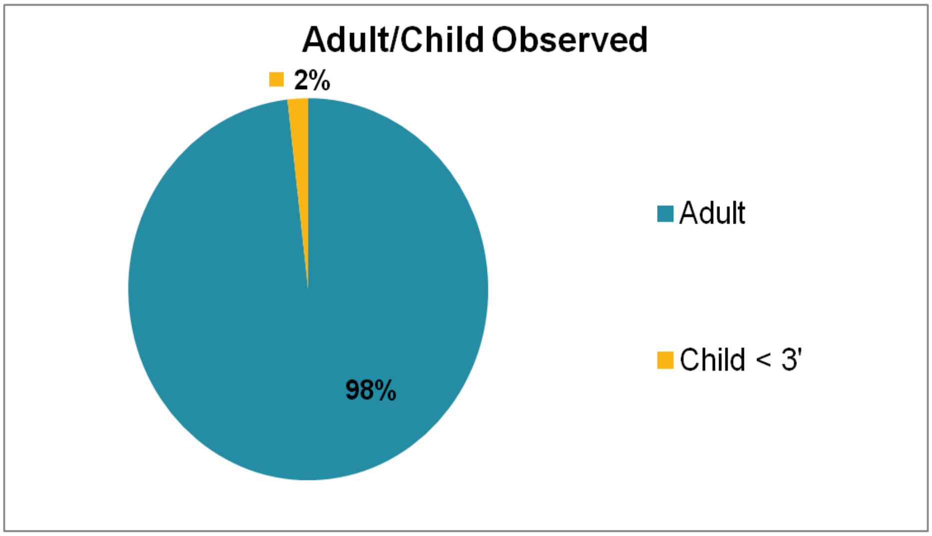


Figure 146: Adult and Child Observations (4,324 Observations)

All scenarios observed during the CIB ROAD Trip are shown in Figure 147. The most frequently observed category of pedestrians was bystanders (S5a, b, c) at 37 percent. Bystanders near the roadside (S5b) accounted for 25 percent of the data and 9 percent involved pedestrians around a parked car (S5c). Although these scenarios were documented during the analysis, the S5 scenario (including variations a-c) do not involve any of the vehicle-pedestrian maneuvers defined for the project (i.e., S1 – S4) and were examined to understand the potential for false positive during real-world driving.

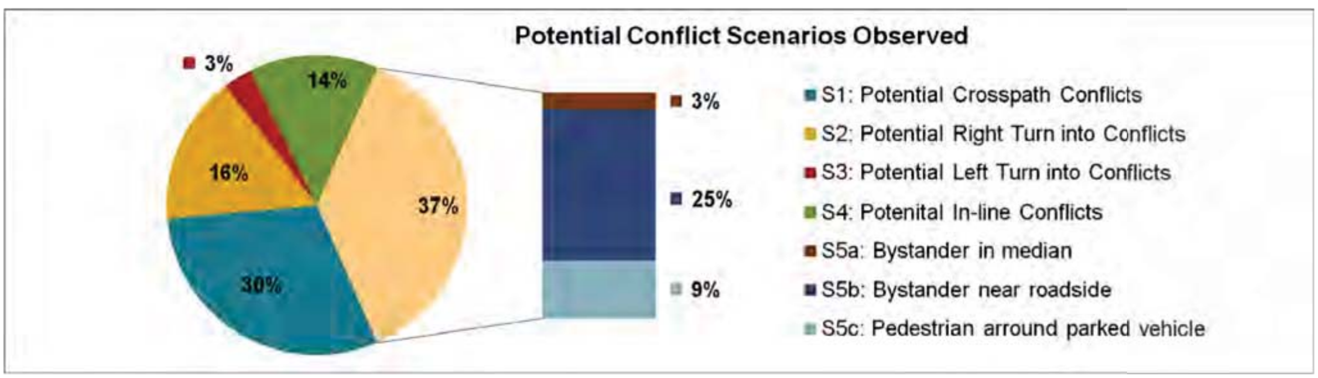


Figure 147: Scenarios S1-S5 Observed During the CIB ROAD Trip (4,324 Observations)

Figure 148 provides insight on the distribution of the PCAM test scenarios that were identified by Volpe. Figure 148 shows that 48 percent of the observations were pedestrians crossing the path of the project vehicle (S1). The least observed scenario was the left turn scenario (S3). However, this may be due to the limited viewing angle of installed vision sensors.

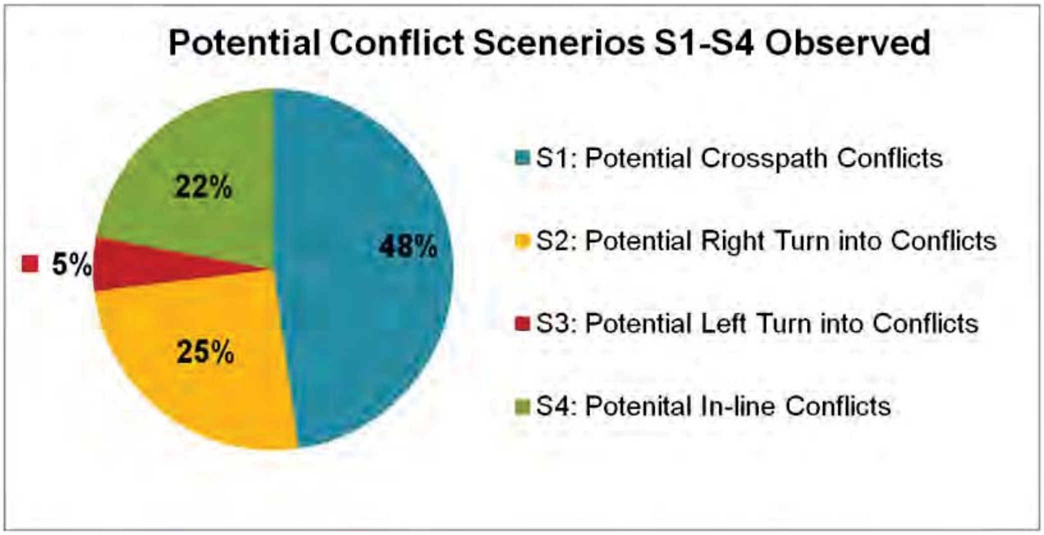


Figure 148: All PCAM Test Scenarios (S1-S4) Observed During the CIB ROAD Trip

B.1.1 S1: Potential Cross Path Conflicts

A total of 1,306 observations were classified for Scenario 1, which involved either a single pedestrian or group of pedestrians crossing the street in front of the host vehicle. Pedestrians crossing the street both properly (at a crosswalk) and improperly (jaywalking) were counted and classified. Scenario 1 was observed at speeds below 35 mph (with one exception) and in all traffic conditions. Pedestrians crossing the path of the vehicle were counted if they were within two car lengths of the host vehicle and clearly visible. See Appendix C for examples.

In the S1 scenario, 583 of the 1,306 observations occurred when the subject vehicle speed was equal to or greater than 1 mph and of these 95 percent of the subject vehicle speed was between 1 – 25 mph. This information is depicted in Figure 149, which indicates that only one observation occurred with a vehicle speed above 35 mph.

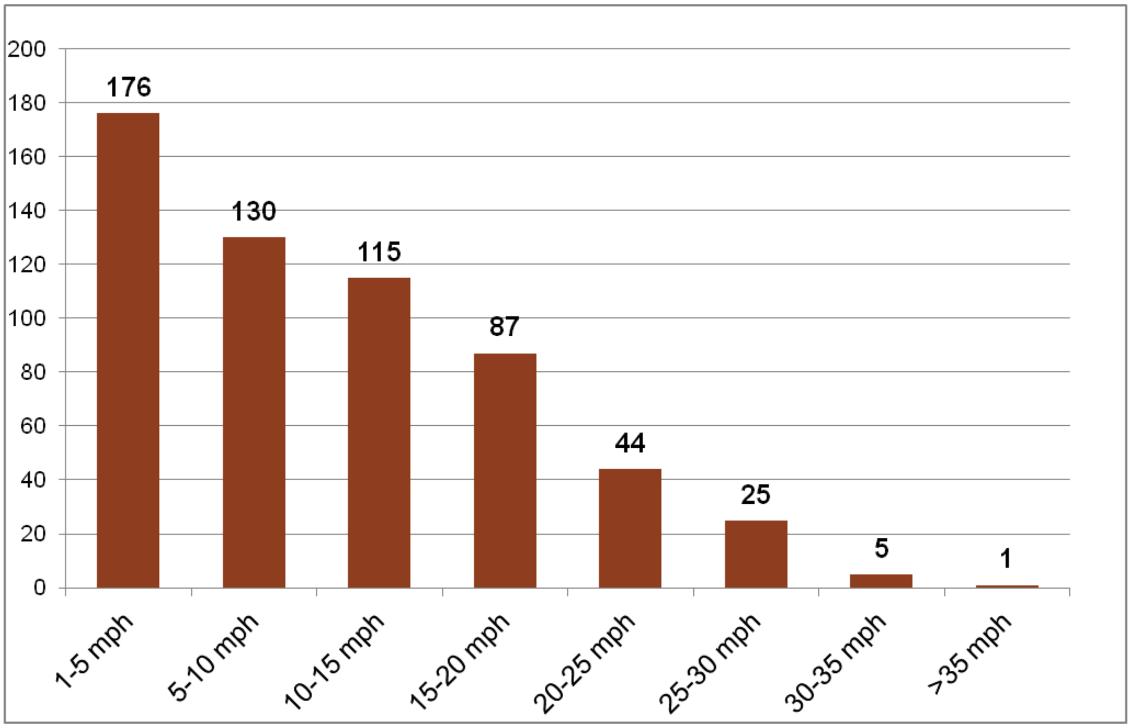


Figure 149: Subject Vehicle Speed Counts Observed for Scenario S1 (Vehicle E)

As shown in Figures 150 through 152, the majority of the pedestrians were unobstructed, moving equally from left to right or right to left and walking across the vehicle's path.

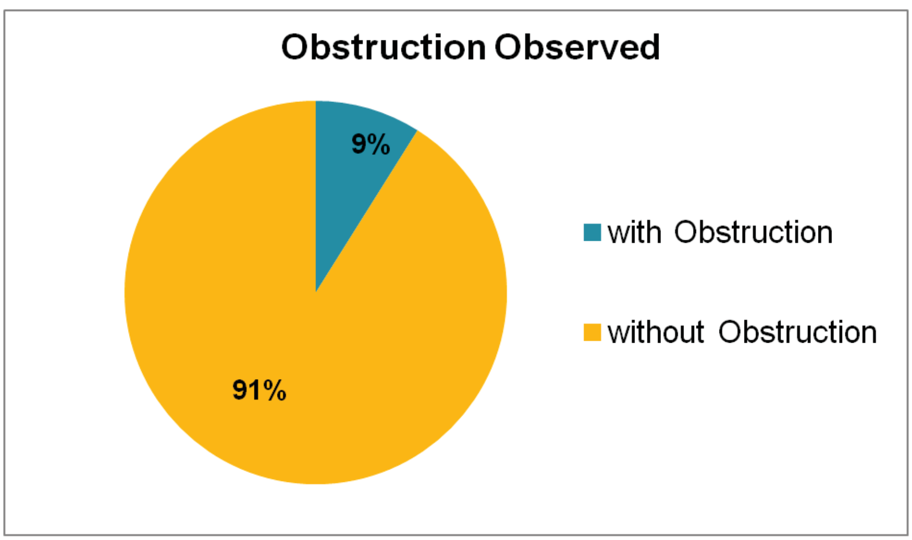


Figure 150: Obstruction Observations for Scenario S1 (Vehicle E)

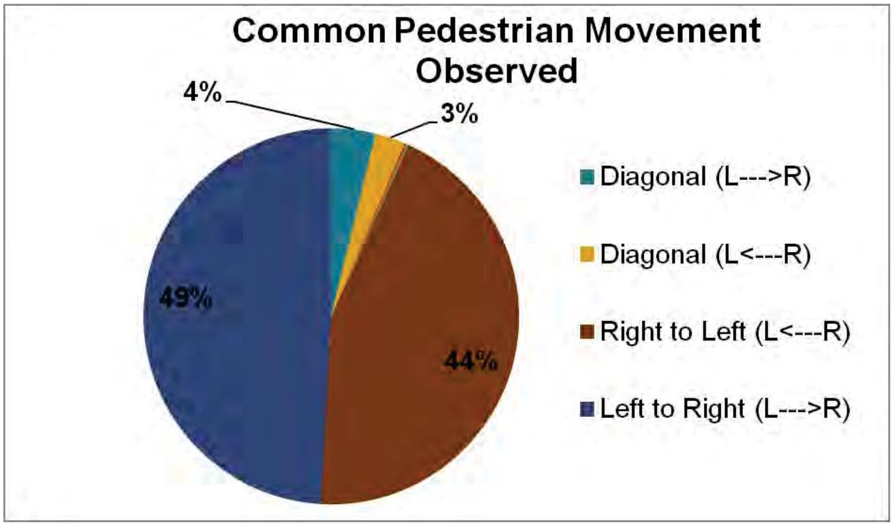


Figure 151: Pedestrian Movement Observed for Scenario S1 (Vehicle E)

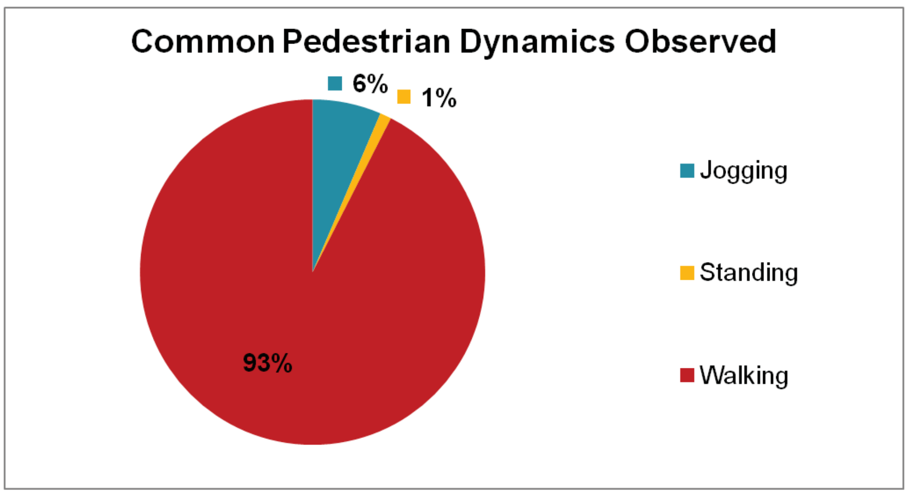


Figure 152: Pedestrian Dynamics Observed for Scenario S1 (Vehicle E)

B.1.2 S2: Potential Right Turn into Conflicts

There were 691 observations classified for Scenario 2, which involved pedestrians crossing the street both properly and improperly. Scenario 2 was observed at a wide range of vehicle speeds and at a variety of intersection types. Pedestrians in a potential right turn into conflict were counted when the host vehicle was turning right and they were in the path of the vehicle. In addition, pedestrians were also counted under the following two conditions. First, the occurrence was counted if the host vehicle could have legally turned right and had a conflict with a pedestrian, but instead continued heading straight (as shown by the “ghost” arrow in Figure 144 for S2). Second, an occurrence was also counted if a clearly visible vehicle traveling one or two positions ahead of the host did or could have had a conflict with a pedestrian in a legal right turn. Situations where the host vehicle was not directly involved with a right turn into conflict were labeled with a “host vehicle did not turn” tag. These cases were classified since they were still considered as potential crash conflicts between the observed pedestrians and vehicles. It should be noted that the camera used to record the road scene for this analysis had a limited field of view. Hence, the data recorded is limited to what was available in the camera’s view and other occurrences just outside the field of view would not have been observed by the data analyst.

Similar to Scenario S1, the majority of the pedestrians were unobstructed, moving equally from left to right or right to left and walking across path.

In addition, vehicle speed was examined to identify the “typical” approach speed for right-turning vehicles observed for the S2 scenario. To obtain the speed data, the analyst recorded the vehicle’s speed at the time a pedestrian was first observed in the road scene camera. The 691 cases observed for S2 were then filtered to retain only those observations in which the vehicle actually turned right. The resulting sample of right-turning vehicles included 406 observations (or 59% of the total observations for this scenario). Figure 153 presents the distribution of speeds observed in the filtered data sample. Note that the frequency of occurrence is also shown at the top of each bar in a speed category. As can be seen in the figure, 75 percent of the observations involved vehicle approach speeds of 25 mph or less. The most frequently occurring approach speed was in the range of 5 to 10 mph.

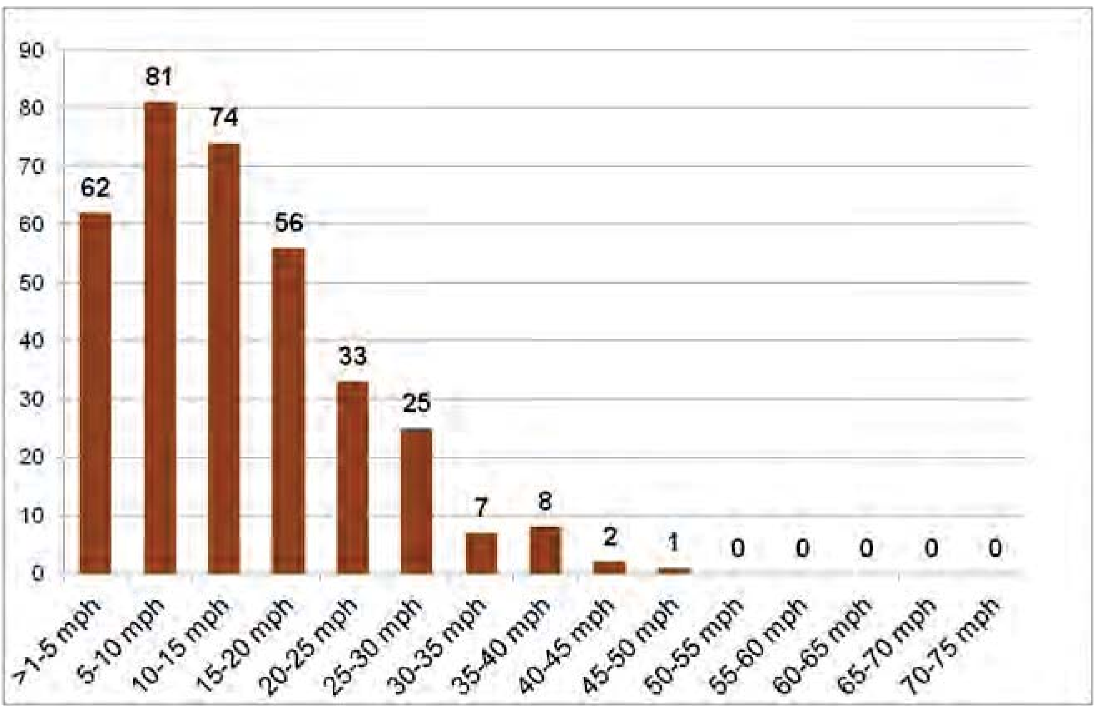


Figure 153: Subject Vehicle Speed Counts for Right-Turning Vehicles Observed for Scenario S2 (Vehicle E)

B.1.3 S3: Potential Left Turn Into Conflicts

Only 133 observations were classified for Scenario 3, which involved pedestrians crossing the street both properly and improperly. Scenario 3 was observed at a wide range of vehicle speeds and intersection types. Pedestrians in a potential left turn into conflict were counted when the host vehicle was turning left and they were in the path of the vehicle. In addition, pedestrians were also counted in two additional conditions. First, the occurrence was counted if the host vehicle could have legally turned left and potentially resulted in a conflict with a pedestrian, but continued heading straight (as shown by the “ghost” arrow in Figure 144 for Scenario S3). Second, an occurrence was also counted if a clearly visible vehicle traveling one or two positions ahead of the host vehicle did or could have a conflict with a pedestrian in a legal left turn. Situations where the host vehicle was not directly involved with a left turn into conflict were labeled with a “host vehicle did not turn” tag. These cases were classified since they were still considered as potential crash conflicts between the observed pedestrians and vehicles.

Similar to Scenario S2, vehicle speed was examined for the S3 scenario to identify the “typical” approach speed for left-turning vehicles. Again, vehicle speed was recorded by the analyst at the time a pedestrian was first observed in the road scene camera. The data were subsequently filtered to retain only those observations in which the vehicle actually turned left. The resulting sample included 103 of the 133 observations recorded for S3 (77%). Figure 154 presents the distribution of speeds observed in the filtered data sample along with the frequency of occurrence for each speed category. As shown in this figure, 91 percent of the observed approach speeds were 25 mph or less. The most frequently occurring observed approach speed was in the range of 5-10 mph, the same as for right-turning vehicles in Scenario S2.

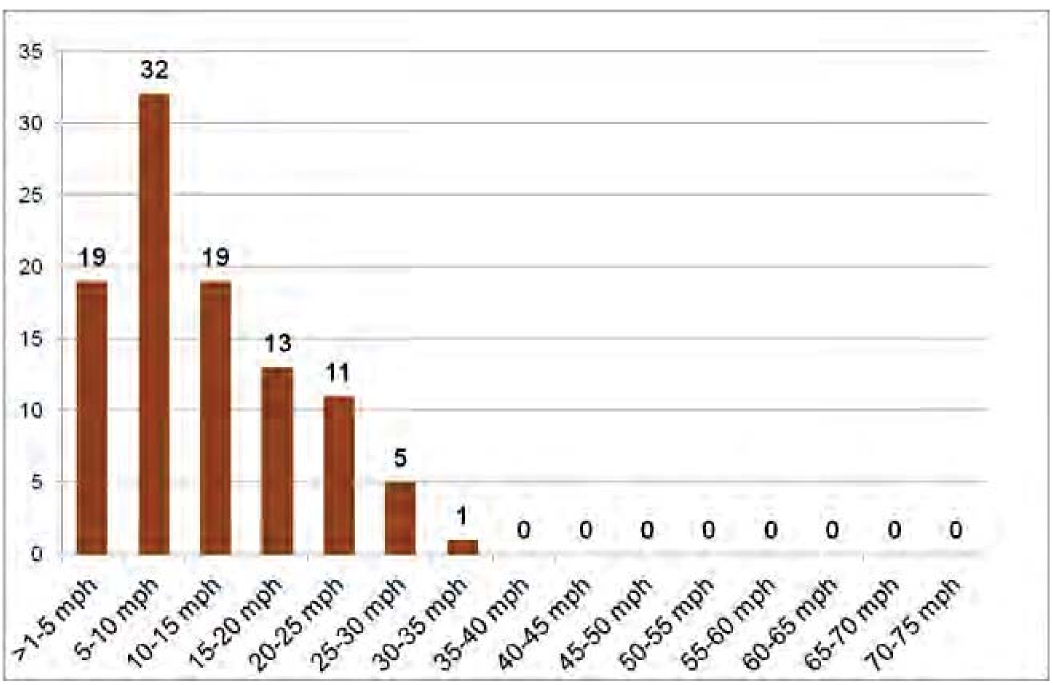


Figure 154: Subject Vehicle Speed Counts for Left-Turning Vehicles Observed for Scenario S3 (Vehicle E)

Since the vision system on the video logging equipment had a limited view of pedestrians during a potential left turn scenario, the data is limited and the occurrences are lower than might be expected. The field of view limitation is even more constraining in left turn situations than when compared to right turns. This is because the pedestrians in the left turn scenarios are typically one or two lanes offset from the vehicle's path and even further out of the field of view than in right turns.

B.1.4 S4: Potential In-Line Conflicts

There were 604 observations classified for Scenario 4, which involved a single pedestrian or group of pedestrians moving in-line with the host vehicle. Scenario 4 was observed at a wide range of vehicle speeds and traffic conditions. On a two-way street, pedestrians within approximately three feet of the edge of the road on the right hand side of the vehicle were counted. On a one-way street, pedestrians within three feet of the edge of the road on both sides of the vehicle were counted. In a small number of city situations, the sidewalk is within three feet of the edge of the road (usually the curb), and in this case, pedestrians were only counted when they were especially close to the curb. The pedestrian was counted even if the host vehicle was not in the lane nearest to the pedestrian. See Appendix C for examples.

In the S4 scenario, 512 of the 604 observations occurred when the subject vehicle speed was equal to or greater than 1 km/h and, of these, 95 percent of the subject vehicle speeds were between 1- 40 mph. This information is depicted in Figure 155.

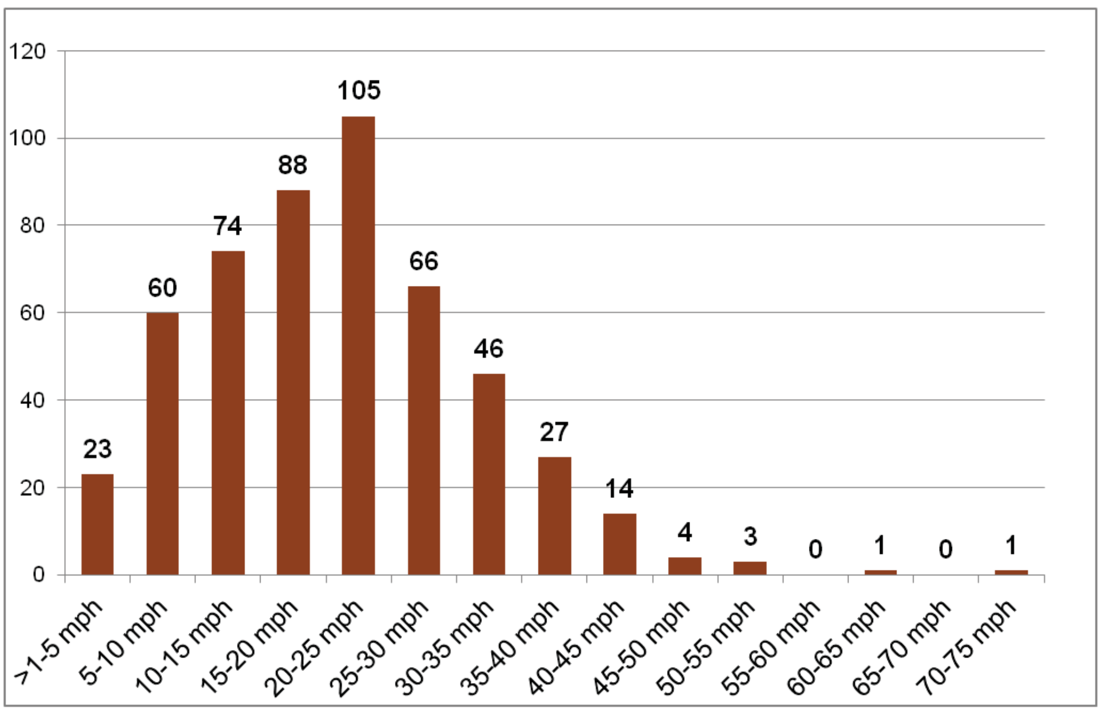


Figure 155: Subject Vehicle Speeds Observed for Scenario 4 (Vehicle E)

Figure 156 through Figure 158 illustrate common pedestrian dynamics observed during the CIB ROAD Trip. Figure 156 shows that the vast majority of pedestrians were observed without obstructions (96%). Figure 157 illustrates that pedestrians were moving with traffic or away from traffic in approximately equal percentages. Finally, Figure 158 shows that pedestrians were walking when observed during the study (92%).

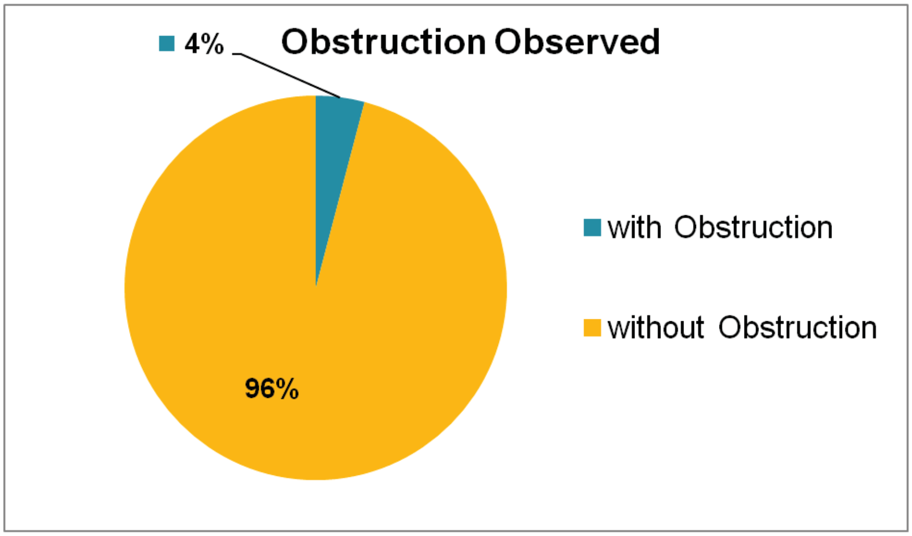


Figure 156: Obstruction Observations for Scenario 4 (Vehicle E)

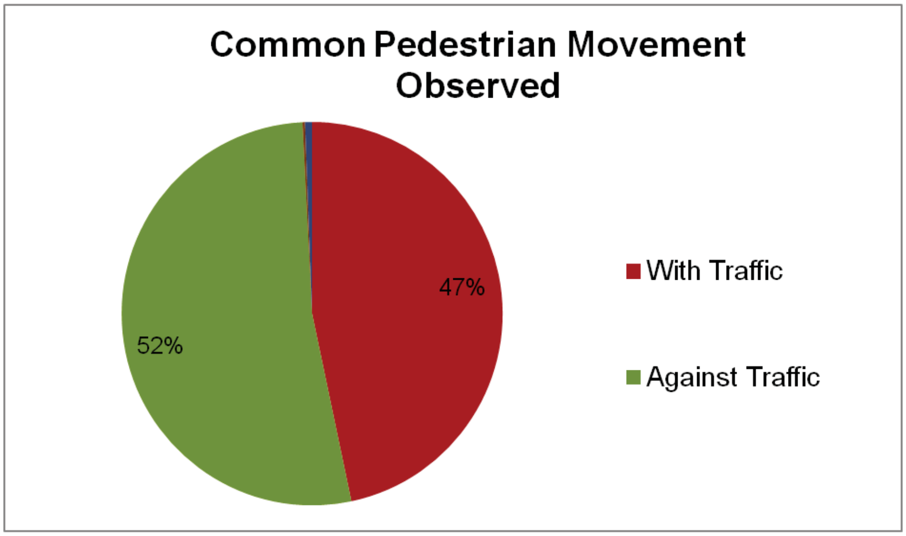


Figure 157: Pedestrian Movement Observed for Scenario 4 (Vehicle E)

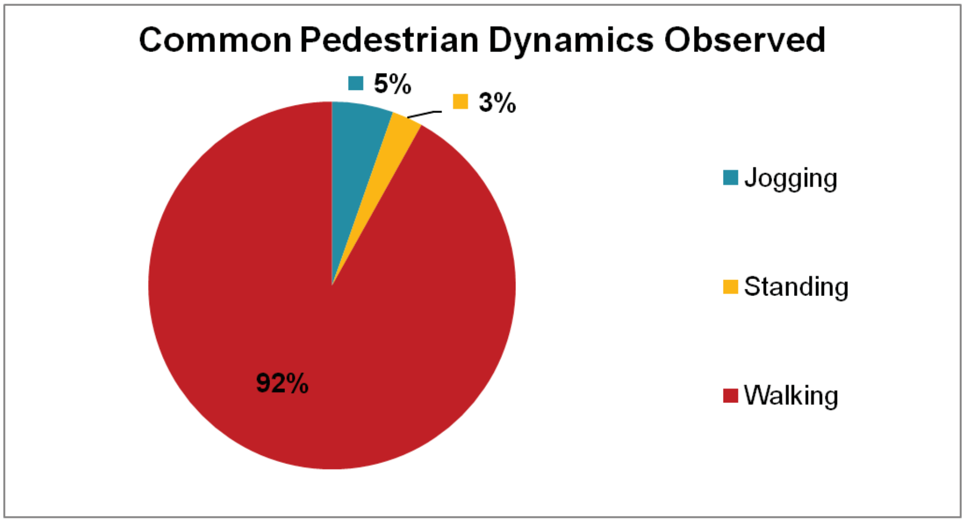


Figure 158: Pedestrian Dynamics Observed for Scenario 4 (Vehicle E)

B.1.5 S5a, b, c: Bystanders and Potential False Positives

There were 1,590 observations classified as bystanders in Scenario 5. Scenario S5a applied to bystanders between lanes or in the median. S5b applied to bystanders on the curbside or near the road. As in S4, pedestrians were considered near the road if they were within approximately three feet of the edge of the road (usually the curb). On two-way streets, only pedestrians on the right side of the road could be counted, whereas pedestrians on both sides of one-way streets could be counted. S5c applied to pedestrians moving or standing around parked vehicles. This scenario focused on pedestrians near cars that were parked on the roadside. Frequently occurring S5c situations involved people getting in and out of vehicles, people unloading trunks, people preparing to jaywalk between parked cars, delivery drivers walking around and unloading trucks, and construction workers working near roadside equipment.

Appendix C Examples of Various Scenarios for Vehicle E

Several examples of each scenario extracted from video recorded by the camera in Vehicle E are provided below.

C.1 S1:Potential Cross-Path Conflicts

Figures 159 through 161 illustrate examples of pedestrian occurrences that were classified as S1.

Figure 159 shows an improperly crossing pedestrian directly in front of the host vehicle. Figure 160 shows another improperly crossing pedestrian within two car lengths of the host. Figure 161 shows properly crossing pedestrians, and although they were not directly in front of the host vehicle, they were clearly visible and within two car lengths shortly after this screenshot was taken. Therefore, this occurrence was also classified as an S1 case.

Figure 159: Example of Pedestrian Crossing in Front of Host Vehicle

Figure 160: Example of Pedestrian Crossing Within Two Car Length of Host Vehicle

Figure 161: Example of Crossing Pedestrians Not Directly in Front of Host Vehicle

C.2 S2: Potential Right Turn into Conflicts

Figures 162 through 164 show examples of occurrences that were classified as S2.

Figure 162 shows pedestrians crossing at the start of a right turn.

Figure 163 shows a situation where the vehicle two cars ahead of the host vehicle could have legally made a right turn (but incidentally did not) and had a conflict with a pedestrian. Since the vehicle is only two car lengths ahead of the host and the potential pedestrian conflict is clearly visible, this event was classified as S2. Since the host vehicle was not directly involved in the conflict, the event would be tagged as “host vehicle did not turn.”

Figure 164 shows another vehicle approximately two car lengths ahead of the host, but this time at an unconventional intersection. Despite the lack of a traditional intersection, the event occurred during a right turn and would therefore be classified as S2. Again, this event would be tagged a “host vehicle did not turn” since the host vehicle was not involved in the event.

Figure 162: Example of Pedestrians Crossing at the Start of a Right Turn

Figure 163: Example of Potential Pedestrian Conflict Affecting a Vehicle in Front of Host Vehicle

Figure 164: Example of Potential Pedestrian Conflict Resulting From an Unusual Intersection Geometry

C.3 S3: Potential Left Turn into Conflicts

Figures 165 through 167 show examples of occurrences that were classified as S3.

Figure 165 shows a direct conflict between the left turning host vehicle and a crossing pedestrian.

Figure 166 shows a situation where the pedestrian is not in direct danger of being struck by the host vehicle, but is still in close proximity. The subject remains a potential conflict, so the event is classified as S3.

Figure 167 shows a situation where the host vehicle could have turned left and had a conflict but did not, making the event an S3 with tagged as a "host vehicle did not turn."

Figure 165: Example of a Potential Pedestrian Conflict as Host Vehicle Turns Left

Figure 166: Example of a Potential Pedestrian Conflict as Host Vehicle Turns Left

Figure 167: Example of a Potential Pedestrian Conflict if Host Vehicle Turned Left but Host Vehicle Continued Straight

C.4 S4: Potential In-Line Conflicts

Figures 168 and 169 show examples of occurrences that were classified as S4.

Figure 168 shows a direct inline conflict between the host vehicle and a jogger within three feet of the edge of the road (parking area notwithstanding).

Figure 169 shows a similar situation where the host vehicle happens to be traveling in a curve. Since there is no intersection involved, the event is classified as S4.

Figure 168: Example of a Direct In-line Potential Pedestrian Conflict

Figure 169: Pedestrian In-line Conflict in Which the Host Vehicle Is Traveling in a Curve

C.5 S5: Bystanders and Potential False Positives

Figures 170 through 175 show examples of occurrences that were classified as S5. Scenario S5 represents an additional scenario classification developed during the analysis of the CIB ROAD Trip data for bystanders and potential false positive situations that could occur in the field.

Figures 170 and 171 show examples of bystanders between lanes or in the median that were classified as S5a. Scenario S5a refers to bystanders between lanes in the roadway or in the median.

Figure 170 shows a pedestrian in the median looking to cross the street. She is very close to the edge of the road (curb) and is therefore a potential conflict classified as S5a.

Figure 171 shows a similar multiple pedestrian observation that is also an S5a event.

Figure 170: Example of S5a Pedestrian/Bystander on Median Near Roadside

Figure 171: Example of S5a Multiple Pedestrian/Bystanders on Median Near Roadside

Figure 172 and Figure 173 show examples of bystanders on the curbside or near the road that were classified as S5b. Scenario S5b refers to bystanders on the curb or near the road.

Figure 172 shows a bystander well within three feet of the right side of the road, and is therefore classified as S5b.

Figure 173 shows multiple bystanders, again within three feet of the right side of the road, making the event an S5b.

Figure 172: Example of S5b Pedestrian/Bystanders Near Roadside Curb

Figure 173: Example of S5b Multiple Pedestrian/Bystander Near Roadside Curb

Figures 174 and 175 show examples of bystanders moving or standing around parked vehicles that were classified as S5c. Scenario S5c refers to pedestrians moving or standing around parked cars.

Figure 174 shows a pedestrian unloading the trunk of a vehicle parked on the roadside, making the situation an S5c.

Figure 175 shows a bystander obstructed by a parked car and near the edge of the road, so this occurrence is also an S5c.

Figure 174: Example of S5c Pedestrian/Bystander Accessing or Loading Car a Parked Car

Figure 175: Example of S5c Pedestrian/Bystander Partially Obstructed between Parked Cars

Appendix D Crash Factors Relative to 20 Pedestrian Crash Scenarios

All tables in this appendix were provided by the Volpe National Transportation Systems Center.

Roadway Alignment

Rank (FYL)	Maneuver	Scenario Classification	Roadway Alignment: Straight	Curve	Grand Total
	OTHER SCENARIOS		153,675	7,509	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	49,625	544	50,169
2	Going Straight & Darting or Running Into Road	S1	47,584	344	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	8,480	168	8,649
4	Going Straight & Walking With Traffic	S4	8,231	232	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	2,631	15	2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	14	1,090	1,105
7	Negotiating a curve & Walking With Traffic	S4		750	750
8	Going Straight & Walking Against Traffic	S4	2,828	271	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	5,662	116	5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	228		228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,935	31	1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	294	307	601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	198		198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	1,051		1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	838		838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	644	14	658
17	Turning left & Darting or Running Into Road	S3	1,474	32	1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	1,486	16	1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	1,005		1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	462		462
	Total		288,346	11,440	299,786

Roadway Profile

Rank (FYL)	Maneuver	Scenario Classification	Roadway Profile: Level	Grade	Hillcrest	Sag	Grand Total
	OTHER SCENARIOS		140,777	18,771	1,504	133	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	45,657	4,028	460	24	50,169
2	Going Straight & Darting or Running Into Road	S1	42,475	4,985	440	28	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	7,392	1,058	198		8,649
4	Going Straight & Walking With Traffic	S4	6,968	1,408	87		8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	2,064	471	111		2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	955	149			1,105
7	Negotiating a curve & Walking With Traffic	S4	510	240			750
8	Going Straight & Walking Against Traffic	S4	2,364	736			3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	5,320	444	14		5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	168	59			228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,809	141	16		1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	579	22			601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	108	90			198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	976	74			1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	786	52			838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	596	43	19		658
17	Turning left & Darting or Running Into Road	S3	1,364	142			1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	1,098	394	10		1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	940	65			1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	443	19			462
	Total		263,350	33,391	2,860	185	299,786

Roadway Surface

Rank (FYL)	Maneuver	Scenario Classification	Roadway Surface Condition: Dry	Wet	Ice	Sand, dirt, or oil	Snow or slush	Other	Grand Total
	OTHER SCENARIOS		133,448	24,505	992	32	1,986	223	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	41,002	8,035	329	14	653	136	50,169
2	Going Straight & Darting or Running Into Road	S1	42,185	5,554	37	21	115	16	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	7,229	1,220	56	15	129		8,649
4	Going Straight & Walking With Traffic	S4	6,533	1,524	77		316	12	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	2,236	410					2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	1,054	51					1,105
7	Negotiating a curve & Walking With Traffic	S4	704	27			19		750
8	Going Straight & Walking Against Traffic	S4	2,520	247	294		39		3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	4,495	1,248	16		19		5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	213	14					228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,531	435					1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	556	45					601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	198						198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	994	57					1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	691	131			16		838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	465	193					658
17	Turning left & Darting or Running Into Road	S3	1,106	116			284		1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	1,398	104					1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	938	68					1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	443	19					462
	Total		**249,939**	**44,002**	**1,801**	**81**	**3,575**	**387**	**299,786**

Light Condition

Rank (FYL)	Maneuver	Scenario Classification	Light Condition: Daylight	Dark-Not lighted	Dark-Lighted	Dawn	Dusk	Dark-unknown lighting	Grand Total
	OTHER SCENARIOS		97,601	11,879	44,083	2,018	5,154	449	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	22,934	6,380	17,447	1,099	2,295	15	50,169
2	Going Straight & Darting or Running Into Road	S1	33,649	2,872	9,103	128	2,100	76	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	3,644	2,487	2,180	38	299		8,649
4	Going Straight & Walking With Traffic	S4	2,636	3,773	1,779	88	187		8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	1,631	505	496		15		2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	589	137	337	41			1,105
7	Negotiating a curve & Walking With Traffic	S4	442	259	34		14		750
8	Going Straight & Walking Against Traffic	S4	1,076	1,130	545	310	39		3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	3,626	502	1,103	280	267		5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	63	146	19				228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,170	144	384	253	15		1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	209	14	71	307			601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	96	90	12				198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	840	52	116		43		1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	277	144	396		21		838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	376	33	230		19		658
17	Turning left & Darting or Running Into Road	S3	1,029	47	418		12		1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	963	55	478	6			1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	576	122	295	12			1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	406		56				462
	Total		**173,834**	**30,771**	**79,582**	**4,578**	**10,481**	**539**	**299,786**

Weather

Rank (FYL)	Maneuver	Scenario Classification	Weather: No Adverse Atmospheric Conditions	Rain	Snow	Fog	Other: Smog, Smoke, Blowing Sand/Snow/Dust, Crosswind, etc.	Sleet	Sleet And Fog	Grand Total
	OTHER SCENARIOS		141,492	15,137	2,566	932	978	81		161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	43,513	5,778	431	259	178	9		50,169
2	Going Straight & Darting or Running Into Road	S1	45,256	2,108	219	210	96	38		47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	7,672	767	148	28	16	17		8,649
4	Going Straight & Walking With Traffic	S4	7,093	1,095	96	105	73			8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	2,561	84						2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	1,090	14						1,105
7	Negotiating a curve & Walking With Traffic	S4	735	14						750
8	Going Straight & Walking Against Traffic	S4	2,572	196	312				21	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	4,931	736	51	12	49			5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	213	14						228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,639	327						1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	571	30						601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	198							198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	1,013	38						1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	703	120				16		838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	498	160						658
17	Turning left & Darting or Running Into Road	S3	1,425	81						1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	1,417	64			21			1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	970	19		16				1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	443	19						462
	Total		266,007	26,802	3,822	1,563	1,409	161	21	299,786

Obscured Vision

Rank (FYL)	Maneuver	Scenario Classification	Fog	Rain, Snow, Fog, Smoke, Sand, Dust	Reflected Glare, Bright Sunlight, Headlights	Hit & Run Vehicle	Not on PAR	Not Coded	Unknown Whether Vision Was Obscured	Vision Obscured - No Details	Other Visual Obstruction	Broken or Improperly Cleaned Windshield	Inadequate Defrost or Defog System	Obstructing Angles on Vehicle	Obstruction Interior to the Vehicle	Building, Billboard, or Other Structure	Curve, Hill, or Other Roadway Design Feature	Moving In-Transport MV (Including Load)	Not-in-Transport MV (parked, working)	Trees, Crops, Vegetation	No Obstruction noted	Grand Total
			Vision Obscured By																			
			weather/light/glare			unknown if obstructed or unknown obstruction						obstructed by subject vehicle feature				Obstructed by outside obstacle						
	OTHER SCENARIOS			1,293	5,741	36,551	9,513	4,797	9,458	406	398	82	22	925	373	55	332	788	2,934	38	87,480	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1		964	381	4,133	2,852	2,277	1,315	352	88	34			21		17	1,267	3,996	48	32,425	50,169
2	Going Straight & Darting or Running Into Road	S1	27		155	1,370	1,907	1,823	1,731	92	74			21		211	105	1,612	9,936	67	28,796	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1		429	499	2,499	344	21	343		60	24						37	81		4,313	8,649
4	Going Straight & Walking With Traffic	S4		417	421	3,456	61	247	340		14						49				3,457	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1				79	303	14	19								95	147	137		1,853	2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1				323	14	16	23								52	15			662	1,105
7	Negotiating a curve & Walking With Traffic	S4				15	11	19			12						108				585	750
8	Going Straight & Walking Against Traffic	S4		37		1,321	85	38	148								12				1,457	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3		139	163	72	691	44	99	41		20			18			47	375		4,070	5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1				26	19		39										35	14	95	228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2		30	15	124	81	48	31	28						105					1,504	1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1					16												450		136	601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4																			198	198
14	Decelerating in traffic lane & Darting or Running Into Road	S1		52	52	12	67		31										177		660	1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1				21	16											10	15		776	838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1			14	14	64											85	17		463	658
17	Turning left & Darting or Running Into Road	S3		10	11	29		36	15		19							344		12	1,031	1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3		30	16	42	49	14	57									10	55		1,228	1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1				132	30		374												470	1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1					16		321		12								19		94	462
	Total		27	3,401	7,468	50,217	16,140	9,394	14,344	919	677	159	22	946	412	371	770	4,361	18,225	180	171,751	299,786

Corrective Action Taken

Rank (FYL)	Maneuver	Scenario Classification	Corrective Action Attempted												
			No Avoidance Maneuver	Accelerating	Accelerating and Steering Right	Steering Left	Steering Right	Braking (Lockup)	Braking (No lockup)	Braking and Steering Left	Braking and Steering Right	Braking (Lockup Unknown)	Other action	Unknown if Driver Attempted Corrective Action	Grand Total
	OTHER SCENARIOS		28,571	224		1,571	1,215	1,507	3,337	428	759	1,059	310	122,203	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	6,515		16	1,793	802	1,446	2,050	467	534	1,455	649	34,444	50,169
2	Going Straight & Darting or Running Into Road	S1	5,611		12	1,225	480	1,773	3,258	578	312	2,070	328	32,280	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	1,087			429	159	216	581	75	73	244	30	5,754	8,649
4	Going Straight & Walking With Traffic	S4	1,776			104	35	73	25	143	52		138	6,117	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	428			27	19	411	89			64	15	1,593	2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	295			12	16		52					729	1,105
7	Negotiating a curve & Walking With Traffic	S4	562						20					168	750
8	Going Straight & Walking Against Traffic	S4	465			109	52		64	52		12	20	2,326	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	628			12		15	11			53	41	5,019	5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	95			84								49	228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	556			12		12				20		1,366	1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1								16				586	601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4												198	198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	75						157		36	51		731	1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	123					126	35			114		441	838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	74						35	19		14	19	497	658
17	Turning left & Darting or Running Into Road	S3	515				26	18	48					899	1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	272			15								1,215	1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	677	34										295	1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	34											428	462
	Total		48,358	258	28	5,393	2,804	5,597	9,761	1,779	1,765	5,158	1,550	217,336	299,786

Pre-Crash Vehicle Control

Rank (FYL)	Maneuver	Scenario Classification	Pre-Crash Vehicle Control: Tracking	Skidding longitudinally->rotation less than 30 degrees	Skidding laterally->clockwise rotation	Skidding laterally->counterclockwise rotation	Precrash stability unknown	Other vehicle loss-of-control	Grand Total
	OTHER SCENARIOS		150,506	2,066	118	484	7,955	57	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	46,952	2,159		55	1,002		50,169
2	Going Straight & Darting or Running Into Road	S1	45,476	2,036			416		47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	7,777	515	35		322		8,649
4	Going Straight & Walking With Traffic	S4	8,136	125			202		8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	2,235	411					2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	814				291		1,105
7	Negotiating a curve & Walking With Traffic	S4	735				14		750
8	Going Straight & Walking Against Traffic	S4	2,461	27	21		591		3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	5,763	16					5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	228						228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,954	12					1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	546	55					601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	198						198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	1,030				20		1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	587	126			125		838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	639				19		658
17	Turning left & Darting or Running Into Road	S3	1,488	18					1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	1,477	25					1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	1,005						1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	462						462
	Total		280,470	7,591	173	540	10,956	57	299,786

Pre-Crash Location

Rank (FYL)	Maneuver	Scenario Classification	Pre-Crash Location: Vehicle Stayed In Traffic Lane	Vehicle Stayed On Roadway But Left Travel Lane	Vehicle Stayed On Roadway, Not Known If Left Travel Lane	Vehicle Departed Roadway	Vehicle Remained Off Roadway	Vehicle Returned To Roadway	Entered roadway	Vehicle Path After Corrective Action Unknown	Grand Total
	OTHER SCENARIOS		128,174	3,725	6,972	4,608	2,245	77	5,387	9,998	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	46,981	587	1,638	312	19		41	591	50,169
2	Going Straight & Darting or Running Into Road	S1	45,773	712	1,246	50			36	112	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	7,370	165	990				80	43	8,649
4	Going Straight & Walking With Traffic	S4	7,542	178	108	171				465	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	2,625			21					2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	747	16	51					291	1,105
7	Negotiating a curve & Walking With Traffic	S4	735			14					750
8	Going Straight & Walking Against Traffic	S4	1,783	521	631	21				144	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	4,594	12	302	17			853		5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	40	152	36						228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	1,874		12				80		1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1	195	390	17						601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	198								198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	1,051								1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	519	320							838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	589	69							658
17	Turning left & Darting or Running Into Road	S3	1,436						53	18	1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	1,210		52				240		1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	977	15						13	1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	107	20		31				304	462
	Total		**254,518**	**6,882**	**12,054**	**5,245**	**2,264**	**77**	**6,768**	**11,978**	**299,786**

Traffic Way

Rank (FYL)	Maneuver	Scenario Classification	Traffic Way: Divided Trafficway (median strip,barrier,etc)	One way traffic	Not physically divided (center 2way left turn ln)	Not physically divided (two way traffic)	Unknown	Grand Total
	OTHER SCENARIOS		14,046	7,329	4,052	70,259	65,498	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	11,294	1,527	3,324	21,351	12,674	50,169
2	Going Straight & Darting or Running Into Road	S1	7,070	2,157	1,898	24,567	12,236	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	886	368	365	4,823	2,207	8,649
4	Going Straight & Walking With Traffic	S4	544	238	304	6,335	1,042	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1	270	45	177	1,576	578	2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1	212	33	31	806	23	1,105
7	Negotiating a curve & Walking With Traffic	S4	26			723		750
8	Going Straight & Walking Against Traffic	S4	176	15	159	2,416	333	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	680	126	193	2,515	2,265	5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	109		32	86		228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	272	77	135	923	559	1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1			28	508	65	601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4	96			102		198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	485	34	22	479	31	1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1	210		197	241	191	838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1	217	49	141	135	117	658
17	Turning left & Darting or Running Into Road	S3	228	16	370	391	502	1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3	41	33	105	1,050	273	1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	81	55		476	393	1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1		40		91	331	462
	Total		**36,943**	**12,141**	**11,533**	**139,853**	**99,316**	**299,786**

Number of Lanes

Rank (FYL)	Maneuver	Scenario Classification	Divided Trafficway (median strip,barrier,etc)								One way traffic					
			One	Two	Three	Four	Five	Six	Seven or more	Unknown	One	Two	Three	Four	Five	Unknown
	OTHER SCENARIOS		452	5,391	3,158	2,078	542	55		2,372	2,549	1,321	1,435	755	42	1,227
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	138	4,792	4,017	1,550	370	65		361	933	102	331	103	12	45
2	Going Straight & Darting or Running Into Road	S1	152	2,771	2,145	902	228	380		490	1,290	238	449	37	17	126
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	29	217	399	152	35		13	42	208	35	52	73		
4	Going Straight & Walking With Traffic	S4	32	311	37	119				45	82	121				35
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1		122	148											45
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1		19	58					136	33					
7	Negotiating a curve & Walking With Traffic	S4		11	16											
8	Going Straight & Walking Against Traffic	S4	14	113	31	19						15				
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	10	158	45	105	286			76		56	50	20		
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1		80	19	10										
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2	12	189	38	33					15	16	35	11		
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1														
13	Going Straight & Non-Motorist Pushing A Vehicle	S4				96										
14	Decelerating in traffic lane & Darting or Running Into Road	S1		344	105	36					20	13				
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1		61	139	10										
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1		65	83	38	17			14			24			24
17	Turning left & Darting or Running Into Road	S3		17	43	140		10		18	16					
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3								41		16	16			
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1		16	45	20					55					
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1									20	20				
	Total		**840**	**14,675**	**10,525**	**5,307**	**1,478**	**511**	**13**	**3,594**	**5,221**	**1,956**	**2,392**	**999**	**71**	**1,502**

Number of Lanes (Continued)

Rank (FYL)	Maneuver	Scenario Classification	Not physically divided (center 2way left turn In)								Not physically divided (two way traffic)							
			One	Two	Three	Four	Five	Six	Seven or more	Unknown	One	Two	Three	Four	Five	Six	Seven or more	Unknown
	OTHER SCENARIOS			80	522	65	2,890	53	204	238	599	40,804	4,079	7,649	3,824	976	580	11,747
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1		29	267	138	2,304	34	506	46	39	11,426	1,248	4,509	1,438	541	232	1,919
2	Going Straight & Darting or Running Into Road	S1		36	462	10	1,172	24	104	90	40	14,000	724	4,411	1,254	80	273	3,784
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1			63		140	140		22	10	3,541	67	454	237	12	16	485
4	Going Straight & Walking With Traffic	S4			152		151				58	5,002	165	277	19			814
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1			16		161					1,144	12	60	19			341
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1			15		16					789			17			
7	Negotiating a curve & Walking With Traffic	S4										669						54
8	Going Straight & Walking Against Traffic	S4		80	11		68					1,819		22	33			542
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3	52			15	101			25	27	895	326	401	495			372
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1					32					39	14	33				
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2							80	55		318	12	200	27			366
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1							28			163		16				329
13	Going Straight & Non-Motorist Pushing A Vehicle	S4										102						
14	Decelerating in traffic lane & Darting or Running Into Road	S1							22			378	21	62				18
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1				20	143		35			26		11	25	126		52
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1					69	59	12			14			62		16	42
17	Turning left & Darting or Running Into Road	S3			11	16	20		323			252		38	51			50
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3					105					780	12	103				154
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1									22	347			16			91
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1										56		19				16
	Total		52	224	1,519	264	7,373	311	1,314	476	796	82,564	6,680	18,265	7,517	1,736	1,118	21,177

Number of Lanes (Continued)

Rank (FYL)	Maneuver	Scenario Classification	Unknown								Grand Total
			One	Two	Three	Four	Five	Six	Seven or more	Unknown	
	OTHER SCENARIOS		1,740	6,545	315	928	366	85	19	55,501	161,185
1	Going Straight & Improper Crossing Of Roadway Or Intersection	S1	334	1,940	176	422	17	276	11	9,497	50,169
2	Going Straight & Darting or Running Into Road	S1	924	1,921	136	128	17			9,109	47,927
3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1	64	73			12			2,058	8,649
4	Going Straight & Walking With Traffic	S4		194						848	8,463
5	Going Straight & Inattentive (Talking, Eating, Etc.)	S1		508						70	2,646
6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	S1								23	1,105
7	Negotiating a curve & Walking With Traffic	S4									750
8	Going Straight & Walking Against Traffic	S4	247							86	3,100
9	Turning left & Improper Crossing Of Roadway Or Intersection	S3		562	19	14				1,669	5,778
10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1									228
11	Turning right & Improper Crossing Of Roadway Or Intersection	S2		13						546	1,966
12	Passing or overtaking another vehicle & Darting or Running Into Road	S1								65	601
13	Going Straight & Non-Motorist Pushing A Vehicle	S4									198
14	Decelerating in traffic lane & Darting or Running Into Road	S1	15							16	1,051
15	Changing lanes & Improper Crossing Of Roadway Or Intersection	S1					127			63	838
16	Decelerating in traffic lane & Improper Crossing Of Roadway Or Intersection	S1		19	19			14		65	658
17	Turning left & Darting or Running Into Road	S3		6						496	1,507
18	Turning left & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S3			18					255	1,502
19	Starting in traffic lane & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	S1								393	1,005
20	Entering a parking position & Improper Crossing Of Roadway Or Intersection	S1	15							316	462
	Total		**3,339**	**11,780**	**683**	**1,492**	**539**	**376**	**30**	**81,077**	**299,786**

Posted Speed Limit

1	Going Straight & Improper Crossing Of Roadway Or Intersection	Posted Speed Limit														
		10	15	20	25	30	35	40	45	50	55	60	65	70	No Limit	Total
Travel Speed (mph)	0											15				15
	1 - 5		15		329	60	251	27								682
	6 - 10	46	186		627	96	180		305							1,441
	11 - 15				1,023	91	206	16	69						33	1,438
	16 - 20				777	97	233	342	156	104						1,710
	21 - 25				574	86	920	67	61		35					1,744
	26 - 30			10	23	312	889	547	118	11						1,911
	31 - 35		12		353	119	1,064	493	471		124	14	20			2,670
	36 - 40					16	489	821	506		17	19				1,868
	41 - 45						35	27	1,081	13	74					1,229
	46 - 50							123	71	304	209					708
	51 - 55						35				34	14				83
	56 - 60											12	20			32
	61 - 65												110			110
	71 - 75												13			13
	Not Reported		61		920	12	228	140	197	32	57	18		19	16	1,699
	Unknown	35	110	250	7,468	4,722	9,126	4,350	3,420	342	1,792	819	206	75	103	32,816

1	Going Straight & Improper Crossing Of Roadway Or Intersection	Posted Speed Limit														
		10	15	20	25	30	35	40	45	50	55	60	65	70	No Lim	Total
Travel Speed (mph)	0	-	-	-	-	-	-	-	-	-	-	1.00	-	-	-	1.00
	1 - 5	-	0.02	-	0.48	0.09	0.37	0.04	-	-	-	-	-	-	-	1.00
	6 - 10	0.03	0.13	-	0.44	0.07	0.13	-	0.21	-	-	-	-	-	-	1.00
	11 - 15	-	-	-	0.71	0.06	0.14	0.01	0.05	-	-	-	-	-	0.02	1.00
	16 - 20	-	-	-	0.45	0.06	0.14	0.20	0.09	0.06	-	-	-	-	-	1.00
	21 - 25	-	-	-	0.33	0.05	0.53	0.04	0.04	-	0.02	-	-	-	-	1.00
	26 - 30	-	-	0.01	0.01	0.16	0.47	0.29	0.06	0.01	-	-	-	-	-	1.00
	31 - 35	-	0.00	-	0.13	0.04	0.40	0.18	0.18	-	0.05	0.01	0.01	-	-	1.00
	36 - 40	-	-	-	-	0.01	0.26	0.44	0.27	-	0.01	0.01	-	-	-	1.00
	41 - 45	-	-	-	-	-	0.03	0.02	0.88	0.01	0.06	-	-	-	-	1.00
	46 - 50	-	-	-	-	-	-	0.17	0.10	0.43	0.30	-	-	-	-	1.00
	51 - 55	-	-	-	-	-	0.42	-	-	-	0.41	0.17	-	-	-	1.00
	56 - 60	-	-	-	-	-	-	-	-	-	-	0.38	0.62	-	-	1.00
	61 - 65	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	1.00
	71 - 75	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	1.00
	Not Reported	-	0.04	-	0.54	0.01	0.13	0.08	0.12	0.02	0.03	0.01	-	0.01	0.01	1.00
	Unknown	0.00	0.00	0.01	0.23	0.14	0.28	0.13	0.10	0.01	0.05	0.02	0.01	0.00	0.00	1.00
	Total	0.00	0.01	0.01	0.24	0.11	0.27	0.14	0.13	0.02	0.05	0.02	0.01	0.00	0.00	1.00

Posted Speed Limit (Continued)

2	Going Straight & Darting or Running Into Road	Posted Speed Limit														
		5	10	15	20	25	30	35	40	45	50	55	60	65	70	No Limit	Total
Travel Speed (mph)	0					17											17
	1 - 5			88		464	310	400		18				20		15	1,316
	6 - 10		22	238		814	62	589	75	25		86				11	1,922
	11 - 15			404	75	978	431	377	40	141							2,446
	16 - 20			55	38	1,281	113	305	86	435							2,314
	21 - 25		14			1,614	503	625	45	586							3,387
	26 - 30					458	380	746	102	187		39					1,910
	31 - 35					107	49	1,299	474	239	16	17		26			2,226
	36 - 40					20	14	96	375	250	52	62					869
	41 - 45								16	296	104	22		113			551
	46 - 50							10			30	12					53
	56 - 60												19	13			32
	61 - 65													10			10
	Not Reported				310	209	456	442	41	38	32	34				15	1,576
	Unknown	31	61	997	1,395	7,523	6,096	7,191	2,226	2,398	279	539	221	40	19	285	29,300
	Total	31	96	1,782	1,818	13,484	8,414	12,080	3,479	4,611	514	812	239	222	19	326	47,927

2	Going Straight & Darting or Running Into Road	Posted Speed Limit														
		5	10	15	20	25	30	35	40	45	50	55	60	65	70	No Limit	Total
Travel Speed (mph)	0	-	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	1.00
	1 - 5	-	-	0.07	-	0.35	0.24	0.30	-	0.01	-	-	-	0.02	-	0.01	1.00
	6 - 10	-	0.01	0.12	-	0.42	0.03	0.31	0.04	0.01	-	0.04	-	-	-	0.01	1.00
	11 - 15	-	-	0.17	0.03	0.40	0.18	0.15	0.02	0.06	-	-	-	-	-	-	1.00
	16 - 20	-	-	0.02	0.02	0.55	0.05	0.13	0.04	0.19	-	-	-	-	-	-	1.00
	21 - 25	-	0.00	-	-	0.48	0.15	0.18	0.01	0.17	-	-	-	-	-	-	1.00
	26 - 30	-	-	-	-	0.24	0.20	0.39	0.05	0.10	-	0.02	-	-	-	-	1.00
	31 - 35	-	-	-	-	0.05	0.02	0.58	0.21	0.11	0.01	0.01	-	0.01	-	-	1.00
	36 - 40	-	-	-	-	0.02	0.02	0.11	0.43	0.29	0.06	0.07	-	-	-	-	1.00
	41 - 45	-	-	-	-	-	-	-	0.03	0.54	0.19	0.04	-	0.21	-	-	1.00
	46 - 50	-	-	-	-	-	-	0.19	-	-	0.58	0.23	-	-	-	-	1.00
	56 - 60	-	-	-	-	-	-	-	-	-	-	-	0.59	0.41	-	-	1.00
	61 - 65	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	1.00
	Not Reported	-	-	-	0.20	0.13	0.29	0.28	0.03	0.02	0.02	0.02	-	-	-	0.01	1.00
	Unknown	0.00	0.00	0.03	0.05	0.26	0.21	0.25	0.08	0.08	0.01	0.02	0.01	0.00	0.00	0.01	1.00
	Total	0.00	0.00	0.04	0.04	0.28	0.18	0.25	0.07	0.10	0.01	0.02	0.00	0.00	0.00	0.01	1.00

Posted Speed Limit (Continued)

3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	Posted Speed Limit														
		10	15	20	25	30	35	40	45	50	55	60	65	70	No Limit	Total
Travel Speed (mph)	1 - 5		10		23	22	25								13	93
	6 - 10				78	243	52									373
	11 - 15				135	10	9		20						35	208
	16 - 20				273	19	22		17							330
	21 - 25				124	30	291		12							457
	26 - 30				266	115	78				10		23			492
	31 - 35						71	35								106
	36 - 40					35		258			12					305
	41 - 45								237							237
	46 - 50										9	19	12			41
	51 - 55					19					107					126
	56 - 60												105			105
	61 - 65											5	34			39
	Not Reported	13		21	32	41	38	19			39					203
	Unknown		44	148	1,548	623	1,178	301	749	295	245	93	156	12	141	5,534
	Total	13	54	169	2,478	1,157	1,765	613	1,034	295	422	117	330	12	189	8,649

3	Going Straight & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	Posted Speed Limit														
		10	15	20	25	30	35	40	45	50	55	60	65	70	No Lim	Total
Travel Speed (mph)	1 - 5	-	0.11	-	0.24	0.23	0.27	-	-	-	-	-	-	-	0.14	1.00
	6 - 10	-	-	-	0.21	0.65	0.14	-	-	-	-	-	-	-	-	1.00
	11 - 15	-	-	-	0.65	0.05	0.05	-	0.09	-	-	-	-	-	0.17	1.00
	16 - 20	-	-	-	0.83	0.06	0.07	-	0.05	-	-	-	-	-	-	1.00
	21 - 25	-	-	-	0.27	0.07	0.64	-	0.03	-	-	-	-	-	-	1.00
	26 - 30	-	-	-	0.54	0.23	0.16	-	-	-	0.02	-	0.05	-	-	1.00
	31 - 35	-	-	-	-	-	0.67	0.33	-	-	-	-	-	-	-	1.00
	36 - 40	-	-	-	-	0.12	-	0.84	-	-	0.04	-	-	-	-	1.00
	41 - 45	-	-	-	-	-	-	-	1.00	-	-	-	-	-	-	1.00
	46 - 50	-	-	-	-	-	-	-	-	-	0.23	0.47	0.30	-	-	1.00
	51 - 55	-	-	-	-	0.15	-	-	-	-	0.85	-	-	-	-	1.00
	56 - 60	-	-	-	-	-	-	-	-	-	-	-	1.00	-	-	1.00
	61 - 65	-	-	-	-	-	-	-	-	-	-	0.13	0.87	-	-	1.00
	Not Reported	0.06	-	0.10	0.16	0.20	0.19	0.09	-	-	0.19	-	-	-	-	1.00
	Unknown	-	0.01	0.03	0.28	0.11	0.21	0.05	0.14	0.05	0.04	0.02	0.03	0.00	0.03	1.00
	Total	0.00	0.01	0.02	0.29	0.13	0.20	0.07	0.12	0.03	0.05	0.01	0.04	0.00	0.02	1.00

Posted Speed Limit (Continued)

4	Going Straight & Walking With Traffic	Posted Speed Limit														
		10	15	20	25	30	35	40	45	50	55	60	65	70	No Limit	Total
Travel Speed (mph)	1 - 5				58		10									68
	6 - 10				246											246
	11 - 15				54	29			12							95
	16 - 20				36	35		16								87
	21 - 25				52		35				20					106
	26 - 30				111	98	68	52			17					345
	31 - 35						278		130		17					425
	36 - 40				260		12	36	41		12					362
	41 - 45					35			63		150					248
	46 - 50						17	84	68	12	55					236
	51 - 55										222		105			327
	56 - 60								45							45
	66 - 70													52		52
	Not Reported				82	40	19	27	13		21					202
	Unknown	31	81	46	1,658	918	1,278	306	689	140	362	3			107	5,618
	Total	31	81	46	2,556	1,155	1,716	521	1,062	152	876	3	105	52	107	8,463

4	Going Straight & Walking With Traffic	Posted Speed Limit														
		10	15	20	25	30	35	40	45	50	55	60	65	70	No Lim	Total
Travel Speed (mph)	1 - 5	-	-	-	0.85	-	0.15	-	-	-	-	-	-	-	-	1.00
	6 - 10	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	1.00
	11 - 15	-	-	-	0.57	0.31	-	-	0.13	-	-	-	-	-	-	1.00
	16 - 20	-	-	-	0.41	0.40	-	0.19	-	-	-	-	-	-	-	1.00
	21 - 25	-	-	-	0.49	-	0.33	-	-	-	0.18	-	-	-	-	1.00
	26 - 30	-	-	-	0.32	0.28	0.20	0.15	-	-	0.05	-	-	-	-	1.00
	31 - 35	-	-	-	-	-	0.65	-	0.31	-	0.04	-	-	-	-	1.00
	36 - 40	-	-	-	0.72	-	0.03	0.10	0.11	-	0.03	-	-	-	-	1.00
	41 - 45	-	-	-	-	0.14	-	-	0.25	-	0.61	-	-	-	-	1.00
	46 - 50	-	-	-	-	-	0.07	0.36	0.29	0.05	0.23	-	-	-	-	1.00
	51 - 55	-	-	-	-	-	-	-	-	-	0.68	-	0.32	-	-	1.00
	56 - 60	-	-	-	-	-	-	-	1.00	-	-	-	-	-	-	1.00
	66 - 70	-	-	-	-	-	-	-	-	-	-	-	-	1.00	-	1.00
	Not Reported	-	-	-	0.41	0.20	0.09	0.13	0.06	-	0.10	-	-	-	-	1.00
	Unknown	0.01	0.01	0.01	0.30	0.16	0.23	0.05	0.12	0.02	0.06	0.00	-	-	0.02	1.00
	Total	0.00	0.01	0.01	0.30	0.14	0.20	0.06	0.13	0.02	0.10	0.00	0.01	0.01	0.01	1.00

Posted Speed Limit (Continued)

5	Going Straight & Inattentive (Talking, Eating, Etc.)	Posted Speed Limit									
		10	15	25	30	35	40	45	50	55	Total
Travel Speed (mph)	6 - 10			15		27					42
	11 - 15			305							305
	16 - 20			68		271					338
	21 - 25			105							105
	26 - 30			301		55					356
	31 - 35					58		12			70
	41 - 45							134			134
	51 - 55									45	45
	Not Reported					64					64
	Unknown	10	13	565	186	207	59	27	25	95	1,185
	Total	10	13	1,358	186	682	59	174	25	140	2,646

5	Going Straight & Inattentive (Talking, Eating, Etc.)	Posted Speed Limit									
		10	15	25	30	35	40	45	50	55	Total
Travel Speed (mph)	6 - 10	-	-	0.35	-	0.65	-	-	-	-	1.00
	11 - 15	-	-	1.00	-	-	-	-	-	-	1.00
	16 - 20	-	-	0.20	-	0.80	-	-	-	-	1.00
	21 - 25	-	-	1.00	-	-	-	-	-	-	1.00
	26 - 30	-	-	0.84	-	0.16	-	-	-	-	1.00
	31 - 35	-	-	-	-	0.83	-	0.17	-	-	1.00
	41 - 45	-	-	-	-	-	-	1.00	-	-	1.00
	51 - 55	-	-	-	-	-	-	-	-	1.00	1.00
	Not Reported	-	-	-	-	1.00	-	-	-	-	1.00
	Unknown	0.01	0.01	0.48	0.16	0.17	0.05	0.02	0.02	0.08	1.00
	Total	0.00	0.00	0.51	0.07	0.26	0.02	0.07	0.01	0.05	1.00

Posted Speed Limit (Continued)

6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	Posted Speed Limit						
		25	30	35	40	45	50	Total
Travel Speed (mph)	1 - 5	243						243
	6 - 10					12		12
	11 - 15					52		52
	21 - 25	18						18
	26 - 30			12				12
	31 - 35			10				10
	Unknown	17	14	549	16	39	122	757
	Total	278	14	572	16	103	122	1,105

6	Negotiating a curve & Improper Crossing Of Roadway Or Intersection	Posted Speed Limit						
		25	30	35	40	45	50	Total
Travel Speed (mph)	1 - 5	1.00	-	-	-	-	-	1.00
	6 - 10	-	-	-	-	1.00	-	1.00
	11 - 15	-	-	-	-	1.00	-	1.00
	21 - 25	1.00	-	-	-	-	-	1.00
	26 - 30	-	-	1.00	-	-	-	1.00
	31 - 35	-	-	1.00	-	-	-	1.00
	Unknown	0.02	0.02	0.73	0.02	0.05	0.16	1.00
	Total	0.25	0.01	0.52	0.01	0.09	0.11	1.00

Posted Speed Limit (Continued)

7	Negotiating a curve & Walking With Traffic	Posted Speed Limit					
		25	30	35	40	45	Total
Travel Speed (mph)	16 - 20	28					28
	21 - 25					15	15
	31 - 35					32	32
	36 - 40					20	20
	41 - 45				139		139
	Not Reported	323					323
	Unknown		80	80		33	193
	Total	352	80	80	139	99	750

7	Negotiating a curve & Walking With Traffic	Posted Speed Limit					
		25	30	35	40	45	Total
Travel Speed (mph)	16 - 20	1.00	-	-	-	-	1.00
	21 - 25	-	-	-	-	1.00	1.00
	31 - 35	-	-	-	-	1.00	1.00
	36 - 40	-	-	-	-	1.00	1.00
	41 - 45	-	-	-	1.00	-	1.00
	Not Reported	1.00	-	-	-	-	1.00
	Unknown	-	0.41	0.42	-	0.17	1.00
	Total	0.47	0.11	0.11	0.19	0.13	1.00

Posted Speed Limit (Continued)

8	Going Straight & Walking Against Traffic	Posted Speed Limit											
		15	20	25	30	35	40	45	50	55	60	70	Total
Travel Speed (mph)	1 - 5			52									52
	6 - 10					271							271
	11 - 15			52									52
	16 - 20			23	14								37
	21 - 25			55				45					100
	26 - 30			18	12	45		35					110
	31 - 35						10	17		45			72
	51 - 55									18			18
	56 - 60									62			62
	66 - 70											15	15
	Not Reported					17			23				39
	Unknown	19	203	1,096	501	99	142	108	13	59	33		2,272
	Total	19	203	1,296	527	431	152	205	35	183	33	15	3,100

8	Going Straight & Walking Against Traffic	Posted Speed Limit											
		15	20	25	30	35	40	45	50	55	60	70	Total
Travel Speed (mph)	1 - 5	-	-	1.00	-	-	-	-	-	-	-	-	1.00
	6 - 10	-	-	-	-	1.00	-	-	-	-	-	-	1.00
	11 - 15	-	-	1.00	-	-	-	-	-	-	-	-	1.00
	16 - 20	-	-	0.62	0.38	-	-	-	-	-	-	-	1.00
	21 - 25	-	-	0.55	-	-	-	0.45	-	-	-	-	1.00
	26 - 30	-	-	0.17	0.11	0.41	-	0.32	-	-	-	-	1.00
	31 - 35	-	-	-	-	-	0.14	0.24	-	0.62	-	-	1.00
	51 - 55	-	-	-	-	-	-	-	-	1.00	-	-	1.00
	56 - 60	-	-	-	-	-	-	-	-	1.00	-	-	1.00
	66 - 70	-	-	-	-	-	-	-	-	-	-	1.00	1.00
	Not Reported	-	-	-	-	0.42	-	-	0.58	-	-	-	1.00
	Unknown	0.01	0.09	0.48	0.22	0.04	0.06	0.05	0.01	0.03	0.01	-	1.00
	Total	0.01	0.07	0.42	0.17	0.14	0.05	0.07	0.01	0.06	0.01	0.00	1.00

Posted Speed Limit (Continued)

9	Turning left & Improper Crossing Of Roadway Or Intersection	Posted Speed Limit								
		20	25	30	35	40	45	70	No Limit	Total
Travel Speed (mph)	1 - 5		380	17	86		52		346	880
	6 - 10		301	89	146	15	68		52	670
	11 - 15		18	30	94	14				157
	16 - 20		78	22	27		45			171
	21 - 25			10	27					37
	Not Reported		13	35	61	30				139
	Unknown	95	958	1,169	1,070	110	104	19	199	3,724
	Total	95	1,747	1,372	1,510	169	269	19	597	5,778

9	Turning left & Improper Crossing Of Roadway Or Intersection	Posted Speed Limit								
		20	25	30	35	40	45	70	No Limit	Total
Travel Speed (mph)	1 - 5	-	0.43	0.02	0.10	-	0.06	-	0.39	1.00
	6 - 10	-	0.45	0.13	0.22	0.02	0.10	-	0.08	1.00
	11 - 15	-	0.12	0.19	0.60	0.09	-	-	-	1.00
	16 - 20	-	0.45	0.13	0.16	-	0.26	-	-	1.00
	21 - 25	-	-	0.27	0.73	-	-	-	-	1.00
	Not Reported	-	0.09	0.25	0.43	0.22	-	-	-	1.00
	Unknown	0.03	0.26	0.31	0.29	0.03	0.03	0.01	0.05	1.00
	Total	0.02	0.30	0.24	0.26	0.03	0.05	0.00	0.10	1.00

Posted Speed Limit (Continued)

10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	Posted Speed Limit							
		25	30	35	40	45	55	70	Total
Travel Speed (r	16 - 20				10				10
	21 - 25			35					35
	46 - 50						45		45
	Not Reported	39				17			56
	Unknown		44	19				19	82
	Total	39	44	54	10	17	45	19	228

10	Changing lanes & Playing, Working, Sitting, Lying, Standing, etc. In Roadway	Posted Speed Limit							
		25	30	35	40	45	55	70	Total
Travel Speed (r	16 - 20	-	-	-	1.00	-	-	-	1.00
	21 - 25	-	-	1.00	-	-	-	-	1.00
	46 - 50	-	-	-	-	-	1.00	-	1.00
	Not Reported	0.70	-	-	-	0.30	-	-	1.00
	Unknown	-	0.54	0.23	-	-	-	0.23	1.00
	Total	0.17	0.19	0.24	0.04	0.07	0.20	0.08	1.00

Appendix E Baseline Test Apparatus Structure

E.1 Truss and Equipment Lift/Permanent Support

The aluminum truss (presented in Figure 176) provides a lightweight and strong structural member which can be positioned and lifted to the desired height for a particular test scenario. During testing, the system will be lifted and held in position via boom style equipment lifts. This truss supports the mannequin conveyance apparatus which includes the carriage track, the carriage, and the drivetrain. This truss is constructed in a modular fashion such that it can more easily be stored between tests, transported between sites, and assembled without the use of heavy lifting equipment.

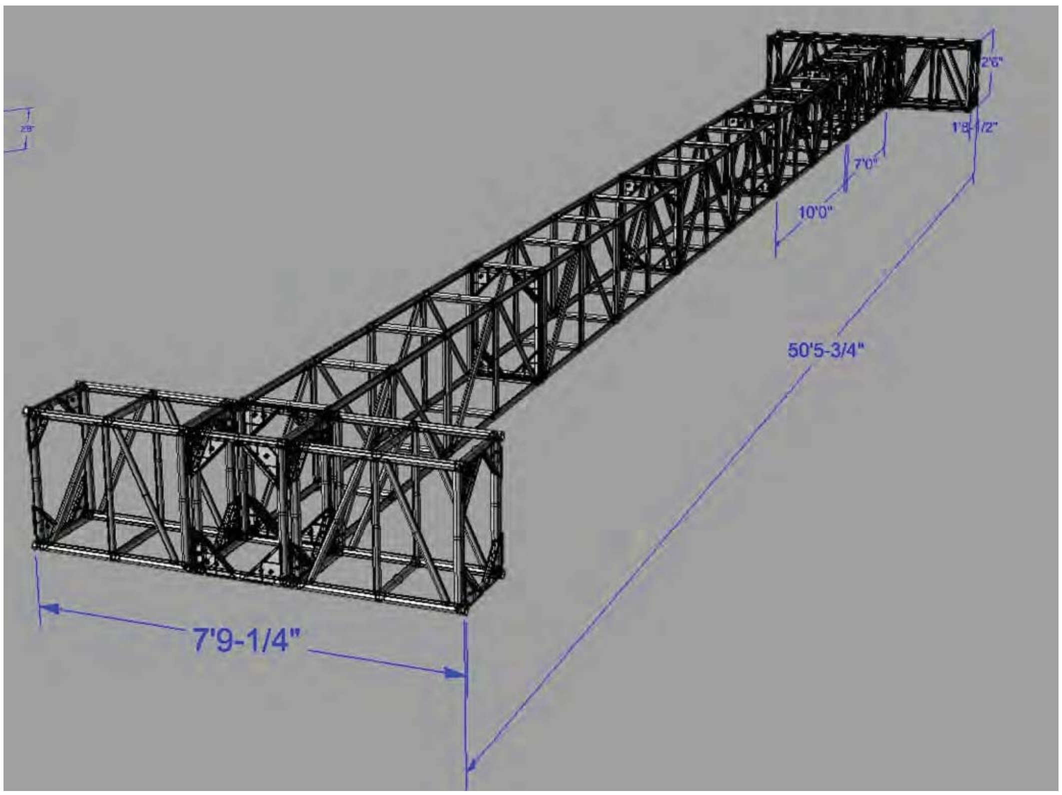


Figure 176: Illustration of Support Truss

E.1.1 Mannequin Carriage Track With Adjustability

The aluminum carriage track, illustrated in Figures 177 and 178, provides a uniform rail on which the mannequin carriage is guided. The carriage track has groove features which guide the carriage wheels in order to enable the desired motion of the mannequin. The track is connected to the truss via adjustable upright sections which allow the track height to be adjusted relative to the truss. This feature, coupled with the somewhat flexible nature of the track, will allow the track to be easily adjusted such that it can mimic reasonable amounts of sloping or crowning of the test road surface. In this way, the mannequin's feet can be kept in close proximity to the road surface throughout the range of the mannequin motion. The carriage track is constructed in a modular fashion such that it can more easily be stored between tests, transported between sites, and assembled without the use of heavy lifting equipment.

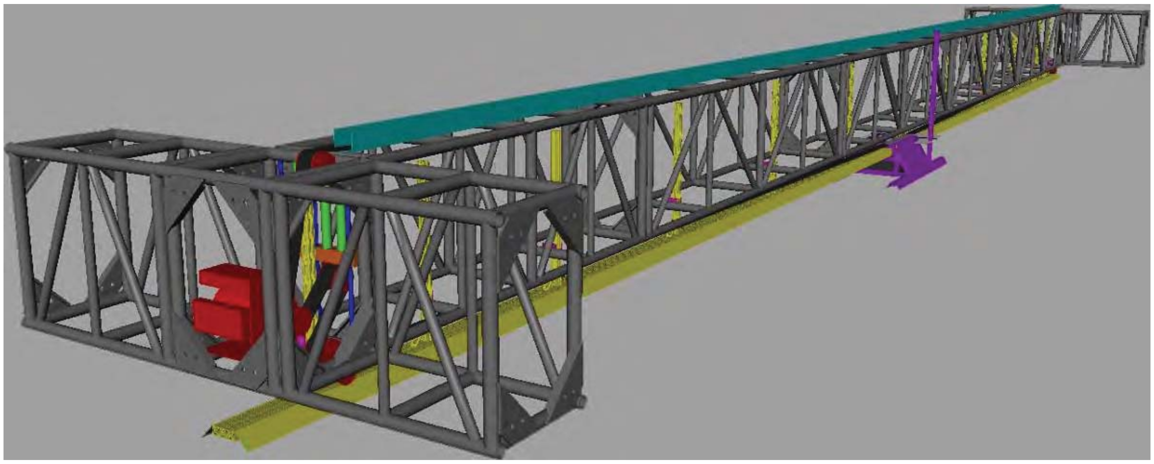


Figure 177: Illustration of Truss With Carriage Track, Carriage and Belt Trough

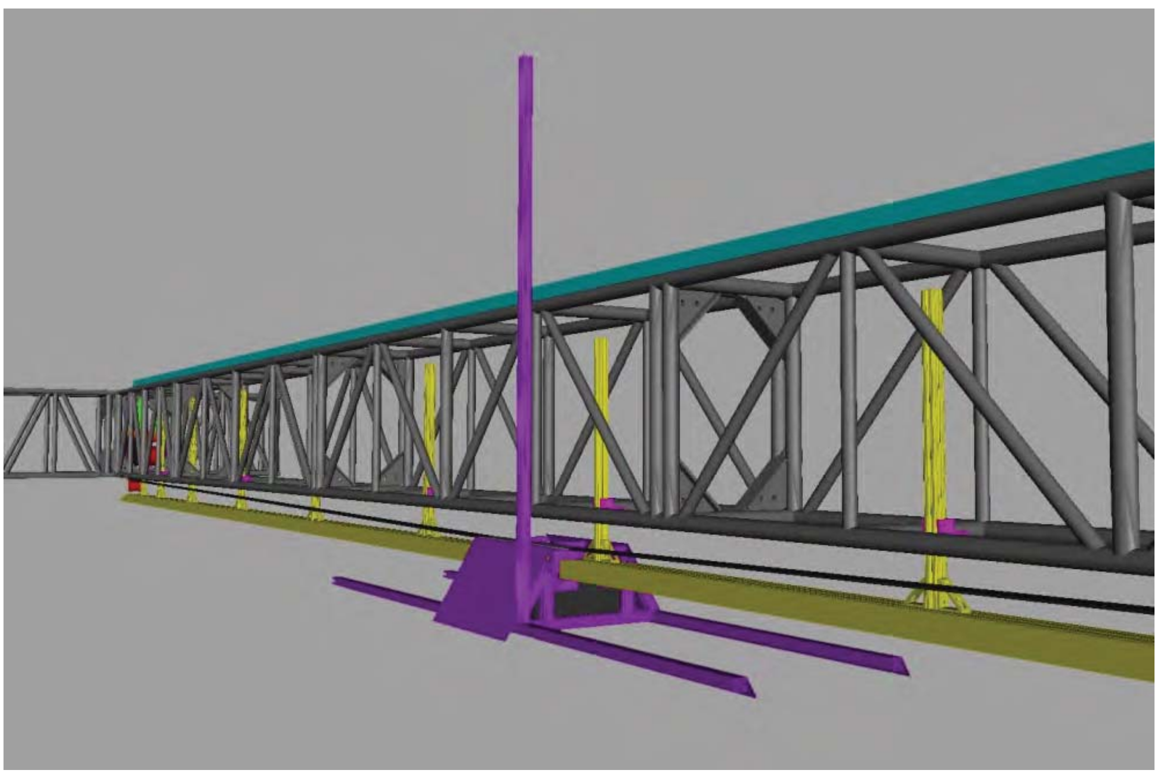


Figure 178: Illustration of Carriage Track and Carriage With Mannequin Suspension Beams

E.1.2 Mannequin Carriage With Radar-masking Reflectors, Ground Truth System, and Mannequin Interfaces

The aluminum mannequin carriage is driven along the carriage track and supports the mannequin via break-away suspension lines which will disconnect from the mannequin if the loads on these lines exceed a prescribed limit. This protects the mannequin and the carriage from excessive loading during vehicle/mannequin impacts. The carriage includes wheels to accurately and smoothly guide the carriage along the track, as well as an accessible weather-proof housing (illustrated in Figure 179) to hold the ground-truthing equipment used to measure mannequin position during testing. Mounting locations for the ground-truthing equipment antennas are also provided on this carriage. The carriage also includes various reflective shields that will be used to reduce the radar cross section of this carriage in order to minimize the effects that this carriage might have on pedestrian detection systems using radar sensing. The reflective shields are also shown in Figure 179.

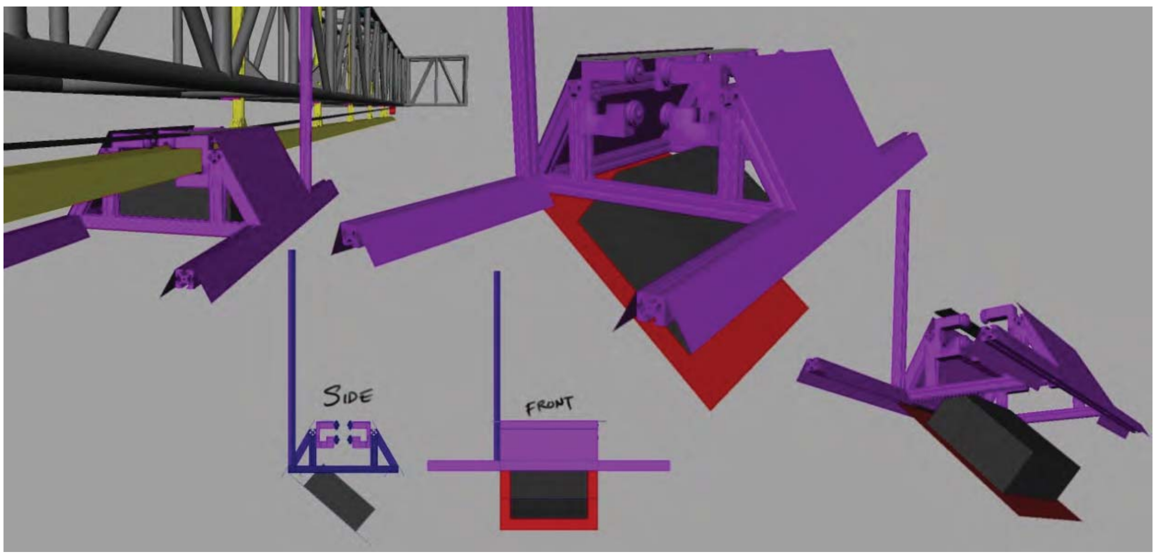


Figure 179: Illustration of Carriage with Radar Reflectors and Hinged Door Access to Ground-Truthing Box

E.2 Test Apparatus Drivetrain

E.2.1 Series Wound DC Motor

The 10-HP motor, shown in Figure 180, provides the torque that drives the mannequin carriage along the track. This motor, used in the prior CIB Project, was chosen because of easy availability (the motor is used in the electric golf cart industry), torque, speed, and 48-volt DC operation. Although a 220-volt AC 3-phase motor is typically suggested for industrial applications of this type, a power source of that type would not be easily available at the site of the PCAM field tests.

E.2.2 Electrically Released Brake

The brake, also shown in Figure 180, provides a means of controlling the deceleration of the drive train, carriage, and mannequin. This brake engages fully when power is not supplied to the brake coil. In this mode, this brake can be used to stop these moving components in an emergency situation or when the carriage is nearing the end of the track. The brake coil power can also be modulated such that the brake will supply less braking torque to decelerate the mannequin in a controlled fashion to simulate a pedestrian halting during walking or running maneuvers.

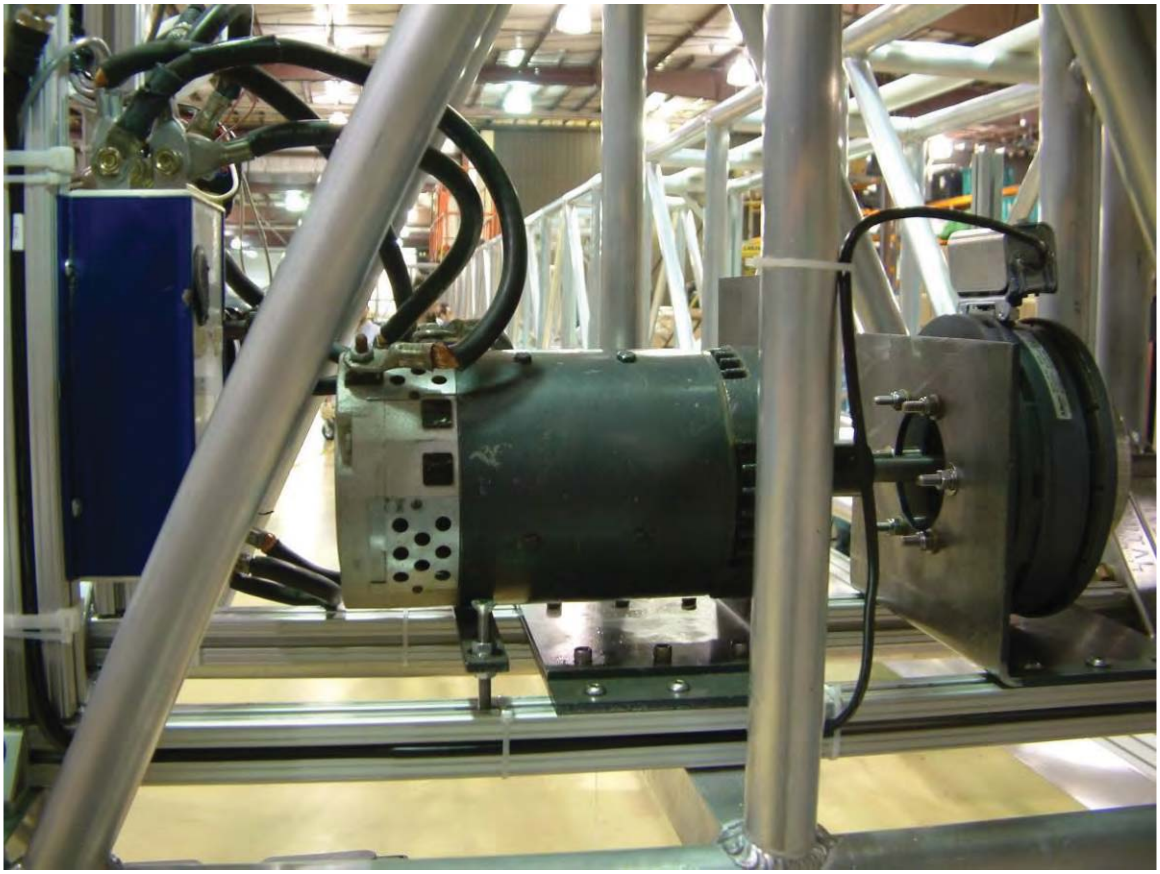


Figure 180: Illustration of Motor Controller (left), Motor (center) and Brake (right)

E.2.3 Gear Box

The gear box is shown in Figure 181. The gear box provides a rotational speed decrease and torque increase between the motor and the drive pulley. This enables the motor and brake to effectively accelerate and decelerate the drive pulley, drive belt, carriage, and mannequin at the desired rates.

Figure 181: Illustration of Brake (rear), Gear Box (center), and Shaft Encoder (foreground)

E.2.4 Cogged Drive Pulley

The cogged drive pulley provides a means of transferring the rotational motion of the drive train to drive belt in order to achieve the desire carriage and mannequin motion. The drive pulley is shown in Figure 182.

Figure 182: Illustration of Drive Pulley (lower right) and Tensioner Assembly (left)

E.2.5 Cogged Drive Belt

The drive belt, depicted in Figure 183, is a cogged, flexible belt which transfers the rotational motion of the drive train to the required linear motion of the carriage. This closed loop drive belt and the associated cogged drive pulley described above enable accurate control of the position, speed, and direction of the carriage and mannequin. The drive belt ends are attached to the carriage in a manner that allows the belt loop length to be adjusted as the track height is adjusted relative to the truss.

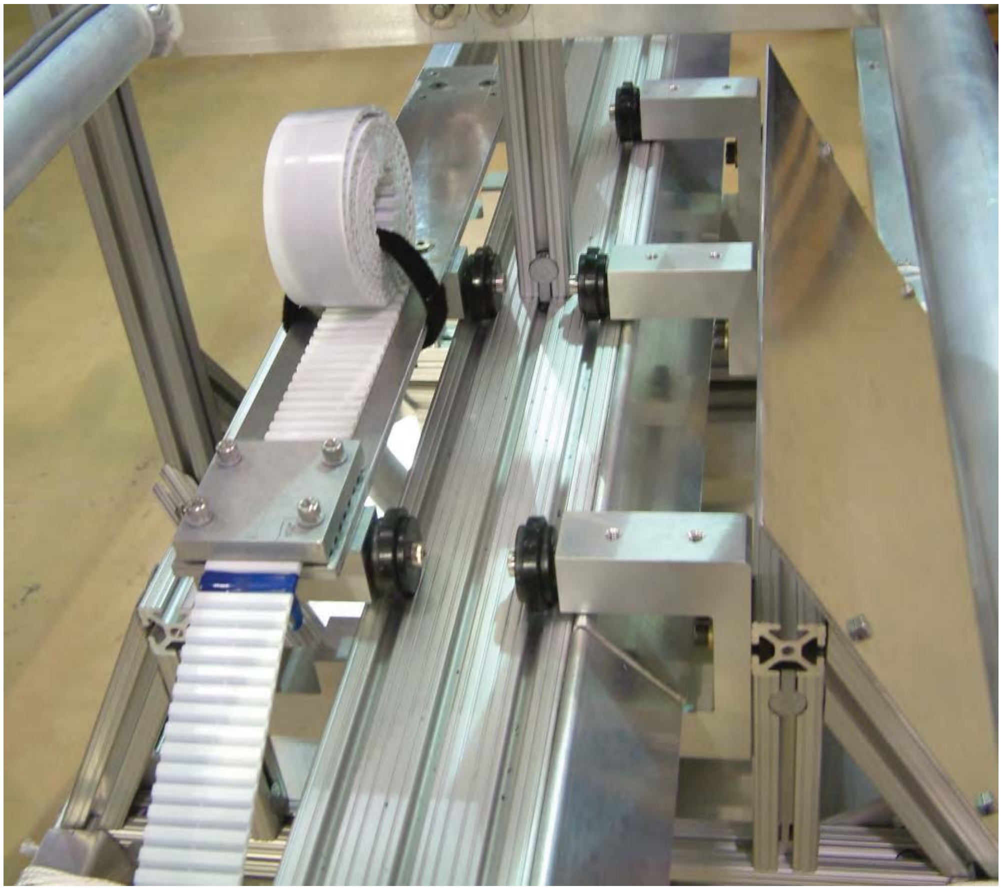


Figure 183: Illustration of Drive Belt and Carriage Attachment to Rail

E.2.6 Tensioner

The belt tensioner, shown earlier in Figure 182, tightens the drive belt such that it will not slip at the cogged drive pulley interface and thereby decrease the control accuracy of the mannequin position, speed, and direction. The tensioner is adjustable via regulated air pressure (provided by compressor and/or storage tank) acting upon the tensioner air cylinder.

E.2.7 Cogged Idler, Tensioner Pulleys and Belt Trough

The cogged idler, tensioner pulleys, and the belt through direct the closed loop drive belt through to the appropriate routing in order to achieve the desire carriage and mannequin motion.

E.2.8 Batteries – 48 Volt

Four 12-volt batteries are connected in series to create a 48-volt DC power supply to operate the apparatus drive train. Deep cycle batteries were chosen to take advantage of high cranking current, high capacity, price and availability. These batteries can be constantly charged while in use via a four-bank battery charger. A spare set of batteries and separate charger are available to ensure adequate voltage is available throughout testing and to maintain battery life. The batteries, battery chargers and transport cart are shown in Figure 184.

Figure 184: Illustration of Batteries and Battery Chargers

E.3 Test Apparatus Motion Control System

E.3.1 Motor Controller

Figure 185 depicts the motor controller and contactors. The motor controller is a production controller for series wound DC motors. This controller was chosen because it is readily available, it is designed to control the motor described above, and it was previously used in the CAMP CIB Project. This controller is capable of providing 650 Amps of DC current to the motor. The controller is also capable of reversing the DC motor to move the system in the opposite direction.

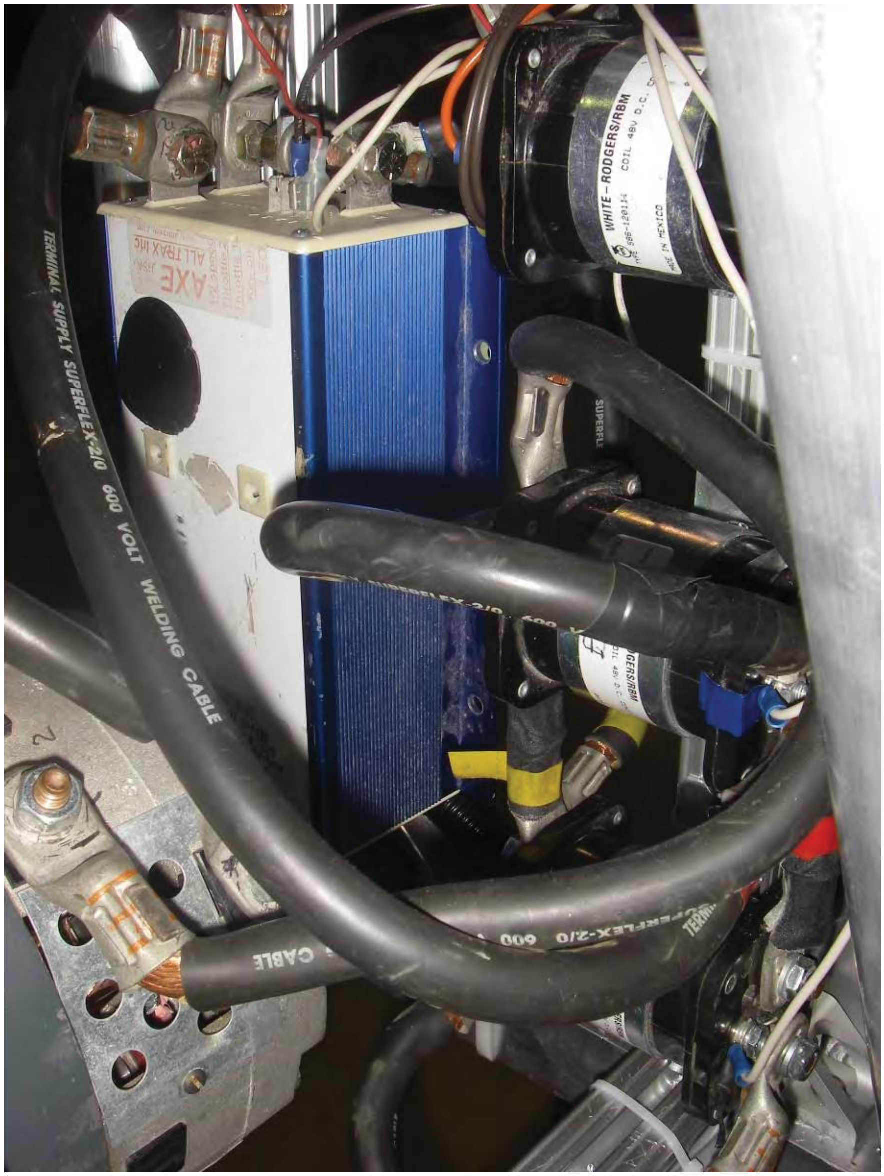


Figure 185: Illustration of the Controller With Contactors

E.3.2 Main Contactor and Reversing Contactors

The main contactor allows the current from the 48-volt battery pack to be used by the motor controller setup, and it can also provide a safety function as it can be opened via the emergency stop buttons described in Section E.3.4. The reversing contactors control directional flow for the motor drive current. The contactors are shown on the right side of Figure 185.

E.3.3 Shaft Encoder

The shaft encoder, shown in Figure 186, provides position, speed, and direction information that are used in the control of the drive train, the carriage, and the mannequin. The encoder sends a signal which is used to determine the current position, speed, and direction of the carriage motion. The control system uses this information to make any necessary adjustments to the motor throttle and brake engagement settings in order to achieve the desired mannequin motion.

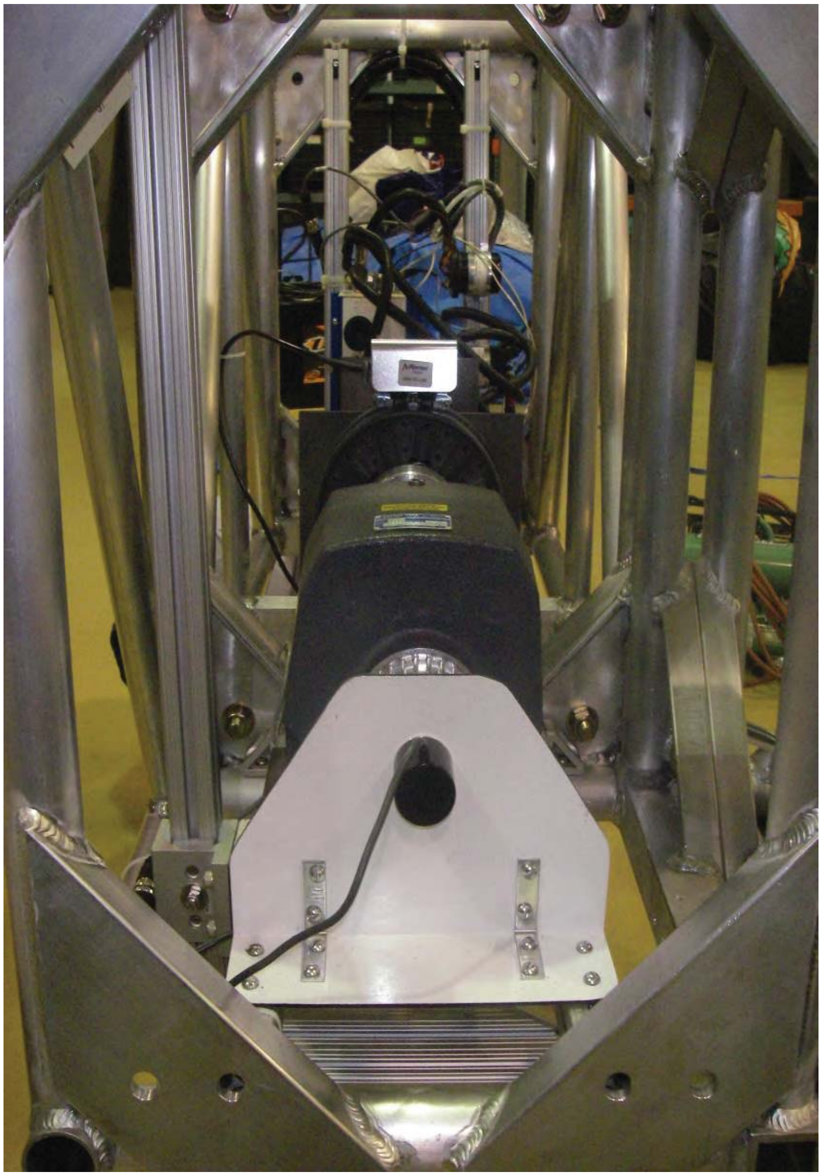


Figure 186: Illustration of Drive Train With Shaft Encoder Shown in Foreground

E.3.4 Emergency Stop Buttons

The emergency stop buttons are used in order to command the controller to remove power from the system. This disengages the motor and applies braking force to stop all system motion. The brake will hold the system in the stopped condition until the emergency has been alleviated.

E.3.5 End-of-Travel Switches

The end-of-travel switches are used to ensure that the carriage is not driven against the ends of the track. These switches are positioned so that the signal they send can be interpreted by the controller to command the motor and brake to stop the motion of the system, prior to the carriage reaching either end of the track. Figure 187 provides an illustration of one of the end-of-travel switches.

Figure 187: Illustration of End-of-Travel Switch

E.3.6 Control Box

The control box, shown in Figures 188 and 189, is the main interface between the user and the apparatus. The control box houses the controller which adjusts the throttle and directional input to the motor controller, monitors the signals from the shaft encoder, and controls the brake activation. The control box allows the user to control the mannequin carriage motion parameters as discussed below. The control box also processes the emergency stop button and end-of-travel switch signals in order to switch off power to the motor system and initiate prescribed levels of brake application.

Figure 188: Illustration of Control Box With Emergency Stop Button and Touch Screen

Figure 189: Illustration of Control Box Showing Programmable Logic Controller, Brake Power Supply, and Brake Amplifier

E.3.6.1 Programmable Logic Controller

The programmable logic controller (PLC) processes the input signals (shaft encoder, emergency stop buttons, and end-of-travel switches) as directed by the logic of the selected control program in order to provide output signals that control the motor speed, direction, and braking torque. The PLC and the touch screen user interface described below allow the user to define and modify the motion parameters of the drive train and carriage in order to achieve a desired mannequin motion profile. Multiple programmed motion profiles can be stored in the PLC for easy retrieval, either manually or via automated trigger mechanisms, to initiate a specified motion profile when the test vehicle is at a prescribed distance from the test apparatus.

E.3.6.2 Touch Screen

The touch screen enables the user to interface with the PLC in order to select and modify various motion profile parameters. This user interface can also be used to manually initiate various system control commands during troubleshooting and test preparation activities.

E.3.6.3 Brake Power Supply and Brake Amplifier

The brake power supply and brake amplifier receive brake activation signals from the PLC and provide the necessary electrical power to release the brake such that it provides the desired braking torque.

Appendix F Mannequin Characterization Testing

Nine Clothing Combinations Tested

	Shirt color	Pant color
1	Dark red	Blue
2	Dark red	Beige
3	Dark red	Black
4	White	Blue
5	White	Beige
6	White	Black
7	Yellow	Blue
8	Yellow	Beige
9	Yellow	Black

Figure 190: Illustration of the Nine Clothing Combinations Examined During Mannequin Characterization Testing

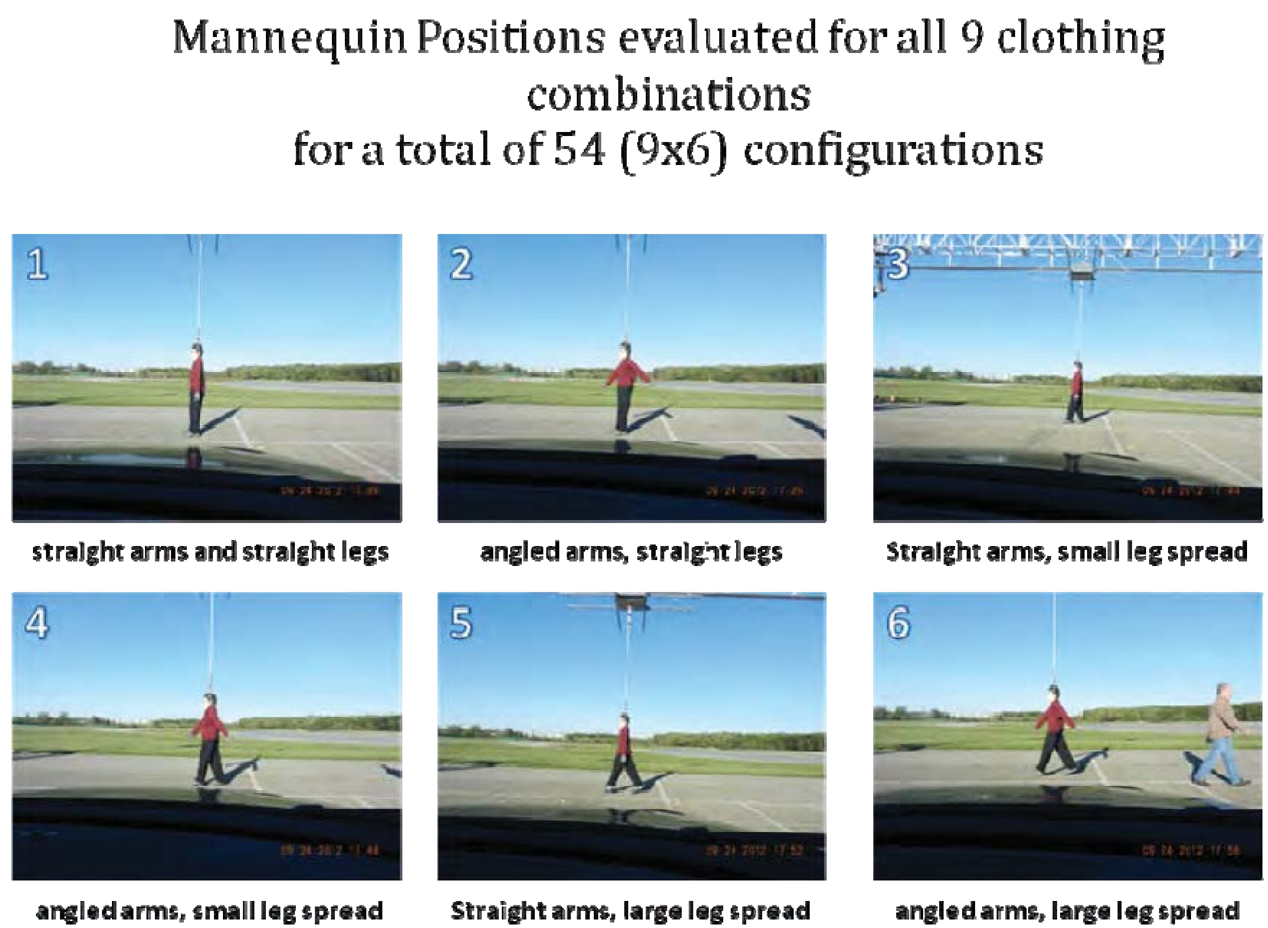


Figure 191: Illustration of the Mannequin Positions Evaluated During Characterization Testing

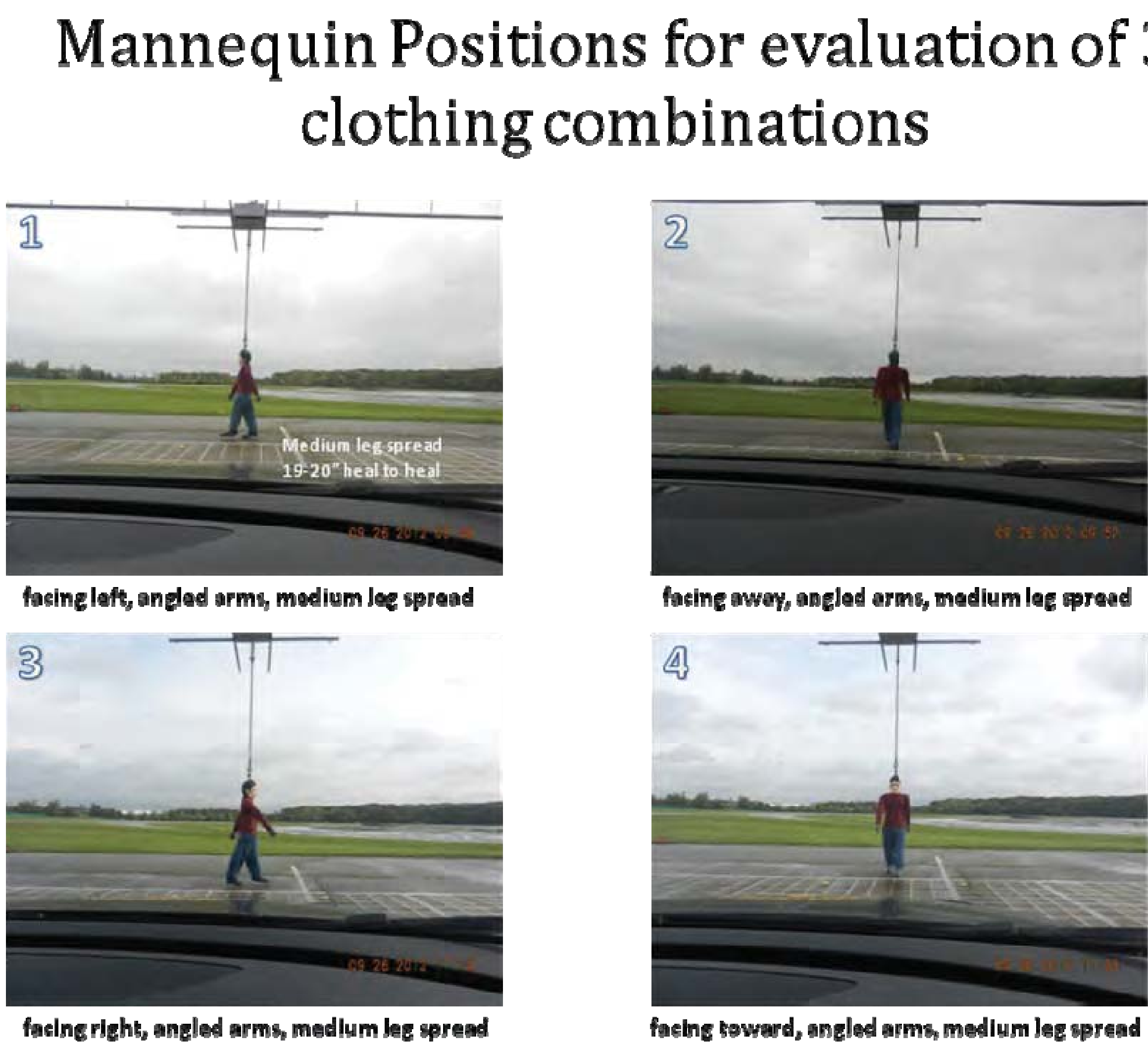
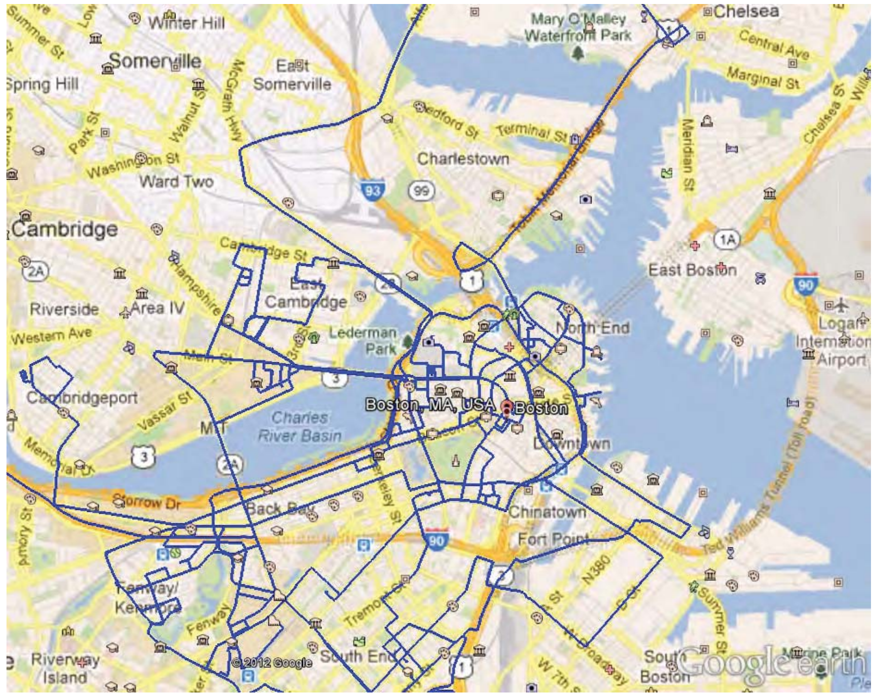


Figure 192: Illustration of Mannequin Positions Used During Characterization Testing

Appendix G ROAD Trip Driving Routes by City and Test Vehicle



Vehicle 1

Figure 193: Vehicle 1 Driving Routes in Boston, Massachusetts; Vehicle 2 Routes Not Available

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Vehicle 1

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Vehicle 2

Figure 194: Vehicle 1 and Vehicle 2 Driving Routes in New York City

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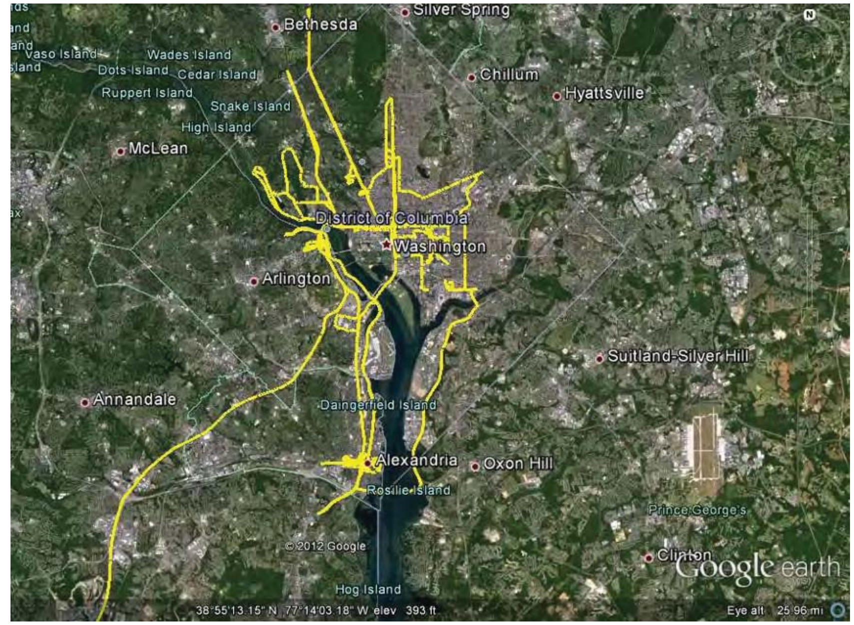
Vehicle 1



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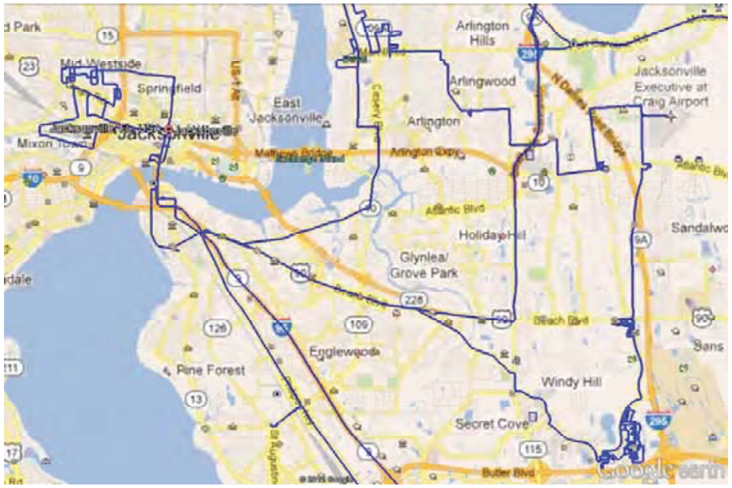
Vehicle 2

Figure 195: Vehicle 1 and Vehicle 2 Driving Routes in Washington, DC



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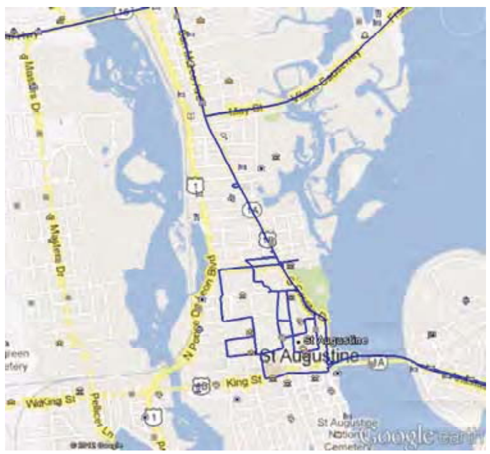

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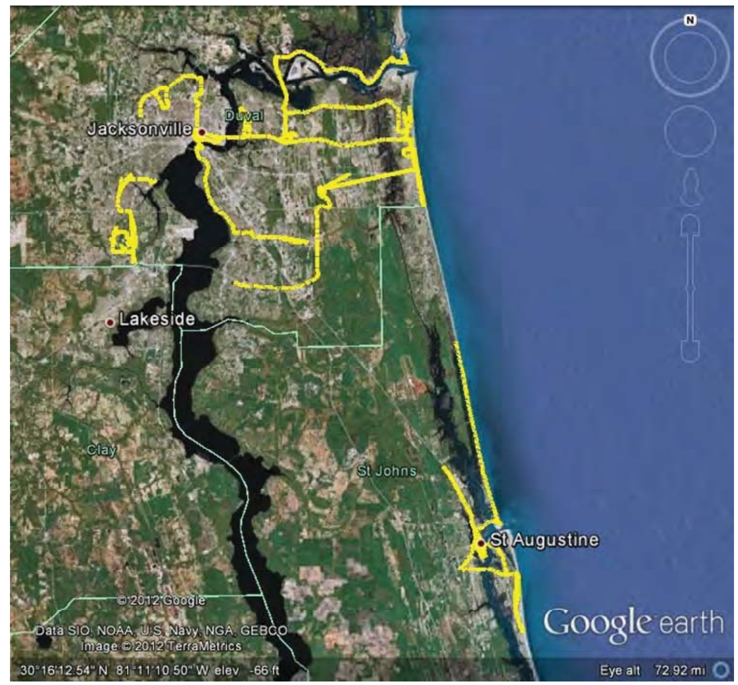

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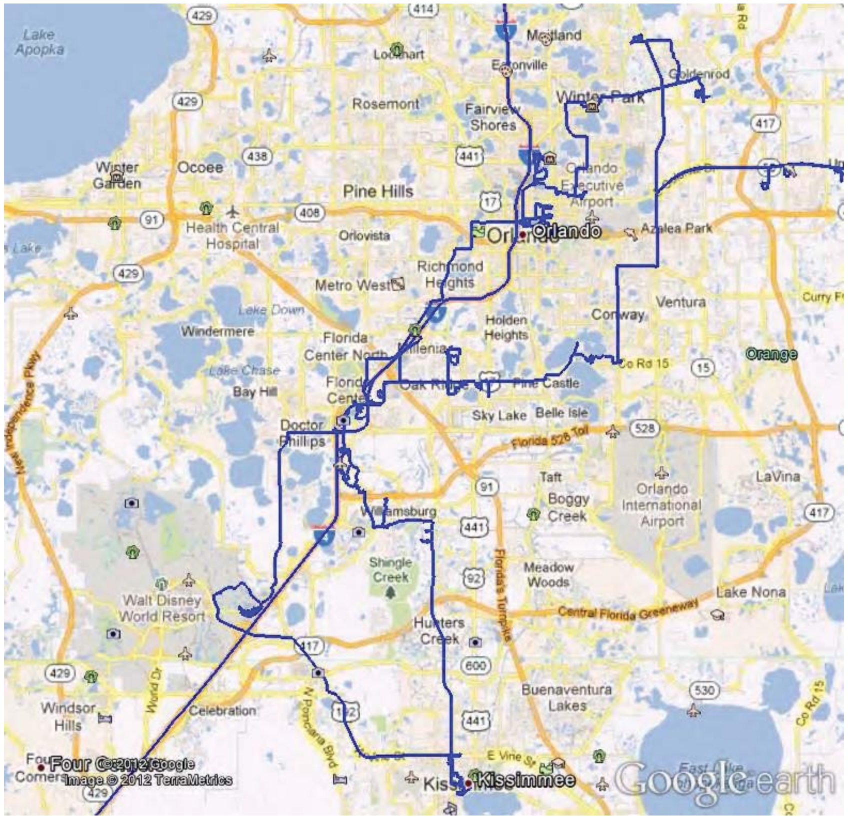
Vehicle 1

Vehicle 2

Figure 196: Vehicle 1 and Vehicle 2 Driving Routes in Jacksonville and St. Augustine, Florida



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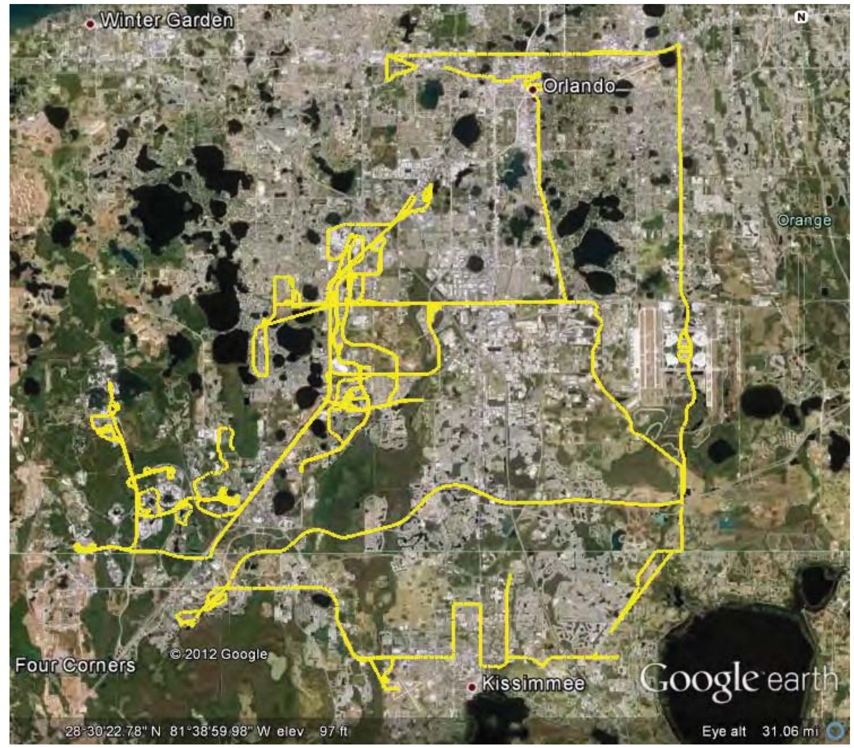
Vehicle 1



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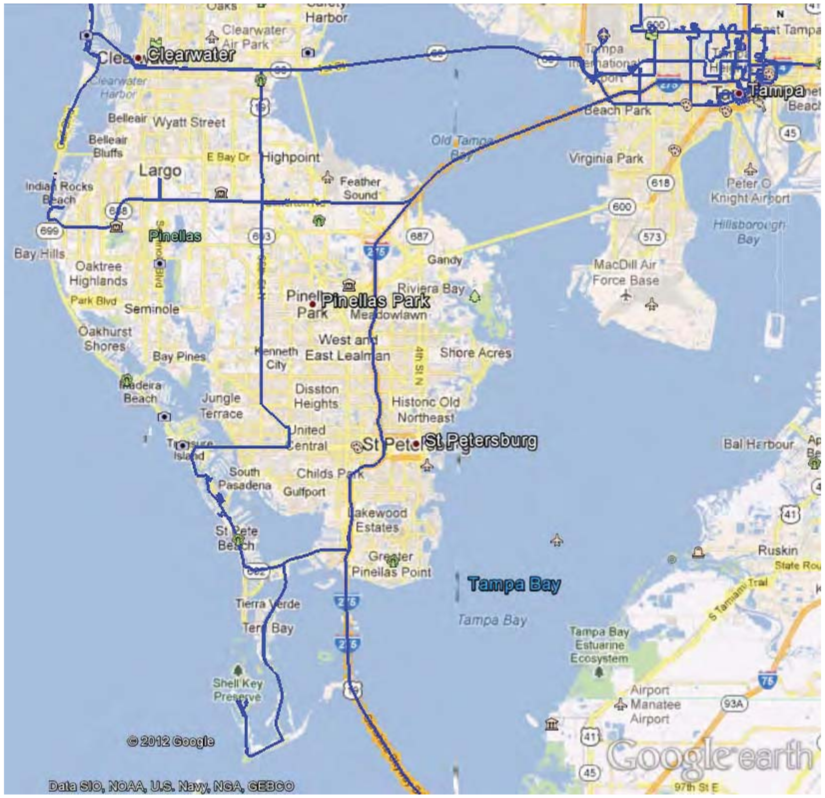
Vehicle 2

Figure 197: Vehicle 1 and Vehicle 2 Driving Routes in Orlando, Florida



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Vehicle 1

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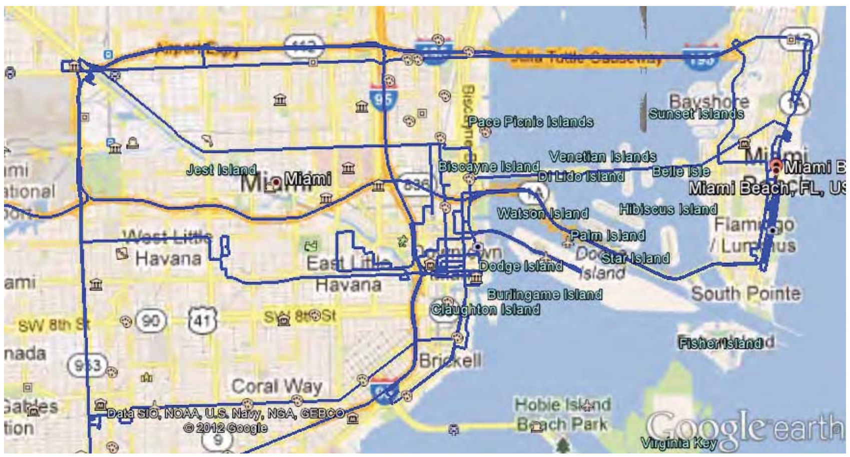
Vehicle 2

Figure 198: Vehicle 1 and Vehicle 2 Driving Routes in Tampa and St. Petersburg, Florida



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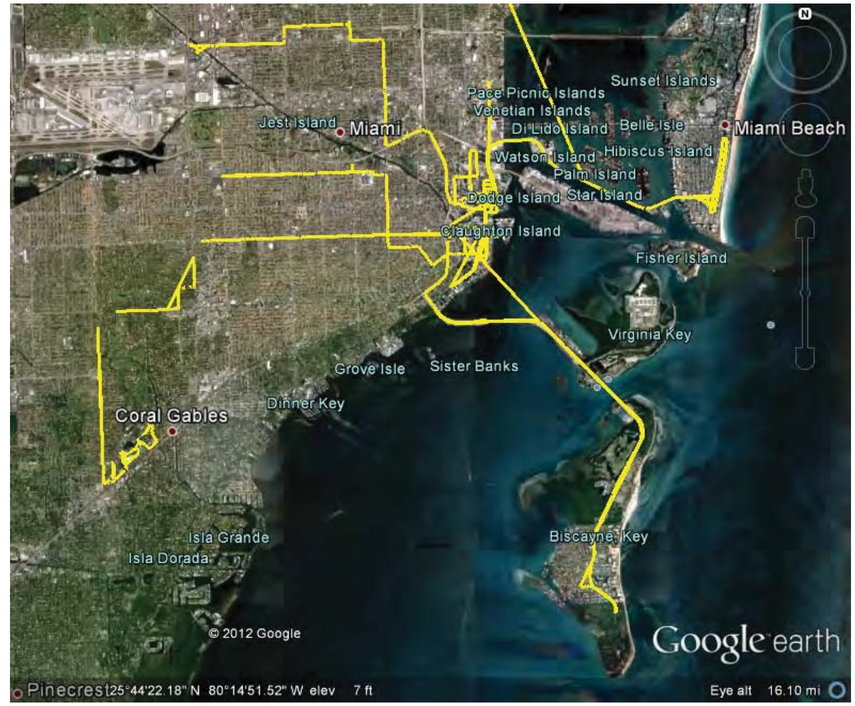
Vehicle 1



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Vehicle 2

Figure 199: Vehicle 1 and Vehicle 2 Driving Routes in Miami, Florida

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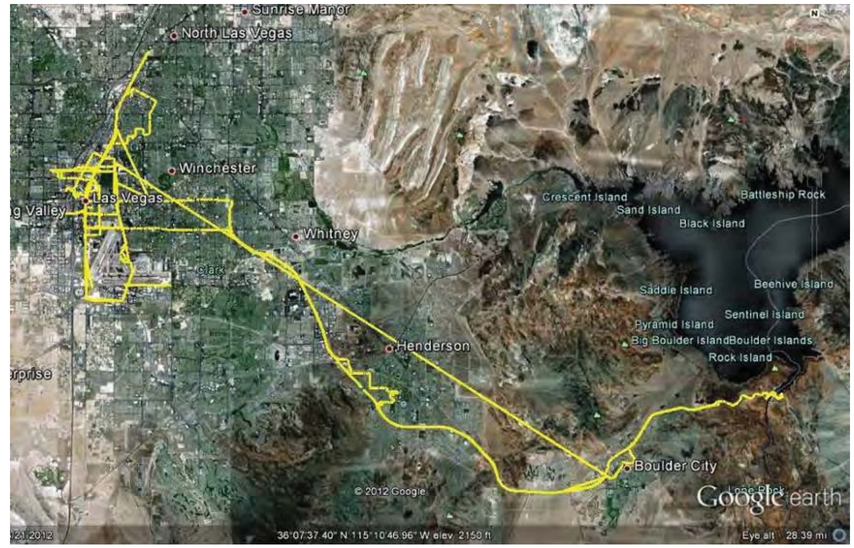
Vehicle 1



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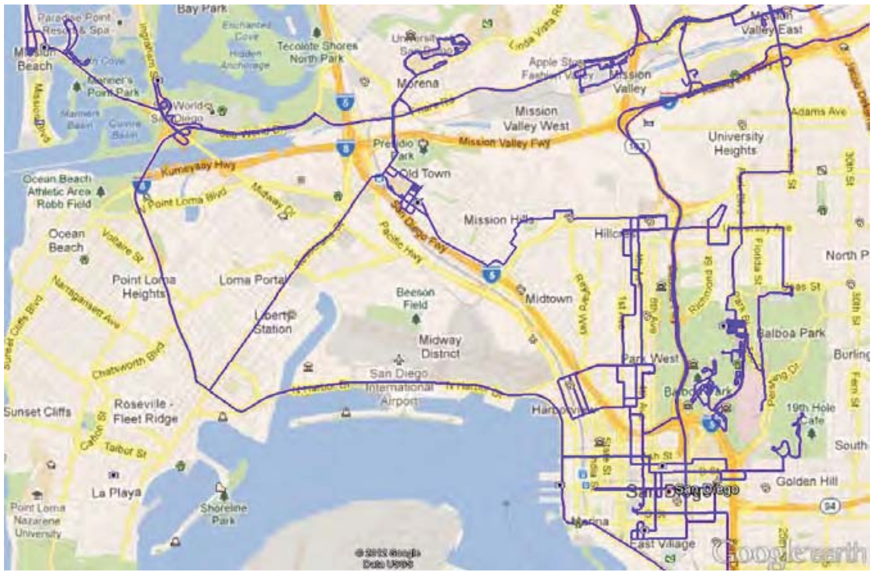
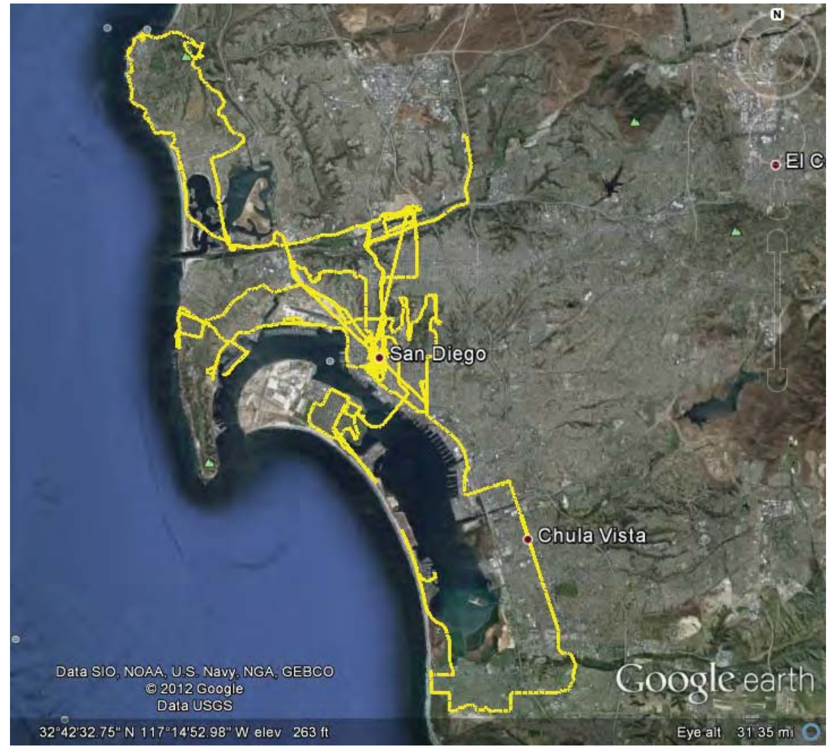
Vehicle 2

Figure 200: Vehicle 1 and Vehicle 2 Driving Routes in Las Vegas, Nevada





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Vehicle 1

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Vehicle 2

Figure 201: Vehicle 1 and Vehicle 2 Driving Routes in San Diego, California

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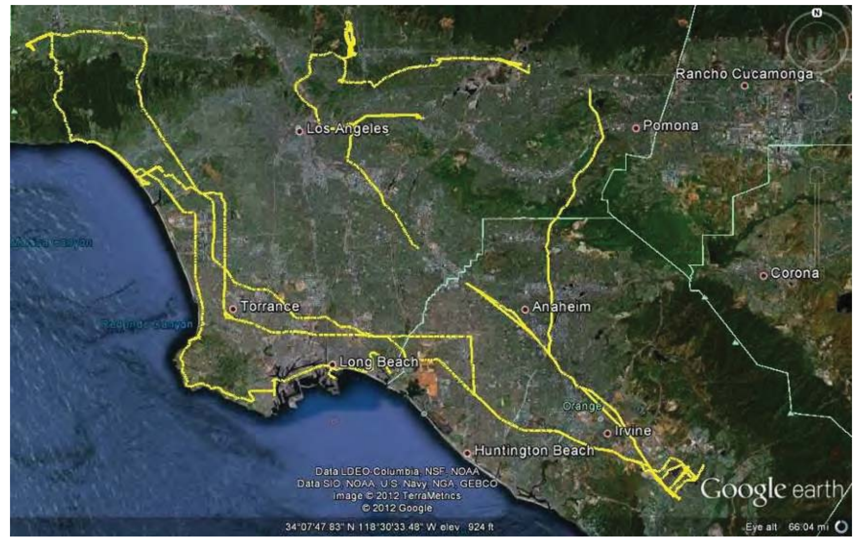

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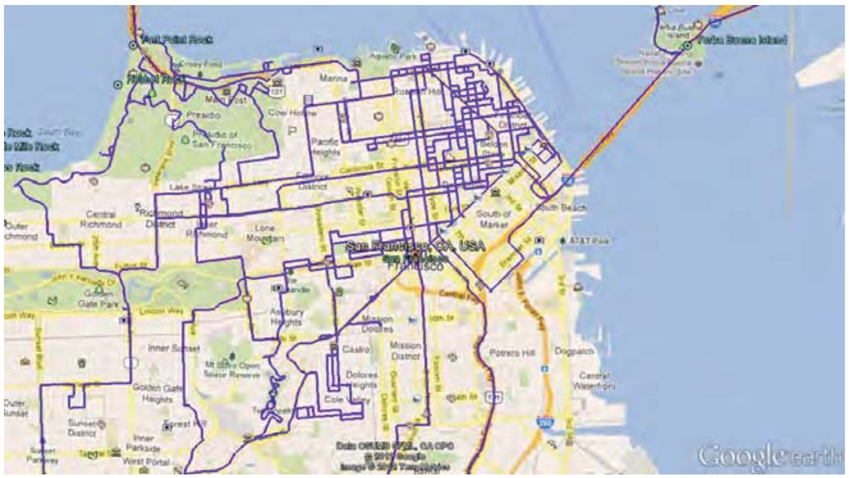
Vehicle 1 **Vehicle 2**

Figure 202: Vehicle 1 and Vehicle 2 Driving Routes in Los Angeles, California



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Vehicle 1

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Vehicle 2

Figure 203: Vehicle 1 and Vehicle 2 Driving Routes in San Francisco, California

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June 2014

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