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Test Procedures With Countermeasure Timing Constraints for Intersection Movement and Left Turn Assist Safety Applications

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16. Abstract

This report describes test procedures with countermeasure timing constraints used to qualify the performance of intersection movement assist and left turn assist safety applications. These applications warn the driver of an imminent straight-crossing-paths or left-turn-across-path/opposite-direction collision at a road junction. The test procedures focus on controlled track testing of light vehicles (i.e., passenger vehicles and light duty trucks with a gross vehicle weight rating of less than or equal to 10,000 pounds). The test procedures are designed so that vehicle maneuvers in each test scenario reflect naturalistic driving behaviors. The test procedures include crash-imminent test scenarios where the applications would be expected to warn the driver of a potential threat, non-crash-imminent test scenarios where the applications would be expected to suppress a warning to the driver because there is no threat due to differences in timing between the vehicles, and false-alert style test scenarios where no warnings would be expected to be issued because the paths of the vehicles do not overlap. The timing of alerts in the crash-imminent and non-crash-imminent scenarios is designed to reflect the timing of when normal drivers are unable to safely navigate intersections (resulting in crashes) and when drivers are able to safely navigate intersections without crashing.

17. Key Words		18. Distribution Statement	
test procedures, timing constraints, countermeasures, test track, test validity, data requirements, safety applications, crossing paths, intersection movement assist, IMA, straight crossing paths, SCP, left turn assist, LTA, left turn across path/opposite direction, LTAP/OD, safety benefits		Document is available to the public from the National Technical Information Service www.ntis.gov	
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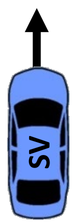
LIST OF ACRONYMS

a_{POV}	POV acceleration level
a_{SV}	SV acceleration level
DW	do-warn test scenarios
EDR	event data recorder
FARS	Fatality Analysis Reporting System
GES	General Estimates System
IMA	Intersection Movement Assist
LTA	Left Turn Assist
LTAP/OD	left turn across path/opposite direction
MNW	may-or-may-not-warn
NW	No-Warn test scenario
POV	principal other vehicle
POV2	obstructing principal other vehicle
$R_{POV\text{-}Action}$	range when POV takes an action
$R_{POV\text{-}Steady}$	range when POV at steady speed
$R_{SV\text{-}Action1}$	range when SV takes first action
$R_{SV\text{-}Action2}$	range when SV takes second action
$R_{SV\text{-}Bail}$	range when SV should bail
$R_{SV\text{-}Steady}$	range when SV at steady speed
SCP	straight crossing paths
SV	subject vehicle
SW	suppress-warn test scenario
TTC	time-to-collision
TTI	time-to-intersection
ΔTTI	difference in TTI between SV and POV
$V_{POV\text{-}initial}$	initial speed of POV
$V_{SV\text{-}final}$	final speed of SV
$V_{SV\text{-}initial}$	initial speed of SV

LEGEND OF IMAGES USED IN DIAGRAMS

Left Turn Signal	
Right Turn Signal	
Vehicle Moving at Constant Speed	
Vehicle Stopped	
Vehicle Decelerating	
Vehicle Accelerating From Stop	
Subject Vehicle	
Principal Other Vehicle	
Principal Other Vehicle 2	

EXECUTIVE SUMMARY

This report describes the test procedures with countermeasure timing constraints for intersection movement assist (IMA) and left turn assist (LTA) safety applications that warn the driver of imminent crashes at a road junction and do not warn the driver when a crash is not imminent. These tests are limited to light vehicles (i.e., passenger vehicles and light-duty trucks with gross vehicle weight ratings of less than or equal to 10,000 pounds) under closed track and clear weather conditions.[1] The Volpe National Transportation Systems Center (Volpe), in collaboration with the National Highway Traffic Safety Administration and the Intelligent Transportation Systems Joint Program Office, has developed these test procedures. Volpe, in association with the United States Army's Aberdeen Test Center, applied an initial version of these test procedures to aftermarket IMA and LTA safety applications to collect data to refine and improve the procedures.

These performance test procedures are aimed to qualify the safety applications' abilities to operate within the countermeasure timing constraints. The performance metrics are derived from naturalistic driving data and crash reconstructions and are based on when real-world drivers:

1. Are able to safely clear the intersection ahead of/in front of crossing-paths traffic;
2. Are able to safely clear the intersection after/behind previously crossing-paths traffic; and
3. Are unable to safely clear the intersection, and a collision occurs with crossing-paths traffic.

This is done so that the timing of warnings in the safety applications

1. Reflect when a driver will benefit from a warning; and
2. Limits the number of warnings that may be considered nuisances to the driver.

Vehicle kinematic parameters (speed, acceleration, etc.) and the timing of key events within a test trial (turn signal application, the length of time between when the driver releases the brake and applies the throttle, etc.) are also derived from naturalistic driving data so that all actions committed by the driver during testing are representative of actions taken by actual drivers.

The test procedures consist of crash-imminent, non-crash-imminent, and false-alert style scenarios. They also consist of test variables, validity criteria, safety criteria, and driving instructions.

Crash-imminent test scenarios (i.e., Do-Warn scenarios) for the IMA and LTA applications represent the most common and costly intersection-based pre-crash scenarios derived from data in the 2011-2015 Fatality Analysis Reporting System and the National Automotive Sampling System General Estimates System databases (Swanson et al., in press).

The procedures include test scenarios where the subject vehicle (the vehicle that is issued a warning) is initially moving at a constant speed, is initially stopped before moving, or is initially

[1] While not recommended, the procedures could be run in adverse weather conditions at the test conductor's discretion.

stopped but its view of the crossing-paths vehicle is obstructed. The procedures that include an obstruction are used only for the crash-imminent scenarios.

These test procedures are offered as recommendations to safety application developers and do not constitute any requirement by NHTSA.

1. INTRODUCTION

This report describes test procedures used to qualify the successful performance of two crash warning applications to operate within countermeasure timing constraints for crossing-paths crashes at road junctions:

- Intersection Movement Assist (IMA), which alerts the driver in the subject vehicle (SV) to a principal other vehicle (POV) approaching from a lateral direction at an intersection (or any road junction).
- Left Turn Assist (LTA), which alerts the SV driver of a POV approaching from the opposite direction when the SV is attempting a left turn at an intersection (or any road junction).

The IMA and LTA safety applications address the two most frequent and costly intersection-based crash types derived from data in the 2011-2015 Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System General Estimates System (GES) databases for crashes where both vehicles involved in the critical event[2] of the crash are light vehicles (Swanson et al., in press).[3] The IMA safety application addresses the straight crossing paths (SCP) scenario.[4] The LTA safety application addresses the left turn across path/opposite direction (LTAP/OD) scenario. Table 1 shows a breakdown of the crossing-paths crash types by number of crashes and by percentage of total comprehensive costs (Blincoe et al., 2015).

Table 1. Comparison of Crossing-Paths Pre-Crash Scenarios

Pre-Crash Scenario	All Crashes[5]	Fatal Crashes[6]	Percent of Cost
Straight Crossing Paths	379,385	1,329	53%
Left Turn Across Path/Opposite Direction	254,503	430	31%
Left Turn Across Path/Lateral Direction	108,731	229	11%
Right Turn Into Path	52,943	18	2%
Left Turn Into Path	44,653	23	2%
Right Turn Across Path	17,572	8	1%

[2] The critical event is the event which made the crash occur (e.g., a left turn across path from the opposite direction)
[3] A light vehicle is defined as a passenger car, van, minivan, SUV, or light-duty truck with a gross vehicle weight rating of less than or equal to 10,000 pounds.
[4] The IMA application also addresses the left turn across path/lateral direction, left turn into path, right turn into path, and right turn across path crossing-paths scenarios. However, these account for a significantly smaller number and cost of crashes and are not included in this report.
[5] Determined from the GES database.
[6] Determined from the FARS database.

These tests are limited to light vehicles and devised to run under closed track and clear weather conditions. Other vehicle types may require different timing constraints.

The test procedures address test scenarios where the intended paths of the SV and POV cross at an intersection. The test scenarios consist of:

- Potential crash-imminent scenarios (i.e., Do-Warn scenarios) where the paths of the two vehicles overlap and the two vehicles arrive at the intersection at the same time.
- Non-crash-imminent test scenarios (i.e., Suppress-Warn scenarios) where the paths of the two vehicles overlap but the two vehicles do not arrive at the intersection at the same time.
- False alert scenarios (i.e., No-Warn scenarios) where the paths of the two vehicles do not overlap but the vehicles initially are projected to arrive at the intersection at the same time.

The purpose of the procedures included in this report is to qualify the ability of the IMA and LTA safety applications to warn or not warn the driver within a set of time constraints for a potential crash threat or non-threat.

2. INTERSECTION MOVEMENT ASSIST

This section contains information relevant to the IMA safety application. It discusses the scenarios, critical kinematic parameters, and warning criteria; and it includes the test procedures.

2.1. Scenarios

The SCP scenarios used to test the IMA application each have one of three initial states.

1. The SV and POV each accelerate to a set speed and maintain that constant speed throughout the trial.
2. The POV accelerates to a set speed and maintains that constant speed throughout the trial. The SV is initially stopped before attempting to accelerate through the intersection.
3. The POV accelerates to a set speed and maintains that constant speed throughout the trial. The SV is initially stopped before attempting to accelerate through the intersection. The view is obstructed by an additional larger vehicle (POV2).

The test scenarios contain three types of warning conditions:

1. The application does issue a warning (DW) because the paths of the SV and POV cross and their times-to-intersection (TTI) are similar.
2. The application would be expected to suppress a warning (SW) because the paths of the SV and POV cross but their TTIs are not similar (i.e., one vehicle can safely navigate the intersection before the other).
3. The application would be expected to not warn (NW) because the paths of the SV and POV do not cross at all. Their initial TTIs are similar.

2.2. Vehicle Kinematic Values

The speeds used in the test procedures for the IMA application are based on the cumulative comprehensive costs of all SCP crashes.[7] Figure 1 shows a plot of the comprehensive costs organized by vehicle travel speed. It includes data that shows the speeds of both vehicles in an SCP scenario where both vehicles are initially moving.[8] It also includes POV speeds for when the SV is initially stopped.

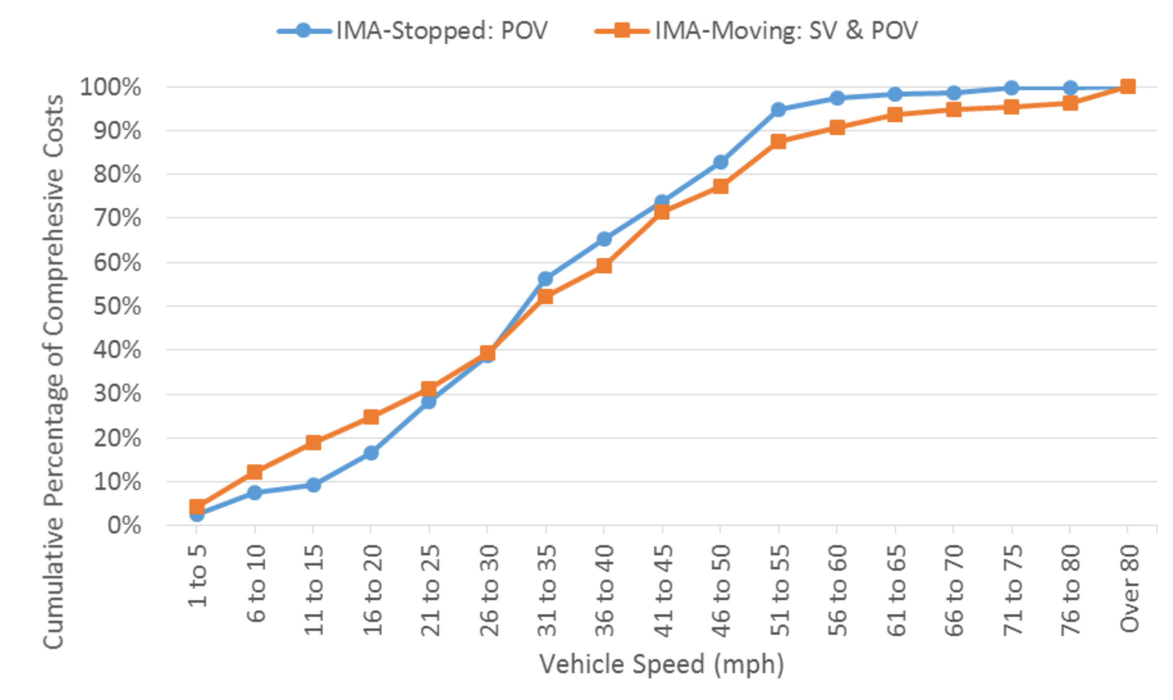


Figure 1. Cumulative Comprehensive Costs of SCP Crashes by Vehicle Speed

In test scenarios where the SV is initially stopped, the acceleration limits are defined using naturalistic driving data from similar on-road situations.

Figure 2 shows the final speeds corresponding to the distribution of acceleration levels from the naturalistic driving data. The final speeds correspond to the time until the center of the SV reaches the center of the intersection.

[7] "All SCP crashes" refers to crashes that occurred from 2011 to 2015 (from GES and FARS databases) where only two vehicles are involved, both vehicles are light vehicles, and where neither vehicle made an avoidance maneuver.
[8] In an SCP where both vehicles are initially moving, both vehicles are assumed to have been at a constant speed "well enough" in advance of the crash that their previous speeds did not affect the outcome of the crash. There is no discernible human action to determine when a warning would be expected to occur, and the SV and POV are indistinguishable in the data. For this reason, the SV and POV speeds are selected from the same data.

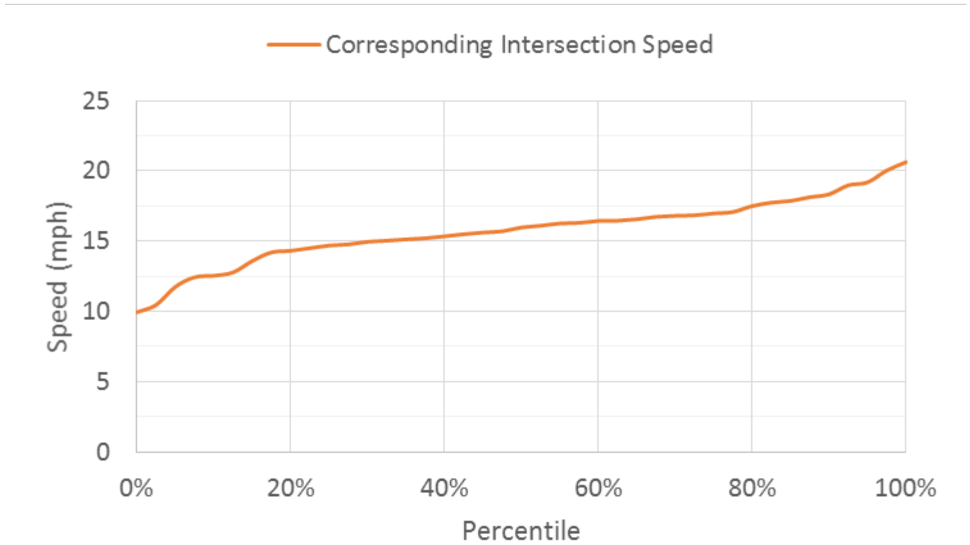


Figure 2. Center-of-Intersection Speeds of SV When Initially Stopped in SCP Scenario

Table 2 provides a summary of all the speeds used in testing of the IMA application and an explanation for selecting each speed.

Table 2. Summary Table of Speeds Used in IMA Testing

IMA Scenario	Metric	Speed	Reasoning
Both vehicles moving	SV speed when there's a speed differential	25 mph	Approximate 25th percentile of IMA-moving speeds from Figure 1
Both vehicles moving	SV/POV speed when speeds are equal	35 mph	Approximate 50th percentile of IMA-moving speeds from Figure 1
Both vehicles moving	POV speed when there's a speed differential	45 mph	Approximate 75th percentile of IMA-moving speeds from Figure 1
SV initially stopped	POV speed	35 mph	Approximate 50th percentile of IMA-stopped POV speeds from Figure 1
SV initially stopped	SV speed at center of intersection	12-19 mph	Speed from 10th to 90th percentile of acceleration from Figure 2.

2.3. Warning Criteria

This section contains information on the warning criteria and how they were selected for scenarios when the SV is initially stopped or is initially moving at a constant speed. This applies only to the DW and SW scenarios.

2.3.1. IMA: SV Initially Stopped

Warning criteria for the IMA application where the SV is initially stopped were derived using a combination of naturalistic driving data and reconstructions of SCP crashes where both vehicles were equipped with a crash event data recorder (EDR).

This exercise involved analyzing the timing of the crashes when

1. The SV crossed the intersection safely before the POV (from naturalistic data);
2. The SV crashed into the POV (from EDR data); and
3. The SV crossed the intersection safely after the POV (from naturalistic data).

Figure 3 shows the frequencies of POV TTIs when the SV begins moving through the intersection (Stevens et al., in press).

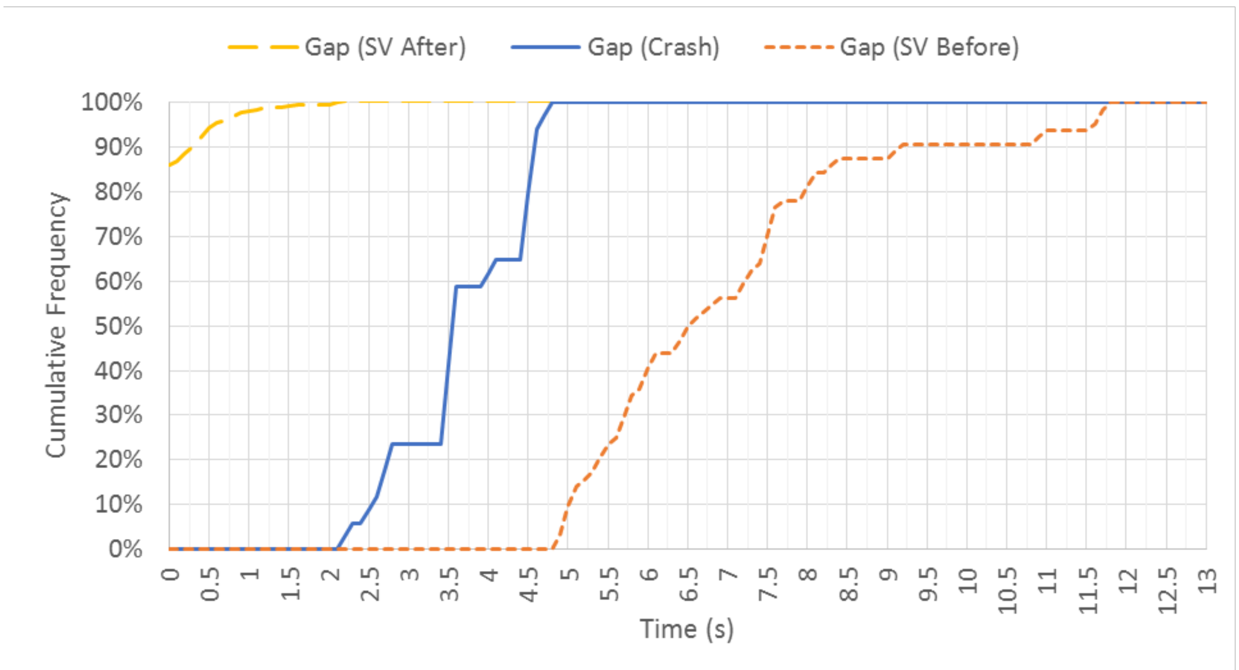


Figure 3. POV TTIs at SV Acceleration in SCP Scenarios When SV Is Initially Stopped

Table 3 shows the time ranges used to define the DW and SW test scenarios. The range between when a system would be expected to warn and when it would be expected to suppress a warning is the may-or-may-not-warn range (MNW). It would be up to the application developer to know if a warning is necessary based on additional kinematic parameters and intersection geometry.

Table 3. Summary Table of Warning and Suppressed Warning Boundaries

Warning Type	Scenario Description	Range (s)
SW	SV Crosses After POV	$TTI_{POV} \leq 0.3$
MNW	SV Crosses After POV	$0.3 < TTI_{POV} < 2.6$
DW	Crash Imminent	$2.6 \leq TTI_{POV} \leq 4.6$
MNW	SV Crosses Before POV	$4.6 < TTI_{POV} < 8.0$
SW	SV Crosses Before POV	$8.0 \leq TTI_{POV}$

2.3.2. IMA: SV Initially Moving

Warning times for the IMA application for when the SV is initially moving were determined based on how far in advance of the intersection that a driver be warned in order to avoid a collision. Footnote 8 on page 4 gives a detailed explanation for why crash data was not used in determining warning times for this scenario.

A Monte Carlo simulation was run to determine the frequency of drivers' abilities to stop in advance of the intersection when given warnings at varying times.

Driver behavior was modelled using lognormally distributed driver braking response times (Olson et al., 1984) and normally distributed braking levels (Kiefer et al., 2005). The response times are seen in Table 4. Figure 4 shows a chart of this distribution.

Table 4. Lognormal Distribution Values of Driver Braking Response Times

Parameter	Value (s)
Mean	1.1
Standard Deviation	0.3
Minimum	0
Maximum	5

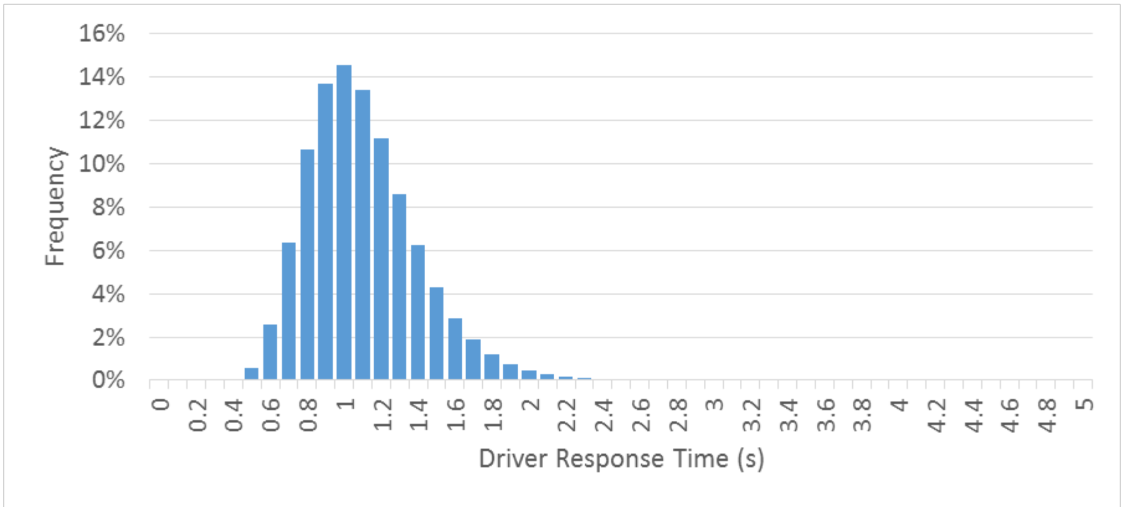


Figure 4. Distribution of Driver Braking Response Time

The normally distributed driver braking levels are seen in Table 5. Figure 5 shows a chart of this distribution.

Table 5. Normal Distribution Values of Driver Brake Level

Parameter	Value (g)
Mean	0.5
Standard Deviation	0.1
Minimum	0.25
Maximum	0.75

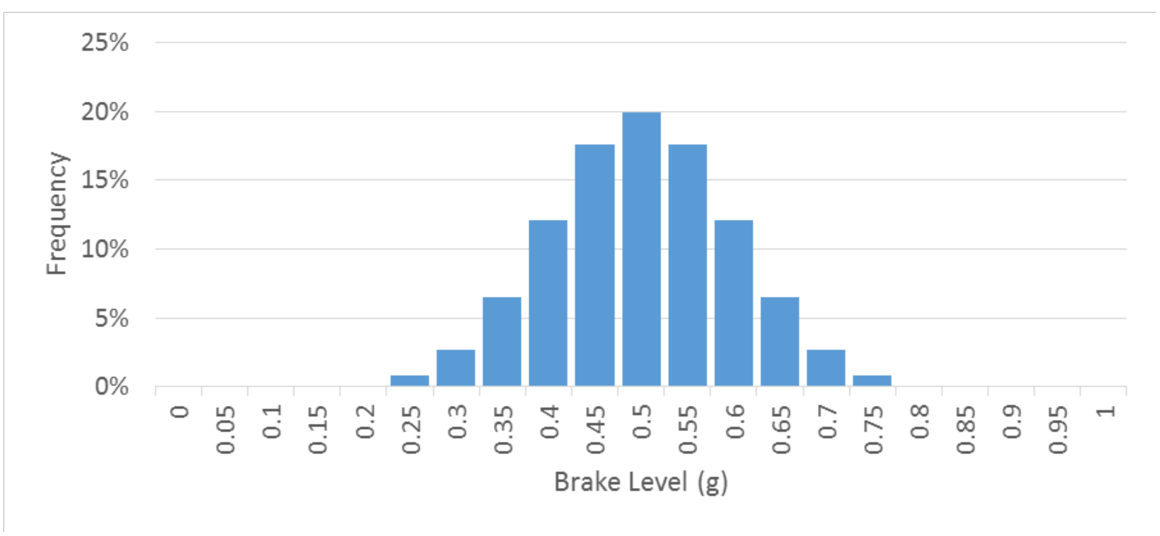


Figure 5. Normal Distribution of Driver Brake Levels

The simulation was run as follows:

- Warnings were simulated from 1.0 to 6.0 seconds at 0.1 second intervals;
- Each warning time was simulated a total of 100,000 times
- Driver behavior was randomly sampled from the two distributions for each iteration of the simulation;
- The ability of the driver to stop 30 feet in advance of the intersection was assessed; and
- This was repeated for multiple SV speeds.

Figure 6 shows the percentage of drivers who would be able to stop at different warning times. It shows the plots for SVs initially travelling at 25 mph and 35 mph.

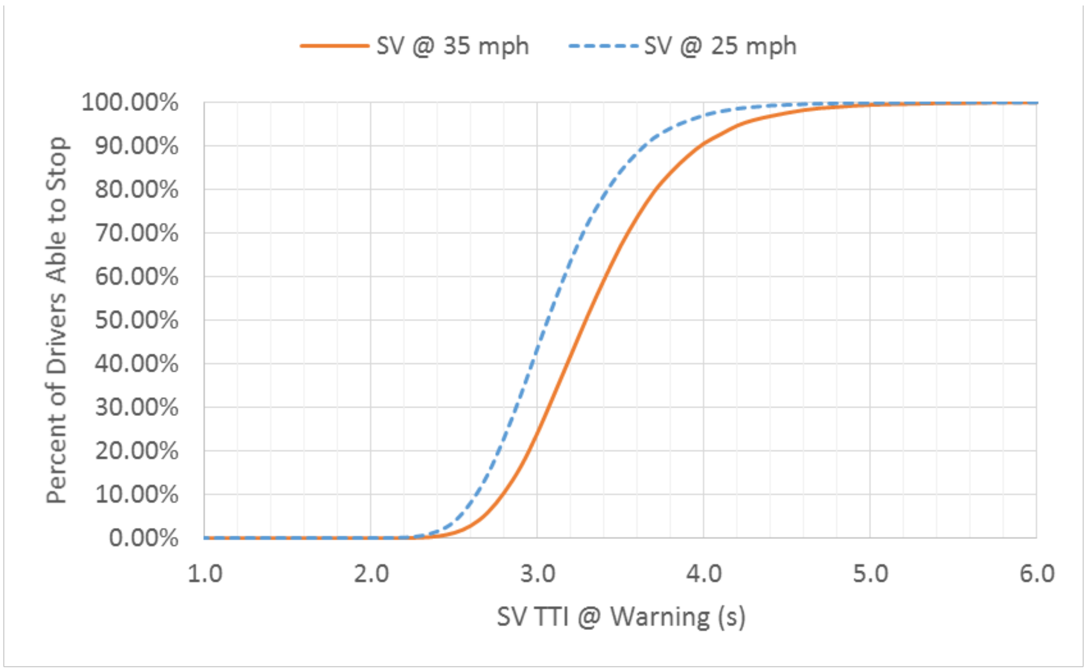


Figure 6. Driver Ability to Stop Based on Warning Times

Warning times used in the procedures allow for 90 to 99 percent of drivers to stop their vehicles in advance of the intersection. Drivers may avoid potential crashes with any other crossing vehicles by stopping the SV before reaching the intersection. The SV could avoid a crash with the initial POV by slowing down and passing behind it, but it may still be in a conflict with any other crossing-paths vehicle.

Table 6 contains the upper and lower limits of warning times in the IMA scenario where both vehicles are initially moving.

Table 6. Boundaries of Warning Times for IMA: SV Initially Moving

SV Speed (mph)	Lower Limit of Warning Range (s)	Upper Limit of Warning Range (s)
25	3.7	4.4
35	4.0	4.9

A breakdown of driver ability to stop by warning time for a wider selection of speeds is shown in Table 32 of Appendix A.

2.4. Test Procedures

This section contains test procedures relevant to the IMA application and SCP scenario. There are procedures for when:

1. The SV and POV are both initially moving at constant speed and their speeds are equal;
2. The SV and POV are both initially moving at constant speed and there is a speed differential between the two vehicles;
3. The SV is initially stopped before moving into the intersection while the POV is at constant speed;
4. The SV is initially stopped before moving into the intersection while the POV is at constant speed and the view is obstructed by a second larger POV2; and
5. The paths of the two vehicles do not cross (false alert).

All distances in this section are based on center-to-center measurements between two vehicles (i.e., longitudinal or latitudinal range between the centers of the two vehicles). The intersection is therefore not based on the road geometry, but on the location of where the paths of the two vehicles overlap.

2.4.1. IMA: SV Initially Moving, Both Vehicles at Same Speed

This section contains the test procedures for DW and SW scenarios in the SCP pre-crash scenario when both vehicles are initially moving at the same constant speed.

2.4.1.1. IMA-DW-1: Crash Imminent

In this scenario, the SV and POV are both traveling at the same constant speed and a crash is initially imminent.

A summary of the key parameters and their values for this scenario is shown in Table 7.

Table 7. Key Parameters for IMA-DW-1

Variable	Value
$V_{SV\text{-}initial}$	35 ± 1 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
ΔTTI	0 ± 0.75 s
TTI @ Warning	4.0-4.9 s
$R_{SV\text{-}Steady}$	308 ft
$R_{POV\text{-}Steady}$	308 ft
$R_{SV\text{-}Bail}$	103 ft

Both vehicles should accelerate to their test speed and maintain their test speed when they are at least 6 seconds from the intersection. The difference between their TTIs (ΔTTI) should be less than 0.75 seconds when they are at steady state.

A warning would be expected to be issued when the SV is 4.0-4.9 seconds from the intersection and the driver of the SV should immediately apply the brakes.

If a warning is not issued by the time the SV driver is 2.0 seconds from the intersection, then the SV driver should consider taking an evasive maneuver and apply the brakes if necessary to avoid a potential collision.

A schematic of this scenario is shown in Figure 7.

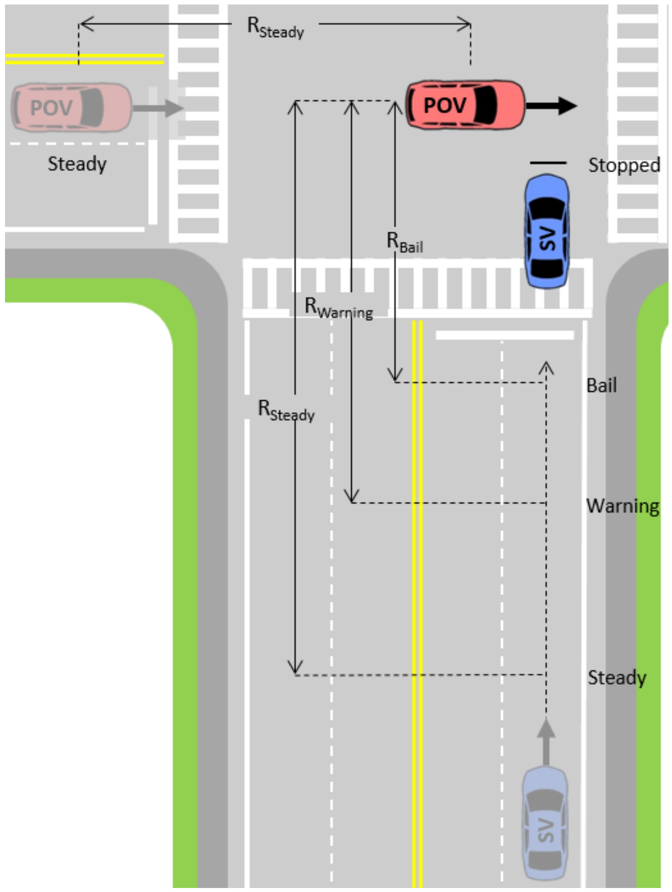


Figure 7. IMA-DW-1 Scenario Diagram

2.4.1.2. IMA-SW-1a: SV Crosses Before POV

In this scenario the SV and POV are both traveling at the same constant speed and the SV crosses the intersection before the POV.

A summary of the key parameters and their values for this scenario is shown in Table 8.

Table 8. Key Parameters for IMA-SW-1a

Variable	Value
$V_{SV\text{-}initial}$	35 ± 1 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
ΔTTI	3.25 ± 0.75 s
$R_{SV\text{-}Steady}$	205 ft
$R_{POV\text{-}Steady}$	411 ft

Both vehicles should accelerate to their test speed. The SV should be at a steady speed when it is at least 4 seconds from the intersection. The POV should be at a steady speed when it is at least 8 seconds from the intersection.[9]

The SV should cross the intersection 2.5 to 4 seconds before the POV, and no warning would be expected to be issued.

Both vehicles should slow to a stop after crossing the intersection.

A schematic of this scenario is shown in Figure 8.

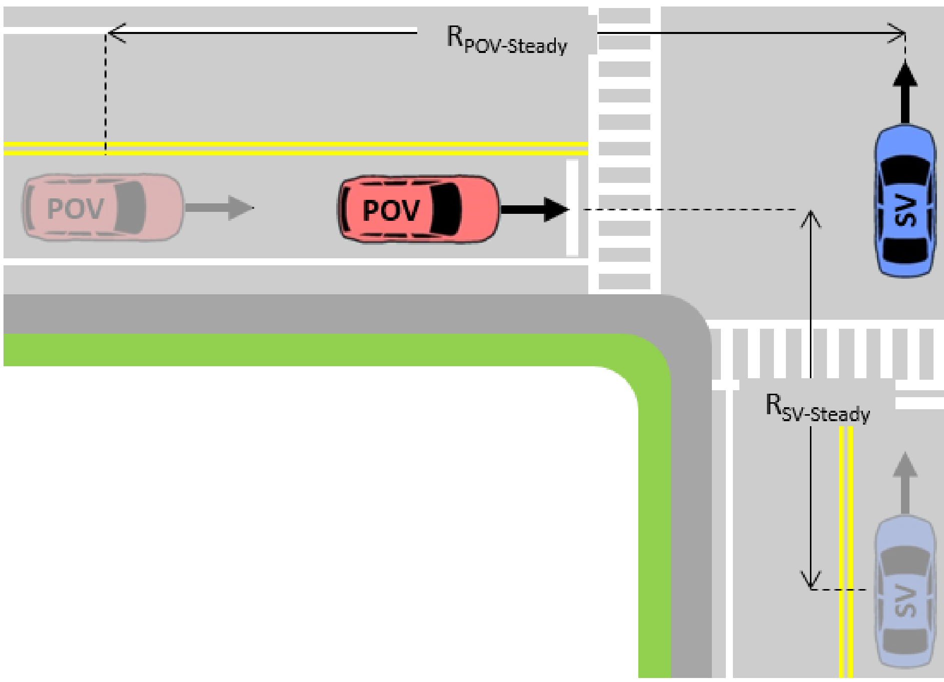


Figure 8. IMA-SW-1a Scenario Diagram

2.4.1.3. IMA-SW-1b: SV Crosses After POV

In this scenario, the SV and POV are both traveling at the same constant speed and the SV crosses the intersection after the POV.

A summary of the key parameters and their values for this scenario is shown in Table 9.

[9] If testing is to occur on a test track with limited road space, these procedures could be run using the $R_{SV\text{-}Steady}$ and $R_{POV\text{-}Steady}$ from the IMA-DW-1 procedures, and by delaying the POV's start by 3.25 seconds. It should be up to the discretion of the test conductor to decide if this method is necessary.

Table 9. Key Parameters for IMA-SW-1b

Variable	Value
$V_{SV\text{-initial}}$	35 ± 1 mph
$V_{POV\text{-initial}}$	35 ± 1 mph
ΔTTI	3.25 ± 0.75 s
$R_{SV\text{-Steady}}$	411 ft
$R_{POV\text{-Steady}}$	205 ft

Both vehicles should accelerate to their test speed. The SV should be at a steady speed when it is at least 8 seconds from the intersection. The POV should be at a steady speed when it is at least 4 seconds from the intersection.[10]

The SV should cross the intersection 2.5 to 4 seconds after the POV, and no warning would be expected to be issued.

Both vehicles should slow to a stop after crossing the intersection.

A schematic of this scenario is shown in Figure 9.

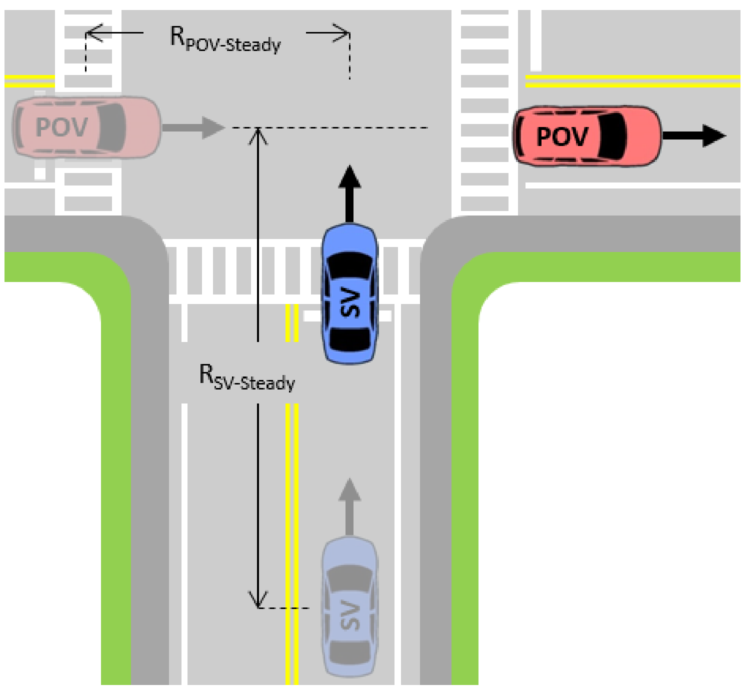


Figure 9. IMA-SW-1b Scenario Diagram

[10] If testing is to occur on a test track with limited road space, these procedures could be run using the $R_{SV\text{-Steady}}$ and $R_{POV\text{-Steady}}$ from the IMA-DW-1 procedures, and by delaying the SV's start by 3.25 seconds. It should be up to the discretion of the test conductor to decide if this method is necessary.

2.4.2. IMA: SV Initially Moving, Speed Differential

This section contains the test procedures for DW and SW scenarios in the SCP pre-crash scenario when both vehicles are initially moving at different speeds.

2.4.2.1. IMA-DW-2: Crash Imminent

In this scenario the SV and POV are traveling at different speeds and a crash is initially imminent.

A summary of the key parameters and their values for this scenario is shown in Table 10.

Table 10. Key Parameters for IMA-DW-2

Variable	Value
$V_{SV\text{-}initial}$	25 ± 1 mph
$V_{POV\text{-}initial}$	45 ± 1 mph
ΔTTI	0 ± 0.75 s
TTI @ Warning	3.7-4.4 s
$R_{SV\text{-}Steady}$	220 ft
$R_{POV\text{-}Steady}$	396 ft
$R_{SV\text{-}Bail}$	73 ft

Both vehicles should accelerate to their test speeds and maintain their test speeds when they are at least 6 seconds from the intersection. Their ΔTTI should be less than 0.75 seconds when they are at steady state.

A warning would be expected to be issued when the SV is 3.7 to 4.4 seconds from the intersection (when it statistically has a 90% to 99% chance of stopping before the intersection) and the driver of the SV should immediately apply the brakes.

If a warning is not issued by the time the SV driver is 2.5 seconds from the intersection, then the SV driver should consider taking an evasive maneuver and apply the brakes if necessary to avoid a potential collision.

A schematic of this scenario is shown in Figure 7 in section 2.4.1.1.

2.4.2.2. IMA-SW-2a: SV Crosses Before POV

In this scenario, the SV and POV are traveling at different speeds and the SV crosses the intersection before the POV.

A summary of the key parameters and their values for this scenario is shown in Table 11.

Table 11. Key Parameters for IMA-SW-2a

Variable	Value
$V_{SV\text{-}initial}$	25 ± 1 mph
$V_{POV\text{-}initial}$	45 ± 1 mph
ΔTTI	3.25 ± 0.75 s
$R_{SV\text{-}Steady}$	147 ft
$R_{POV\text{-}Steady}$	528 ft

Both vehicles should accelerate to their test speed. The SV should be at a steady speed when it is at least 4 seconds from the intersection. The POV should be at a steady speed when it is at least 8 seconds from the intersection.[11]

The SV should cross the intersection 2.5 to 4 seconds before the POV, and no warning would be expected to be issued.

Both vehicles should slow to a stop after crossing the intersection.

A schematic of this scenario is shown in Figure 8 in section 2.4.1.2.

2.4.2.3. IMA-SW-2b: SV Crosses After POV

In this scenario, the SV and POV are traveling at different speeds and the SV crosses the intersection after the POV.

A summary of the key parameters and their values for this scenario is shown in Table 12.

Table 12. Key Parameters for IMA-SW-2b

Variable	Value
$V_{SV\text{-}initial}$	25 ± 1 mph
$V_{POV\text{-}initial}$	45 ± 1 mph
ΔTTI	3.25 ± 0.75 s
$R_{SV\text{-}Steady}$	293 ft
$R_{POV\text{-}Steady}$	264 ft

[11] If testing is to occur on a test track with limited road space, these procedures could be run using the $R_{SV\text{-}Steady}$ and $R_{POV\text{-}Steady}$ from the IMA-DW-2 procedures, and by delaying the POV's start by 3.25 seconds. It should be up to the discretion of the test conductor to decide if this method is necessary.

Both vehicles should accelerate to their test speeds. The SV should be at a steady speed when it is at least 8 seconds from the intersection. The POV should be at a steady speed when it is at least 4 seconds from the intersection.[12]

The SV should cross the intersection 2.5 to 4 seconds after the POV, and no warning would be expected to be issued.

Both vehicles should slow to a stop after crossing the intersection.

A schematic of this scenario is shown in Figure 9 in section 2.4.1.3.

2.4.3. IMA: SV Initially Stopped

This section contains the test procedures for DW and SW scenarios in the SCP pre-crash scenario when the POV is initially moving at a constant speed and the SV is initially stopped.

2.4.3.1. IMA-DW-3: Crash Imminent

In this scenario, the POV is initially moving at a constant speed while the SV is initially stopped until the SV tries to cross the intersection at the same time as the POV.

A summary of the key parameters and their values for this scenario is shown in Table 13.

Table 13. Key Parameters for IMA-DW-3

Variable	Value
$V_{SV\text{-initial}}$	0 mph
$V_{SV\text{-Final}}$	12-19 mph
$V_{POV\text{-initial}}$	35 ± 1 mph
TTI_{POV} @ Warning	2.6-4.6 s
$R_{long\text{-initial}}$	39 ft
$R_{POV\text{-Steady}}$	308 ft
$R_{SV\text{-Action1}}$	205-257 ft

The POV should accelerate to its test speed and maintain its speed when it is at least 6 seconds from the intersection. The SV should initially be 39 feet from the intersection, should release the brake when the POV is 4.5-5.5 seconds from the intersection ($SV_{Action1}$), and should begin accelerating towards the intersections 0.5 to 1.0 seconds later when the POV is 4-5 seconds from the intersection.

A warning would be expected to be issued when the POV is 2.6 to 4.6 seconds from the intersection and the driver of the SV should immediately apply the brakes and bring the SV to a stop.

[12] If testing is to occur on a test track with limited road space, these procedures could be run using the $R_{SV\text{-Steady}}$ and $R_{POV\text{-Steady}}$ from the IMA-DW-2 procedures, and by delaying the SV's start by 3.25 seconds. It should be up to the discretion of the test conductor to decide if this method is necessary.

A schematic of this scenario is shown in Figure 10.

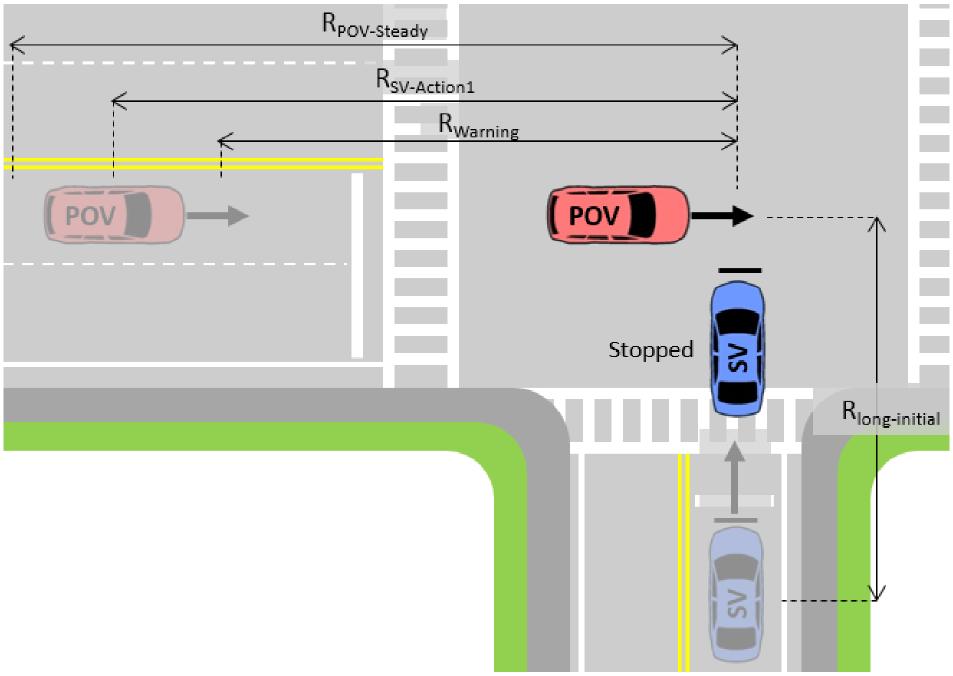


Figure 10. IMA-DW-3 Scenario Diagram

2.4.3.2. IMA-SW-3a: SV Crosses Before POV

In this scenario, the POV is initially moving at a constant speed while the SV is initially stopped until the SV crosses the intersection before the POV.

A summary of the key parameters and their values for this scenario is shown in Table 14.

Table 14. Key Parameters for IMA-SW-3a

Variable	Value
$V_{SV\text{-}initial}$	0 mph
$V_{SV\text{-}Final}$	12-19 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
$R_{long\text{-}initial}$	39 ft
$R_{POV\text{-}Steady}$	660 ft
$R_{SV\text{-}Action1}$	561-627 ft

The POV should accelerate to its test speed and maintain its speed when it is at least 10 seconds from the intersection. The SV should initially be 39 feet from the intersection, should release the brake when the POV is 8.5 to 9.5 seconds from the intersection ($R_{SV\text{-}Action1}$), and should begin accelerating towards the intersections 0.5 to 1.0 seconds later when the POV is 8 to 9 seconds from the intersection.

The SV should cross the intersection ahead of the POV and no warning would be expected to be issued.

A schematic of this scenario is shown in Figure 11.

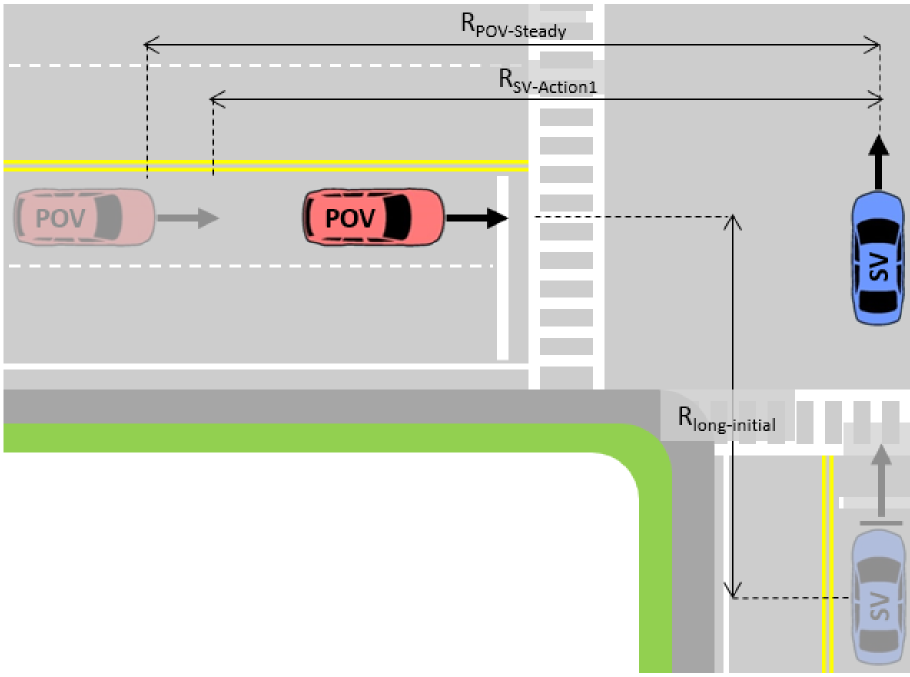


Figure 11. IMA-SW-3a Scenario Diagram

2.4.3.3. IMA-SW-3b: SV Crosses After POV

In this scenario, the POV is initially moving at a constant speed while the SV is initially stopped until the SV crosses the intersection after the POV.

A summary of the key parameters and their values for this scenario is shown in Table 15.

Table 15. Key Parameters for IMA-SW-3b

Variable	Value
$V_{SV\text{-}initial}$	0 mph
$V_{SV\text{-}Final}$	12-19 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
$R_{long\text{-}initial}$	39 ft
$R_{POV\text{-}Steady}$	132 ft
$R_{SV\text{-}Action1}$	(-13)-53 ft

The POV should accelerate to its test speed and maintain its speed when it is at least 2 seconds from the intersection. The SV should initially be 39 feet from the intersection, should release the brake when the POV is 0.8 to (-0.2) seconds from the intersection ($SV_{Action1}$), and should begin accelerating towards the intersections 0.5 to 1.0 seconds later when the POV is 0.3 to (-0.7) seconds from the intersection.

The SV should cross the intersection after the POV and no warning would be expected to be issued.

A schematic of this scenario is shown in Figure 12.

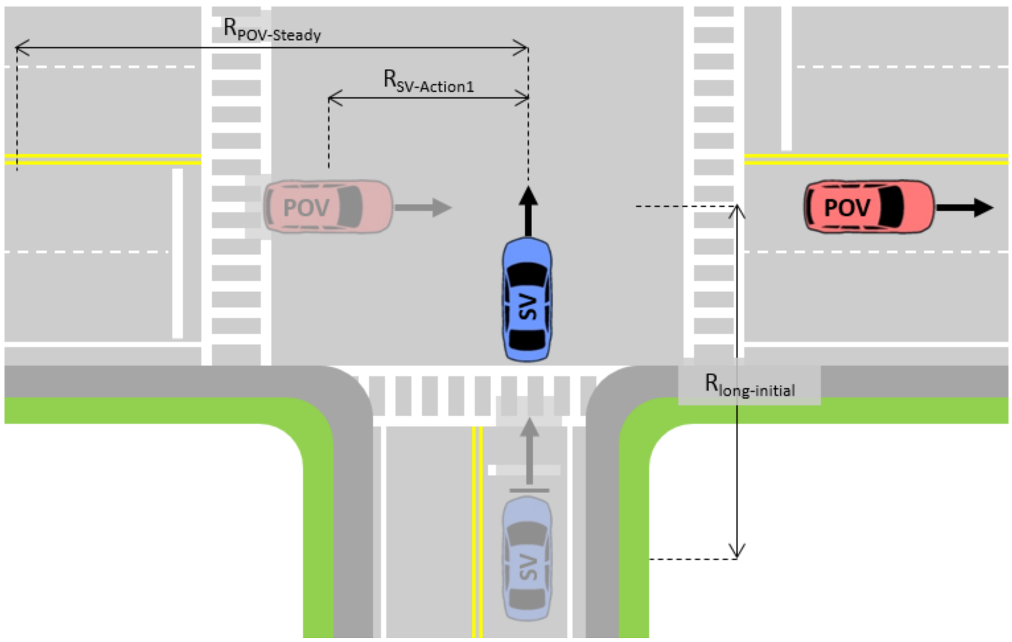


Figure 12. IMA-SW-3b Scenario Diagram

2.4.4. IMA: SV Initially Stopped, View Obstructed

This section contains the test procedures for the DW SCP pre-crash scenario when the POV is initially moving at a constant speed and the SV is initially stopped while a second larger POV2 obstructs the view.

2.4.4.1. IMA-DW-4: Crash Imminent

In this scenario, the POV is initially moving at a constant speed while the SV is initially stopped until the SV tries to cross the intersection at the same time as the POV. The view is obstructed.

A summary of the key parameters and their values for this scenario is shown in Table 16.

Table 16. Key Parameters for IMA-DW-4

Variable	Value
$V_{SV\text{-}initial}$	0 mph
$V_{SV\text{-}Final}$	12-19 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
TTI_{POV} @ Warning	2.6-4.6 s
$R_{long\text{-}initial}$	39 ft
$R_{POV\text{-}Steady}$	308 ft
$R_{SV\text{-}Action1}$	201-262 ft
$R_{lat\text{-}POV2}$	19.5-20.5 ft
$R_{long\text{-}POV2}$	8.5-9.5 ft

A large vehicle (POV2)[13] would be positioned to the left directly next to the SV so that it obstructs the view of the oncoming POV. The lateral distance between the centerlines of the POV2 and the SV should be 20 feet. The longitudinal distance between the centerline of the POV2 and the SV should be 9 feet (the center of the SV should be in front of the center of the POV2)

The POV should accelerate to its test speed and maintain its speed when it is at least 6 seconds from the intersection. The SV should initially be 39 feet from the intersection, should release the brake when the POV is 4.5-5.5 seconds from the intersection ($R_{SV\text{-}Action1}$), and should begin accelerating towards the intersections 0.5 to 1.0 seconds later when the POV is 4-5 seconds from the intersection.

A warning would be expected to be issued when the SV is 2.6 to 4.6 seconds from the intersection and the driver of the SV should immediately apply the brakes and bring the SV to a stop.

A schematic of this scenario is shown in Figure 13.

[13] The POV2 should be a "snout-nosed" schoolbus-style bus with dimensions of 39 ft length, 8 ft width, and 117 inches height. All windows and doors in the bus should be completely shut.

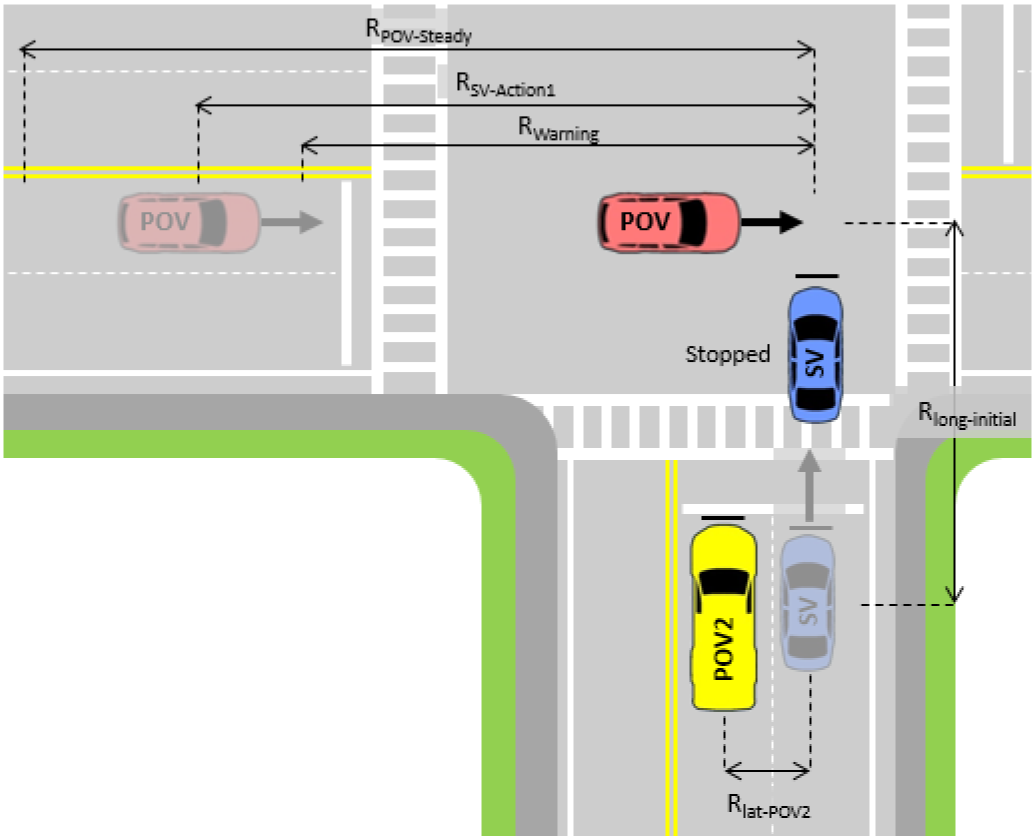


Figure 13. IMA-DW-4 Scenario Diagram

2.4.5. IMA: False Alert Scenarios

This section contains the test procedures for the NW false alert SCP pre-crash scenarios.

2.4.5.1. IMA-NW-1: SV Initially Moving, POV Slows to a Stop

In this scenario, the SV and POV are both initially moving at the same constant speed before the POV slows to a stop in advance of the intersection. A crash is initially imminent.

A summary of the key parameters and their values for this scenario is shown in Table 17.

Table 17. Key Parameters for IMA-NW-1

Variable	Value
$V_{SV\text{-}initial}$	35 ± 1 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
$\Delta TTI_{initial}$	0 ± 0.75 s
$R_{SV\text{-}Steady}$	308 ft
$R_{POV\text{-}Steady}$	385 ft
$R_{POV\text{-}Action}$	282-359 ft
a_{POV}	0.13-0.17 g

The SV and POV should accelerate to their test speeds and maintain their test speed when they are at least 6 and 7.5 seconds from the intersection, respectively. Their ΔTTIs should be less than 0.75 seconds when they are at steady state.

When the POV is 5.5 to 7 seconds from the intersection, the driver of the POV should release the throttle and apply the brakes to bring the POV to a stop ($R_{POV\text{-}Action}$).

The POV driver should aim to stop 30 to 60 feet from the intersection.

No warning is expected to be issued in the SV.

A schematic of this scenario is shown in Figure 14.

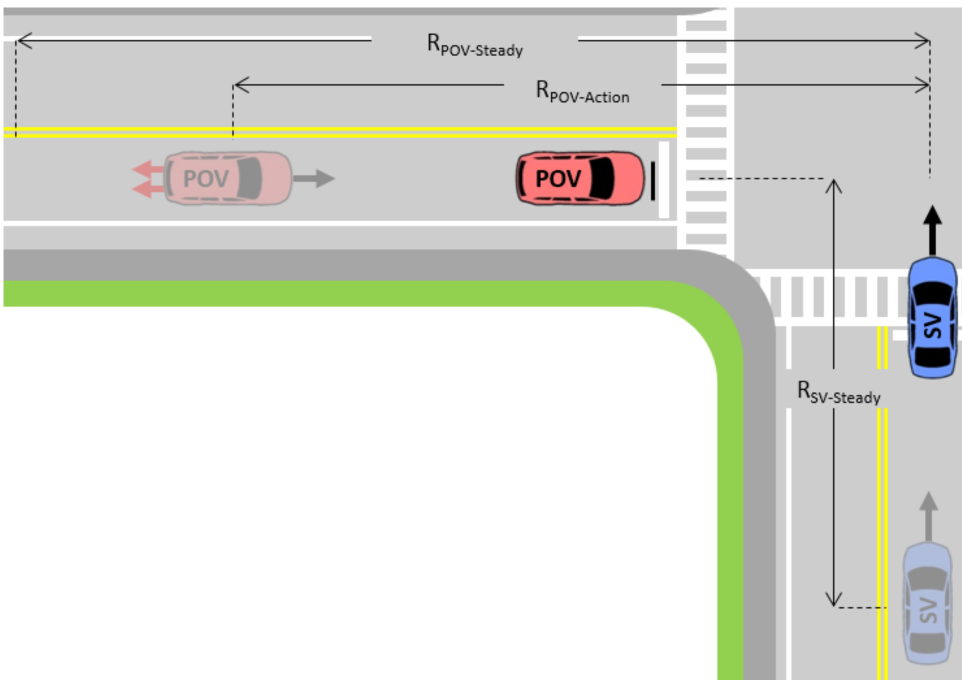


Figure 14. IMA-NW-1 Scenario Diagram

2.4.5.2. IMA-NW-2: SV Initially Stopped, POV Slows to a Stop

In this scenario, the POV is initially moving at a constant speed and the SV is initially stopped. The POV slows to a stop in advance of the intersection and the SV accelerates through the intersection.

A summary of the key parameters and their values for this scenario is shown in Table 18.

Table 18. Key Parameters for IMA-NW-2

Variable	Value
$V_{SV\text{-}initial}$	0 mph
$V_{SV\text{-}Final}$	12-19 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
$R_{POV\text{-}Steady}$	385 ft
$R_{POV\text{-}Action}$	156-203 ft
$R_{SV\text{-}Action1}$	98-149 ft
a_{POV}	0.25-0.35 g

The POV should accelerate to its test speed and maintain its test speed when it is at least 7.5 seconds from the intersection.

When the POV is 3 to 4 seconds from the intersection, the driver of the POV should release the throttle and apply the brakes to bring the POV to a stop ($R_{POV\text{-}Action}$). The POV driver should aim to maintain a constant deceleration and stop 30 to 60 feet from the intersection.

When the POV is 98 to 149 feet from the intersection (1.9 to 2.9 seconds based on the initial speed of the POV) ($R_{SV\text{-}Action1}$), the SV should release the brakes and, 0.5 to 1.0 seconds later, accelerate through the intersection. No warning would be expected to be issued in the SV.

A schematic of this scenario is shown in Figure 15.

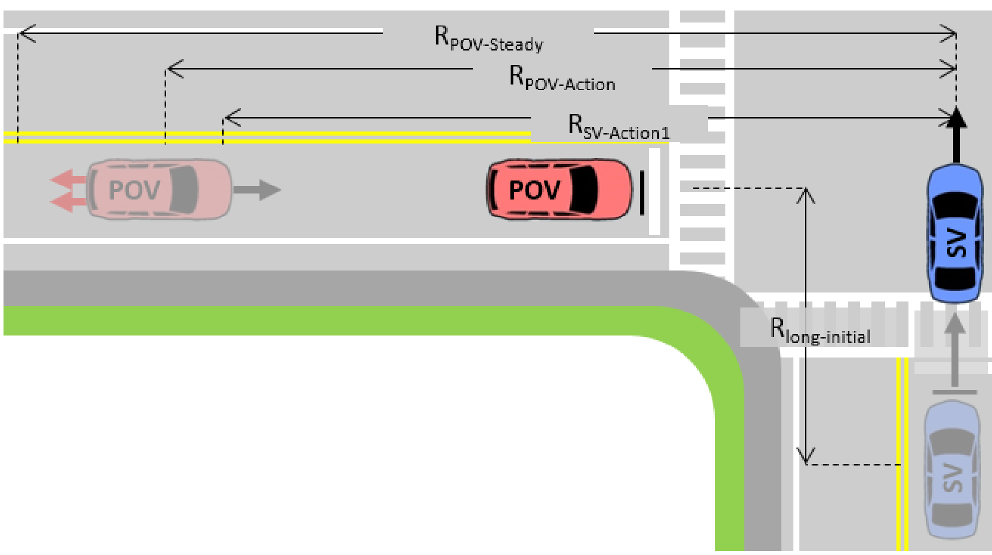


Figure 15. IMA-NW-2 Scenario Diagram

2.4.5.3. IMA-NW-3: SV Initially Moving, SV Slows to a Stop

In this scenario, the SV and POV are initially moving at the same constant speed before the SV slows down and stops in advance of the intersection.

A summary of the key parameters and their values for this scenario is shown in Table 19.

Table 19. Key Parameters for IMA-NW-3

Variable	Value
$V_{SV\text{-}initial}$	35 ± 1 mph
$V_{SV\text{-}Final}$	0 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
$\Delta TTI_{initial}$	0 ± 0.75 s
$R_{SV\text{-}Steady}$	385 ft
$R_{POV\text{-}Steady}$	308 ft
$R_{SV\text{-}Action1}$	282-359 ft
a_{SV}	0.1-0.2 g

The SV and POV should accelerate to their test speeds and maintain their test speed when they are at least 7.5 and 6 seconds from the intersection, respectively. Their ΔTTI should be less than 0.75 seconds when they are at steady state.

When the SV is 5.5 to 7 seconds from the intersection, the driver of the SV should release the throttle and apply the brakes to bring the SV to a stop ($R_{SV\text{-}Action1}$).

The SV driver should aim to stop 30 to 60 feet from the intersection.

No warning is expected to be issued. A schematic of this scenario is shown in Figure 16.

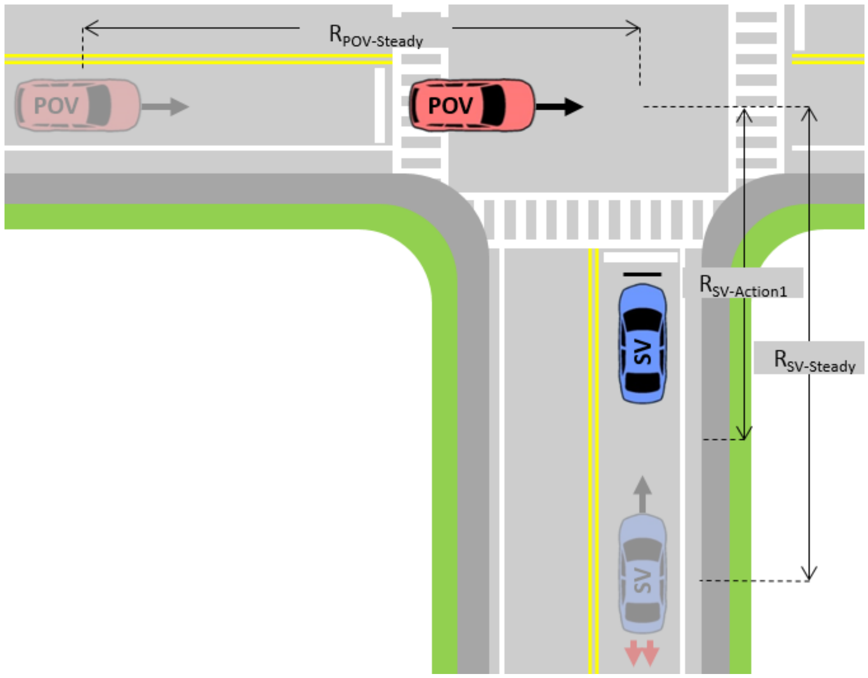


Figure 16. IMA-NW-3 Scenario Diagram

2.4.5.4. IMA-NW-4: SV Initially Moving, POV Coming From Right, SV Turns Right at Intersection

In this scenario, the SV and POV are initially traveling at the same speed before the SV slows down, applies the right turn signal, and turns right at the intersection.

A summary of the key parameters and their values for this scenario is shown in Table 20.

Table 20. Key Parameters for IMA-NW-4

Variable	Value
$V_{SV\text{-}initial}$	35 ± 1 mph
$V_{SV\text{-}Final}$	5-15 mph
$V_{POV\text{-}initial}$	35 ± 1 mph
$\Delta TTI_{initial}$	0 ± 0.75 s
$R_{SV\text{-}Steady}$	334 ft
$R_{POV\text{-}Steady}$	308 ft
$R_{SV\text{-}Action1}$	282-359 ft
a_{SV}	0.1-0.2 g

The SV and POV should accelerate to their test speeds and maintain their test speeds when they are at least 6.5 and 6 seconds from the intersection, respectively. Their ΔTTIs should be less than 0.75 seconds when they are at steady state.

When the SV is 5.5 to 6 seconds from the intersection, the driver of the SV should release the throttle, apply the brakes, and apply the right turn signal.

The SV should slow down to its final velocity range, and it should turn right at the intersection.

No warning is expected to be issued. A schematic of this scenario is shown in Figure 17.

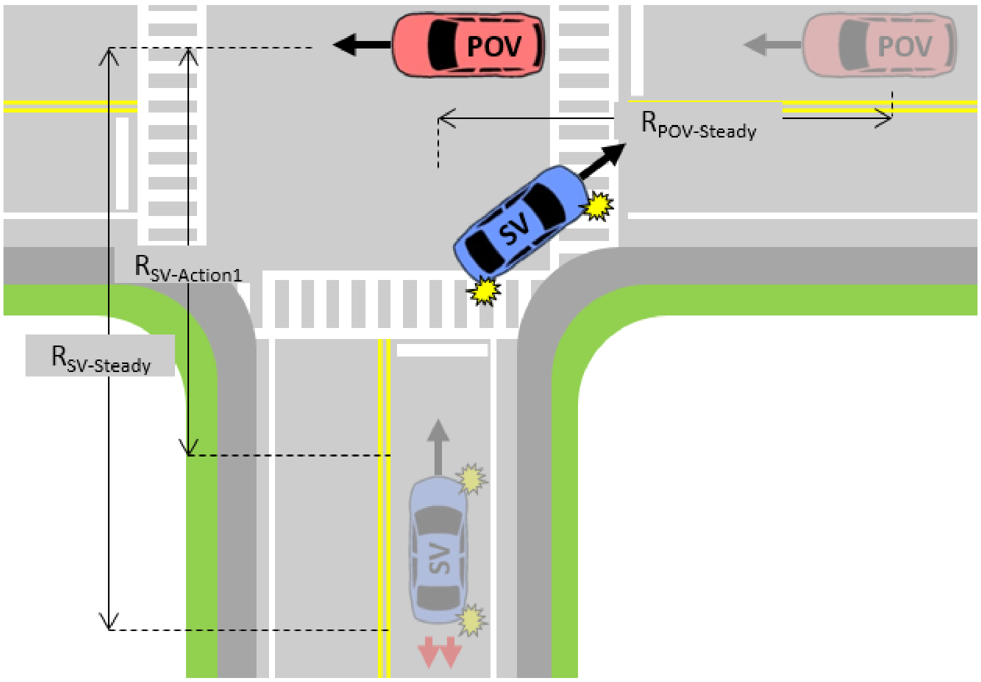


Figure 17. IMA-NW-4 Scenario Diagram

3. LEFT TURN ASSIST

3.1. Scenarios

This section describes the LTAP/OD scenarios that are used for testing the LTA application.

There are three initial states in these scenarios:

1. The SV and POV accelerate to a set speed and maintain that constant speed before the SV reduces its speed to turn left across the path of the POV.
2. The POV accelerates to a set speed and maintains that constant speed throughout the trial. The SV is initially stopped before attempting to accelerate and turn left at the intersection.
3. The POV accelerates to a set speed and maintains that constant speed throughout the trial. The SV is initially stopped before attempting to accelerate and turn left at the intersection. The view is obstructed by an additional larger vehicle (POV2).

Additionally, there are three types of warning conditions in these scenarios. There are conditions where:

1. The paths of the SV and POV cross, their TTIs are similar, and a warning would be expected to be issued;
2. The paths of the SV and POV cross, their TTIs are not similar (i.e., one vehicle can safely navigate the intersection before the other), and a warning would be expected to be suppressed; and
3. The paths of the SV and POV do not cross, their initial TTIs are similar, and no warning would be expected to be issued.

3.2. Vehicle Kinematic Values

The speeds used for the POV in the test procedures for the LTA application are based on the cumulative frequency of comprehensive costs of all LTAP/OD crashes.[14] Figure 18 shows a plot of the comprehensive costs organized by the oncoming POV's travel speed.

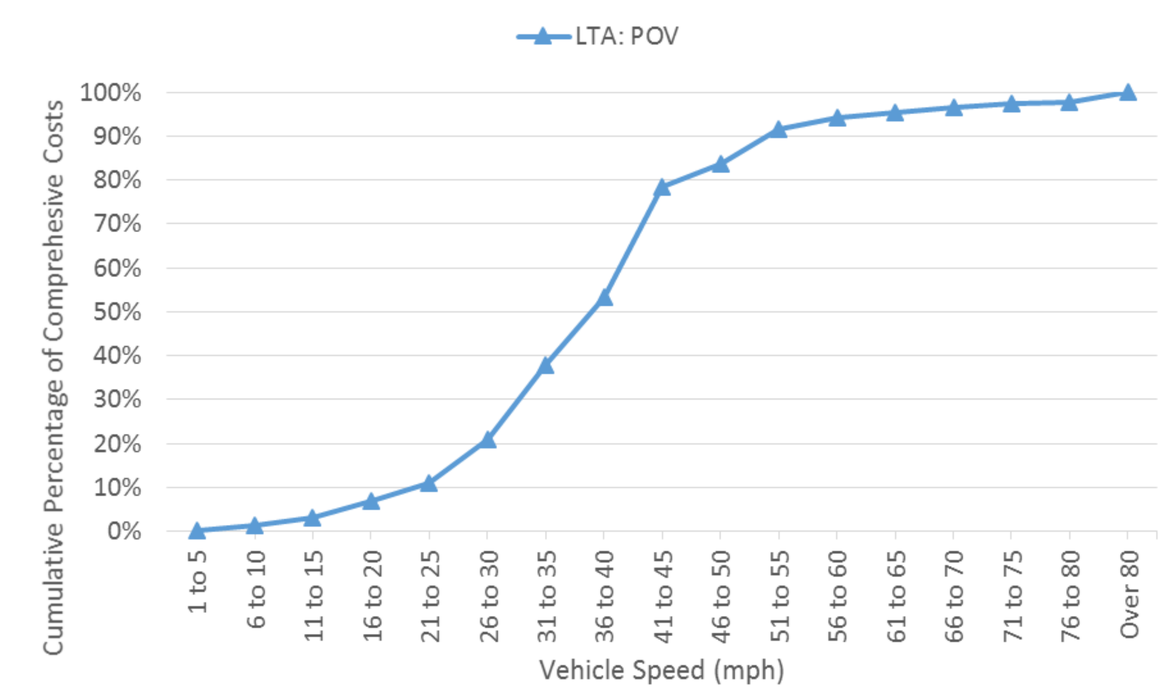


Figure 18. Cumulative Comprehensive Costs of LTAP/OD Crashes by POV Speed

In test scenarios where the SV is initially stopped, acceleration levels are defined using naturalistic driving data from similar on-road scenarios. Figure 19 shows the final speeds corresponding to the distribution of acceleration levels from the naturalistic driving data. The final speeds correspond to the time until the center of the SV reaches the center of the lane where the SV and POV intersect.

[14] "All LTAP/OD crashes" refers to crashes that occurred from 2011 to 2015 (from GES and FARS databases) where only two vehicles are involved, both vehicles are light vehicles, and where neither vehicle made an avoidance maneuver.

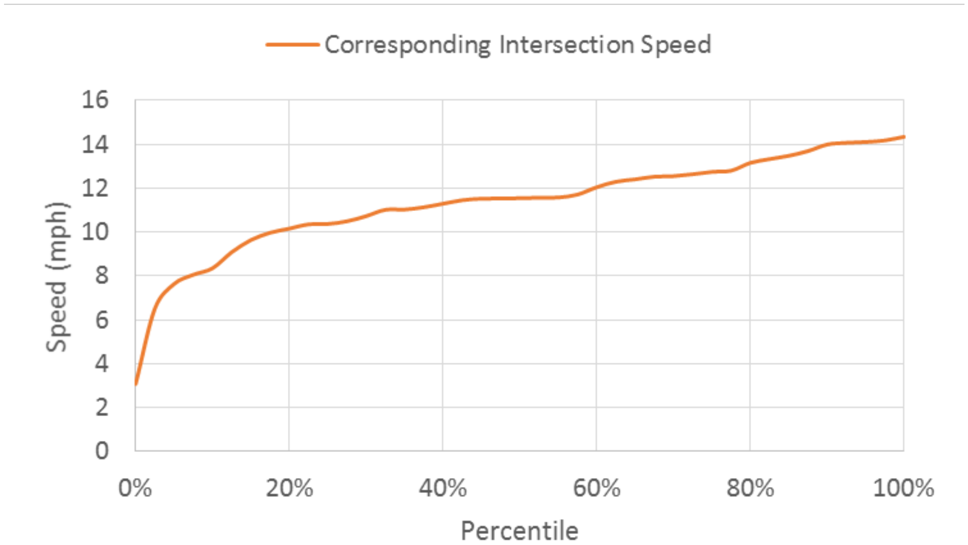


Figure 19. Center-of-Intersection Speeds of SV When Initially Stopped in LTAP/OD Scenario

In scenarios where the SV is initially moving, final turning speeds are defined using a combination of pre-turn deceleration values, SV speeds before decelerating, and the time that the vehicle spends decelerating.[15]

Table 21 provides a summary of all the speeds used in testing of the LTA application and an explanation for selecting each speed.

Table 21. Summary Table of Speeds Used in IMA Testing

IMA Scenario	**Metric**	**Speed**	**Reasoning**
Both vehicles moving	SV initial speed	25 mph	Naturalistic data
Both vehicles moving	SV final speed	5-20 mph	Calculated from naturalistic data
Both vehicles moving	POV speed	40 mph	Approximate 50th percentile of POV speeds
SV initially stopped	SV speed at center of intersection	10-14 mph	Speed from 10th to 90th percentile of acceleration
SV initially stopped	POV Speed	40 mph	Approximate 50th percentile of POV speeds

[15] To prevent distraction from the purpose of this report (the procedures) these values and the calculations required to derive them are not provided in this report.

3.3. Warning Criteria

Warning criteria for the LTA application for all scenarios were derived using data from:

- Naturalistic driving studies; and
- Reconstructions of SCP crashes where both vehicles were equipped with a crash event data recorder (EDR).

The exercise involved analyzing the timing of the crashes when

1. The SV turned left and crossed the intersection safely before the POV (from naturalistic data);
2. The SV turn left and crashed into the POV (from EDR data); and
3. The SV turned left and crossed the intersection safely after the POV (from naturalistic data).

Figures 20 and 21 shows the frequencies of times to collision (TTC) when the SV begins moving through the intersection for scenarios where the SV is initially stopped and initially moving, respectively (Stevens et al., in press). The TTCs are based on the combined speeds of the two vehicles and the longitudinal range between them.

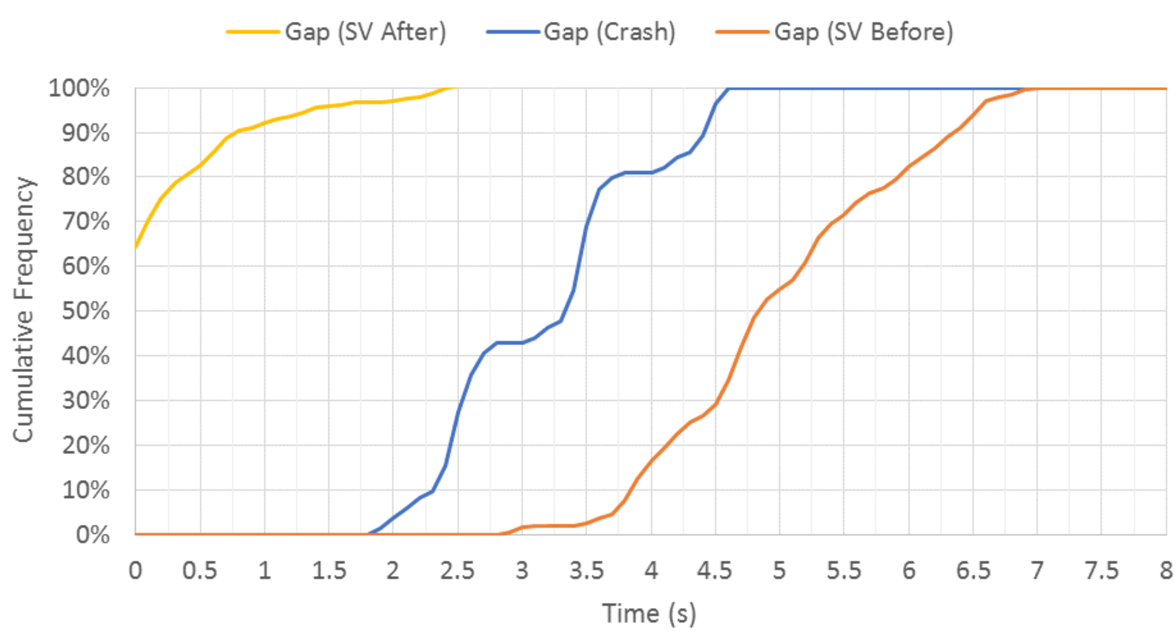


Figure 20. Cumulative Frequency by Time of LTAP/OD Scenarios
Where SV Is Initially Stopped

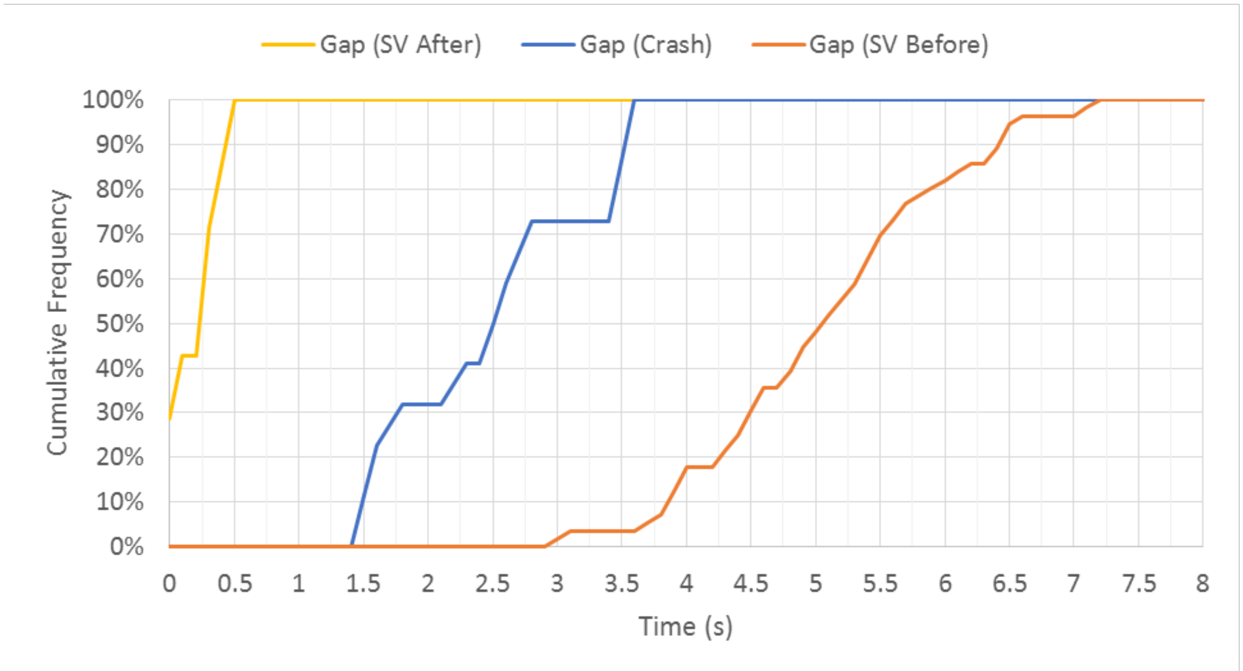


Figure 21. Cumulative Frequency by Time of LTAP/OD Scenarios
Where SV Is Initially Moving

Tables 22 and Table 23 show the time ranges used to define the DW and SW test scenarios for the scenarios where the SV is initially stopped and initially moving, respectively. The range between when a system would be expected to warn and when it would be expected to suppress a warning is the MNW range. It would be up to the application developer to know if a warning is necessary based on additional kinematic parameters and intersection geometry.

Table 22. Summary Table of Warning and Suppressed Warning Boundaries for LTA
Where SV Is Initially Stopped

Warning Type	Scenario Description	Range (s)
SW	SV Crosses After POV	TTC ≤ 0.4
MNW	SV Crosses After POV	0.4 < TTC < 2.4
DW	Crash Imminent	2.4 ≤ TTC ≤ 3.7
MNW	SV Crosses Before POV	3.7 < TTC < 5.9
SW	SV Crosses Before POV	5.9 ≤ TTC

Table 23. Summary Table of Warning and Suppressed Warning Boundaries for LTA Where SV Is Initially Moving

Warning Type	Scenario Description	Range (s)
SW	SV Crosses After POV	TTC ≤ 0.5
MNW	SV Crosses After POV	0.5 < TTC < 1.6
DW	Crash Imminent	1.6 ≤ TTC ≤ 3.5
MNW	SV Crosses Before POV	3.5 < TTC < 5.9
SW	SV Crosses Before POV	5.9 ≤ TTC

3.4. Test Procedures

This section contains test procedures for the LTA application and LTAP/OD scenario. There are procedures for when:

1. The SV and POV are initially moving at constant speed. The SV slows down before attempting the turn.
2. The POV is initially at constant speed. The SV is initially stopped before attempting to turn through the intersection.
3. The POV is initially at constant speed. The SV is initially stopped before attempting to turn through the intersection. The view is obstructed by a larger second POV.
4. The paths of the two vehicles do not cross (false alert).

Distances in this section are measured based on the:

- Center-to-center distances between two vehicles for:
  - The horizontal distance between the SV and POV; and
  - The distances between the SV and POV2; and
- Center of vehicle to center of intersection for individual range measurements for the SV and POV2 (e.g., the distance at when each vehicle needs to be at a steady speed).

3.4.1. LTA: SV Initially Moving

3.4.1.1. LTA-DW-1: Crash Imminent

In this scenario, the SV and POV are initially moving at different constant speeds in opposite directions before the SV slows down and turns left at the intersection while the POV is crossing.

A summary of the key parameters and their values for this scenario is shown in Table 24.

Table 24. Key Parameters for LTA-DW-1

Variable	Value
$V_{SV\text{-}initial}$	25 ± 1 mph
$V_{SV\text{-}final}$	5-20 mph
$V_{POV\text{-}initial}$	40 ± 1 mph
TTC @ Warning	1.6-3.5 s
$R_{SV\text{-}Steady}$	220 ft
$R_{POV\text{-}Steady}$	411 ft
$R_{SV\text{-}Action1}$	183-202 ft
$R_{SV\text{-}Action2}$	76-136 ft
$R_{Lat\text{-}initial}$	12-24 ft

The SV should accelerate to its test speed and maintain it when its TTI is 6 seconds. The POV should accelerate to its test speed (3 seconds after the SV) and maintain its test speed when its TTI is 7 seconds. The lateral distance between the SV and the POV should be 12-24 feet until the SV begins its turn.

The SV should apply the left turn signal when its TTI is 5 to 5.5 seconds ($R_{SV\text{-}Action1}$). The SV should then apply the brakes when its TTI is 5 seconds. It should be within its final speed range when it is between 136 and 76 feet from the intersection ($R_{SV\text{-}Action2}$). When the SV has decelerated to within its final speed range, it should stay within that range but without accelerating. The SV should turn left into the path of the POV when it is at the intersection. The TTC should be 1.6 to 3.5 seconds at this time.

A warning would be expected to be issued when the turn is initiated and the TTC is 1.6 to 3.5 seconds, and the SV driver should immediately apply the brakes and/or steer to the right to avoid a potential collision.

If a warning is not issued, the SV driver should apply the brakes and/or steer to the right to avoid a potential collision.

A schematic of this scenario is shown in Figure 22.

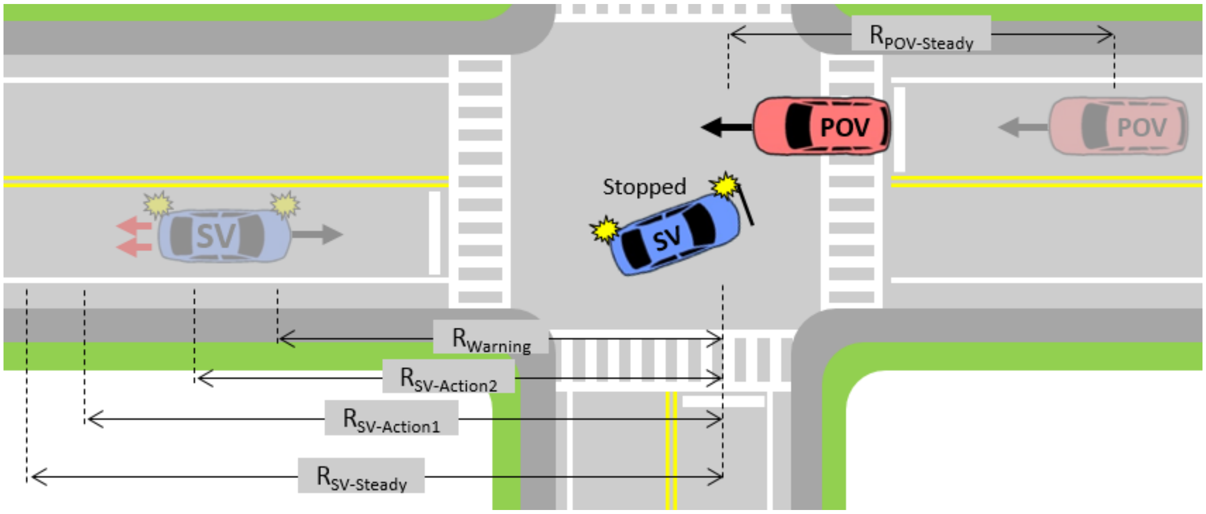


Figure 22. LTA-DW-1 Scenario Diagram

3.4.1.2. LTA-SW-1a: SV Crosses Before POV

In this scenario, the SV and POV are initially moving at different constant speeds in opposite directions before the SV slows down and turns left at the intersection before the POV crosses.

A summary of the key parameters and their values for this scenario is shown in Table 25.

Table 25. Key Parameters for LTA-SW-1a

Variable	Value
$V_{SV\text{-}initial}$	25 ± 1 mph
$V_{SV\text{-}final}$	5-20 mph
$V_{POV\text{-}initial}$	40 ± 1 mph
TTC @ Turn	6-7 s
$R_{SV\text{-}Steady}$	220 ft
$R_{POV\text{-}Steady}$	587 ft
$R_{SV\text{-}Action1}$	183-202 ft
$R_{SV\text{-}Action2}$	76-136 ft
$R_{Lat\text{-}initial}$	12-24 ft

The SV should accelerate to its test speed and maintain it when its TTI is 6 seconds. The POV should accelerate to its test speed and maintain its test speed when its TTI is 10 seconds. The lateral distance between the SV and the POV should be 12-24 feet until the SV begins its turn.

The SV should apply the left turn signal and brakes when its TTI is 5-5.5 seconds ($R_{SV\text{-}Action1}$). It should be within its final speed range when it is between 136 and 76 feet from the intersection ($R_{SV\text{-}Action2}$). When the SV has decelerated to within its final speed range, it should stay within that range but without accelerating. The SV should turn left into the path of the POV when it is at the intersection and cross through the intersection before the POV. The TTC should be about 6-7 seconds when the SV begins its turn.

No warning would be expected to be issued. A schematic of this scenario is shown in Figure 23.

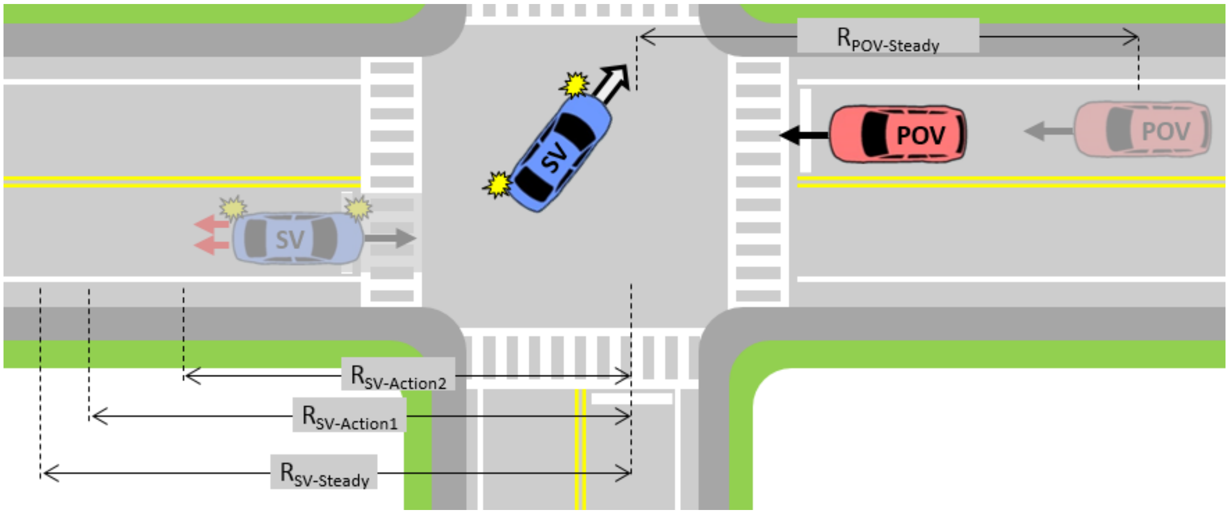


Figure 23. LTA-SW-1a Scenario Diagram

3.4.1.3. LTA-SW-1b: SV Crosses After POV

In this scenario, the SV and POV are initially moving at different constant speeds in opposite directions before the SV slows down and turns left at the intersection after the POV crosses.

A summary of the key parameters and their values for this scenario is shown in Table 26.

Table 26. Key Parameters for LTA-SW-1b

Variable	Value
$V_{SV\text{-}initial}$	25 ± 1 mph
$V_{SV\text{-}final}$	5-20 mph
$V_{POV\text{-}initial}$	40 ± 1 mph
TTC @ Turn	(-0.5)-0.5 s
$R_{SV\text{-}Steady}$	220 ft
$R_{POV\text{-}Steady}$	352 ft
$R_{SV\text{-}Action1}$	202-183 ft
$R_{SV\text{-}Action2}$	76-136 ft
$R_{Lat\text{-}initial}$	12-24 ft

Both vehicles should accelerate to their test speeds at the same time and maintain them when their TTI is at least 6 seconds. The lateral distance between the SV and the POV should be 12 to 24 feet until the SV begins its turn.

The SV should apply the left turn signal and brakes when its TTI is 5 to 5.5 seconds ($R_{SV\text{-}Action1}$). It should be within its final speed range when it is 136 to 76 feet from the intersection ($R_{SV\text{-}Action2}$). When the SV has decelerated to within its final speed range, it should stay within that range but without accelerating. The SV should turn left into the path of the POV when it is at the intersection and cross through the intersection after the POV. The TTC should be about (-0.5)-0.5 seconds when the SV begins its turn.

No warning would be expected to be issued. A schematic of this scenario is shown in Figure 24.

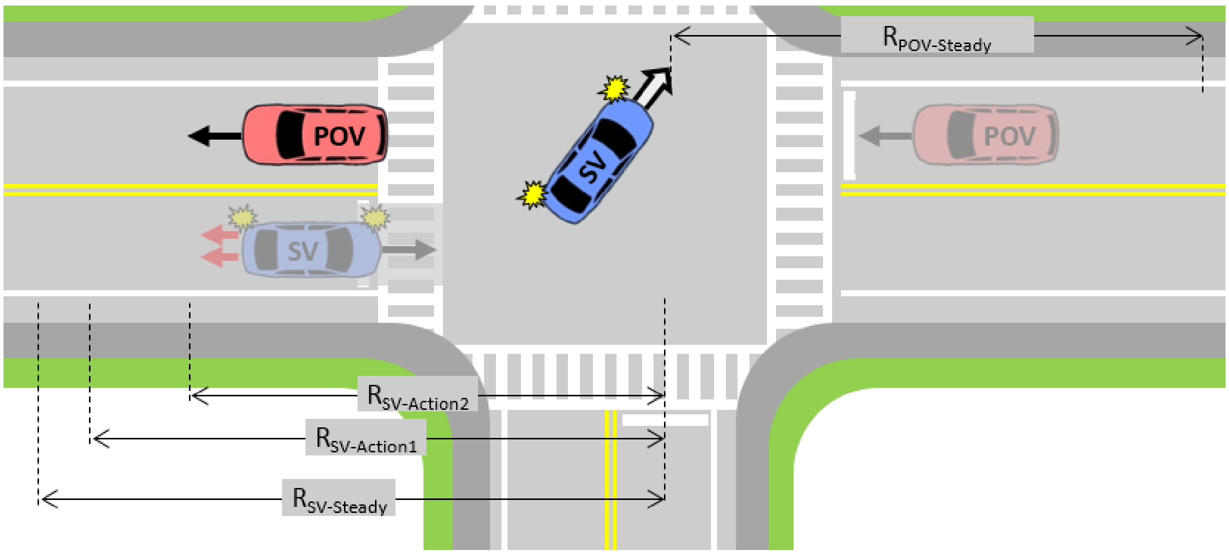


Figure 24. LTA-SW-1b Scenario Diagram

3.4.2. <u>LTA: SV Initially Stopped</u>

3.4.2.1. LTA-DW-2: Crash Imminent

In this scenario, the POV is initially moving at a constant speed towards the SV in the lane adjacent. The SV is initially stopped and accelerates and turns left at the intersection while the POV is crossing.

A summary of the key parameters and their values for this scenario is shown in Table 27.

Table 27. Key Parameters for LTA-DW-2

Variable	Value
$V_{SV\text{-}initial}$	0 mph
$V_{SV\text{-}final}$	3-20 mph
$V_{POV\text{-}initial}$	40 ± 1 mph
TTC @ Warning	2.4-3.7 s
$R_{POV\text{-}Steady}$	587 ft
$R_{SV\text{-}Action1}$	499-528 ft
$R_{SV\text{-}Action2}$	141-217 ft
$R_{Lat\text{-}initial}$	12-24 ft

The POV should accelerate to and maintain its test speed when its TTI is 10 seconds. The SV should be stopped 30 to 45 feet from the center of the intersection. The lateral distance between the SV and the POV should be 12 to 24 feet until the SV begins its turn.

The SV should apply the left turn signal when the POV TTI is 8.5 to 9.0 seconds ($R_{SV\text{-}Action1}$). When the POV TTI is 3.7 to 4.2 seconds, the SV should release its brakes and, 0.5 to 1.0 seconds later, the SV should turn left into the path of the POV ($R_{SV\text{-}Action2}$). The TTC should be 2.4 to 3.7 seconds at this time.

A warning would be expected to be issued when the turn is initiated and the TTC is 2.4 to 3.7 seconds, and the SV driver should immediately apply the brakes and/or steer to the right to avoid a potential collision.

If a warning is not issued, the SV driver should apply the brakes and/or steer to the right to avoid a potential collision. The POV may steer to the right to avoid a potential collision once the SV has initiated its turn.

A schematic of this scenario is shown in Figure 25.

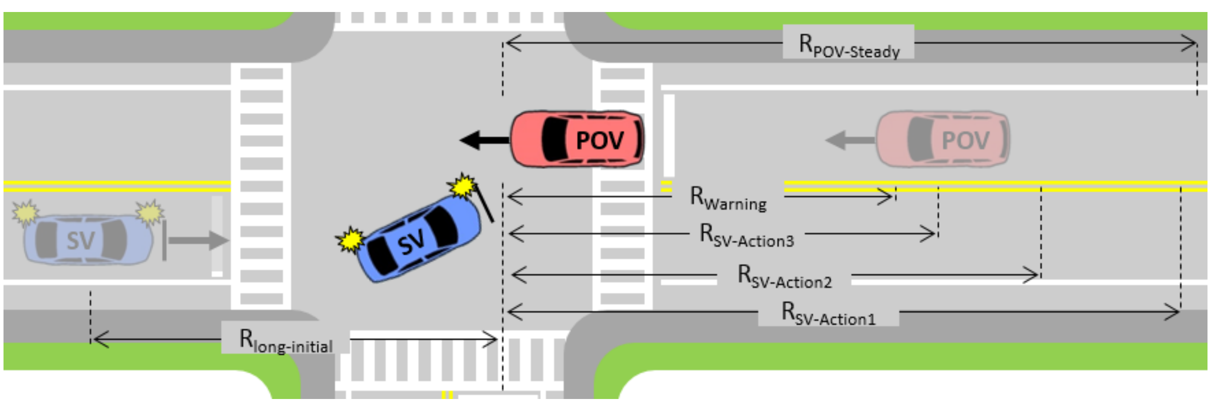


Figure 25. LTA-DW-2 Scenario Diagram

3.4.2.2. LTA-SW-2a: SV Crosses Before POV

In this scenario, the POV is initially moving at a constant speed towards the SV in the lane adjacent. The SV is initially stopped and safely accelerates and turns left at the intersection before the POV crosses.

A summary of the key parameters and their values for this scenario is shown in Table 28.

Table 28. Key Parameters for LTA-SW-2a

Variable	Value
$V_{SV\text{-}initial}$	0 mph
$V_{SV\text{-}final}$	3-20 mph
$V_{POV\text{-}initial}$	40 ± 1 mph
$R_{POV\text{-}Steady}$	763 ft
$R_{SV\text{-}Action1}$	704-733 ft
$R_{SV\text{-}Action2}$	411-440 ft
$R_{Lat\text{-}initial}$	12-24 ft

The POV should accelerate to and maintain its test speed when its TTI is 13 seconds. The SV should be stopped 30 to 45 feet from the center of the intersection. The lateral distance between the SV and the POV should be 12 to 24 feet until the SV begins its turn.

The SV should apply the left turn signal when the POV TTI is 12 to 12.5 seconds ($R_{SV\text{-}Action1}$). When the POV TTI is 7 to 7.5 seconds ($R_{SV\text{-}Action2}$), the SV should release the brake and, 0.5 to 1.0 seconds later, it should turn left into the path of the POV. The TTC should be about 6 to 7 seconds when the SV begins its turn.

The SV should cross safely through the intersection and no warning would be expected to be issued.

A schematic of this scenario is shown in Figure 26.

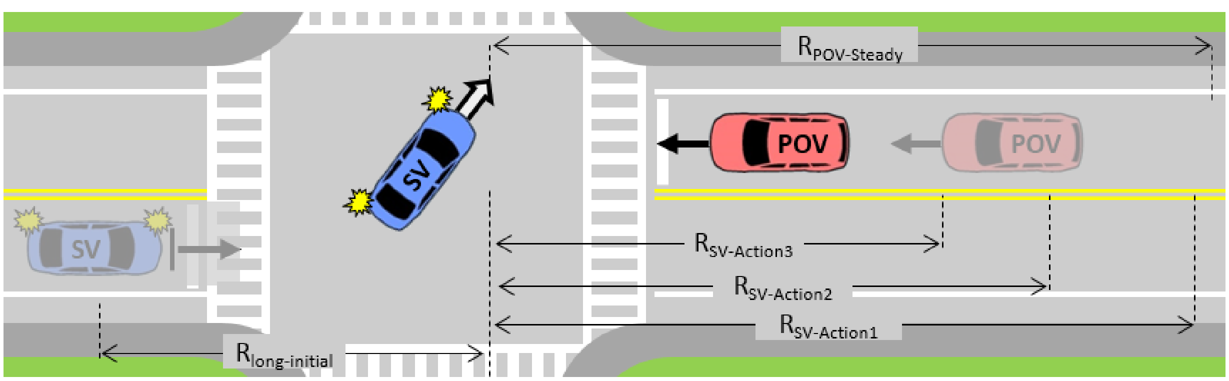


Figure 26. LTA-SW-2a Scenario Diagram

3.4.2.3. LTA-SW-2b: SV Crosses After POV

In this scenario, the POV is initially moving at a constant speed towards the SV in the lane adjacent. The SV is initially stopped and safely accelerates and turns left at the intersection after the POV crosses.

A summary of the key parameters and their values for this scenario is shown in Table 29.

Table 29. Key Parameters for LTA-SW-2b

Variable	Value
$V_{SV\text{-}initial}$	0 mph
$V_{SV\text{-}final}$	3-20 mph
$V_{POV\text{-}initial}$	40 ± 1 mph
$R_{POV\text{-}Steady}$	411 ft
$R_{SV\text{-}Action1}$	352-381 ft
$R_{SV\text{-}Action2}$	(-6)-53 ft
$R_{Lat\text{-}initial}$	12-24 ft

The POV should accelerate to and maintain its test speed when its TTI is 7 seconds. The SV should be stopped 30 to 45 feet from the center of the intersection. The lateral distance between the SV and the POV should be 12 to 24 feet until the SV begins its turn.

The SV should apply the left turn signal when the POV TTI is 6 to 6.5 seconds ($R_{SV\text{-}Action1}$). When the POV TTI is (-0.1) to 0.9 seconds ($R_{SV\text{-}Action2}$), the SV should release the brake and, 0.5 to 1.0 seconds later, the SV should turn left into the path of the POV cross through the intersection after the POV. The TTC should be about (-0.6)-0.4 seconds when the SV begins its turn.

No warning would be expected to be issued. A schematic of this scenario is shown in Figure 27.

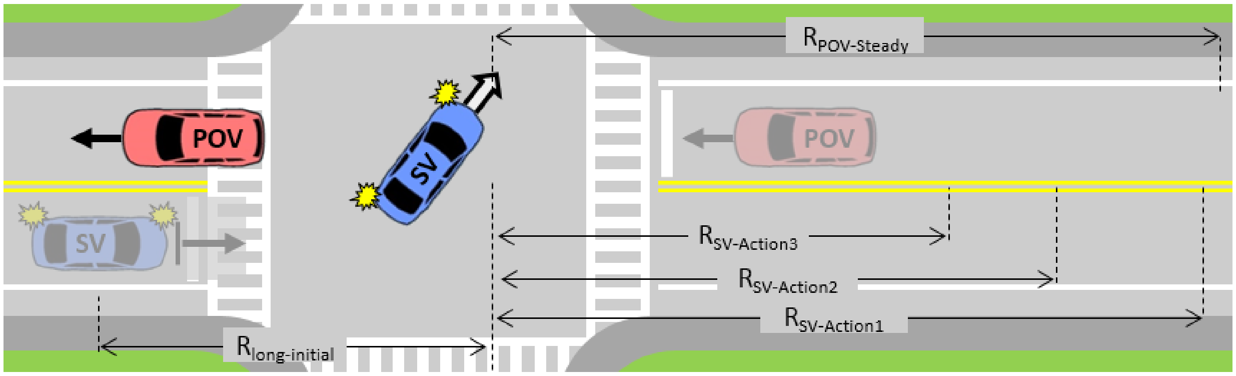


Figure 27. LTA-SW-2b Scenario Diagram

3.4.3. LTA: SV Initially Stopped, View Obstructed

3.4.3.1. LTA-DW-3: Crash Imminent

In this scenario, the POV is initially moving at a constant speed towards the SV in the lane adjacent. The SV is initially stopped and accelerates and turns left at the intersection while the POV is crossing. The view is initially obstructed by a larger POV2.[16]

A summary of the key parameters and their values for this scenario is shown in Table 30.

Table 30. Key Parameters for LTA-DW-3

Variable	Value
$V_{SV\text{-initial}}$	0 mph
$V_{SV\text{-final}}$	3-20 mph
$V_{POV\text{-initial}}$	40 ± 1 mph
TTC @ Warning	2.4-3.7 s
$R_{POV\text{-Steady}}$	587 ft
$R_{SV\text{-Action1}}$	499-528 ft
$R_{SV\text{-Action2}}$	217-246 ft
$R_{Lat\text{-initial}}$	12-24 ft
$R_{Long\text{-POV2}}$	88-92 ft
$R_{Lat\text{-POV2}}$	(-1)-1 ft

The SV should be stopped at the stop line of the intersection.

A large vehicle (POV2) should be parked directly across the intersection from the SV, while facing the SV. The longitudinal distance between the centerlines of the two vehicles should be 90 feet and the latitudinal distance between the two vehicles should be 0 feet.

The POV should accelerate to and maintain its test speed when its TTI is 10 seconds. The lateral distance between the SV and the POV should be 12 to 24 feet until the SV begins its turn.

The SV should apply the left turn signal when the POV TTI is 8.5 to 9.0 seconds ($R_{SV\text{-Action1}}$). When the POV's TTI is 3.7 to 4.2 seconds ($R_{SV\text{-Action2}}$), the SV should release its brakes and, 0.5 to 1.0 seconds later, the SV should turn left into the path of the POV. The TTC should be 2.7 to 3.7 seconds at this time.

A warning would be expected to be issued when the turn is initiated and the TTC is 2.4 to 3.7 seconds, and the SV driver should immediately apply the brakes and/or steer to the right to avoid a potential collision.

[16] The POV2 should be a "snout-nosed" schoolbus-style bus with dimensions of 39 ft length, 8 ft width, and 117 inches height. All windows and doors in the bus should be completely shut.

If a warning is not issued, the SV driver should apply the brakes and/or steer to the right to avoid a potential collision. The POV may steer to the right to avoid a potential collision once the SV has initiated its turn.

A schematic of this scenario is shown in Figure 28.

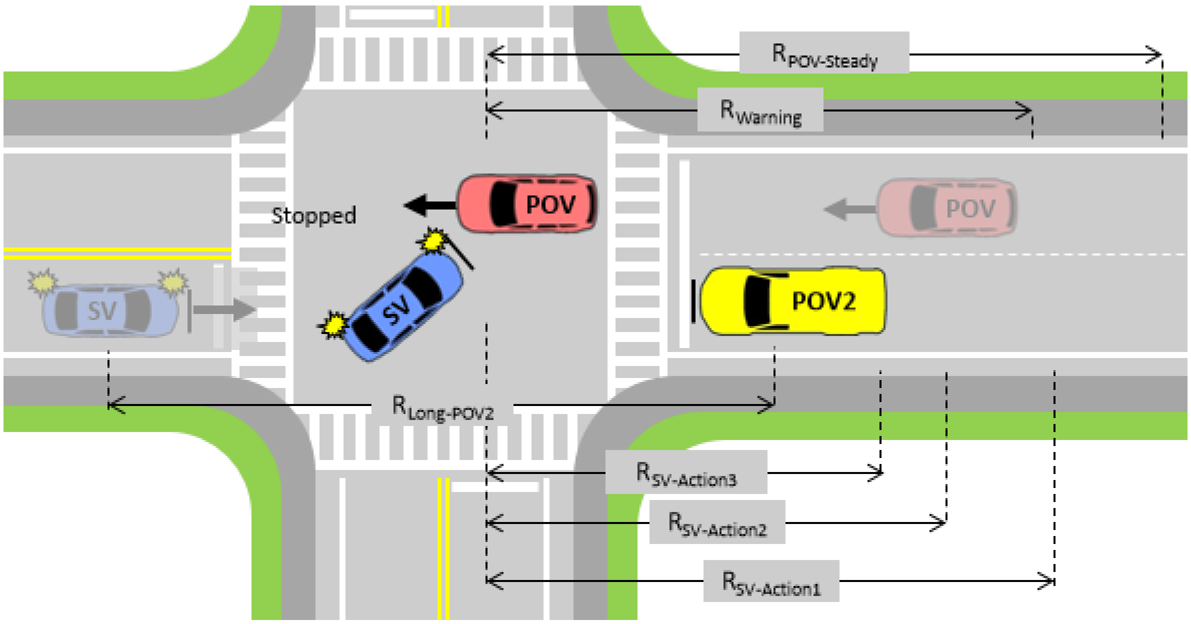


Figure 28. LTA-DW-3 Scenario Diagram

3.4.4. LTA: False Alert Scenario

3.4.4.1. LTA-NW-1: SV Initially Moving, POV Slows to a Stop

In this scenario, the SV and POV are initially moving at different constant speeds in opposite directions before the SV slows down and turns left at the intersection while the POV is crossing.

A summary of the key parameters and their values for this scenario is shown in Table 31.

Table 31. Key Parameters for LTA-NW-1

Variable	Value
$V_{SV\text{-}initial}$	25 ± 1 mph
$V_{SV\text{-}final}$	5-20 mph
$V_{POV\text{-}initial}$	40 ± 1 mph
TTC @ Warning	1.6-3.5 s
$R_{SV\text{-}Steady}$	257 ft
$R_{POV\text{-}Steady}$	411 ft
$R_{POV\text{-}Action}$	352-381 ft
$R_{SV\text{-}Action1}$	183-202 ft
$R_{SV\text{-}Action2}$	76-136 ft
$R_{Lat\text{-}initial}$	12-24 ft

The SV should accelerate to its test speed and maintain it when its TTI is 7 seconds. The POV should accelerate to its test speed and maintain its test speed when its TTI is 7 seconds. The lateral distance between the SV and the POV should be 12 to 24 feet until the SV begins its turn.

The POV should apply its brakes when its TTI is 6 to 6.5 seconds ($R_{POV\text{-}Action}$) and come to a stop when it is 30-60 feet from the center of the intersection.

The SV should apply the left turn signal and begin braking when its TTI is 5 to 5.5 seconds ($R_{SV\text{-}Action1}$). It should be within its final speed range when it is 136 to 76 feet from the intersection ($R_{SV\text{-}Action2}$). When the SV has decelerated to within its final speed range, it should stay within that range but without accelerating. The SV should turn left into the path of the POV when it is at the intersection and should cross safely through the intersection.

A schematic of this scenario is shown in Figure 29.

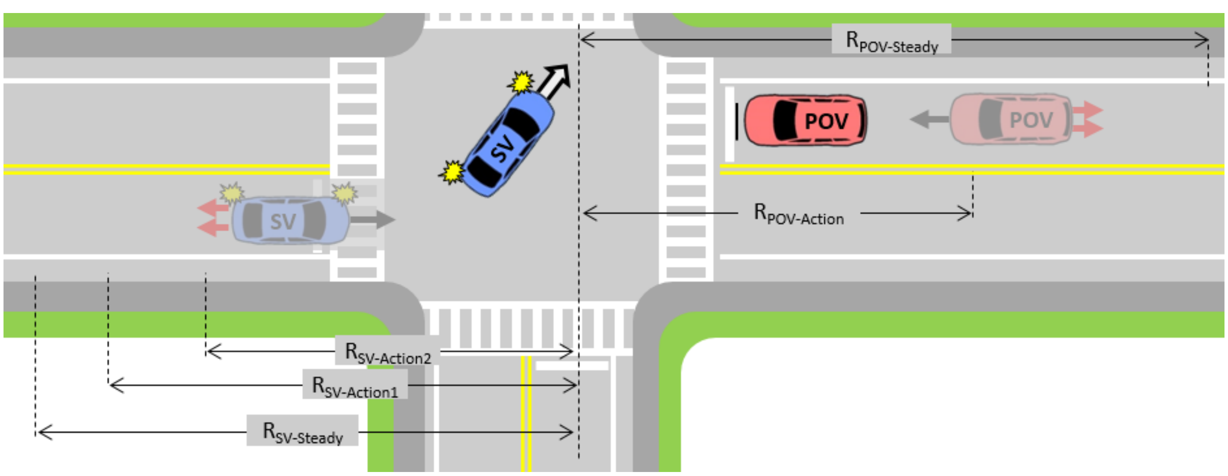


Figure 29. LTA-NW-1 Scenario Diagram

4. CONCLUSION

This report describes the test procedures used to qualify the performance of IMA and LTA safety applications when given countermeasure timing constraints. It includes scenarios that were selected based on frequency of crashes and overall comprehensive costs of crashes.

Vehicle speeds, acceleration profiles, and the timing of events were all taken from samples of naturalistic driving data and crash reconstructions. This was done to ensure that the procedures best reflect how a range of regular drivers might perform their actions while on the road.

With timing constraints and vehicle performance reflecting how drivers actually perform, the procedures can be used to qualify any IMA and LTA safety application regardless of methodology.

Testing of a previous draft version of these procedures was conducted at the Aberdeen Test Center in Aberdeen, MD. The review of data collected during testing allowed for the procedures to be revised and improved. Also, several key lessons were learned that may help to facilitate testing and increase test validity:

1. The drivers' task in performing the procedures would be made easier with a digital heads-up display of the ground truth vehicle speed. The stock vehicle speedometer and the vehicle-measured wheel speed may be insufficient for the driver to know their speed.
2. The stock cruise control could be used (especially by the POV) to ensure that it better maintains its speed within the specified range. This may also allow the driver to better focus on their surroundings, improving safety.
3. A guided soft target vehicle could be used in place of the POV to improve safety. This may see the most benefit in the crash imminent DW scenarios.
4. The drivers' task in performing the procedures would be made easier with a system to alert them when to take critical actions (e.g., brake, turn, accelerate, etc.). Orange traffic cones that were used to mark distances to the intersection were found to be insufficient in notifying drivers of the correct timing for actions.

5. REFERENCES

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Appendix: Driver Ability to Stop by Warning Time When Initially Traveling at Varying SV Speeds

Table 32 shows a larger set of data for driver stopping abilities. Includes speeds from 20 mph to 60 mph in increasing increments.

Table 32. Percentage of Drivers Able to Stop With Changes in Warning Timing

	SV Speed (mph)								
TTI @ Warning (s)	20	25	30	35	40	45	50	55	60
6	100.0%	100.0%	100.0%	99.9%	99.8%	99.6%	99.1%	98.5%	97.4%
5.9	100.0%	100.0%	99.9%	99.9%	99.7%	99.5%	99.1%	98.2%	97.0%
5.8	100.0%	100.0%	99.9%	99.8%	99.7%	99.4%	98.8%	97.9%	96.4%
5.7	100.0%	100.0%	99.9%	99.8%	99.6%	99.3%	98.6%	97.4%	95.6%
5.6	100.0%	100.0%	99.9%	99.8%	99.6%	99.1%	98.3%	97.0%	94.8%
5.5	100.0%	100.0%	99.9%	99.8%	99.5%	99.0%	98.0%	96.4%	94.1%
5.4	100.0%	100.0%	99.9%	99.7%	99.4%	98.8%	97.6%	95.8%	92.8%
5.3	100.0%	99.9%	99.9%	99.6%	99.3%	98.5%	97.1%	94.9%	91.3%
5.2	100.0%	99.9%	99.8%	99.6%	99.0%	98.1%	96.5%	93.7%	89.7%
5.1	100.0%	99.9%	99.8%	99.5%	98.8%	97.6%	95.7%	92.5%	87.9%
5	99.9%	99.9%	99.7%	99.3%	98.5%	97.1%	94.8%	91.0%	85.6%
4.9	99.9%	99.8%	99.6%	99.2%	98.1%	96.4%	93.6%	88.9%	83.0%
4.8	99.9%	99.8%	99.5%	98.9%	97.6%	95.5%	92.1%	86.9%	79.9%
4.7	99.9%	99.7%	99.3%	98.5%	97.1%	94.5%	90.3%	84.2%	76.2%
4.6	99.8%	99.6%	99.1%	98.1%	96.3%	93.1%	88.0%	81.2%	72.0%
4.5	99.7%	99.4%	98.8%	97.5%	95.3%	91.4%	85.3%	77.6%	67.6%
4.4	99.6%	99.3%	98.5%	96.9%	93.9%	89.2%	82.1%	73.2%	62.5%
4.3	99.4%	98.9%	97.9%	95.8%	92.3%	86.7%	78.5%	68.3%	56.6%
4.2	99.1%	98.5%	97.2%	94.2%	90.1%	83.3%	74.5%	62.7%	50.7%
4.1	98.7%	97.8%	96.0%	92.9%	87.3%	79.4%	68.9%	57.0%	44.1%
4	98.1%	97.0%	94.7%	90.4%	84.1%	74.6%	63.5%	50.3%	37.8%
3.9	97.2%	95.8%	92.8%	87.7%	79.8%	69.3%	56.9%	43.6%	31.5%
3.8	95.6%	94.1%	90.1%	84.1%	74.9%	62.9%	49.7%	36.8%	24.9%
3.7	93.8%	91.7%	86.9%	79.2%	68.7%	56.1%	42.4%	29.9%	19.2%
3.6	91.0%	88.4%	82.8%	73.8%	61.9%	48.7%	34.9%	23.4%	14.3%
3.5	87.4%	84.0%	77.1%	66.7%	54.2%	40.8%	27.8%	17.6%	9.8%
3.4	81.9%	78.9%	70.5%	59.4%	46.1%	33.0%	21.2%	12.2%	6.4%
3.3	75.5%	71.8%	63.2%	50.8%	37.7%	25.5%	15.4%	8.2%	4.0%
3.2	67.1%	63.5%	54.4%	41.7%	29.3%	18.5%	10.2%	5.0%	2.3%
3.1	57.2%	54.0%	44.5%	32.8%	21.6%	12.6%	6.4%	3.0%	1.2%
3	46.1%	43.5%	34.7%	24.0%	14.8%	8.0%	3.7%	1.6%	0.5%

	SV Speed (mph)								
TTI @ Warning (s)	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
2.9	34.6%	32.8%	25.3%	16.5%	9.3%	4.5%	1.9%	0.7%	0.2%
2.8	23.7%	23.1%	17.0%	10.4%	5.5%	2.3%	0.9%	0.3%	0.1%
2.7	14.7%	14.5%	10.2%	5.9%	2.7%	1.1%	0.3%	0.1%	0.0%
2.6	7.9%	8.1%	5.5%	2.9%	1.2%	0.4%	0.1%	0.0%	0.0%
2.5	3.4%	3.9%	2.7%	1.2%	0.5%	0.1%	0.0%	0.0%	0.0%
2.4	1.3%	1.5%	1.0%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%
2.3	0.3%	0.5%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
2.2	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.8	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.7	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.6	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1.1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

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