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Test Track Evaluation of FCW and BSW Installed on Motorcycles

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16. Abstract

The work in this report used modified NHTSA light-vehicle test methods to research motorcycle-based forward collision warning (FCW) and blind spot warning (BSW) system operation on the test track. A modified version of the FMVSS No. 127 and NHTSA NCAP automatic emergency braking test procedures were used for FCW research, whereas a modified version of the NHTSA NCAP BSW test procedure was used for motorcycle BSW testing. Both motorcycles tested issued FCW alerts during trials performed with a moving or decelerating lead vehicle, however neither responded to a stationary lead vehicle. Comparison of the motorcycle FCW responses to those observed during similar tests performed with light vehicles found the motorcycle onset TTCs generally fell within the distribution of the light-vehicle values, although some differences were observed during decelerating lead vehicle trials performed at 50 km/h, a 40 m headway, and a 0.5g lead vehicle deceleration. The consistency of BSW issuance varied between the two models, with data suggesting that lateral lane offsets can affect system operation. The study shows that NHTSA's light-vehicle FCW and BSW procedures can be adapted for motorcycles by accounting for their observed motion characteristics and smaller size.

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List of Acronyms

AEB	automatic emergency braking
ADAS	advanced driver assistance systems
BSW	blind spot warning
DRI	Dynamic Research, Inc.
FCW	forward collision warning
FMVSS	Federal Motor Vehicle Safety Standard
ISO	International Organization for Standardization
LVD	lead vehicle decelerating
LVM	lead vehicle moving
LVS	lead vehicle stopped
NCAP	New Car Assessment Program
OXTS	Oxford Technical Solutions, Inc.
POV	principal other vehicle
STP	steel trench plate
TRC	Transportation Research Center, Inc.
TTC	time-to-collision
VTD	vehicle test device

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Executive Summary

Advanced driver assistance systems are increasingly available on motorcycles. Two such applications are forward collision warning and blind spot warning.

Program Objectives

The three objectives for this study were:

- modify existing light-vehicle FCW and BSW test methods, as needed, to facilitate conduct of track-based motorcycle research.
- use the modified test methods to research the FCW and BSW system operation of two motorcycles, a 2024 BMW R 1300 GS and a 2024 Moto Guzzi Stelvio; and
- compare the motorcycle versus light vehicle FCW onset time-to-collision for cases where light vehicle FCW data were available from previous NHTSA testing.

System Descriptions

An FCW system is a warning-based ADAS designed to notify the driver of an imminent rear-end crash with another vehicle positioned or being operated within its travel lane. Federal Vehicle Motor Vehicle Safety Standard No. 127, *Automatic emergency braking systems for light vehicles*, requires an FCW to be present on new passenger cars and multipurpose passenger vehicles, trucks, and buses with a gross vehicle weight rating of 10,000 pounds or less sold in the United States after September 1, 2029 (NHTSA, 2024). However, this requirement does not apply to motorcycles.

A BSW system is a warning-based ADAS designed to help drivers avoid lane change and merge crashes. More specifically, a BSW helps drivers recognize that other vehicles are approaching or being operated within the blind zones of their vehicles in adjacent lanes. For light vehicles to receive NHTSA New Car Assessment Program credit for having a BSW, the system must provide at least one alert during tests performed without the subject vehicle's turn signal being activated, and at least two alerts during tests performed with the subject vehicle (SV) turn signal activated (NHTSA, 2024). However, these NCAP tests are not applicable to motorcycles.

Program Overview

The test scenarios used to assess motorcycle FCW responses were adapted from those developed by NHTSA for testing light vehicle automatic emergency braking in FMVSS No. 127 (NHTSA, 2024). However, since the motorcycle FCW tests performed in this study were only intended to evaluate alert onset timing, these trials concluded immediately after the FCW alert was presented (i.e., the rider was required to manually steer away from the lead vehicle present in the travel lane immediately ahead of the motorcycle). In the rare cases where an FCW alert was not presented, the professional rider used for these tests manually steered away from the lead vehicle at a time based on the rider's best judgement. The motorcycle FCW tests performed in this study used one or two SV lateral offsets relative to the lead vehicle.

The test scenarios evaluating motorcycle BSW responses were similar to NHTSA's to evaluate light vehicle BSW performance for its NCAP. Depending on the scenario, up to three lateral offsets within the travel lane were used for the motorcycle BSW tests performed in this study.

Research Findings

Only minor adjustments to applicable NHTSA light-vehicle test procedures were required to perform the motorcycle-based FCW and BSW tests used in this study.

To account for the unique physical and operational characteristics of two-wheeled vehicles, some test tolerance defined in the light vehicle test procedures were revised to facilitate conduct of valid trials. For all tests, the yaw rate tolerance was increased from 0 ± 1°s per second (°/s) used for light vehicles to 0 ± 3°/s to accommodate the observed motion characteristics differing from light vehicles (e.g., those associated with the continuous balance corrections performed by the motorcycle rider). The longitudinal headway used for straight lane converge and diverge BSW tests was reduced from 1.0 m to 0.3 m to account for the difference in motorcycle versus light vehicle lengths typically present for these vehicle classes.

FCW operation was quantified by considering whether an FCW was presented during a given test trial, and if so, the TTC at FCW onset. Both motorcycles issued an FCW during each lead vehicle moving test trial. The BMW R 1300 GS also provided an FCW during all lead vehicle decelerating trials performed. The Moto Guzzi Stelvio presented an FCW during most LVD trials (9 of 12) but did not activate during three trials performed with a 40 m headway and 0.5 g (gravitational force equivalent) deceleration. Due to safety and operational challenges observed during LVD tests performed with a 12 m headway, only 23 of the 48 planned trials were completed. Neither motorcycle was designed to respond to stationary objects and neither issued an FCW during any trial inclusive of a stopped lead vehicle. Neither motorcycle presented an FCW during any steel trench plate or pass-through false positive trial.

Comparison of the motorcycle FCW onset TTC responses to those observed during similar LVM and LVD tests performed with 12 light vehicles found the motorcycle-based values generally fell within the distribution of those from comparable light vehicle tests. However, the BMW R 1300 GS produced an FCW alert earlier than those observed for the light vehicles compared in this study during 2 of 3 trials performed with a 50 km/h test speed, a 40 m headway, a 0.5 g lead vehicle deceleration, and a 50 percent offset.

BSW operation generally satisfied the thresholds defined in NHTSA's light vehicle NCAP BSW test procedure: during 92 of 96 trials performed with the BMW R 1300 GS and during 76 of 96 trials performed with the Moto Guzzi Stelvio. Test results indicate that BSW response may be affected by changes in relative lateral distance where lane offsets shift the SV farther away from the POV. Comparison of the results observed in this study to NCAP light vehicle BSW thresholds is provided for context only, not to infer or imply they are appropriate measures for motorcycle performance.

Although the modified light vehicle protocols used for the work described in this report can be used to support motorcycle FCW and BSW testing, it is important to acknowledge the study focused on test conduct and reporting of results, not on the development or validation of what may be appropriate motorcycle performance criteria.

Introduction

ADAS are increasingly available on motorcycles. Two such applications are FCW and BSW.

An FCW system is a warning-based ADAS designed to notify the driver of an imminent rear-end crash with another vehicle positioned or being operated within their travel lane. FMVSS No. 127 requires an FCW to be present on all light vehicles sold in the United States after September 1, 2029 (NHTSA, 2024). However, this requirement does not apply to motorcycles.

A BSW system is a warning-based ADAS designed to help a driver avoid lane change and merge crashes. More specifically, a BSW helps a driver recognize that another vehicle is approaching, or being operated within, the blind zone of their vehicle in an adjacent lane. For light vehicles to receive NHTSA NCAP credit for being equipped with a BSW, the system must provide at least one alert during tests performed without the SV's turn signal activated, and at least two alerts during tests performed with the SV turn signal activated (NHTSA, 2024). However, these NCAP tests are not applicable to motorcycles.

Although NHTSA has performed considerable FCW and BSW research, contemporary test track work has been limited to evaluations of systems installed on light and heavy vehicles, not motorcycles equipped with these systems. The work described in this report attempts to address this research gap.

Test Objectives

The three objectives for this study were:

- modify existing light vehicle FCW and BSW test methods, as needed, to facilitate conduct of track-based motorcycle research;[1]
- use the modified test methods to research the FCW and BSW system operation of two motorcycles, a 2024 BMW R 1300 GS and a 2024 Moto Guzzi Stelvio; and
- compare the motorcycle versus light vehicle FCW onset time-to-collision for cases where light vehicle FCW data were available from previous NHTSA testing.

Test Details and Conditions

Subject Vehicles

Two motorcycles were used as the SV for this study.

- 2024 BMW R 1300 GS with riding assistant
- 2024 Moto Guzzi Stelvio

Both had radar-based ADAS systems that include FCW and BSW. Regarding the operational design domain of the FCW systems, the owner's manual for each motorcycle states that the respective systems detect only moving objects.

[1] Methods adapted from light vehicles were used to develop the tests used in the study because motorcycle- specific FCW and BSW test protocols were not available at the time this study was performed.

> Radar-based rider assistance systems detect only moving vehicles. This means that, for example, pedestrians, animals and stationary vehicles are not detected. Cyclists cannot be reliably detected. (BMW, 2024)

> *"*Radar-based systems cannot detect stationary objects or objects moving at low speed. They are therefore unable to intervene in the case of pedestrians, slow-moving car queues, bicycles, and similar.*"* (Piaggo & C. SpA, 2024)

Figures 1 and 2 show the BMW R 1300 GS and the Moto Guzzi Stelvio as tested and fully instrumented configurations, respectively. Motorcycle stock photos and ADAS information are available in Appendix A.

Rider-Configurable SV Settings

The rider-configurable FCW alert onset timing was set to the middle setting for the BMW R 1300 GS and to "on" for the Moto Guzzi Stelvio for all trials performed. Neither SV had the ability to manually adjust BSW operation; both motorcycles were operated with BSW enabled. Each motorcycle was operated in the default "Road" riding mode.

Ignition or Start/Stop Switch Cycling (Cycling of the Power System)

The SVs were both power-cycled via the ignition switch or power button after completion of each test trial.



Figure 1. The 2024 BMW R 1300 GS, as tested



Figure 2. The 2024 Moto Guzzi Stelvio, as tested

Principal Other Vehicles

Most tests performed in this study involved identification of when the motorcycle FCW or BSW system alerted the rider of the presence of another vehicle (i.e., a principal other vehicle or POV). For FCW testing, the test scenarios involved crash-imminent situations where the motorcycle was approaching a lead vehicle present in the travel lane. For these trials the POV was an artificial but realistic looking test surrogate known as a vehicle test device (VTD). For BSW testing, the test scenarios involved the POV moving into and then away from the motorcycle blind spot. Since these scenarios did not present crash-imminent riding situations, a real vehicle was used as the POV during BSW testing.

Vehicle Test Device POV

The VTD used for the FCW tests described in this report was an AB Dynamics Soft Car 360, [2] shown in Figure 3, with characteristics representative of a small passenger car. More specifically, this VTD is designed to satisfy specifications defined in ISO 19206-3:2021, "requirements for passenger vehicle 3D targets," to facilitate it being classified as a real vehicle by ADAS sensors. The VTD was attached to an AB Dynamics GST 120 robotic platform that allowed its travel path, speed, and deceleration to be accurately controlled during conduct of FCW testing.[3]



Figure 3. AB Dynamics Soft Car 360

Passenger Car POV

For the BSW tests, the POV was a 2023 Toyota Corolla Hybrid XLE, a high-production passenger car. Figure 4 shows the fully instrumented and as-tested Toyota Corolla used in this study.



Figure 4. The 2023 Toyota Corolla AWD Hybrid

[2] AB Dynamics, Bradford on Avon, United Kingdom. https://www.abdynamics.com/app/uploads/2024/01/AB-Dynamics-DRI-Soft-Car-360-Product-Specification-ROW.pdf

[3] AB Dynamics, Bradford on Avon, United Kingdom. https://www.abdynamics.com/app/uploads/2025/12/AB-Dynamics-GST-120-Plus-Product-Specification-ROW.pdf

SV Blind Zone Definition

For research purposes, the SV blind zones were defined by two rectangular regions that extended laterally from each side and the rear of the SV (see Figure 5).

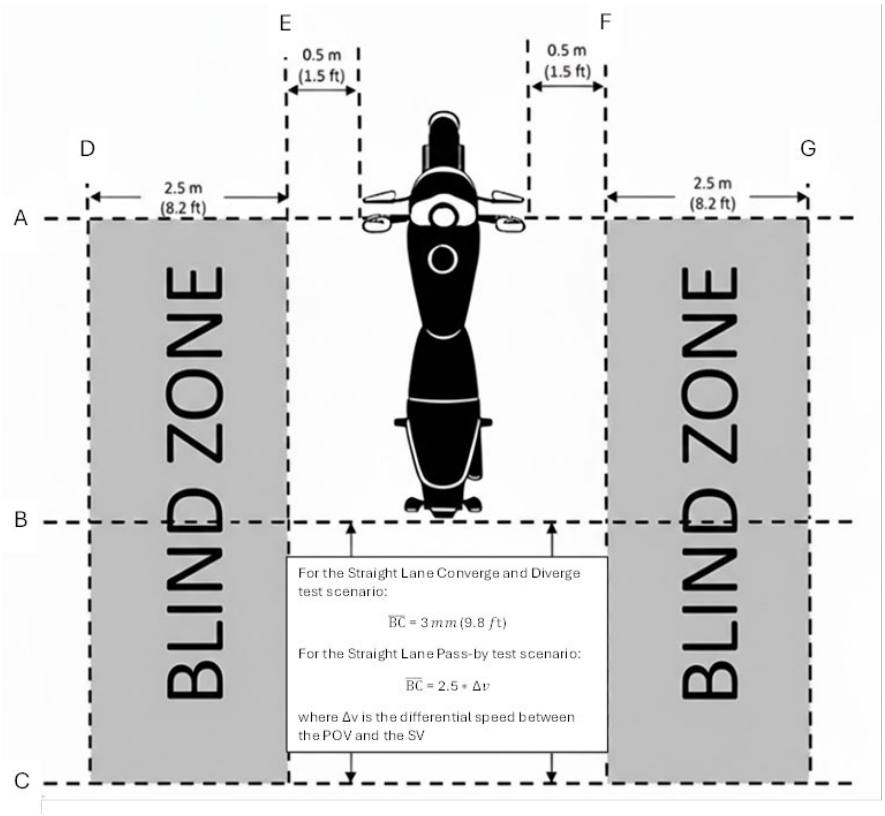


Figure 5. SV blind zone (not to scale)

Each rectangle was 2.5 m (8.2 ft) wide and was bound by the following lines:

- Lines D and E (left) and lines F and G (right) were parallel to the SV longitudinal centerline.
- Lines E and F are parallel to the centerline and are located 0.5 m (1.6 ft) from the outermost edge of the SV body (excluding side-view mirrors).
- The longitudinal aspect of each rectangle begins at line A – positioned at the outermost point of the SV handlebars and perpendicular to the centerline – and ends at line C, which was also perpendicular to the centerline.
- Line B, perpendicular to the centerline and located at the SV's rearmost edge, divides the area between A and C.
- The distance between A and B depended on the SV's length.
- The distance between B and C varied with the test scenario and the relative speed difference (Δv) between the SV and the POV.

The blind zone dimensions were nearly identical to those specified in the NHTSA NCAP BSW test procedure. However, since motorcycle mirrors can be moved based on rider preference, line A was changed to reference the motorcycle's handlebars (line A is located at the rearmost part of the side-view mirrors for NHTSA's light vehicle BSW testing).

Test Equipment and Instrumentation

A summary of the test equipment and instrumentation used to perform the tests in this study is provided in Appendix B Tables 25 and 26. While all GPS-enhanced inertial measurement units were Oxford Technical Solutions RT 3000 series, Version V3 units were installed in the Toyota Corolla POV. Version V4 units were selected for the side-mounted enclosures on both SVs due to their more compact physical dimensions (Figure 6).

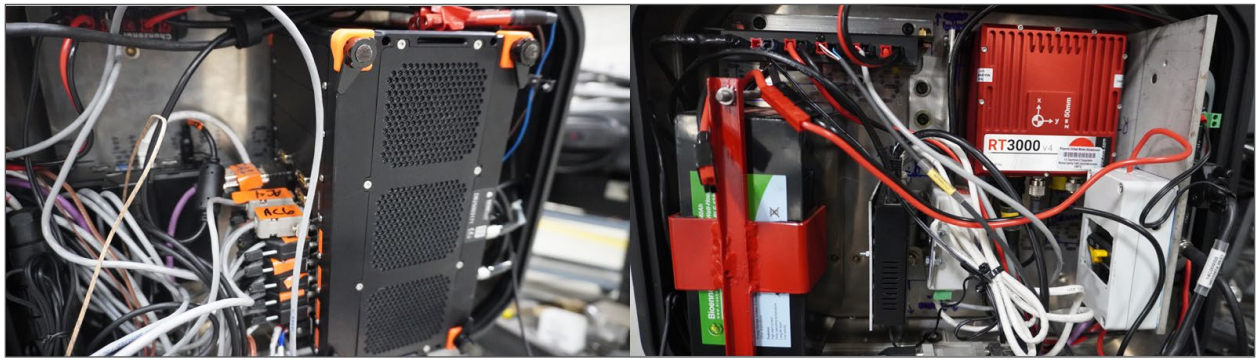


Figure 6. Instrumentation installed in the SV side cases

Robotic control of the Toyota Corolla POV steering wheel (Figure 7) and accelerator pedal was used to ensure accurate control of its travel path and test speeds (lateral and longitudinal) during conduct of BSW testing.



Figure 7. Robotic steering controller installed in the Toyota Corolla POV

Test Facilities

The FCW and BSW testing required a travel lane that was sufficiently long to conduct all trials at the required speeds. This included a three-second steady-state period once the desired test speed(s) were achieved, prior to the onset of the applicable validity period for each test trial. The travel lanes were also specified to be straight and flat, with a consistent slope between level and 1 percent. To meet these test specifications, all trials were conducted on the south leg of the Transportation Research Center SMARTCenter high-speed intersection in East Liberty, Ohio.

Environmental Conditions

The NHTSA light-vehicle AEB and BSW test procedures both specify environmental test conditions that are adhered to during testing. The requirements from these procedures were combined for this study, meaning the tolerances selected ensure environmental conditions were met for all test procedures used. These conditions are provided in Table 1.

Table 1. Environmental conditions

Environmental Condition	Criteria
Sun angle (daytime testing only)	Greater than 15°
Ambient lighting	Daytime: ≥ 2,000 lux
Precipitation	None
Surface wetness	Dry
Ambient temperature	7 ˚C to 40 ˚C (45 °F to 104 °F)
Wind	Up to 35.4 km/h (22 mph)

Test Scenarios and Conduct

Use of Repeated Test Trials

Where applicable, the SV speed was iteratively increased for each scenario, and each combination of scenario/speed nominally included three repeated trials to assess the consistency of the FCW and BSW system operation. However, for some test conditions three repeated trials were not performed. In cases where an ADAS response was not anticipated (e.g., during all FCW trials using the stopped lead vehicle FCW test scenario), a single trial was conducted to confirm test performability. Other trials were limited or not performed due to challenges incurred from high speeds and close headways (i.e., during some FCW trials using the LVD test scenario).

FCW Testing

During each trial, the status of the FCW was noted as activated or not. If the FCW was activated during a trial, then the TTC at the onset of FCW activation was calculated and recorded. To avoid contact with the POV, the SV riders initiated a swerve-out maneuver either immediately following an FCW or, in the absence of an FCW, once the TTC reached approximately 0.5 seconds. The following five test scenarios were used for the FCW research performed in this study.

Lead Vehicle Stopped

The SV approaches a stationary lead vehicle (i.e., the POV) located in the forward path of the SV. The test speeds used for conduct of LVS trials increased from 10 to 80 km/h in 10 km/h increments. Since neither SV was expected to activate its respective FCW during LVS trials, only one trial per test speed was used for each lateral offset.

Lead Vehicle Moving

The SV approaches a slower-moving POV traveling at a constant speed in the forward path of the SV. During LVM testing, the SV test speed increased from 40 to 80 km/h in 10 km/h increments. The POV speed remained at 20 km/h for each of these trials.

Lead Vehicle Decelerating

After a short period of the SV following a POV in its forward path with a constant speed and headway, the POV is braked to a stop using a constant deceleration. For LVD testing, both the SV and POV travel speed was either 50 or 80 km/h. Beginning at the onset of the test validity period, both vehicles maintained a constant speed and headway (either 12 m or 40 m) until the POV initiated braking, after which the POV braked to a stop using an average nominal deceleration magnitude of 0.3 or 0.5 g. The target POV deceleration was established within 1.5 seconds of being initiated, and the average POV deceleration remained at the desired magnitude until 250 ms before the POV speed first reached zero.

Steel Trench Plate

The SV encounters a longitudinally oriented steel plate centered and secured in its travel lane to observe whether the FCW system inappropriately identifies the scenario as being crash-imminent and produces an FCW alert. During the STP test, the SV traveled at 40 or 80 km/h while remaining centered in its travel lane.

Pass-Through

The SV passes between two stationary POVs (VTDs) present in adjacent lanes (i.e., to the right and left of the SV travel lane) to observe whether the FCW system inappropriately identifies the scenario as being crash-imminent and produces an FCW alert. For these tests, the two VTDs are secured in a stationary position in parallel with a lateral distance of 4.5 m between the VTDs' closest front wheels. The pass-through tests performed in this study did not include multiple SV lateral offset conditions; the SVs remained centered in the travel lane for the duration of each trial. Tests were conducted with the SV traveling at either 40 or 80 km/h.

SV-to-POV Lateral Offsets

For each LVS, LVM, and LVD test scenario, the SV-to-POV lateral offset was either 50- or 75-percent of the POV width (Figure 8). All indicated percentages are based on a coordinate system that uses 0 and 100 percent as the right and left side of the POV, respectively.

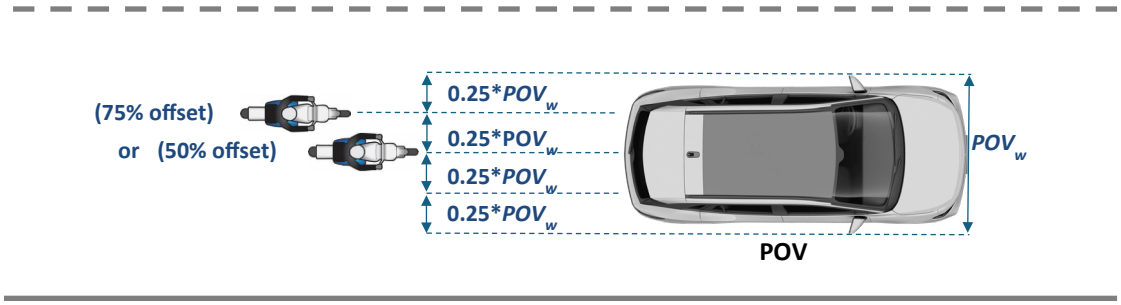


Figure 8. Lateral offsets used for motorcycle SVs

FCW Test Scenario Summary

Table 2 presents a summary of the nominal SV and POV test speeds, SV-to-POV headways, POV decelerations, and POV lateral offsets used for each FCW test scenario discussed in this report. A summary of the FCW test validity criteria used in this study are shown in Table 3.

Table 2. FCW matrix

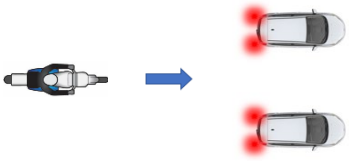
Test scenario	Test speeds (km/h)		Headway (m)	POV decel. (g)	SV lateral offset (% of POV width)
	SV	POV			
 Lead vehicle stopped (LVS)	10, 40, 50, 60, 70, 80	0	--	--	50, 75
 Lead vehicle moving (LVM)	40, 50, 60, 70, 80	20	--	--	50, 75
 Lead vehicle decelerating (LVD)	50, 80	50, 80 (same as SV)	12, 40	0.3, 0.5	50, 75
 Steel trench plate (STP)	40, 80	--	--	--	50
 Pass-through	40, 80	0	--	--	--

Table 3. FCW test validity criteria

Parameter	Acceptable Range	Assessment Interval (for valid test conduct)	Scenario				
			LVS	LVM	LVD	STP	Pass-Through
SV speed	Nominal ± 1.6 km/h	From TTC = 3.0 seconds to FCW onset or EOT*	✓	✓	✓	✓	✓
POV speed	Nominal ± 1.6 km/h	From TTC = 3.0 seconds to FCW onset or EOT*		✓			
POV speed	Nominal ± 1.6 km/h	From TTC = 3.0 seconds until POV deceleration = 0.05 g			✓		
SV yaw rate	0 ± 3°	From TTC = 3.0 seconds to FCW onset or EOT*	✓	✓	✓	✓	✓
SV path deviation	0 ± 0.3 meters	From TTC = 3.0 seconds to FCW onset or EOT*	✓	✓	✓	✓	✓
POV placement	0 ± 0.1 meters	From TTC = 3.0 seconds to FCW onset or EOT*	✓				✓
STP placement	0 ± 0.1 meters	From TTC = 3.0 seconds to FCW onset or EOT*				✓	
POV path deviation	0 ± 0.3 meters	From TTC = 3.0 seconds to FCW onset or EOT*		✓	✓		
SV-to-POV path deviation	0 ± 0.3 meters	From TTC = 3.0 seconds to FCW onset or EOT*	✓	✓	✓		
SV-to-STP path deviation	0 ± 0.3 meters	From TTC = 3.0 seconds to FCW onset or EOT*				✓	
POV brake onset threshold	POV deceleration = 0.05 g	≥ 3 seconds after test validity assessment is initiated			✓		
POV deceleration onset	Nominal ± 10%	Within 1.25 ± 0.25 s after POV brake onset			✓		
POV average deceleration magnitude	Nominal ± 10%	From 1.5 seconds after POV brake onset until (1) impact or (2) 250 ms before the POV has stopped			✓		

*EOT = end of test.

BSW Testing

Two test scenarios were used for the BSW research performed in this study: 1) straight lane converge and diverge, and 2) straight lane pass-by.

Straight Lane Converge and Diverge

Straight lane converge and diverge tests, shown in Figure 9, began with the POV being driven two lanes away from the SV and the frontmost part of the POV positioned 0.3 m (0.98 ft.) ahead of the rearmost part of the SV.[4] With the SV turn signal off, both vehicles were driven in this formation at a constant speed of 72.4 km/h (45 mph) for a minimum of 3 seconds, after which, the POV then performed a single converging lane change into the lane adjacent to the SV using a lateral velocity of 0.25 to 0.75 m/s (0.8 to 2.5 ft/s). Once the lane change was completed, the POV traveled in the lane adjacent to the SV for at least 3 seconds and then performed a single diverging lane change back into its original outboard lane using a lateral velocity of 0.25 to 0.75 m/s (0.8 to 2.5 ft/s). The test concluded once the POV had remained in the original travel lane for at least 1 second.

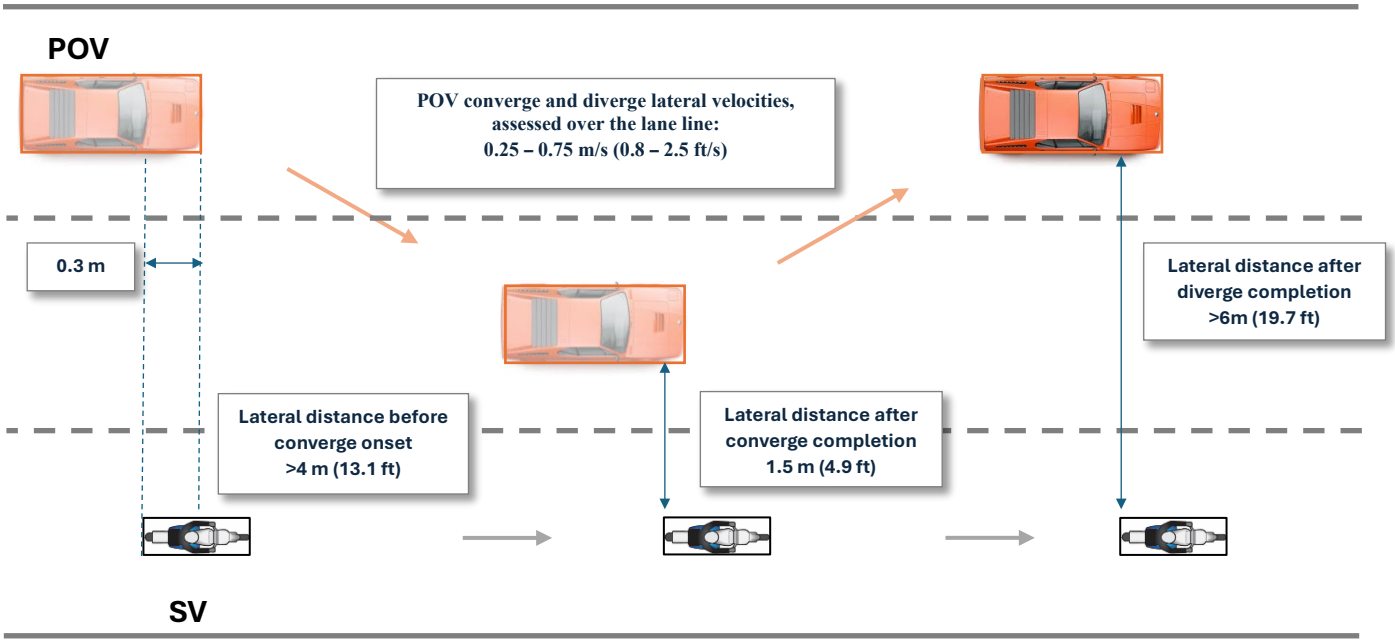


Figure 9. Straight lane converge and diverge test (left-side POV approach is shown)

[4] Longitudinal headway overlap was defined by the rearmost part of the SV to a vertical plane defined by the frontmost part of the POV. The 0.3 m used in this study was a reduction from the 1.0 m defined in the NHTSA NCAP BSW test procedure used for light vehicles (NHTSA, 2024). Given the lesser length of the motorcycle SVs versus the light vehicles evaluated by the NCAP, this adjustment more appropriately positioned the POV in the SV blind zone for this study (i.e., since use of a 1.0 m headway would have placed the front of the POV along the side the rider rather than behind them).

The POV approach was from the left and the right side of the SV. The SV turn signal indicator was off for all straight lane converge and diverge trials. The SV speed, POV speed, and SV-to-POV longitudinal proximity were constant during each trial within the test validity period. The straight lane converge and diverge test validity criteria used in this study are shown in Table 4.

Table 4. Straight lane converge and diverge test validity criteria

SV speed	72.4 ± 1.6 km/h (45 ± 1 mph)
POV speed	72.4 ± 1.6 km/h (50 ± 1 mph)
POV lateral velocity during converge or diverge maneuver, assessed during lane line crossing (see Figure 9)	0.25 to 0.75 m/s (0.8 to 2.5 ft/s)
Longitudinal headway overlap distance between the front of SV and the rear of POV at validity period onset	0.3 ± 0.3 m (1 ± 1 ft)
SV yaw rate	0 ± 3.0°/s
SV and POV lateral path tolerance	0 ± 0.5 m (0 ± 1.6 ft)
SV-to-POV lateral distance before converge	> 4 m (13.1 ft)
SV-to-POV lateral distance after converge	1.5 m (4.9 ft)
SV-to-POV lateral distance after diverge	> 6 m (19.7 ft)

Straight-Lane Pass-By

Straight-lane pass-by tests, shown in Figure 10, began with the SV and POV driven at their respective constant speeds. While in a lane adjacent to the SV travel lane, the POV approached the SV from behind and then passed by the SV. For each trial, the SV was driven at a constant speed of 72.4 km/h (45 mph) whereas the POV was driven at one of the four constant speeds shown in Table 5. The straight lane pass-by test validity criteria used in this study are also shown in Table 5.

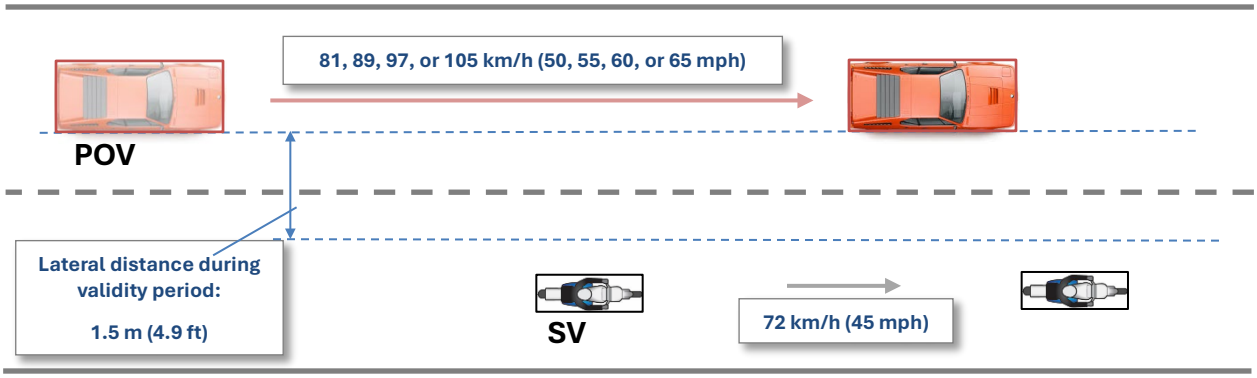


Figure 10. Straight lane pass-by test (left-side POV pass-by is shown)

Table 5. Straight lane pass-by test speeds and validity criteria

SV speed	72.4 ± 1.6 km/h (45 ± 1 mph)	72.4 ± 1.6 km/h (45 ± 1 mph)	72.4 ± 1.6 km/h (45 ± 1 mph)	72.4 ± 1.6 km/h (45 ± 1 mph)
POV speed	80.5 ± 1.6 km/h (50 ± 1 mph)	88.5 ± 1.6 km/h (55 ± 1 mph)	96.6 ± 1.6 km/h (60 ± 1 mph)	104.6 ± 1.6 km/h (65 ± 1 mph)
SV-to-POV differential speed	8.0 ± 1.6 km/h (5 ± 1 mph)	16.1 ± 1.6 km/h (10 ± 1 mph)	24.1 ± 1.6 km/h (15 ± 1 mph)	32.2 ± 11.6 km/h (20 ± 1 mph)
Longitudinal distance between SV and POV at onset of validity period (nominally a 4-second gap)	8.9 m (29.3 ft)	17.9 m (58.7 ft)	26.8 m (88.0 ft)	35.8 m (117.3 ft)
SV yaw rate	0 ± 3.0°/s			
SV and POV lateral path tolerance	0 ± 0.5 m (0 ± 1.6 ft)			
Lateral distance between SV and POV	1.5 ± 0.5 m (4.9 ± 1.6 ft)			

The POV pass-by occurred on the left and right sides of the SV, and with the SV turn signal indicator enabled and disabled. The SV speed, POV speed, and SV-to-POV lateral proximity were held constant during each trial within the test validity period. For trials requiring an active turn signal, the indicator was engaged in the direction of the POV travel prior to the POV accelerating to the desired test speed.

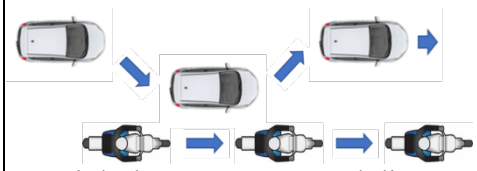
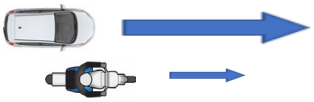
SV-to-POV Lateral Offsets

For the straight lane converge and diverge BSW test scenario, the SV-to-POV lateral offset was 50 percent of the lane width. For the straight lane pass-by tests, the SV-to-POV lateral offset was either 25-, 50-, or 75-percent of the lane width. All indicated percentages are based on a coordinate system that uses 0 and 100 percent as the right and left side of the lane, respectively.

BSW Test Scenario Summary

Table 6 shows a summary of the nominal SV and POV test speeds, POV approach direction, SV turn signal status, and SV lane offsets used for each test scenario discussed in this report.

Table 6. BSW test matrix

Test Scenario	Test Speeds (km/h)		POV Direction of Approach	SV Travel Lane Offsets (%)	SV turn Signal
	SV	POV			
 Straight lane converge and diverge	72.4	72.4	Right	50	Disabled
			Left	50	Disabled
 Straight lane pass-by	72.4	80.5	Right	25, 50, 75	Enabled or disabled
			Left	25, 50, 75	Enabled or disabled
		88.5	Right	25, 50, 75	Disabled
			Left	25, 50, 75	Disabled
		96.6	Right	25, 50, 75	Disabled
			Left	25, 50, 75	Disabled
		104.6	Right	25, 50, 75	Disabled
			Left	25, 50, 75	Disabled

Comments Regarding BSW Test Validity

The BSW tests described in this report were performed within the test specifications shown in Tables 4 and 5, except for the SV yaw rate tolerance. This value was increased from 1°deg/s to 3°/s. This adjustment accommodated for the inherent yaw motion of motorcycles traveling along a straight path (balancing the motorcycle) versus that typically observed for passenger vehicles. However, increasing the yaw rate tolerance for the motorcycles did not require any accompanying increase in the allowable lateral path deviation; that tolerance remained at the 0 ± 0.3 m value.

Test Results

For the FCW tests the TTC values at the onset of the alerts are shown for each trial performed. If a TTC value is not presented in the tabulated results, no FCW was issued. For the LVS, LVM, LVD scenarios, an FCW non-activation means no warning was presented at a TTC greater than approximately 0.5 s when the test was aborted for the safety of the rider. For the STP and pass-through trials, the absence of a TTC value means no warning was presented in a non-critical riding situation where an alert was not expected to be activated (i.e., since a crash was not imminent).

For the BSW tests, the distances between the SV and POV at the time of the alert are shown. For the converge and diverge tests, the lateral distances from the SV to the POV when the BSW was first presented during the converge part of the tests, and when the BSW was first terminated during the diverge part of the tests, are presented. For the straight lane pass-by test, the longitudinal distances between the rear of the SV and front of the POV are shown.

For informative purposes, the motorcycle FCW onset responses observed in this study were also compared to FCW onset values collected during previously performed NHTSA light-vehicle AEB testing. Similarly, motorcycle BSW responses were also compared to the respective criteria used to assess light-vehicle BSW performance for NHTSA's NCAP.

FCW Results

Tables 7 to 10 show results from the FCW tests performed in this study. For the cells in these tables, the following color convention is used.

Green shading:

- For LVS, LVM, and LVD trials, an FCW was presented. The TTC at the onset of the FCW is shown.
- For STP and pass-through trials, no FCW was presented.

Yellow shading:

- An FCW was not presented during an LVS, LVM, or LVD test trial. For these trials, the TTCs at initiation of the respective avoidance maneuver are shown.

BMW R 1300 GS FCW Testing

BMW R 1300 GS FCW onset TTC results for tests performed with 50- and 75-percent offsets are shown in Tables 7 and 8. No FCW was presented during the single LVS trials performed for each combination of SV speed and lateral offset.

For each of the three LVM trials performed per test condition, FCW alerts were presented during each combination of SV speed, POV speed, and SV lateral offset.

For each of the repeated trials performed for a given LVD test condition, FCW alerts were presented during each combination of SV speed, POV speed, SV-to-POV headway, POV deceleration, and SV lateral offset.

No FCW alerts were presented during any of the STP or pass-through trials performed with the BMW R 1300 GS in this study.

Moto Guzzi Stelvio FCW Testing

Moto Guzzi Stelvio FCW onset TTC results for tests performed with 50 and 75 percent offsets are shown in Tables 9 and 10. No FCW was presented during the single LVS trials performed for each combination of SV speed and lateral offset.

FCW alerts were presented during each of the three LVM trials performed per test condition.

An FCW was produced during each of the 12 LVD trials performed with the combination of an 80 km/h test speed and a 40 m headway. An FCW was also produced for each of the six LVD trials performed with the combination of a 50 km/h test speed, a 40 m headway, and a POV deceleration of 0.3 g. However, when the POV deceleration was increased to 0.5 g during trials performed with this test combination (i.e., 50 km/h test speed and a 40 m headway), an FCW was only produced during 1 of 3 trials performed with a 50 percent offset and during 2 of 3 trials performed with a 75 percent overlap. For the tests where an FCW was not presented, the TTC at the onset of the rider's avoidance input ranged from 0.36 to 0.41 s.

An FCW was produced during each of the limited LVD trials performed with the Moto Guzzi Stelvio and a 12 m headway (i.e., during six 50 km/h trials performed with a 75 percent overlap and either a 0.3 g or 0.5 g POV deceleration).

No FCW alerts were presented during any of the STP or pass-through trials performed with the Moto Guzzi Stelvio in this study.

Table 7. BMW R 1300 GS FCW TTC summary, 50 percent SV lateral offset (s)

2024 BMW R 1300 GS																										
Overlap:		50% (Of target for lead vehicle tests; of lane for false positive tests)																								
Scenario:		LVS			LVM-20			LVD-40-0.3			LVD-40-0.5			LVD-12-0.3			LVD-12-0.5			STP			Pass-Through		
SV Speed (kph)	40	0.8			1.8	1.8	1.8																			
	50	0.8			1.9	1.9	1.9	2.7	2.9	2.3	2.5	2.2	2.6	2.2	2.0	2.0	1.4	1.4	1.3						
	60	0.9			2.1	2.1	2.2																			
	70	1.1			2.2	2.1	2.1																			
	80	1.2			2.1	1.8	1.9	3.7	3.2	3.4	2.2	2.7	2.9													

FCW presented No FCW presented, TTC at swerve to avoid No FCW presented as intended

Table 8. BMW R 1300 GS FCW TTC summary, 75 percent SV lateral offset (s)

2024 BMW R 1300 GS																										
Overlap:		75 percent (Of target for lead vehicle tests; of lane for false positive tests)																								
Scenario:		LVS			LVM			LVD-40-0.3			LVD-40-0.5			LVD-12-0.3			LVD-12-0.5			STP			Pass-Through		
SV Speed (kph)	40	1.0			1.8	1.8	1.7																			
	50	0.9			1.9	1.2	1.9	2.3	2.3	2.8	2.5	2.5	2.6	2.0	2.0	2.0	1.4	1.4	1.4						
	60	1.1			2.1	1.9	1.7																			
	70	1.2			1.6	1.8	1.8																			
	80	1.1			1.8	1.9	1.5	2.7	2.5	3.4	2.8	2.8	2.7	1.8	1.9	1.9	2.4	2.2								

FCW presented

No FCW presented, TTC at swerve to avoid

No FCW presented as intended

*Table 9. Moto Guzzi Stelvio FCW 50 percent **offset TTC (s)***

2024 Moto Guzzi Stelvio																									
Overlap:		50% (Of target for lead vehicle tests; of lane for false positive tests)																							
Scenario:		LVS			LVM-20			LVD-40-0.3			LVD-40-0.5			LVD-12-0.3			LVD-12-0.5			STP			Pass-Through		
SV Speed (kph)	40	1.0			1.8	1.5	1.8																		
	50	0.9			1.8	1.7	1.6	1.2	1.4	1.1	0.4	0.4	1.4												
	60	1.2			2.0	2.0	1.6																		
	70	1.3			2.3	2.1	2.2																		
	80	1.4			2.5	2.6	2.0	1.5	1.5	1.5	1.3	1.3	1.1												

FCW presented

No FCW presented, TTC at swerve to avoid

No FCW presented as intended

Table 10. Moto Guzzi Stelvio FCW 75 percent offset TTC (s)

2024 Moto Guzzi Stelvio																								
Overlap:		75 percent (Of target for lead vehicle tests; of lane for false positive tests)																						
Scenario:		LVS			LVM			LVD-40-0.3			LVD-40-0.5			LVD-12-0.3			LVD-12-0.5			STP			Pass-Through		
SV Speed (kph)	40	0.9			1.8	1.7	1.8																		
	50	1.1			1.8	1.7	1.7	1.4	1.4	1.3	1.3	0.4	1.3	1.1	1.1	1.2	1.0	0.9	1.0						
	60	1.0			2.1	1.8	1.8																		
	70	1.1			2.3	2.3	2.3																		
	80	1.1			2.2	2.6	2.5	1.6	1.5	1.4	1.3	1.1	1.3												

FCW presented No FCW presented, TTC at swerve to avoid No FCW presented as intended

FCW TTC Comparison With Light-Vehicle Test Results

As part of a program used to evaluate light-vehicle AEB performance, NHTSA performed a series of LVS, LVD, and LVM tests nearly equivalent to those used in this study. Although FCW data was not formally presented in this report, it was collected during each test trial. In this section a comparison of the light vehicle and motorcycle FCW onsets is provided for trials where comparable data were available. This comparison serves as a reference point only; numerous operational factors differ significantly between motorcycles and standard light vehicles, including vehicle dynamics, manufacturer-specific alert logic, and the distinct warning-response behaviors of motorcycle riders compared to light-vehicle operators. Specifically, three distinct scenario comparisons were analyzed:

First, LVM trials performed with a 50 percent lateral offset are shown in Figures 11 through 15. For this comparison, the SV speeds ranged from 40 to 80 km/h and the POV speed was 20 km/h. For each speed combination, the FCW onset TTCs observed for both motorcycle SVs were within the distribution of those observed for the light vehicles.

Second, LVD trials performed with a 40 m headway, 0.5 g POV deceleration, and a 50 percent POV lateral offset are shown in Figure 16. In this comparison, 2 of 3 FCW onset TTCs observed for the BMW R 1300 GS were produced earlier than for most of the light vehicles; only 1 of 3 trials was within the distribution of the light-vehicle FCW onsets, and the FCW TTC for this trial was only lower than that of one light vehicle. The Moto Guzzi Stelvio produced FCW TTCs within the distribution of those observed for the light vehicles.

Finally, results from LVD trials performed with the BMW R 1300 GS, a 12 m headway, 0.5 g POV deceleration, and a 50 percent POV lateral offset are shown in Figure 17. In this test condition, the FCW TTC onset of the BMW R 1300 GS was within the distribution of those observed for the light vehicles. The Moto Guzzi Stelvio was not evaluated in this test condition.

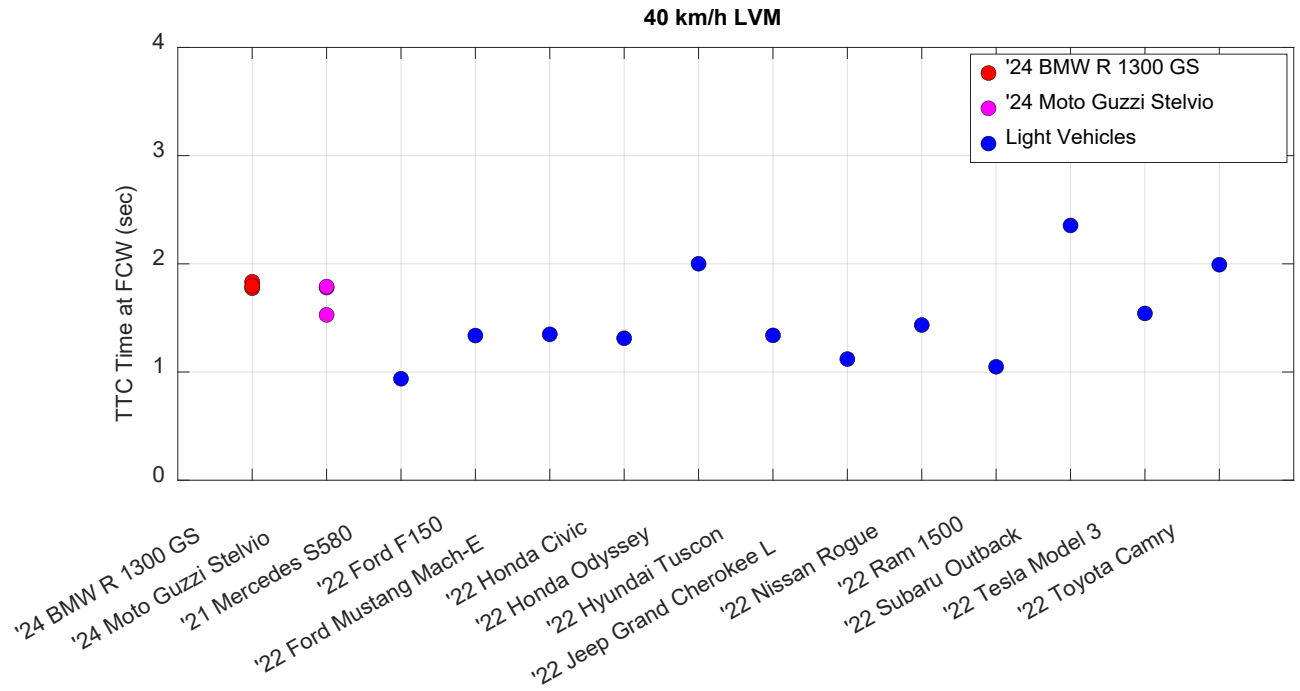


Figure 11. LVM FCW TTC comparison at 50% offset, 40 km/h

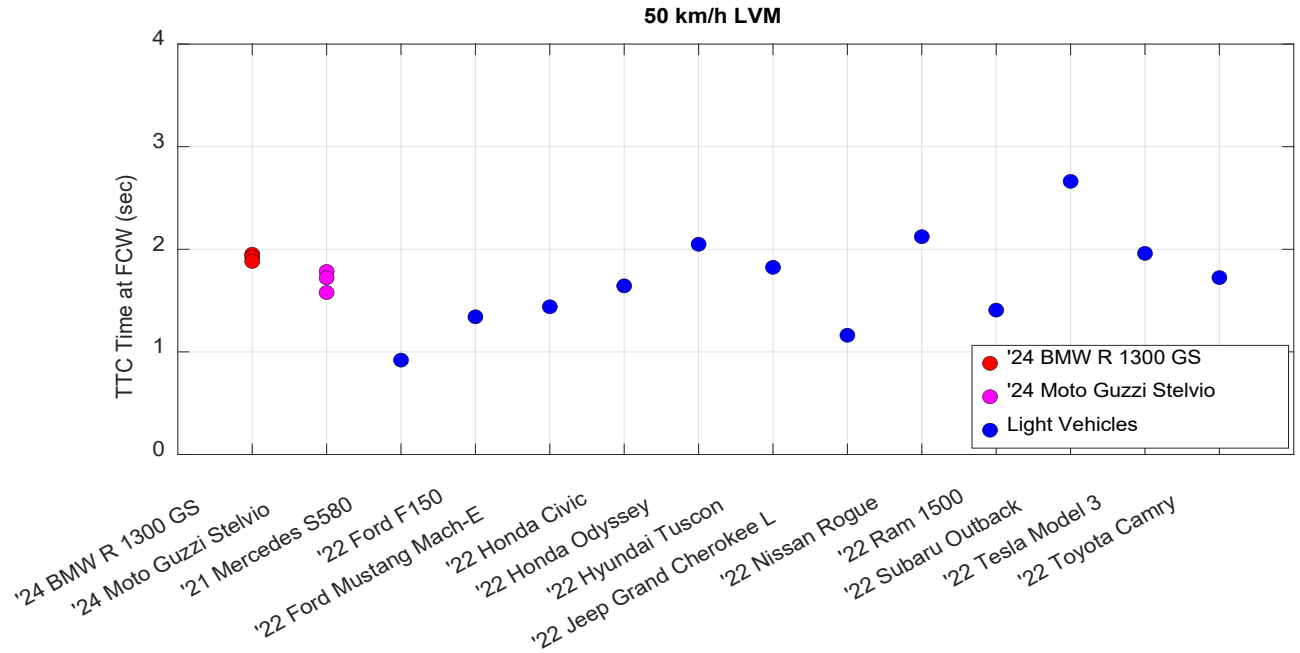


Figure 12. LVM FCW TTC comparison at 50% offset, 50 km/h

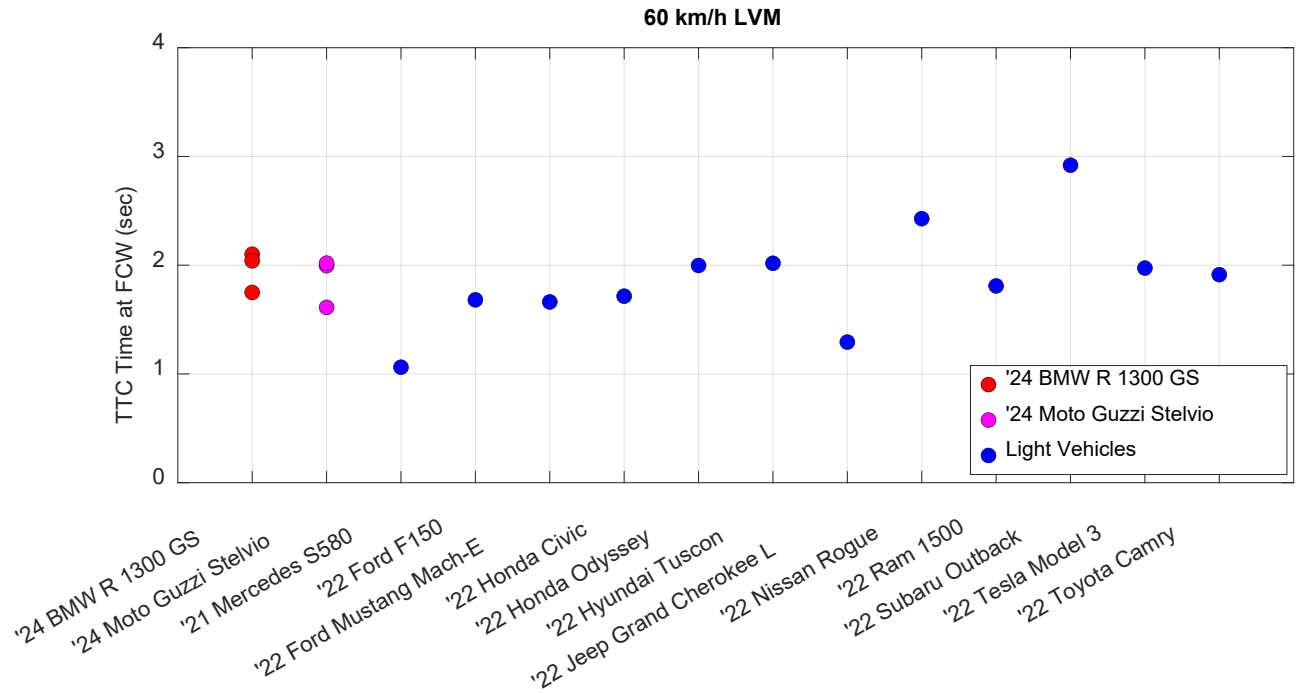


Figure 13. LVM FCW TTC comparison at 50% offset, 60 km/h

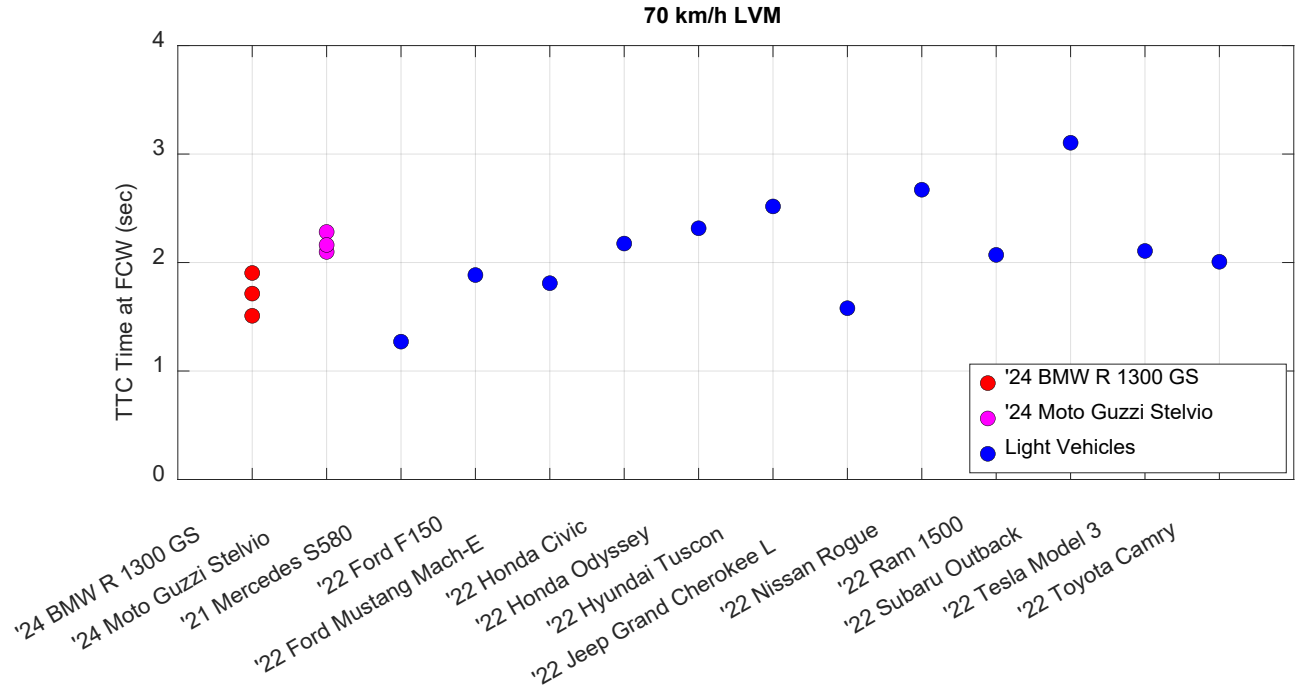


Figure 14. LVM FCW TTC comparison at 50% offset, 70 km/h

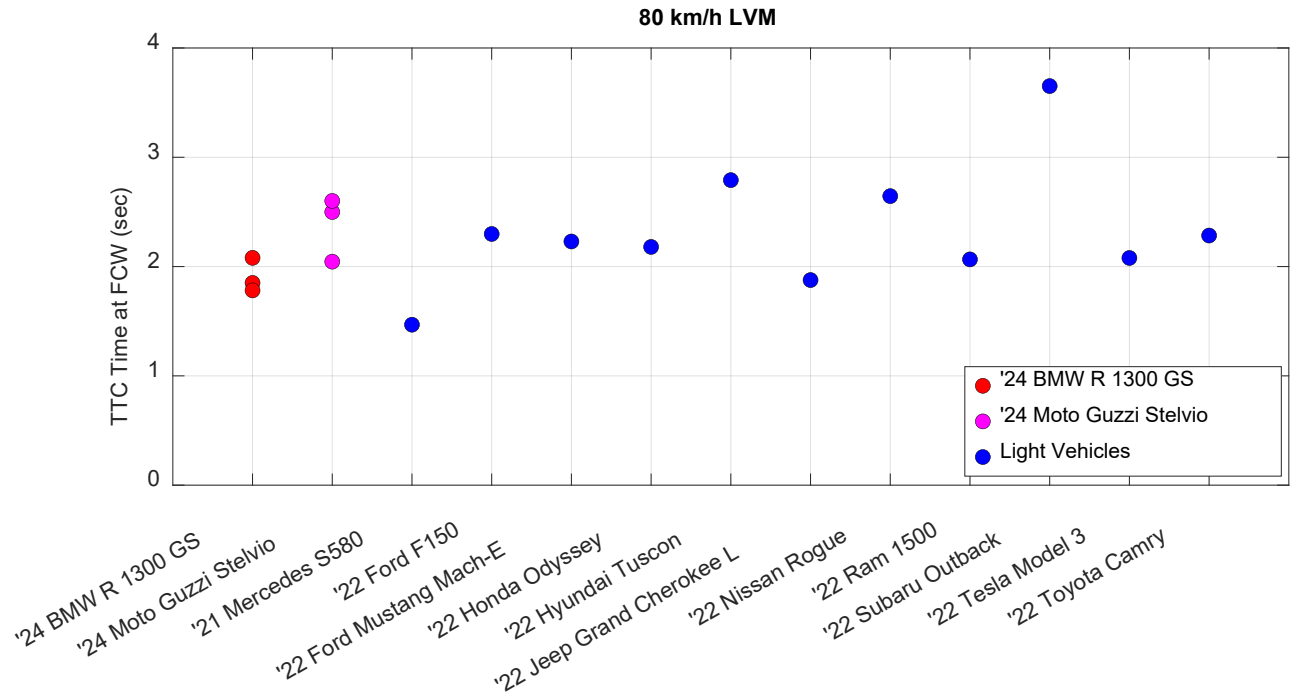


Figure 15. LVM FCW TTC comparison at 50% offset, 80 km/h

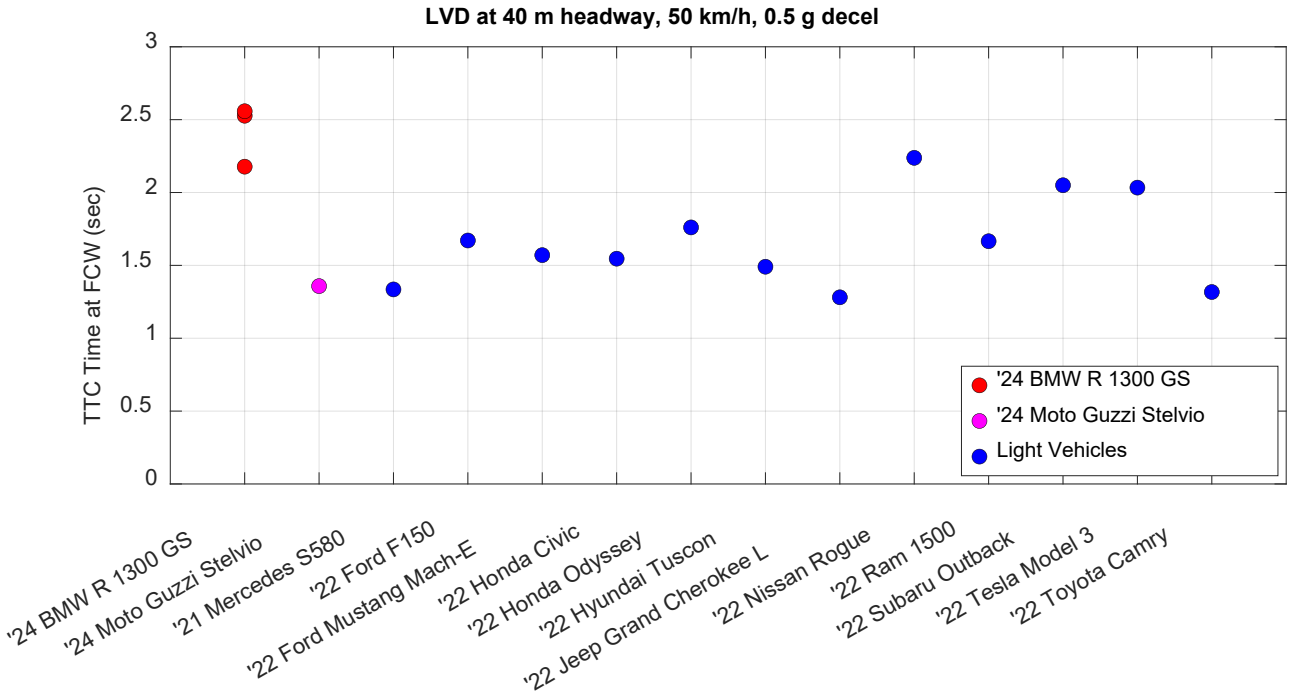


Figure 16. LVD FCW TTC comparison (50 km/h, 50% offset, 40 m headway, 0.5 g POV decel)

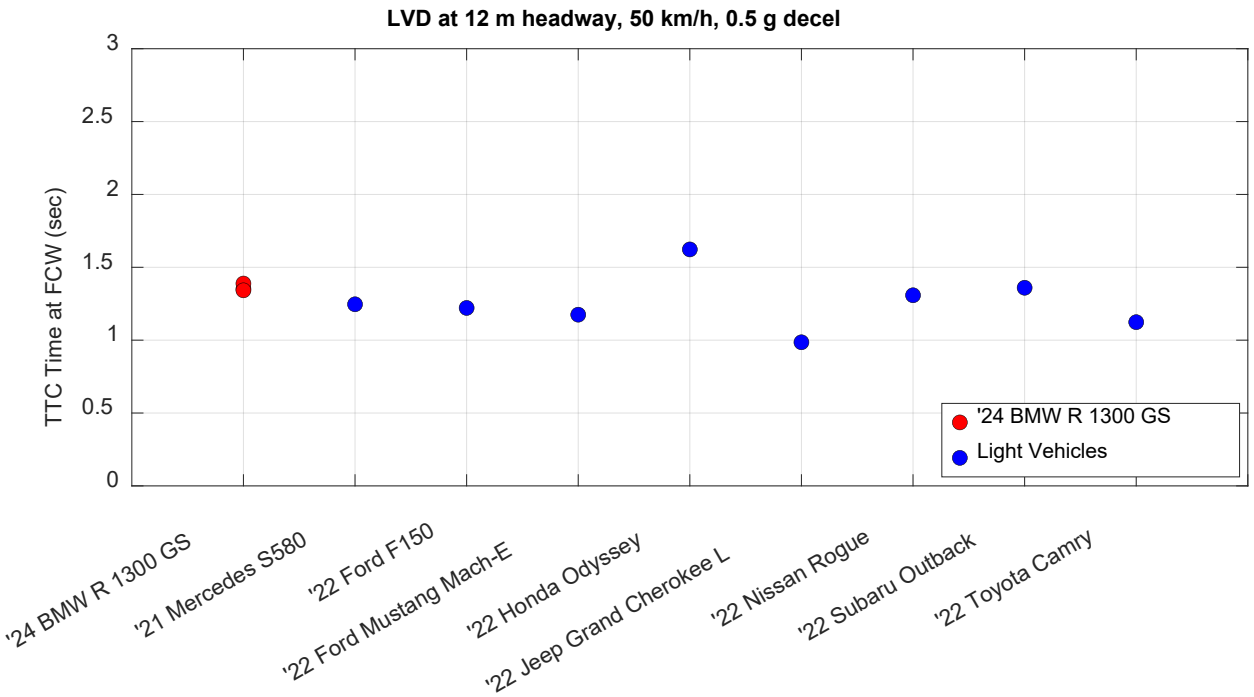


Figure 17. LVD FCW TTC comparison (50 km/h, 50% offset, 12 m headway, 0.5 g POV decel)

Motorcycle FCW Testing Challenges

While the AEB test procedure adopted to perform the FCW tests in this study was nearly equivalent to that used for light vehicles, there were some important changes made to improve test safety and practicability when used with motorcycle SVs.

Unlike FCW or AEB tests conducted with a light vehicle, rider safety considerations prohibit contact with a VTD-based POV when the SV is a motorcycle. Although this is difficult to ensure since achieving a crash avoidance outcome depends on the SV rider's perception of the riding situation, its criticality and ultimately their response to it, LVD tests performed with a 12 m SV-to-POV headway introduced a particularly demanding set of test conditions. A 12 m headway is inherently short, and the nonlinear TTC degradation resulting from a braking lead vehicle requires the rider to respond shortly after the POV initiates its braking regardless of whether an FCW is produced. At best, this requires the rider to steer around the decelerating POV very late in the pre-crash timeline during a test where they are expecting POV braking. However, if an unforeseen situation, such as a test equipment malfunction, causes unexpected POV braking (requiring the rider to quickly and necessarily respond with an aggressive avoidance maneuver), the rider may not have enough time to avoid contact. For these reasons, only a limited number of LVD trials were performed with a 12 m headway before the condition was removed from the test matrix.

The second adjustment made to the light-vehicle test procedures affected FCW and BSW test tolerance. For ADAS tests performed with a light vehicle, the SV yaw rate tolerance within the test validity period is 0 ± 1°/s—a specification that is generally not difficult to satisfy. However, for a motorcycle-based SV, the yaw motion inherent to a motorcycle traveling along a straight path was found to vary more than that typically observed for a passenger vehicle. For this reason,

the yaw rate tolerance used for this study increased to 0 ± 3°/s. However, despite this being a significant increase, it was still possible to achieve a 0 ± 0.3 m lateral path tolerance after the change had been implemented.

BSW Results

For research purposes, the onset and termination timing of the BSW alerts were measured and compared to research metrics based on those specified in the NHTSA BSW NCAP test procedure.[5]

Straight Lane Converge and Diverge Research Metrics

For this study, and recalling Figure 9, the following research metrics were considered when reviewing the straight lane converge and diverge test results.

- Was the BSW produced by a time no later than 300 ms after any part of the POV enters the SV blind zone defined by the intersections of lines A, C, D, and E for left-side tests, and of lines A, C, F, and G for right-side tests, and did it remain on while any part of the POV resided within the SV blind zone?
- During the diverging lane changes, did the BSW alert(s) remain active while the lateral distance between the SV and POV is >3 m (9.8 ft), but ≤6 m (19.7 ft)? Was the BSW alert active once the lateral distance between the SV and POV was >6 m (19.7 ft)?

Table 11. Converge and diverge research metrics

SV Speed	POV Speed	BSW Lateral Onset	BSW Lateral Termination
72.4 ± 1.6 km/h (45 ± 1 mph)	72.4 ± 1.6 km/h (45 ± 1 mph)	≤300 ms after the POV first enters the SV blind zone (laterally)	1. After the SV-to-POV lateral distance is >3 m (9.8 ft), but 2. Before the SV-to-POV lateral distance is ≤6 m (19.7 ft).

Straight Lane Pass-By Research Metrics

For this study, and recalling Figure 10, the research metrics used for the straight lane pass-by test were the following.

- Was the BSW produced by a time no later than 300 ms after the front-most part of the POV enters the blind zone defined by the intersections of lines A, C, D, and E for left-side tests and of lines A, C, F, and G for right-side tests, and did it remain on while the front-most part of the POV resided behind line A?

[5] While nearly equivalent, there is a difference between where the front-most location of the blind zone defined for a light vehicle in the NCAP BSW test procedure (longitudinally oriented at the rear of the SV side mirrors) versus the rear of the handlebar grips for the motorcycle-based research tests.

- Was the BSW present once the longitudinal distance between the front-most part of the SV and the rear-most part of the POV exceeded the BSW termination headway distances shown in Table 12?

Table 12. Straight lane pass-by research metrics

SV Speed	POV Speed	BSW Onset Headway[1]	BSW Termination Headway[2]
72.4 ± 1.6 km/h (45 ± 1 mph)	80.5 ± 1.6 km/h (50 ± 1 mph)	≤300 ms after $\overline{BC}$ = 5.6 m (18.3 ft) *(Nominal min: 4.93 m)*	1. After the frontmost part of the POV passes line A (see Figure 5) and, 2. Before the rearmost part of the POV is >2.2 m (7.3 ft) longitudinally ahead of the frontmost part of the SV.
72.4 ± 1.6 km/h (45 ± 1 mph)	88.5 ± 1.6 km/h (55 ± 1 mph)	≤300 ms after $\overline{BC}$ = 11.2 m (36.7 ft) *(Nominal min: 9.86 m)*	1. After the frontmost part of the POV passes line A (see Figure 5) and, 2. Before the rearmost part of the POV is >4.5 m (14.7 ft) longitudinally ahead of the frontmost part of the SV.
	96.6 ± 1.6 km/h (60 ± 1 mph)	≤300 ms after $\overline{BC}$ = 16.8 m (55.0 ft) *(Nominal min: 14.78 m)*	1. After the frontmost part of the POV passes line A (see Figure 5) and, 2. Before the rearmost part of the POV is >6.7 m (22.0 ft) longitudinally ahead of the frontmost part of the SV.
	104.6 ± 1.6 km/h (65 ± 1 mph)	≤300 ms after $\overline{BC}$ = 22.4 m (73.3 ft) *(Nominal min: 19.72 m)*	1. After the frontmost part of the POV passes line A (see Figure 5) and, 2. Before the rearmost part of the POV is >8.9 m (29.3 ft) longitudinally ahead of the frontmost part of the SV.

[1] The BSW onset headway nominally occurs 2.5 seconds before the front-most part of the POV passes by the rear-most part of the SV.

[2] The BSW termination headway nominally occurs 1 second after the rear-most part of the POV passes by the front-most part of the SV.

Tables 13 to 22 show results from the BSW tests performed in this study. For the cells in these tables, the following color convention is used:

Green shading:

- For the converge part of the converge and diverge tests, the lateral distance at the onset of the BSW agreed with the research metric defined in Table 11.
- For the diverge part of the converge and diverge tests, the lateral distance at termination of the BSW agreed with the research metric defined in Table 11.
- For the approach part of the straight lane pass-by tests, the longitudinal distance at the onset of the BSW agreed with the research metric defined in Table 12.
- After the POV had driven by the SV during the straight lane pass-by tests, the longitudinal distance at termination of the BSW agreed with the research metric defined in Table 12.

Yellow shading:

- For the converge part of the converge and diverge tests, the lateral distance at the onset of the BSW was not within the metric defined in Table 11.
- For the diverge part of the converge and diverge tests, the lateral distance at termination of the BSW was not within the metric defined in Table 11.
- For the approach part of the straight lane pass-by tests, the longitudinal distance at the onset of the BSW was not within the metric defined in Table 12.
- After the POV had driven by the SV during the straight lane pass-by tests, the longitudinal distance at termination of the BSW was not within the metric defined in Table 12.

BMW R 1300 GS BSW Testing

Test results for straight lane converge and diverge trials performed with the BMW R 1300 GS are shown in Table 13. For these tests, a BSW was produced during all six trials performed.

Table 13. BMW R 1300 GS BSW converge and diverge distance (m)

2024 BMW R 1300 GS BSW Converge and Diverge												
Warning	Onset						Termination					
Turn signal	Disabled						Disabled					
Approach	Left			Right			Left			Right		
Lane offset	50%						50%					
Lateral distance (m)	4.6	4.6	4.5	3.4	3.3	3.4	6.1	6.1	6.2	5.2	5.2	5.3

BSW research metric satisfied BSW research metric not satisfied

Although the BSW onset (converge) research metrics were met for trials performed with the POV on both sides of the SV, the research termination (diverge) metrics were only satisfied during the three trials performed with the POV to the right of the SV. For the diverge part of the

test, the BMW R 1300 GS presented the BSW beyond the termination point during each of the three trials performed with the POV to the left of the SV.

The BMW R 1300 GS produced a BSW during each of the 18 straight lane pass-by trials performed with the turn signal enabled. The BSW onset results are shown in Table 14. The BMW R 1300 GS met the research onset metrics for all SV lateral offset and POV approach configurations tested.

Table 14. BMW R 1300 GS pass-by with turn signal BSW distance at onset (m)

2024 BMW R 1300 GS Straight Lane Pass-By Longitudinal Headway at BSW Onset (m)									
Turn Signal	Enabled								
POV Speed	80.5 km/h								
Lane Offset	75%			50%			25%		
Left	7.0	7.2	7.1	7.8	7.0	7.1	7.4	7.0	7.0
Right	7.3	7.6	7.5	7.1	7.1	7.2	7.1	7.4	7.2

BSW research metric satisfied BSW research metric not satisfied

The straight lane pass-by BSW termination results for BMW R 1300 GS trials performed with the turn signal enabled are shown in Table 15. The research termination metrics were satisfied for each of the six trials performed with a 75 percent SV lateral offset. When a 50 percent lateral offset was used, 5 of 6 trials met the research termination metrics, with one right approach trial presenting the BSW beyond the termination point. The research termination metrics were satisfied for each of the six trials performed with a 25 percent SV lateral offset.

Table 15. BMW R 1300 GS pass-by with turn signal BSW distance at termination (m)

2024 BMW R 1300 GS Straight Lane Pass-By Longitudinal Headway at BSW Termination (m)									
Turn Signal	Enabled								
POV Speed	80.5 km/h								
Overlap	75%			50%			25%		
Left	-0.4	-0.2	-0.5	-0.9	-0.4	-0.3	-0.6	-1.2	-1.2
Right	-0.8	-0.8	-0.7	2.9	-0.6	-0.4	-0.7	-0.8	-0.4

BSW research metric satisfied BSW research metric not satisfied

The BMW R 1300 GS produced a BSW during each of the 72 straight lane pass-by trials performed without the turn signal enabled. The BSW onset results are shown in Table 16. Research onset metrics were met for all SV lateral offset, POV speed, and POV approach configurations tested.

Table 16. BMW R 1300 GS pass-by without turn signal BSW distance at onset (m)

2024 BMW R 1300 GS Straight Lane Pass-By Longitudinal Headway at BSW Onset (m)										
Turn signal		Disabled								
Approach		Left								
Lane Offset		75%			50%			25%		
POV Speed (km/h)	80.5	7.4	7.2	7.1	7.2	7.4	7.1	7.2	7.1	7.9
	88.5	15.7	14.7	14.4	14.5	15.0	14.8	15.0	15.6	15.1
	96.6	22.6	22.2	22.1	21.5	23.1	23.0	21.6	21.7	22.9
	104.6	30.2	30.1	30.0	29.8	29.5	30.2	29.6	30.3	30.5
Approach		Right								
POV Speed (km/h)	80.5	7.1	7.6	7.4	7.7	7.2	7.2	6.0	7.0	7.0
	88.5	14.7	14.8	16.1	15.3	15.1	13.4	15.1	14.9	14.3
	96.6	22.8	23.3	22.8	22.3	23.2	22.6	22.4	22.1	22.1
	104.6	29.9	29.7	29.4	29.8	30.4	30.9	30.1	30.0	29.1

BSW research metric satisfied BSW research metric not satisfied

Table 17 shows the straight lane pass-by BSW termination results for the BMW R 1300 GS trials performed without turn signal activation. The BMW R 1300 GS satisfied the research termination metrics for all SV lateral offset, POV speed, and POV approach configurations tested.

Table 17. BMW R 1300 GS pass-by without turn signal BSW distance at termination (m)

2024 BMW R 1300 GS Straight Lane Pass-By Longitudinal Headway at BSW Termination (m)										
Turn Signal		Disabled								
Approach		Left								
Overlap		75%			50%			25%		
POV Speed (kph)	80.5	-0.5	-0.5	-0.4	-0.6	-0.5	-0.6	-0.7	-0.8	-0.7
	88.5	1.6	1.2	0.8	0.9	0.9	0.9	0.9	1.3	1.2
	96.6	2.4	2.4	2.2	2.0	1.9	2.3	1.6	2.2	2.1
	104.6	1.9	1.8	2.4	2.0	2.3	1.9	2.1	2.6	2.7
Approach		Right								
Overlap		75%			50%			25%		
POV Speed (kph)	80.5	-0.7	-0.7	-0.8	-0.5	-0.5	-0.6	0.0	-0.3	-0.3
	88.5	1.0	1.0	1.2	1.4	0.9	1.1	1.5	1.4	1.4
	96.6	2.5	2.5	1.7	2.2	2.1	1.9	1.4	2.2	2.1
	104.6	2.2	2.1	2.4	1.9	2.5	2.5	2.0	2.1	1.8

BSW research metric satisfied BSW research metric not satisfied

Moto Guzzi Stelvio BSW Testing

Test results for straight lane converge and diverge trials performed with the Moto Guzzi Stelvio are shown in Table 18. For these tests, a BSW was produced during all 12 trials performed, and the BSW research onset metrics were satisfied for trials performed with the POV on both sides of the SV. The research termination metrics were satisfied during 4 of 6 trials; for all three trials with the POV to the right of the SV, and during one trial (33.3%) with the POV to the left of the SV. For the two trials where the Moto Guzzi Stelvio did not satisfy the research termination metrics, the BSW remained active beyond the termination point.

Table 18. Moto Guzzi Stelvio BSW converge and diverge distance (m)

2024 Moto Guzzi Stelvio BSW Converge and Diverge												
Warning	Onset						Termination					
Turn Signal	Disabled						Disabled					
Approach	Left			Right			Left			Right		
Lane Offset	50%						50%					
Lateral Distance (m)	4.1	4.1	4.1	3.3	3.3	3.1	5.9	6.1	6.0	5.1	5.2	5.4

BSW research metric satisfied BSW research metric not satisfied

The Moto Guzzi Stelvio produced a BSW during each of the 18 straight lane pass-by trials performed with the turn signal enabled. The BSW onset results are shown in Table 19. For these trials, the research onset metrics were satisfied for 16 of 18 trials. The two trials unable to satisfy the respective onset metrics both involved the BSW onset being produced too late (the front longitudinal proximity of the POV was too close to the rear of the SV at the BSW onset), an occurrence noted during one right-side pass-by trial performed with a 75 percent SV lateral offset and during one left-side pass-by trial performed with a 25 percent SV lateral offset.

Table 19. Moto Guzzi Stelvio pass-by with turn signal BSW distance at onset (m)

2024 Moto Guzzi Stelvio Straight Lane Pass-By Longitudinal Headway at BSW Onset (m)									
Turn Signal	Enabled								
POV Speed	80.5 km/h								
Lane Offset	75%			50%			25%		
Left	7.8	7.7	7.8	8.4	7.6	7.0	5.1	1.2	6.5
Right	6.8	4.0	7.0	7.5	6.9	7.8	7.9	7.9	7.9

BSW research metric satisfied BSW research metric not satisfied

The straight lane pass-by BSW termination results for Moto Guzzi Stelvio trials performed with the turn signal enabled are shown in Table 20. The BSW termination metric was satisfied for 15 of 18 trials performed. The BSW terminated prematurely during three trials: one left and one right approach at 50 percent overlap, and during one right approach performed with a 75 percent overlap.

Table 20. Moto Guzzi Stelvio pass-by with turn signal BSW distance at termination (m)

2024 Moto Guzzi Stelvio Straight Lane Pass-By Longitudinal Headway at BSW Termination (m)									
Turn Signal	Enabled								
POV Speed	80.5 km/h								
Overlap	75%			50%			25%		
Left	-2.4	-0.2	-2.7	-2.7	-5.9	-1.6	-2.8	-3.6	-4.6
Right	-3.3	-5.5	-2.7	-2.7	-5.9	-1.6	-2.3	-1.1	-1.4

BSW research metric satisfied BSW research metric not satisfied

The Moto Guzzi Stelvio produced a BSW during each of the 72 straight lane pass-by trials performed without the turn signal enabled. The BSW onset results are shown in Table 21. During left-side pass-by trials, the Moto Guzzi Stelvio satisfied the research onset metrics for all four POV speed conditions when SV lateral offsets of 50 and 75 percent were used. However, when an SV lateral offset of 25 percent was used with a left-side pass-by, the BSW onset of only 2 of 12 trials (16.7%) satisfied the applicable research onset metrics: during one trial performed with

a POV speed of 80.5 km/h and during one trial performed with a POV speed of 88.5 km/h. The BSW alerts were produced too late for the remaining 10 trials.

Table 21. Moto Guzzi Stelvio pass-by without turn signal BSW distance at onset (m)

2024 Moto Guzzi Stelvio Straight Lane Pass-By Longitudinal Headway at BSW Onset (m)										
Turn Signal		Disabled								
Approach		Left								
Lane Offset		75%			50%			25%		
POV Speed (km/h)	80.5	8.1	8.5	8.5	9.1	8.9	8.6	1.8	4.8	7.3
	88.5	17.3	16.4	17.4	17.9	16.4	16.6	11.5	4.1	2.6
	96.6	23.8	22.6	23.4	24.4	23.8	23.2	7.0	1.9	2.8
	104.6	25.5	23.4	23.4	24.5	25.0	25.0	1.8	1.3	1.3
Approach		Right								
POV Speed (km/h)	80.5	8.4	8.1	8.6	8.0	8.3	8.2	8.4	8.5	8.6
	88.5	16.6	15.6	13.1	16.0	13.6	16.9	16.5	17.4	15.4
	96.6	21.5	13.6	21.9	23.9	23.8	23.7	22.2	23.2	22.4
	104.6	20.9	18.2	23.8	23.8	24.6	24.2	25.7	25.2	24.5

BSW research metric satisfied BSW research metric not satisfied

With respect to the right-side pass-by trials, the Moto Guzzi Stelvio satisfied the BSW research onset metrics for 34 of 36 trials (94.4%) performed. The two trials unable to satisfy the research onset metrics occurred when a 75 percent lateral offset was used in conjunction with 96.6 and 104.6 km/h POV speeds (one trial per POV speed).

Table 22 shows the straight lane pass-by BSW termination results for Moto Guzzi Stelvio trials performed without the turn signal activation. The Moto Guzzi did not satisfy the BSW termination criteria for two trials due to the BSW extending beyond the applicable research termination metrics. During these instances the POV passed on the left with the SV in the 75-percent offset lane position.

Table 22. Moto Guzzi Stelvio pass-by without turn signal BSW distance at termination (m)

2024 Moto Guzzi Stelvio Straight Lane Pass-By Longitudinal Headway at BSW Termination (m)										
Turn Signal		Disabled								
Approach		Left								
Overlap		75%			50%			25%		
POV Speed (kph)	80.5	-0.3	2.8	-0.2	-0.4	-0.8	-2.8	-1.4	-1.0	-1.1
	88.5	6.8	2.2	-0.9	0.1	-0.8	-1.2	-1.9	-1.6	-1.2
	96.6	1.8	0.6	4.9	1.2	0.7	1.2	0.9	1.5	3.9
	104.6	3.4	4.0	3.6	3.5	6.1	4.2	6.5	5.9	3.0
Approach		Right								
Overlap		75%			50%			25%		
POV Speed (kph)	80.5	-0.7	-0.9	-0.7	-0.7	-3.8	-4.6	0.0	0.1	-0.1
	88.5	-2.2	2.0	-2.5	-0.9	-2.0	1.7	-0.5	-0.8	-0.8
	96.6	4.1	0.2	0.3	4.4	1.0	1.4	4.1	4.7	4.4
	104.6	3.3	3.3	6.0	4.0	4.1	3.5	3.7	3.8	4.4

BSW research metric satisfied

BSW research metric not satisfied

Motorcycle BSW Testing Challenges

Although the use of manually operated steering, path, and speed control used for this study's motorcycle testing may have contributed to higher test input variability than typically achievable with the robotic controls used for light-vehicle ADAS testing, satisfying the applicable test tolerances defined in the NHTSA NCAP BSW test procedure was generally possible. As previously mentioned, the exception was the yaw rate tolerance, which was increased from 0 ± 1°/s to 0 ± 3°/s for the tests performed in this study.

Conclusions and Observations

The work described in this report used modified NHTSA light-vehicle test methods to research motorcycle-based FCW and BSW system operation on the test track. A modified version of the FMVSS No. 127 and NHTSA NCAP AEB test procedures was used for FCW research, whereas a modified version of the NHTSA NCAP BSW test procedure was used for motorcycle BSW testing.

For both test types, test procedure adjustments included use of multiple SV lateral offsets and an increase in the SV yaw rate test tolerance from 1°/s to 3°/s. For the BSW tests, the longitudinal headway used for converge and diverge tests was also reduced from 1 m to 0.3 m to account for the difference in vehicle length typically present for these vehicle classes. For FCW testing, only a limited number of LVD tests were performed with a 12 m headway due to safety considerations observed while testing. If contact with a VTD occurs during light-vehicle testing, it poses minimal risk to the driver. However, contacting a VTD with a motorcycle can lead to a loss of control and rider injury. With the exception of the FCW LVS tests, each test condition was nominally repeated three times.

While both motorcycles tested issued FCW alerts during trials performed with a moving or decelerating lead vehicle, neither responded to a stationary lead vehicle. The BMW R 1300 GS provided FCW activations during all LVM and LVD trials performed, including those performed with both lateral offsets. The Moto Guzzi Stelvio provided FCW activations during all LVM and most LVD trials. However, the FCW was not activated during three LVD trials performed with a 40 m headway and a 0.5 g lead vehicle deceleration during two trials performed with a 50 percent offset and one trial using a 75 percent offset. Neither motorcycle produced an FCW during any STP or pass-through trial performed.

Comparison of the motorcycle FCW onset TTC responses to those observed during similar LVM and LVD tests performed with 12 light vehicles found the motorcycle-based values generally fell within the distribution of those from comparable light-vehicle tests. However, the BMW R 1300 GS produced an FCW alert earlier than those observed for the light vehicles compared in this study during 2 of 3 trials performed with a 50 km/h test speed, a 40 m headway, a 0.5 g lead vehicle deceleration, and a 50 percent offset.

BSW operation generally satisfied the thresholds defined in NHTSA's light-vehicle NCAP BSW test procedure: during 92 of 96 trials performed with the BMW R 1300 GS and during 76 of 96 trials performed with the Moto Guzzi Stelvio. Test results indicate that BSW response may be affected by changes in relative lateral distance where lane offsets shift the SV farther away from the POV. Comparison of the results observed in this study to NCAP light-vehicle BSW thresholds is provided for context only, not to infer or imply they are appropriate measures for motorcycle performance.

Although the modified light-vehicle protocols used for the work described in this report can be used to support motorcycle FCW and BSW testing, it is important to acknowledge the study focused on test conduct and reporting of results, not on the development or validation of what may be appropriate motorcycle performance criteria.

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Appendix A: Subject Vehicles



Figure 18. The 2024 BMW R 1300 GS with riding assistant

Table 23. BMW R 1300 GS

Air/liquid-cooled, 1,300 cc, four-stroke, horizontally opposed (boxer) engine
Length 2212 mm
Height 1406 mm
Width 1000 mm
Curb weight 237 kg (522 lb)
Weight as received 255 kg (563 lb)
Weight fully instrumented 305 kg (672 lb)
Weight fully instrumented with rider 425 kg (938 lb)
Front and rear mounted radar sensors
Distance control (ACC)
FCW
Lane change warning (SWW)
Rear-end collision warning (RECW)



Figure 19. The 2024 Moto Guzzi Stelvio

Table 24. The 2024 Moto Guzzi Stelvio

Liquid-cooled, 1,042 cc, four-stroke, 90° V-twin engine
Maximum length 2195 mm (86.42 in)
Maximum width (at handlebar) 945 mm (37.20 in)
Height (adjustable at the windshield) 1400–1470 mm (55.12 - 57.87 in)
Wheelbase 1,520 mm (59.84 in)
Curb weight 246 kg (542.34 lb)
Weight as received 259 kg (571 lb)
Weight fully instrumented 308 kg (680 lb)
Weight fully instrumented with rider 430 kg (947 lb)
Front- and rear-mounted radar sensors
Following cruise control (FCC, adaptive cruise control)
Front radar FCW
Rear-radar lane change decision aid system (LCDAS)

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Appendix B: Instrumentation

Table 25. Test equipment description, location, weight

Equipment Description	Equipment Used	Typical Location	Approximate Weight
Data acquisition system (DAS)	DeweSoft DAS and a NUC	SV hard side case	DAS ≈ 5 kg (12 lb) External batteries ≈ 4 kg (8 lb)
Integrated inertial measurement unit and GPS (SV)	Oxford Technical Solutions (OxTS) RT 3000 series V4, NovAtel high precision antenna, FreeWave industrial radio and antenna	Antennas mounted to the top of the rear top case. IMU/GPS securely positioned in the SV hard side case. GPS acquisition and ancillary equipment installed/secured in the SV hard side case.	RT 3000 ≈ 4 kg (8 lb) FreeWave ≈ 1 kg (3 lb)
Integrated inertial measurement unit and GPS (POV)	OxTS RT 3000 series and antenna	Antenna mounted to the POV. IMU/GPS positioned within the POV near the center of the unit. GPS acquisition and ancillary equipment securely positioned within the POV.	≈ 4 kg (8 lb)
Programmable driving robot	AB Dynamics (ABD) SR15 Orbit steering robot, electronics box, battery box, and network antenna	Antenna mounted to the roof of the SV. Driving robot is connected to the steering wheel and windshield. The robot controller electronics box and batteries are typically secured in the SV rear cargo area.	Steering robot ≈ 5 kg (11 lb) Robot controller electronics box ≈ 12 kg (27 lb) Battery box ≈ 18 kg (39 lb) Network antenna ≈ 4 kg (8 lb)
High-speed video camera	DeweSoft DAS, and high-speed camera	DeweSoft mounted in SV side hard case. Camera mounted on fuel tank with unobstructed view of instrument panel.	≈ 5 kg (11 lb)
Vehicle-to-vehicle range receiver *(wireless communication between the SV and POV)*	OxTS RT Range, network antenna, driver displays	Antenna mounted to the roof of the SV. Ancillary equipment secured in the SV rear-cargo area.	RT Range ≈ 2 kg (4 lb) Display boxes ≈ 2 kg (4 lb)

Vehicle-to-vehicle range transmitter *(wireless communication between the SV and POV)*	Network antenna	Antenna mounted to the POV. Ancillary equipment secured within the POV.	≈ 0.5 kg (1 lb)

Table 26. Sensor descriptions and specifications

Type	Output	Range	Resolution	Accuracy
Longitudinal speed sensor	SV and POV longitudinal speed	0.1 – 241 km/h (0.1 – 150 mph)	0.05 km/h (0.031 mph)	± 0.25% of full-scale range
Rate sensor	SV yaw rate	± 100°/s	0.01°/s	± 0.05% of full-scale range
SR torque	SV steering controller torque	0 – 15 N-m (0 – 11 lb-ft)	1.5 N-m (± 1.1 lb-ft)	± 1.5 N-m (± 1.1 lb-ft)
Accelerometer	SV and POV longitudinal deceleration	± 10 g	0.01 g	± 0.01% of full-scale range
Position sensor (string potentiometer)	SV throttle, brake lever, brake pedal and handlebar steering position	0 – 100% (normalized)	0.1%	± 0.1%
Differential GPS	Longitudinal position of SV and POV	N/A	1 mm (0.04 in)	± 10 mm (± 0.4 in)
Vehicle dimensional measurements	Location of SV and POV GPS antennas; SV and POV centerlines; front-most SV bumper position; rear-most POV bumper position.	N/A	1 mm (0.04 in)	± 1 mm (± 0.04 in)
SV-to-POV static range	Distance between POV and rear-most POV bumper position	N/A	1 mm (0.04 in)	± 10 mm (± 0.4 in)
Microphone	Frequency and intensity of FCW alert	20 Hz – 20 kHz 0 – 112 dB	-33 dB at 1 kHz	N/A
FARO	SV and POV dimensional measurements	N/A	1,200,000 points per second	± 0.065 mm (± 0.003 in)

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