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Assessment of Light-Vehicle ADAS Crash Avoidance Technologies in Response to 2-Wheeled Vehicles as Principal Other Vehicles

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16. Abstract

This project examines the characterization testing of automatic emergency braking and blind spot intervention (BSI) system performance when encountering a 2-wheeled principal other vehicle (POV) in either a rear-end crash or lane change crash scenario. Tests conducted represented variations on the NHTSA crash imminent braking (CIB) and BSI test procedures using bicycle and motorcycle surrogates as the POV as a comparison with the passenger vehicle test device. Variables tested included speed (10 km/h to 80 km/h), POV lateral offset, position of POV behind a passenger vehicle test device, and lighting conditions. Testing was conducted for 5 light vehicles representing a mix of body styles and sensor systems (both camera-only and camera-radar fusion). For rear-end crash scenarios, the results suggest that there is no consistent pattern across systems tested in response to the 2-wheeled POVs with collision avoidance demonstrated, but not consistently across variables tested. However, those results generally indicate collision avoidance at higher speeds in response to the passenger vehicle test device than in response to the 2-wheeled POVs. Results for the BSI systems tested did not demonstrate strong patterns for identifying or responding to 2-wheeled POVs.

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advanced driver assistance systems, crash imminent braking, blind spot intervention, motorcycle, bicycle, AEB, BSI	Document is available to the public from the DOT, BTS, National Transportation Library, Repository & Open Science Access Portal, https://rosap.ntl.bts.gov.

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List of Acronyms

ADAS	advanced driver assistance system
AEB	automatic emergency braking
BSI	blind spot intervention
CIB	crash imminent braking
CG	center of gravity
FCW	forward collision warning
GVT	global vehicle target
IBT	initial brake temperature
IMU	inertial measurement unit
LSS	lane support systems
LVS	lead vehicle stopped
LVM	lead vehicle moving
LVD	lead vehicle decelerating
NCAP	New Car Assessment Program
PFC	peak friction coefficient
POV	principal other vehicle
SV	subject vehicle
TTC	time-to-collision
VRU	vulnerable road user

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Executive Summary

This project examined advanced driver assistance system technologies on light vehicles that may avoid or mitigate rear-end and sideswipe crashes with 2-wheeled vehicles. Two-wheeled-vehicle users are particularly vulnerable to injury in crashes when compared to passenger vehicles due to lack of external protection. For rear-end crashes, this project characterized automatic emergency braking system performance with 2-wheeled vehicles, specifically motorcycles and bicycles, as the principal other vehicle. This project also examined lane changes with a motorcycle POV in the test vehicle's blind spot and the resulting blind spot intervention performance. The primary research questions for this project were as follows.

1. How do ADAS crash avoidance systems from a variety of makes and models respond to motorcycles and bicycles in the following crash scenarios?
    a. Rear-end crashes (lead motorcycle or bicycle stopped, lead motorcycle or bicycle decelerating, and lead motorcycle or bicycle moving slower)
    b. Lane change crashes (motorcycle and light vehicle traveling in the same direction)
2. How do the handling and driving characteristics of motorcycles affect test specifications (e.g., lane position and acceleration/braking characteristics)?
3. How do the results of the tests conducted with motorcycles and bicycles as POVs compare with tests conducted with a light vehicle as the POV?
4. How could the draft test procedures be adjusted to account for motorcycles and bicycles given the findings specific to the results of this study?

Five vehicles of varying makes and models were selected in consultation with the National Highway Traffic Safety Administration. The user manual of each selected vehicle explicitly stated the AEB or BSI systems addressed motorcycles and bicycles. All tests were performed with a surrogate (i.e., test device) passenger vehicle, surrogate bicycle, and surrogate motorcycle as the POVs in each scenario.

The test results showed that AEB response to surrogates varied across scenarios. However, there was not a consistent pattern either between or in vehicles in response to either the motorcycle POV or the bicycle POV; each vehicle demonstrated that collision avoidance was possible, but not at all combinations of speed, configuration, or other variables tested. Some test runs also varied the POV offset to represent differences in the driving characteristics of motorcycles and bicycles as they move in a lane; results were similarly inconsistent, with no clear pattern emerging to indicate better or worse performance across systems given the POV offset.

In rear-end test scenarios where the POV tested represented a light vehicle, the tested vehicles generally avoided collision at higher speeds than when the POV represented a motorcycle or bicycle, although the sample size precludes robust statistical analysis. While not the case in all tests, this general trend indicated that the tested systems are usually able to avoid collisions with light vehicles at higher speeds when compared with motorcycles or bicycles. This trend was not clear for BSI systems tested, and ongoing NHTSA research may better characterize performance in the future as such systems which can detect motorcycles become more prevalent.

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Introduction

The vision for this research project was for NHTSA to determine how available ADASs perform in crash imminent scenarios with motorcycles and bicycles. Specifically, this project addressed light vehicle ADAS in rear-end crashes with motorcycles and bicycles, and sideswipe crashes with motorcycles in lane change scenarios. This study addressed the following primary research questions.

1. How do ADAS crash avoidance systems from a variety of makes/models respond to motorcycles and bicycles in several crash conditions?
    a. Rear-end crashes (lead motorcycle or bicycle stopped, lead motorcycle or bicycle decelerating, and lead motorcycle or bicycle moving slower)
    b. Lane change crashes (motorcycle and light vehicle traveling in the same direction)
2. How do the motorcycle handling and driving characteristics affect test specifications such as lane position and acceleration/braking characteristics?
3. How do the results of the tests conducted with motorcycles and bicycles as POVs compare with tests conducted with a light vehicle as the POV?
4. How could the draft test procedures be adjusted to account for motorcycles and bicycles given the findings specific to the results of this study?

Background

Due to a lack of external protection, 2-wheeled vehicle users are particularly vulnerable to injury in crashes when compared to passenger vehicles. In 2022 there were 1,105 bicyclists killed in traffic crashes with motor vehicles (NCSA, 2024a). Additionally, in 2022 there were 3,687 of the 6,359 motorcycles in fatal crashes involved in collisions with motor vehicles; the overall motorcycle fatality rate in 2022 was 26.16 fatalities per 100 million miles traveled by motorcycles. In comparison, the passenger car fatality rate was significantly lower at 1.20 fatalities per 100 million miles traveled (NCSA2024b).

A variety of test procedures from around the world include testing with 2-wheeled POV targets. Euro NCAP, for instance, has procedures to test AEB in response to a bicycle crossing, as well as a longitudinal (i.e. along path) approach, at speeds up to 60 km/h (EuroNCAP, 2023). International standards also exist, with ISO 17387:2008 as an example; the associated test procedure addresses lane change decision aid systems, utilizing a motorcycle with a rider as the POV (International Organization for Standardization, 2018). The scenarios described in the ISO standard were similar to the BSI scenarios evaluated in this program.

Previous versions of Euro NCAP’s vulnerable road user testing included bicyclists, with recent versions increasing the number of test scenarios with bicycle POVs. Test scenarios in version 4.5 (current at the time of writing) that include a bicycle as a POV are car-to-bicyclist farside adult (CBFA), car-to-bicyclist nearside adult (CBNA), car-to-bicyclist longitudinal adult (CBLA), and car-to-bicyclist turning adult (CBTA). These scenario details for bicycle tests are found in Euro NCAP, 2024). Note that EuroNCAP refers to the SV as a vehicle under test (VUT).

Table 1. Euro NCAP Bicycle Scenarios

	CBFA	CBNA		CBLA		CBTA	
Paragraph	7.3.1	7.3.2 & 7.3.3		7.3.4		7.3.5	
Type of Test	AEB	AEB		AEB	FCW/ESS	AEB	
VUT Speed [km/h]	10-60	10-60		25-60	50-80	10,15,20	10
VUT Direction	Forward	Forward		Forward		Farside Turn (Left in US)	Nearside Turn (Right in US)
Obstruction	No	No	Yes	No		No	
Target Speed [km/h]	20	15	10	15	20	15	
Target Direction	Farside	Nearside		Forward		Opposite Direction	
Impact Location [%]	50	50		50	25	50	
Lighting Condition	Day	Day		Day		Day	

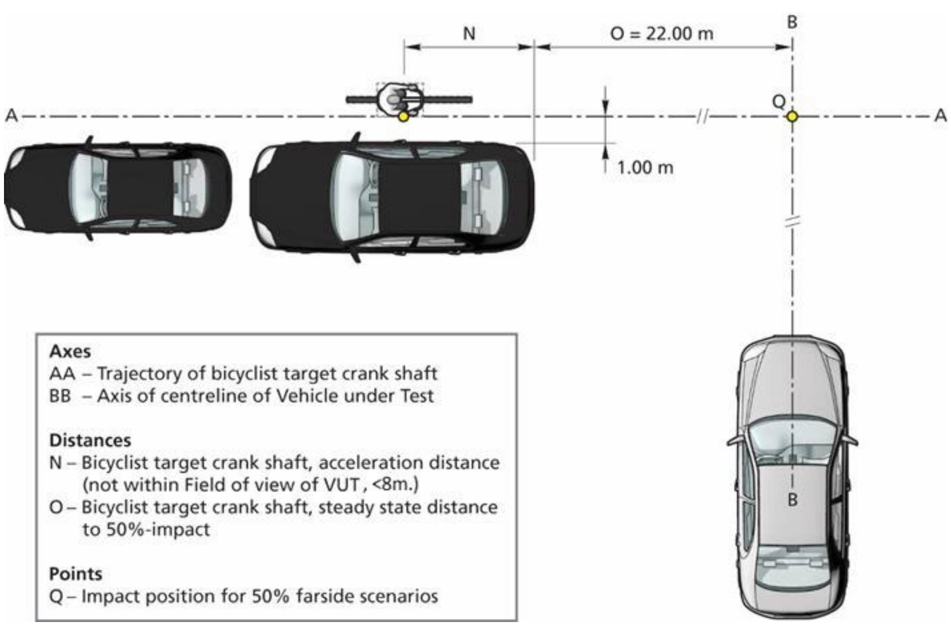

Figure 1. Euro NCAP Car-to-Bicyclist Farside Adult (CBFA)

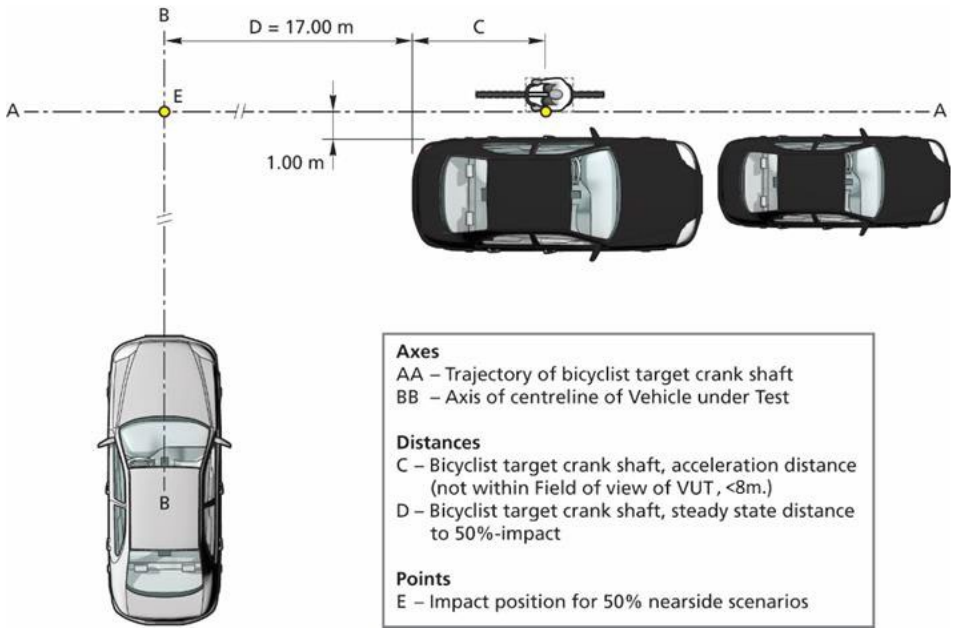

Figure 2. Euro NCAP Car-to-Bicyclist Nearside Adult

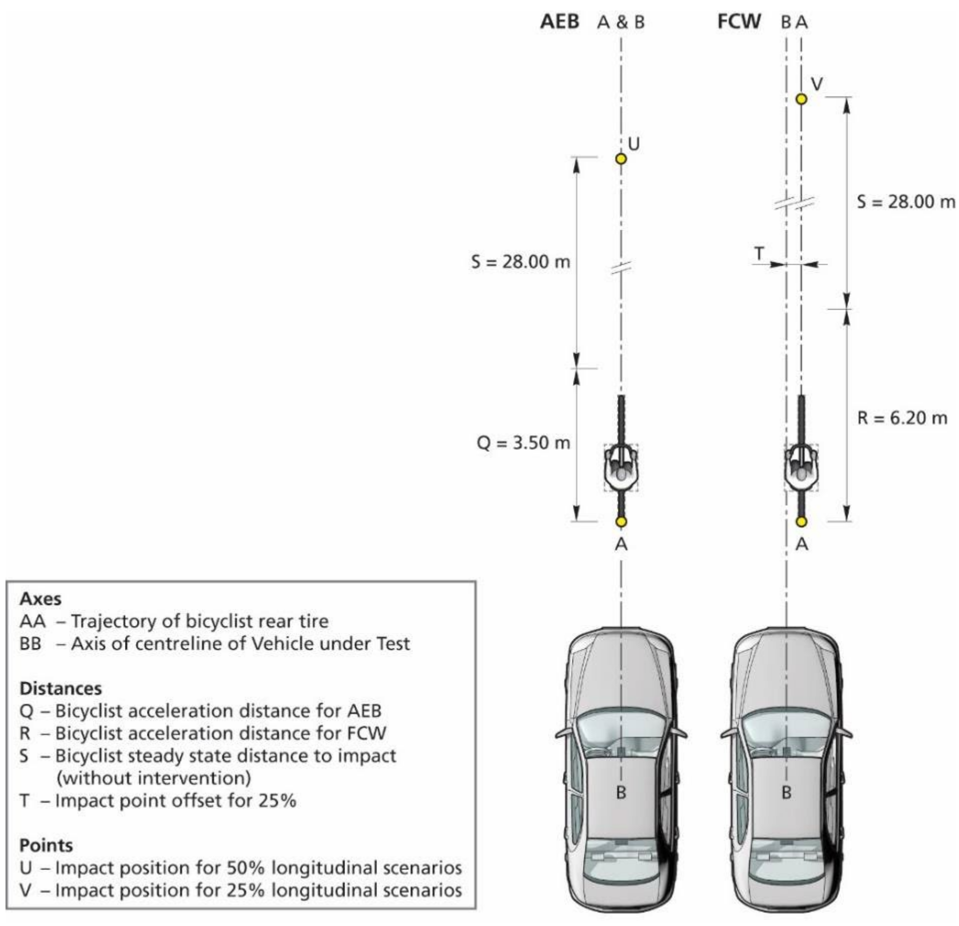

Figure 3. Euro NCAP Car-to-Bicyclist Longitudinal Adult

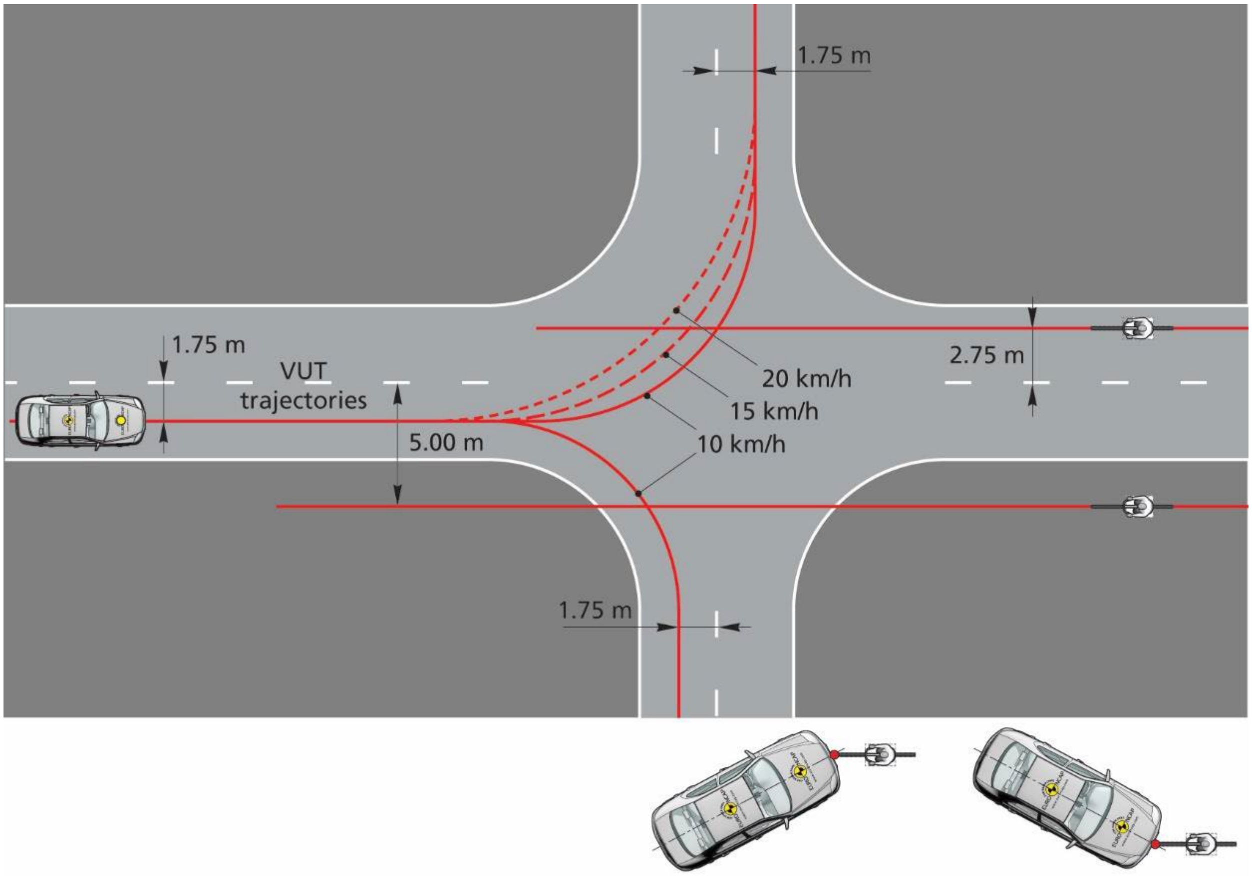

Figure 4. Euro NCAP Car-to-Bicyclist Turning Adult

Additionally, Euro NCAP test scenarios that include a motorcycle as a POV are Car-to-Motorcyclist Rear Stationary (CMRs), Car-to-Motorcyclist Rear Braking (CMRb), Car-to-Motorcyclist Front Turn Across Path (CMFtap), Car-to-Motorcyclist Oncoming (CMoncoming), and Car-to-Motorcyclist Overtaking (CMovertaking). These scenario details for motorcycle tests are found in Table 2.

Table 2. Euro NCAP Motorcycle Scenarios

	CMRs		**CMRb**	**CMFtap**	**CMoncoming**	**CMovertaking**	
Paragraph	7.4.1		7.4.2	7.4.3	7.4.5	7.4.6	
Type of Test	AEB	FCW	AEB/FCW	AEB	LSS	LSS	
VUT Speed [km/h]	10-60	30-60	50	10,15,20	72	50	72
Target Speed [km/h]	0		50	30,45,60	72	60	80
VUT Direction	Forward		Forward	Farside Turn	Forward	Forward	
Impact Location [%]	50		25	50	10	EuroNCAP Motorcycle Target front wheel to VUT rear wheel	
Lighting Condition	Day		Day	Day	Day	Day	

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Execution

The following sections describe the test methods, equipment, and facilities used to conduct this study.

Test Methods

The governing document used for all additional information not specifically mentioned below will be the NHTSA (2015) Crash Imminent Braking Performance Evaluation test procedure, as well as the NHTSA (2019) Draft Blind Spot Intervention System Confirmation Test. For this study, AEB can be defined as a combination of forward collision warning and CIB. Since this work was completed, NHTSA finalized FMVSS No. 127, "Automatic emergency braking for light vehicles," providing a new test procedure for AEB (49 CFR Parts 571, 595, and 596, 2024). Because that standard was under development at the time of this research, the previous CIB test procedure was used.

Crash Imminent Braking Test Procedures

Three scenarios were used to characterize system performance in rear crash scenarios. The scenarios were:

- **Lead Vehicle Stopped** evaluates the ability of the CIB system in the subject vehicle (SV) to detect and respond to a stopped POV immediately in the forward path of the SV.
- **Lead Vehicle Moving** evaluates the ability of the CIB system in the SV to detect and respond to a POV traveling at a constant slower speed immediately in the forward path of the SV.
- **Lead Vehicle Decelerating** evaluates the ability of the CIB system in the SV to detect and respond to a POV initially traveling at the same speed as the SV, but then slowing with a constant deceleration immediately in the forward path of the SV.

In each test, the POV was a passenger vehicle test device (specifically, the GVT), surrogate motorcyclist, or surrogate bicyclist. For each of these scenarios, the SV approached the GVT, motorcycle target, or bicycle target as shown in Figure 5. In addition to the SV centered with the POV, the motorcycle and bicycle POVs were approached at 50 percent and 25 percent offsets from the right edge of the subject vehicle, where 100 percent corresponds to the POV centered with the subject vehicle. These overlaps were selected to represent motorcycle and bicycle behavior, with motorcycles moving typically in the lane, and the 50 percent bicycle overlap aligning with guidance for shared bicycle road markings (National Joint Committee, 2009). Further reference information for the overlaps is shown in Figure 6.

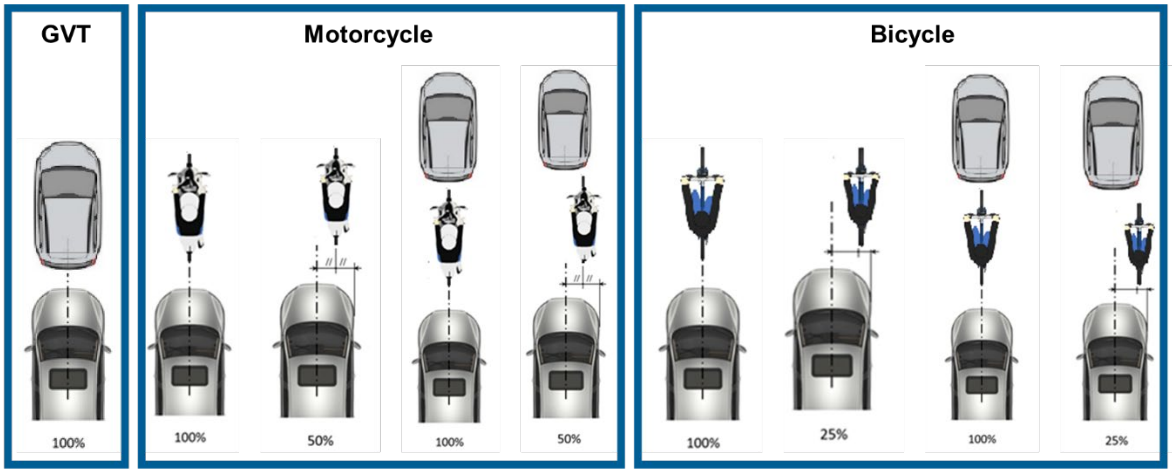


Figure 5. CIB POV Configurations

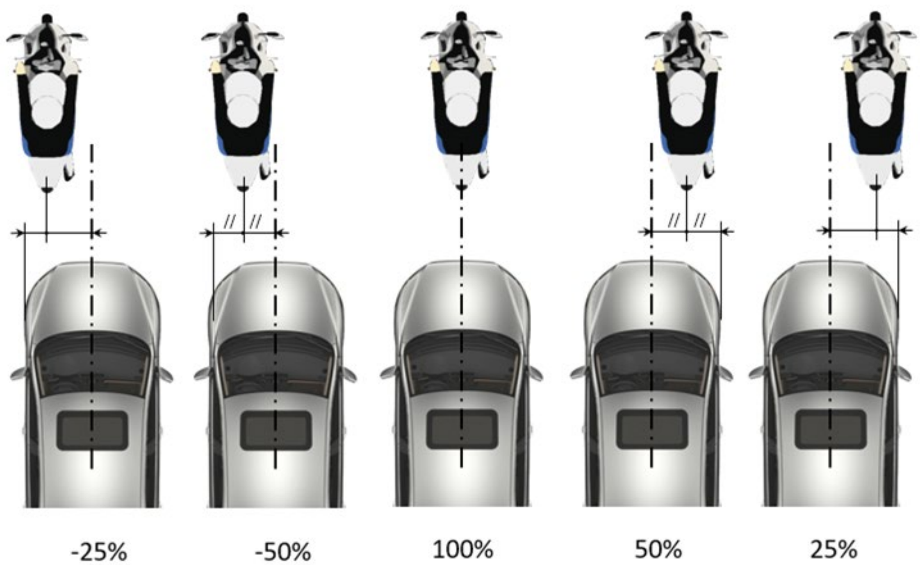


Figure 6. Reference System for POV Target Placement
(Not to Scale: Reference only)

Table 3 through Table 6, below, detail the specifications for each scenario combination performed. Each scenario was selected by starting with the NHTSA CIB test procedure and adjusting for alignment with Euro NCAP procedures, optimization of test runs to answer the research questions, and consistency across tests, specifically comparability with previous procedures involving the GVT. Specifically, these adjustments were incorporated:

- Where a range of test speeds is listed, the first test run was conducted at the lowest listed speed. If the SV did not contact the POV the test was run again with speed increased by the listed step. This aligns with Euro NCAP procedures. However, if the SV did contact the POV subsequent tests were not run. This leads to a maximum number of runs possible in the last column of these tables. Starting speeds were selected to align with Euro NCAP test procedures, and as a result, the maximum number of runs varied across scenarios.

- Euro NCAP uses a range of deceleration rates between 0.2g and 0.6g depending on headway. For simplicity, a deceleration of 0.5g was used consistently for the motorcycle and bicycle surrogates. This deceleration rate is consistent with motorcycle braking dynamics, aligns with previous work by others on cyclist braking (Farniglietti et al., 2020), and informal track testing with a bicycle confirmed that 0.5g is a reasonable maximum braking rate for bicyclists. This was also selected because the smaller robotic platforms available for motorcycle and bicycle surrogates lacked some features (such as ABS) necessary to consistently reach 0.6g.
- When testing was conducted in the dark, conditions were in line with Euro NCAP standards for dark conditions without streetlights, at a measured illuminance of <1 lux. High-beam headlights were used in dark tests. Lights were not used on the motorcycle or bicycle surrogates, although the motorcycle surrogate has reflectors, including a rectangle to approximate a license plate. Only the LVS scenario was chosen to limit the matrix size.
- In the LVM scenario, the motorcycle and bicycle were both travelling at 20 km/h. Euro NCAP uses speeds of 15 or 20 km/h for bicycle testing, but only the upper bound of 20 km/h was evaluated.

Table 3. LVS with Motorcycle

Test Condition	Lighting	POV Target	POV Position	SV Speed (km/h)	POV Speed (km/h)	Maximum Number of Test Runs (at each speed step until collision)
LVS	Daylight	GVT	N/A	10 to 80 km/h; 10 km/h steps; stop after confirmed impact	N/A	8
		Motorcyclist	Centered with SV		0	8
		Motorcyclist 2m behind rear of GVT	Centered with SV		GVT: 0; Motorcycle (MC): 0	8
		Motorcyclist	50% offset from SV		0	8
		Motorcyclist 2m behind rear of GVT	50% offset from SV		GVT: 0; MC: 0	8
	Dark	GVT	Centered with SV	10 to 80 km/h; 10 km/h steps; stop after confirmed impact	0	8
		Motorcyclist	Centered with SV		0	8
		Motorcyclist 2m behind rear of GVT	Centered with SV		GVT: 0; MC: 0	8
		Motorcyclist	50% offset from SV		0	8
		Motorcyclist 2m behind rear of GVT	50% offset from SV		GVT: 0; MC: 0	8

Table 4. LVD and LVM with Motorcycle

Test Condition	Lighting	POV Target	POV Position	SV Speed (km/h)	Headway	POV Speed (km/h)	Maximum Number of Test Runs (at each speed step until collision)
LVD	Daylight	GVT	Centered with SV	50 to 80 km/h; 10 km/h steps; stop after confirmed impact	12 m with 0.5g decel	Same as SV	4
		GVT			40.0 m with 0.5g decel		4
		Motorcyclist	Centered with SV		12 m with 0.5g decel		4
		Motorcyclist			40.0 m with 0.5g decel		4
		Motorcyclist	50% offset from SV		12 m with 0.5g decel		4
		Motorcyclist			40.0 m with 0.5g decel		4
LVM	Daylight	GVT	Centered with SV	60 to 100 km/h; 10 km/h steps; stop after confirmed impact	NA	20	5
		Motorcyclist	Centered with SV		NA	20	5
		Motorcyclist	50% offset from SV		NA	20	5

Table 5. LVS with Bicycle

Test Condition	Lighting	POV Target	POV Position	SV Speed (km/h)	POV Speed (km/h)	Maximum Number of Test Runs (at each speed step until collision)
LVS	Daylight	Bicyclist	Centered with SV	10 to 80 km/h; 10 km/h steps; stop after confirmed impact	0	8
		Bicyclist 2m behind rear of GVT	Centered with SV		GVT: 0; MC: 0	8
		Bicyclist	25% offset from SV		0	8
		Bicyclist 2m behind rear of GVT	25% offset from SV		GVT: 0; MC: 0	8
	Dark	Bicyclist	Centered with SV	10 to 80 km/h; 10 km/h steps; stop after confirmed impact	0	8
		Bicyclist 2m behind rear of GVT	Centered with SV		GVT: 0; MC: 0	8
		Bicyclist	25% offset from SV		0	8
		Bicyclist 2m behind rear of GVT	25% offset from SV		GVT: 0; MC: 0	8

Table 6. LVD and LVM with Bicycle

Test Condition	Lighting	POV Target	POV Position	SV Speed (km/h)	POV Speed (km/h)	Maximum Number of Test Runs (at each speed step until collision)
LVD	Daylight	GVT	Centered with SV	10, 20, 30 km/h; 12 m headway; 0.5g decel; stop after confirmed impact	Same as SV	3
		Bicyclist	Centered with SV			3
		Bicyclist	25% offset from SV			3
LVM	Daylight	GVT	Centered with SV	30 to 80 km/h; 10 km/h steps; stop after confirmed impact	20	6
		Bicyclist	Centered with SV			6
		Bicyclist	25% offset from SV			6

Test Validity

Each test trial must meet the initial validation as outlined in the test methods section of this report. The validity period for each test started at 5.0 seconds of time-to-collision and ended either when the SV came to a speed less than or equal to the POV for 1 second or a collision occurred. Additionally, the following list details other validity requirements for each test run, as specified in the test procedure.

- Yaw rate must not exceed ±1.0 deg/s from the onset of validity until SV has reached 0.25g deceleration.
- Lateral distance of the SV and POV must not vary more than 0.3 m in both lane center and in reference to one another.
- SV driver shall not apply the brake pedal during any portion of the validity period.
- Speeds of both SV and POV shall be within ±1.6 km/h from the specified test speeds.
- The SV driver shall release the throttle pedal within 500 ms after the initial FCW alert.
- The SV brakes shall be kept at an initial brake temperature between 65°C and 100°C.

Blind Spot Intervention Test Procedures

Two scenarios were used to characterize vehicle performance in sideswipe scenarios. The scenarios were:

- **SV Lane Change With Constant Headway Scenario (SVLC_Constant_HW)** evaluates the BSI system's ability to detect and respond to a POV residing in the SV blind spot. For these tests, the POV is driven in a lane adjacent to that of the SV with a constant longitudinal offset from the rear of the SV (a fixed distance measured relative to the SV). During the test, the SV driver engages the turn signal indicator and initiates a manual lane change into the POV's travel lane. For bicycles, this represents a scenario where the bicycle is travelling in an adjacent lane at a low speed and a light vehicle changes lanes in preparation for a turn.
- **SV Lane Change With Closing Headway Scenario (SVLC_Closing_HW)** evaluates the BSI system's ability to detect and respond to a POV approaching the SV blind spot from the rear. For these tests, the POV is driven at a constant speed greater than that of the SV in an adjacent lane. During the test, the SV driver engages the turn signal indicator and initiates a manual lane change into the POV's travel lane.

Figure 7 shows the approach for the sideswipe scenarios.

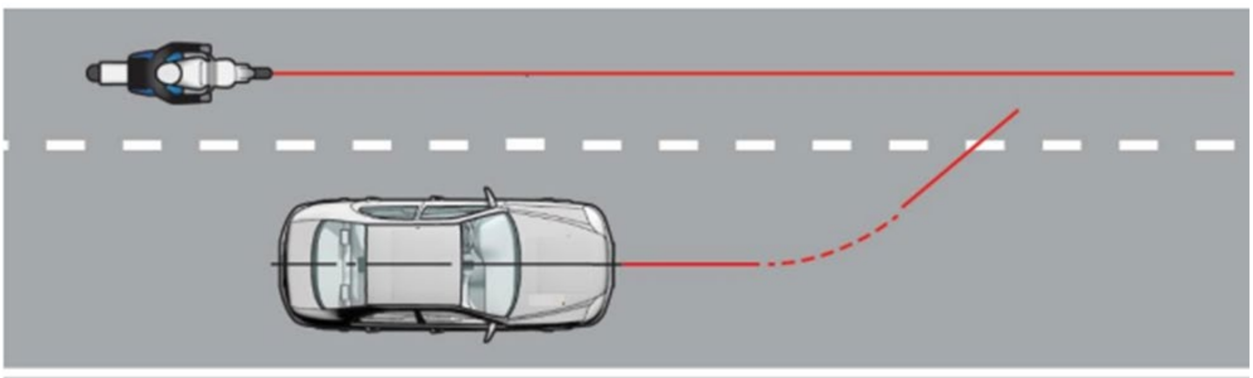


Figure 7. BSI Scenario Approach

Table 7 outlines the vehicle speeds, lighting conditions, positioning, and number of runs for the BSI scenarios.

Table 7. BSI Scenarios

NHTSA Test Procedure	Test Condition	Lighting	Vehicles	Surrogate Position	SV Speed (km/h)	POV Speed (km/h)	Number of Test Runs
BSI Draft	Constant Headway	Daylight	GVT	Adjacent Lane Center	40, 50, 60, 70	Same as SV	4
			Motorcyclist				4
			Bicyclist	Adjacent Lane Center	20, 30, 40	Same as SV	3
BSI Draft	Closing Headway	Daylight	GVT	Adjacent Lane Center	40, 50, 60, 70	80	4
			Motorcyclist				4

In addition to the scenario descriptions above, Table 8 outlines the necessary SV steering parameters to achieve the desired lane change. These parameters were used to program low-profile robotic targets and steering robots to produce the test conditions.

Table 8. SV Steering Parameters

SV Speed (km/h)	SV Angle (degree)	SV Radius (m)	SV Change in Lateral Position (m)	Lateral Velocity to Lane Line (m/s)
40	3.71	248	0.491	0.7
50	2.99	385	0.489	0.7
60	2.51	555	0.490	0.7
70	2.16	765	0.493	0.7

Test Validity

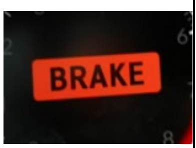
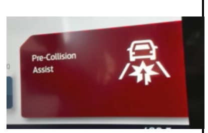
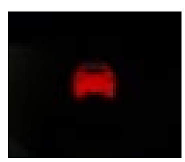
Validation of each test must initially meet the requirements listed in the test methods section of this report. The validity period begins 3 seconds before the SV driver activates the left turn signal indicator until the SV gets within 6 inches of the POV or 3 seconds after the SV has established a heading away from the POV.

Test Vehicle Selection

Using vehicle user manuals and search databases, 37 model year 2021 and 2022 vehicle makes were reviewed to understand their ability to detect 2-wheeled POVs. The Tesla selected for this project was outside of that model year range, but there were no substantive hardware differences and over-the-air software updates made its AEB and BSI systems current at the time of testing. Depending on the vehicle manufacturer and trim level, these systems come as standard or optional equipment. Vehicles of various body types, including trucks, SUVs, sedans, coupes, and compact vehicles, were reported to be capable of 2-wheeled POV detection.

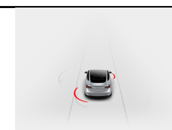
Throughout the review of the vehicle user manuals, maximum CIB and BSI operation speeds were typically noted by the manufacturer, along with descriptions of scenarios where the vehicle should reliably activate the CIB and BSI systems. This project only selected vehicles that specifically noted their AEB systems worked for motorcycles and bicycles; of the 37 vehicles we reviewed, few directly mentioned motorcycle or bicycle detection. For BSI, fewer vehicles noted motorcycle detection and only one noted bicycle detection—motorcycle testing was conducted on vehicles equipped with BSI anyway to characterize systems that did not explicitly call out motorcycles. The selected vehicles are noted in Table 9 and Table 10.

Table 9. CIB Vehicle Selection

Year and Make	**2022 Honda**	**2021 Ford**	**2021 Volvo**	**2022 Lexus**	**2018 Tesla (2022 software)**
Model and Trim	Civic Sport	Bronco	S60	NX 250	Model 3 Dual Motor
Body Style	4-door Sedan	4-door SUV	4-door Sedan	4-door SUV	4-door Sedan
Trade Name	Collision Mitigation Braking System	Pre-Collision Assist	City Safety	Pre-Collision System	Collision Avoidance Assist
Sensors	Camera	Camera	Camera and Radar	Camera and Radar	Camera and Radar (Radar disabled after study)
Sensor Location(s)	Mounted behind windshield near rear view mirror	Mounted behind windshield near rear view mirror	Camera and radar mounted behind windshield near rear view mirror	Camera mounted behind windshield near rear view mirror, radar mounted behind vehicle grille	Camera mounted behind windshield near rear view mirror, radar mounted behind vehicle grille
AEB Alert Icon					
Icon Description	Orange Brake alert across dash	Red flashing Pre-Collision Assist Alert on dash	Orange vehicle flash near top of dash	Red Pre-Collision System in center of the dash (image is from the manual and does not include color)	Vehicle on screen turns red once crash is imminent
Audible Warning	Yes	Yes	Yes	Yes	Yes
Minimum AEB Activation Speed	5 km/h	5 km/h	5 km/h	5 km/h	5 km/h

Maximum AEB Activation Speed	100 km/h	120 km/h	115 km/h	180 km/h	150 km/h

Table 10. BSI Vehicle Selection

Year and Make	**2021 Volvo**	**2022 Lexus**	**2018 Tesla**
Model and Trim	S60	NX 250	Model 3 Dual Motor
Body Style	4-door Sedan	4-door SUV	4-door Sedan
Trade Name	Rear Collision Warning	Lane Tracing Assist	Lane Assist
Sensors	Radar	Radar	Camera
Sensor Location(s)	Left and Right Rear Corner Radar behind the Bumper Cover	Left and Right Rear Corner Radar behind the Bumper Cover	B Pillar Camera
BSI Alert Icon		 Green	
Icon Description	White Front of Vehicle and Hazard Sign in the Center of the Dash	Green Icon showing Vehicle between Dashed Lanes in the Center of the Dash	Vehicle on screen turns red once a potential crash is detected
Stated Motorcycle Capability	No	No	No
Audible Warning	Yes	No	Yes
Minimum BSI Activation Speed	60 km/h	N/A	38 km/h
Maximum BSI Activation Speed	140 km/h	N/A	140 km/h

Test Equipment

The following sections outline the POV targets and data acquisition systems used to conduct this testing.

Principal Other Vehicle

Three different surrogate targets were used as POVs for this testing. For the passenger vehicle test device, the GVT Revision G Soft Car 360 from Dynamic Research, Inc., was used, specifications detailed in Table 11. The Soft Car 360 is shown in Figure 8. The manufacturer states that these devices meet the requirements of ISO 19206-3:2021, and they are also accepted by Euro NCAP.

Table 11. POV Specifications

Target	Vehicle Type	Revision	Length (mm)	Width (mm)	Height (mm)	Weight (kg)
Soft Car 360	Hatchback	G	4023	1712	1427	108

Figure 8. Revision G Soft Car 360

The motorcycle target used was the 4activeMC from the company 4active Systems, shown in Figure 9. At the time of testing, the only available motorcycle surrogate complying with relevant Euro NCAP and ISO standards was the 4activeMC. Motorcycle surrogate specifications can be seen in Table 12; the manufacturer states it complies with ISO 19206-5, and is on the Euro NCAP approved equipment list.

Table 12. Motorcycle POV Specifications

Target	Vehicle Type	Seat Height (mm)	Wheel Base (mm)	Width (mm)	Height (mm)	Weight (kg)
4activeMC	Motorcycle	820	1420	750	1800	15

Figure 9. 4activeMC

The bicycle target, 4activeBS, was also from 4active Systems, shown in Figure 10. At the time of testing, this surrogate was the only available bicycle surrogate on the Euro NCAP approved vendor list. Bicycle specifications can be seen in Table 13; the manufacturer states that the surrogate complies with ISO 19206-4.

Table 13. Bicycle POV Specifications

Target	Vehicle Type	Handlebar Height (mm)	Wheel Base (mm)	Width (mm)	Height (mm)	Weight (kg)
4activeBS	Bicycle	1200	1230	500	1800	10

Figure 10. 4activeBS

To move the POV targets, the Guided Soft Target platform from AB Dynamics was used. The Guided Soft Target is a low-profile robotic platform that allows for accurate path-following control and can also be driven over if intervention of the SV is not sufficient to avoid a collision. The Guided Soft Target specifications are detailed in Table 14 and the platform is shown in Figure 11.

Table 14. Guided Soft Target Specifications

Movement System Model	GST100
Maximum Acceleration	0.22g
Maximum Deceleration	0.8g
Maximum Lateral Acceleration	0.4-0.5g
Length	2950 mm
Width	1680 mm
Height	100 mm
Overall Weight	315 kg
Overrun Capacity	1000 kg per wheel

Figure 11. Guided Soft Target

One challenge discovered during testing was the difficulty of consistently and repeatedly achieving the specified deceleration rate of 0.5g at lower speeds at 10 km/h and 20 km/h. In particular, the 10 km/h test braking distance was only 0.77 m and took 0.55 seconds. Controlling a constant deceleration rate for that short amount of time was very difficult. The GST100 does not have an ABS system, so the condition of consumable parts, such as tires and brakes, directly impacted braking performance at these short-duration, high-deceleration-rate scenarios.

Data Acquisition

The test equipment in Table 15 was used in this study. All test equipment commonly used in ADAS testing meets all requirements specified in the NHTSA CIB and BSI test procedures for range, resolution, and accuracy, given proper calibration tracking and specifications. Motorcycle and bicycle surrogates are specified in the previous section.

Table 15. Data Acquisition System

Test Equipment	Manufacture/Model	Notes
Integrated Inertial Measurements Unit and GPS	OXTS/RT 3003	Main GPS/IMU system that is used for position, speed, yaw rate, and acceleration data
Data Acquisition System	Dewesoft/DEWE43	Collection of all signals from each of the individual data sources
Vehicle-to-Vehicle Range Transmitter	AB Dynamics/ Control Box OR OXTS/ RT Range S	For LVS tests the RT Range S system was used and for LVM and LVD tests the vehicle-to-vehicle data from the AB Dynamics system was used
Thermocouples	Not Specified	K-type thermocouples to monitor brake temperatures at all four tires throughout testing
FCW Data Flag Measurement System	V&A Detection System	Camera and microphone system to capture FCW alerts in real time and act upon them
Thermocouple Reader	Peak Systems/ Thermocouple1 CAN	CAN output of thermocouple data to the data acquisition system
RTK Corrections	Freewave/FGR3-CE-U	Onsite permanent base station providing differentially corrected GPS data
Video Recording via Webcams	Logitech/ Brio	Used to monitor and review scenarios. Dash Facing and Forward Facing cameras
Power Box	TRC/PBSys35	Battery power for all equipment that is independent of vehicle power
Robotic Platform	AB Dynamics/ Guided Soft Target Vehicle	Movement platform for targets
Target Vehicle	DRI Soft Car 360	Latest Revision G used

Test Equipment	Manufacture/Model	Notes
Coordinate Measurement Machine	Faro/Quantum E	Millimeter precision measurements of GPS position, antenna position, and front bumper location
Tire Pressure Gauge	Intercomp/360045	Tire pressures checked each test day
Weight Scales	Mettler Toledo/ B8033	Vehicle corner weights

Test Facility and Weather Conditions

All testing described in this report was conducted at TRC Inc.’s SMARTCenter. For this project specifically, the North Leg of the High-Speed Intersection was used (Figure 12).

Figure 12. SMARTCenter North Leg

This Northern Leg of the High-Speed Intersection has the following characteristics.

- Width allows striping of six 12.5 ft lanes
- 2,000 ft long, with 1,500 ft of white lane markings (striping varies per project)
- All lanes were 11.5 to 12.5 ft wide
- Slope of 0.25 percent
- Free of cracks, bumps, and other irregularities
- Pavement friction coefficient greater than 0.90 (measured by pavement friction sled measuring device)

Additionally, based on both current NHTSA confirmation test procedures (NHTSA, 2015, 2019), the following execution details on weather and facility conditions were used. One adjustment from the procedures was testing occurred below the required 40°F (4.4°C); this change was discussed with NHTSA and conducted due to test schedule considerations. For reference, facility conditions that aligned with NHTSA testing requirements for both CIB and BSI tests are as follows (with the specific change noted with an asterisk due to lower temperature).

- All tests were completed with the following weather conditions: ambient temperature from 32°F (0°C) to 104°F (40°C), maximum wind speed no greater than 22 mph (10 m/s).

- Tests were not performed during inclement weather -- rain, snow, hail, fog, smoke, or ash.
- Daylight tests were conducted during hours when the sun was 15° above the horizon with good atmospheric visibility, defined as an absence of fog and the ability to see clearly for at least 3.1 mi (5.0 km).
- The tests were not conducted with the SV and POV oriented into the sun during very low sun angle conditions (where the sun is 15° or less from horizontal).
- The road test surface was dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road surface was constructed from asphalt or concrete and was free of irregularities, undulations, and/or cracks that could cause the SV to pitch excessively. The road test surface produced a peak friction coefficient of at least 0.9 at a speed of 40 mph without water delivery.
- Each trial was conducted with no other vehicles except the POV, obstructions, or stationary objects within one lane width of either side of the SV lane of travel. The single lane of travel was used for the CIB test and was delineated with two white lane lines (white dashed left of the subject vehicle and white solid right of the subject vehicle). The test lane width was 12 ± 1ft.

Data Summary

The following sections provide summary data for each of the test scenarios performed with the selected test vehicles. There were a total of eight test scenarios, four each for bicycle and motorcycle test targets: LVS daytime, LVS nighttime, LVM, and LVD. Motorcycle target LVD testing was performed at headways of 12 m and 40 m. GVT test results are included in each section for comparison with bicycle and motorcycle targets. All testing was performed without manual brake application (i.e., CIB). A test run refers to a specific test target configuration (e.g., GVT + motorcycle 50%) and subject vehicle speed (e.g., 40 km/h). One test trial was performed for each test run. For each test scenario, three summary tables are provided in each section. The table header descriptions are here.

- **AEB Activation TTC (s)** – TTC in seconds when the SV first reached 5.0 m/s^2 braking, per CIB test procedure definition.
- **FCW Activation TTC (s)** – TTC in seconds when the FCW alert, either visual or audible, first appeared to the driver.
- **Relative Impact Speed (km/h)** – speed difference between SV and POV at time of impact. A speed of 0.00 km/h denotes no impact.

Other relevant descriptions used in the appendix are here.

- **Minimum Distance (m)** – minimum distance between the SV and POV. A distance of 0.00 m denotes impact with the POV.
- **Peak Decel (m/s^2)** – maximum amount of deceleration from the vehicle during the braking event. All acceleration data is filtered with a low-pass 6th-order Butterworth filter with a cutoff corner frequency of 3Hz.
- **POV Speed (km/h)** – initial speed of POV during the test.
- **Speed Reduction (km/h)** – difference between initial SV speed and impact speed. Speed reduction is equal to SV speed if SV brakes to a stop without impact. Calculations depending on the test are described in the NHTSA CIB Test Procedure.
- **SV Speed (km/h)** – initial speed of SV during the test.

In the summary tables, shaded cells with a value indicate that an impact (i.e., contact, collision) occurred. The test procedure states that after an SV impact, no more test runs at higher speeds are to be performed, which are shown as shaded cells without values. In a few cases, it was the judgment of the test engineers to continue testing at the next higher speed; specifically, test engineers continued testing at 20 km/h due to concerns that 10 km/h may have been too low to trigger AEB activation for some systems. These subsequent test runs are included for completeness. Due to performance variations between vehicles and the limited number of vehicles tested, it was generally not possible to identify overall trends from the test results.

CIB LVS

CIB LVS was tested in daytime and nighttime conditions for bicycle and motorcycle targets to evaluate performance differences. The results of bicycle and motorcycle target daytime and nighttime testing are provided in Section 3.

LVS – Bicycle Daytime

For the LVS scenario with bicycle targets in daytime conditions, Table 16 shows the AEB activation TTC, Table 17 shows the FCW activation TTC, and Table 18 shows the relative impact speed. Performance varied between vehicles for the four bicycle target configurations and in relation to the GVT. For the Bronco, impact with the GVT and four bicycle target configurations occurred at the same SV speed of 50 km/h. The FCW activation TTC was earlier, AEB activation TTC was earlier, and the relative impact speed was lower for the GVT than the four bicycle target configurations at 50 km/h. For the Civic, impact with the GVT + bicycle 25 percent configuration occurred at an SV speed of 20 km/h, below the SV speed of 50 km/h where GVT impact occurred. However, impact with the other three bicycle target configurations occurred at SV speeds above 50 km/h, although relative impact speeds varied, ranging from 31 to 46 km/h. Impact occurred at lower SV speeds when the bicycle target was offset 25 percent rather than centered, whether or not the GVT was in front. For the S60, impact with the (centered) bicycle configuration occurred at an SV speed of 70 km/h, which was the SV speed where the impact occurred with the GVT. Impact with the other three bicycle target configurations occurred at SV speeds below 70 km/h. Of the three configurations, impact with the GVT + bicycle 25 percent configuration occurred at the lowest SV speed (40 km/h). For the NX, no impact occurred with the GVT at the maximum SV speed of 80 km/h. Impact with the (centered) bicycle and bicycle 25 percent configurations occurred at an SV speed of 80 km/h, the highest of the vehicles tested. However, impact occurred with the GVT + bicycle and GVT + bicycle 25 percent configurations at lower SV speeds of 40 and 30 km/h, with relative impact speeds of 30 and 29 km/h. For the Model 3, impact with the four bicycle target configurations occurred at SV speeds ranging from 10 to 40 km/h, which was below the SV speed where impact with the GVT occurred (70 km/h) and lower than the majority of other vehicles tested. Impact occurred with the GVT + bicycle configuration at an SV speed of 10 km/h without AEB or FCW activation.

Table 16. Summary of Lead Vehicle Stopped Daytime Bicycle Target Testing AEB Activation TTC (in seconds)

LVS - Daytime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.55	0.38	0.66	0.81	0.76	-	-	-
	Bicycle	0.83	0.80	0.73	0.77	0.71	-	-	-
	Bicycle 25%	0.17	0.74	0.86	0.75	0.72	-	-	-
	GVT + Bicycle	0.70	0.79	0.86	0.74	0.62	-	-	-
	GVT + Bicycle 25%	0.92	0.65	0.79	0.77	0.72	-	-	-
Honda Civic	GVT	0.51	0.42	0.75	0.81	0.83	-	-	-
	Bicycle	0.77	0.77	0.77	0.91	0.97	1.00	1.01	-
	Bicycle 25%	0.92	0.77	0.84	0.85	0.95	0.59	-	-
	GVT + Bicycle	0.64	0.79	0.81	0.88	0.94	1.06	0.62	-
	GVT + Bicycle 25%	0.78	0.00	-	-	-	-	-	-
Volvo S60	GVT	0.42	0.64	0.74	0.91	0.90	0.97	0.96	-
	Bicycle	0.22	0.49	0.72	0.81	0.98	1.02	0.85	-
	Bicycle 25%	0.26	0.56	0.74	0.80	0.92	0.12	-	-
	GVT + Bicycle	0.18	0.48	0.68	0.88	0.93	0.83	-	-
	GVT + Bicycle 25%	0.33	0.54	0.62	0.46	-	-	-	-
Lexus NX	GVT	0.69	0.70	0.85	1.02	1.21	1.26	1.32	1.27
	Bicycle	0.84	0.77	0.82	0.99	1.12	1.15	1.08	1.11
	Bicycle 25%	0.87	0.74	0.67	1.02	1.06	-	1.02	1.04

LVS - Daytime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
	GVT + Bicycle	0.81	0.63	0.79	0.69	-	-	-	-
	GVT + Bicycle 25%	0.00	0.63	0.00	-	-	-	-	-
Tesla Model 3	GVT	0.42	0.54	0.57	0.74	0.90	1.06	1.06	-
	Bicycle	0.63	0.56	0.49	-	-	-	-	-
	Bicycle 25%	0.60	0.48	-	-	-	-	-	-
	GVT + Bicycle	0.00	-	-	-	-	-	-	-
	GVT + Bicycle 25%	0.54	0.37	-	-	-	-	-	-

Table 17. Summary of Lead Vehicle Stopped Daytime Bicycle Target Testing FCW Activation TTC (in seconds)

LVS - Daytime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.64	0.67	1.64	1.86	2.04	-	-	-
	Bicycle	0.90	1.05	1.27	1.53	1.69	-	-	-
	Bicycle 25%	0.71	0.95	1.38	1.51	1.80	-	-	-
	GVT + Bicycle	0.68	0.91	1.00	1.36	1.62	-	-	-
	GVT + Bicycle 25%	0.87	0.77	1.01	1.41	1.67	-	-	-
Honda Civic	GVT	1.20	1.51	1.86	2.23	2.38	-	-	-
	Bicycle	1.37	1.41	1.23	1.48	1.75	1.84	1.85	-
	Bicycle 25%	0.86	1.31	1.52	1.67	1.77	1.98	-	-
	GVT + Bicycle	1.25	1.31	1.43	1.66	1.91	1.78	1.62	-
	GVT + Bicycle 25%	1.28	0.00	-	-	-	-	-	-
Volvo S60	GVT	1.03	1.49	1.92	2.10	2.35	2.80	2.96	-
	Bicycle	1.17	1.30	1.83	2.10	2.15	1.97	1.35	-
	Bicycle 25%	1.26	1.61	1.87	2.08	2.31	1.57	-	-
	GVT + Bicycle	1.17	1.17	1.48	1.83	2.26	2.22	-	-
	GVT + Bicycle 25%	1.32	1.23	1.76	1.77	-	-	-	-
Lexus NX	GVT	1.95	2.00	2.12	2.29	2.39	2.45	2.62	2.73
	Bicycle	2.03	2.02	2.14	2.24	2.26	2.35	2.31	2.36
	Bicycle 25%	1.96	2.02	2.14	2.12	2.34	2.36	2.29	2.35
	GVT + Bicycle	1.87	1.94	2.04	1.80	-	-	-	-
	GVT + Bicycle 25%	1.95	1.96	1.76	-	-	-	-	-
Tesla Model 3	GVT	1.29	1.61	2.27	2.63	3.11	3.03	2.85	-
	Bicycle	1.34	1.62	2.00	2.03	-	-	-	-
	Bicycle 25%	1.39	1.59	1.89	-	-	-	-	-
	GVT + Bicycle	0.00	-	-	-	-	-	-	-
	GVT + Bicycle 25%	1.30	1.41	1.99	-	-	-	-	-

Table 18. Summary of Lead Vehicle Stopped Daytime Bicycle Target Testing Relative Impact Speed (in km/h)

LVS - Daytime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.00	0.00	0.00	0.00	9.94	-	-	-
	Bicycle	0.00	0.00	0.00	0.00	15.84	-	-	-
	Bicycle 25%	0.00	0.00	0.00	0.00	16.92	-	-	-
	GVT + Bicycle	0.00	0.00	0.00	0.00	23.08	-	-	-
	GVT + Bicycle 25%	0.00	0.00	0.00	0.00	15.26	-	-	-
Honda Civic	GVT	0.00	0.00	0.00	0.00	2.38	-	-	-
	Bicycle	0.00	0.00	0.00	0.00	0.00	0.00	31.43	-
	Bicycle 25%	0.00	0.00	0.00	0.00	0.00	35.06	-	-
	GVT + Bicycle	0.00	0.00	0.00	0.00	0.00	0.00	45.72	-
	GVT + Bicycle 25%	0.00	19.87	-	-	-	-	-	-
Volvo S60	GVT	0.00	0.00	0.00	0.00	0.00	0.00	17.86	-
	Bicycle	0.00	0.00	0.00	0.00	0.00	0.00	27.54	-
	Bicycle 25%	0.00	0.00	0.00	0.00	0.00	50.54	-	-
	GVT + Bicycle	0.00	0.00	0.00	0.00	0.00	14.83	-	-
	GVT + Bicycle 25%	0.00	0.00	0.00	17.53	-	-	-	-
Lexus NX	GVT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bicycle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.46
	Bicycle 25%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.36
	GVT + Bicycle	0.00	0.00	0.00	29.63	-	-	-	-
	GVT + Bicycle 25%	0.00	0.00	29.05	-	-	-	-	-
Tesla Model 3	GVT	0.00	0.00	0.00	0.00	0.00	0.00	20.20	-
	Bicycle	0.00	0.00	0.00	32.44	-	-	-	-
	Bicycle 25%	0.00	0.00	10.12	-	-	-	-	-
	GVT + Bicycle	10.08	-	-	-	-	-	-	-
	GVT + Bicycle 25%	0.00	0.00	9.86	-	-	-	-	-

LVS – Bicycle Nighttime

For the LVS scenario with bicycle targets in nighttime conditions, Table 19 shows the AEB activation TTC, Table 20 shows the FCW activation TTC, and Table 21 shows the relative impact speed. Performance varied between vehicles for the four bicycle target configurations and in relation to the GVT, similar to daytime conditions. For the Bronco, impact with the GVT and four bicycle target configurations occurred at lower SV speeds than daytime conditions (50 km/h). Impact with the GVT + bicycle configuration occurred at an SV speed of 20 km/h and impact with the bicycle 25 percent and GVT + bicycle 25 percent configurations occurred at an SV speed of 10 km/h. For these three bicycle target configurations, AEB did not activate and FCW activated with a TTC under one second (0.35 to 0.62). For the Civic, impact with the GVT occurred at an SV speed of 10 km/h, which was lower than daytime conditions (50 km/h), with no AEB activation and an FCW activation of 1.06 seconds. Impact with the four bicycle target configurations occurred at a higher SV speed of 60 km/h. For the GVT + bicycle 25 percent configuration, the SV speed where impact occurred was higher in nighttime conditions (60 km/h) than daytime conditions (20 km/h). For the S60, SV speeds where impact occurred with the GVT and four bicycle target configurations were lower in nighttime conditions. Impact with the bicycle 25 percent, GVT + bicycle, and GVT + bicycle 25 percent configurations occurred at 20 km/h, 20 km/h, and 10 km/h, without AEB activations. For the NX, no impact occurred with the GVT at an SV speed of 80 km/h, similar to daytime conditions. Impact with the (centered) bicycle and bicycle 25 percent configurations occurred at 80 km/h, similar to daytime conditions, with higher relative impact speeds. Impact with the GVT + bicycle and GVT + bicycle 25 percent configurations occurred at 60 km/h, which was higher than daytime conditions (40 km/h and 30 km/h). For the Model 3, impact with the GVT and GVT + bicycle configurations occurred at SV speeds that were the higher than daytime conditions. Impact with the (centered) bicycle and GVT + bicycle 25 percent configurations occurred at SV speeds that were the same as daytime conditions. Impact with the bicycle 25 percent configuration occurred at 10 km/h, which was lower than daytime conditions (30 km/h), with no AEB activation and FCW activation TTC of 1.27 seconds.

Table 19. Summary of Lead Vehicle Stopped Nighttime Bicycle Target Testing AEB Activation TTC (in seconds)

LVS – Nighttime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.32	0.35	0.51	0.00	-	-	-	-
	Bicycle	0.24	0.33	0.63	0.58	-	-	-	-
	Bicycle 25%	0.00	-	-	-	-	-	-	-
	GVT + Bicycle	0.60	0.00	-	-	-	-	-	-
	GVT + Bicycle 25%	0.00	-	-	-	-	-	-	-
Honda Civic	GVT	0.00	-	-	-	-	-	-	-
	Bicycle	0.82	0.83	0.77	0.95	1.06	0.79	-	-
	Bicycle 25%	0.35	0.59	0.82	0.97	0.92	0.00	-	-
	GVT + Bicycle	0.36	0.78	0.80	0.91	0.89	0.49	-	-
	GVT + Bicycle 25%	0.61	0.81	0.63	0.93	0.93	0.51	-	-
Volvo S60	GVT	0.41	0.56	0.00	-	-	-	-	-
	Bicycle	0.20	0.47	0.66	0.77	0.00	-	-	-
	Bicycle 25%	0.24	0.00	-	-	-	-	-	-
	GVT + Bicycle	0.16	0.00	-	-	-	-	-	-
	GVT + Bicycle 25%	0.00	-	-	-	-	-	-	-
Lexus NX	GVT	0.80	0.72	0.82	1.00	1.18	1.27	1.25	1.25
	Bicycle	0.71	0.66	0.82	0.98	1.12	1.15	1.16	0.46
	Bicycle 25%	0.86	0.71	0.75	0.97	1.01	1.02	0.96	0.92
	GVT + Bicycle	0.75	0.72	0.67	1.01	1.07	0.87	-	-
	GVT + Bicycle 25%	0.83	0.69	0.72	1.00	0.98	0.00	-	-
Tesla Model 3	GVT	0.44	0.54	0.58	0.74	0.89	1.07	1.02	1.03
	Bicycle	0.52	0.53	0.44	0.42	-	-	-	-
	Bicycle 25%	0.00	-	-	-	-	-	-	-
	GVT + Bicycle	0.51	0.55	0.00	-	-	-	-	-
	GVT + Bicycle 25%	0.58	0.49	0.35	-	-	-	-	-

Table 20. Summary of Lead Vehicle Stopped Nighttime Bicycle Target Testing FCW Activation TTC (in seconds)

LVS – Nighttime		**10 km/h**	**20 km/h**	**30 km/h**	**40 km/h**	**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	0.71	0.63	1.41	0.00	-	-	-	-
	Bicycle	0.55	0.64	1.20	1.34	-	-	-	-
	Bicycle 25%	0.50	-	-	-	-	-	-	-
	GVT + Bicycle	0.76	0.62	-	-	-	-	-	-
	GVT + Bicycle 25%	0.35	-	-	-	-	-	-	-
Honda Civic	GVT	1.06	-	-	-	-	-	-	-
	Bicycle	1.14	1.39	1.42	1.64	1.67	1.47	-	-
	Bicycle 25%	1.21	1.44	1.81	1.69	2.14	1.28	-	-
	GVT + Bicycle	1.06	1.07	1.08	1.23	0.89	1.04	-	-
	GVT + Bicycle 25%	1.50	1.36	1.51	2.03	2.28	2.34	-	-
Volvo S60	GVT	1.27	1.19	0.00	-	-	-	-	-
	Bicycle	1.15	0.51	1.73	1.34	2.21	-	-	-
	Bicycle 25%	1.22	1.17	-	-	-	-	-	-
	GVT + Bicycle	1.15	0.87	-	-	-	-	-	-
	GVT + Bicycle 25%	1.23	-	-	-	-	-	-	-
Lexus NX	GVT	1.84	1.99	2.18	2.25	2.42	2.42	2.67	2.55
	Bicycle	1.60	1.93	2.11	2.19	2.31	2.31	2.33	0.95
	Bicycle 25%	1.97	1.97	2.10	2.13	2.28	2.28	2.35	1.48
	GVT + Bicycle	1.85	1.98	2.13	2.06	1.60	2.22	-	-
	GVT + Bicycle 25%	1.88	1.99	2.12	1.95	1.37	1.65	-	-
Tesla Model 3	GVT	1.22	1.55	2.16	2.56	2.98	2.94	2.96	2.88
	Bicycle	1.30	1.61	2.06	2.34	-	-	-	-
	Bicycle 25%	1.27	-	-	-	-	-	-	-
	GVT + Bicycle	1.31	0.79	1.19	-	-	-	-	-
	GVT + Bicycle 25%	1.35	1.54	1.71	-	-	-	-	-

Table 21. Summary of Lead Vehicle Stopped Nighttime Bicycle Target Testing Relative Impact Speed (in km/h)

LVS – Nighttime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.00	0.00	0.00	39.49	-	-	-	-
	Bicycle	0.00	0.00	0.00	8.21	-	-	-	-
	Bicycle 25%	8.82	-	-	-	-	-	-	-
	GVT + Bicycle	0.00	18.43	-	-	-	-	-	-
	GVT + Bicycle 25%	9.36	-	-	-	-	-	-	-
Honda Civic	GVT	9.76	-	-	-	-	-	-	-
	Bicycle	0.00	0.00	0.00	0.00	0.00	22.61	-	-
	Bicycle 25%	0.00	0.00	0.00	0.00	0.00	58.39	-	-
	GVT + Bicycle	0.00	0.00	0.00	0.00	0.00	39.02	-	-
	GVT + Bicycle 25%	0.00	0.00	0.00	0.00	0.00	39.10	-	-
Volvo S60	GVT	0.00	0.00	29.05	-	-	-	-	-
	Bicycle	0.00	0.00	0.00	0.00	48.10	-	-	-
	Bicycle 25%	0.00	18.90	-	-	-	-	-	-
	GVT + Bicycle	0.00	17.35	-	-	-	-	-	-
	GVT + Bicycle 25%	10.62	-	-	-	-	-	-	-
Lexus NX	GVT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bicycle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.42
	Bicycle 25%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.27
	GVT + Bicycle	0.00	0.00	0.00	0.00	0.00	46.55	-	-
	GVT + Bicycle 25%	0.00	0.00	0.00	0.00	0.00	57.64	-	-
Tesla Model 3	GVT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.37
	Bicycle	0.00	0.00	0.00	17.06	-	-	-	-
	Bicycle 25%	9.47	-	-	-	-	-	-	-
	GVT + Bicycle	0.00	0.00	25.74	-	-	-	-	-
	GVT + Bicycle 25%	0.00	0.00	10.80	-	-	-	-	-

LVS – Motorcycle Daytime

For the LVS scenario with motorcycle targets in daytime conditions, Table 22 shows the AEB activation TTC, Table 23 shows the FCW activation TTC, and Table 24 shows the relative impact speed. Performance varied between vehicles for the four motorcycle target configurations and in relation to the GVT. For the Bronco, impact with the motorcycle 50 percent and GVT + motorcycle 50 percent configurations occurred at an SV speed of 50 km/h, which was the SV speed where impact occurred with the GVT. Impact with the (centered) motorcycle and GVT + motorcycle configurations occurred at a lower SV speed of 40 km/h, with relative impact speeds of 25.56 and 14.87 km/h. The Bronco impacted the GVT + motorcycle configuration at an SV speed of 10 km/h without AEB or FCW activation, however, the judgement of the test engineers was to continue testing at the next higher speed. For the Civic, impact with the (centered) motorcycle, motorcycle 50 percent, and GVT + motorcycle configurations occurred at SV speeds above 50 km/h, the SV speed where impact occurred with the GVT. The GVT + motorcycle 50 percent was the only configuration where impact occurred at a lower SV speed (40 km/h) than the GVT. For the S60, impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at SV speeds of 60 and 70 km/h, which were similar to the GVT (70 km/h). However, impact with the GVT + motorcycle and GVT + motorcycle 50 percent configurations occurred at a lower SV speed of 10 km/h, without AEB activation. For the NX, impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at an SV speed of 80 km/h, the highest of the vehicles tested. However, impact with the GVT + motorcycle and GVT + motorcycle 50 percent configurations occurred at a lower SV speed of 20 km/h, without AEB activation. For the Model 3, impact with the four motorcycle target configurations occurred at SV speeds ranging from 10 to 30 km/h, which was below the SV speed where impact with the GVT occurred (70 km/h). Impact with the GVT + motorcycle 50 percent configuration at a SV speed of 10 km/h occurred without AEB activation.

Table 22. Summary of Lead Vehicle Stopped Daytime Motorcycle Target Testing AEB Activation TTC (in seconds)

LVS – Daytime		**10 km/h**	**20 km/h**	**30 km/h**	**40 km/h**	**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	0.55	0.38	0.66	0.81	0.76	-	-	-
	Motorcycle	0.86	0.76	0.74	0.33	-	-	-	-
	Motorcycle 50%	0.73	0.76	0.72	0.74	0.69	-	-	-
	GVT + Motorcycle	0.00	0.78	0.65	0.74	-	-	-	-
	GVT + Motorcycle 50%	0.83	0.81	0.70	0.69	0.67	-	-	-
Honda Civic	GVT	0.51	0.42	0.75	0.81	0.83	-	-	-
	Motorcycle	0.85	0.85	0.85	1.00	0.98	0.98	0.96	-
	Motorcycle 50%	0.78	0.85	0.88	0.96	1.07	1.07	1.09	-
	GVT + Motorcycle	0.87	0.86	0.69	0.90	1.01	0.92	-	-
	GVT + Motorcycle 50%	0.62	0.65	0.76	0.06	-	-	-	-
Volvo S60	GVT	0.42	0.64	0.74	0.91	0.90	0.97	0.96	-
	Motorcycle	0.24	0.52	0.72	0.72	1.03	0.83	-	-
	Motorcycle 50%	0.22	0.48	0.68	0.93	0.94	0.87	0.47	-
	GVT + Motorcycle	0.00	-	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.00	-	-	-	-	-	-	-
Lexus NX	GVT	0.69	0.70	0.85	1.02	1.21	1.26	1.32	1.27
	Motorcycle	0.90	0.64	0.83	1.04	1.12	1.12	1.16	1.14
	Motorcycle 50%	0.77	0.71	0.81	0.99	1.01	1.05	1.03	1.07
	GVT + Motorcycle	0.84	0.00	-	-	-	-	-	-
	GVT + Motorcyle 50%	0.00	0.00	-	-	-	-	-	-
Tesla Model 3	GVT	0.42	0.54	0.57	0.74	0.90	1.06	1.06	-
	Motorcycle	0.46	0.18	-	-	-	-	-	-
	Motorcycle 50%	0.34	0.10	-	-	-	-	-	-
	GVT + Motorcycle	0.53	0.53	0.00	-	-	-	-	-
	GVT + Motorcycle 50%	0.00	-	-	-	-	-	-	-

Table 23. Summary of Lead Vehicle Stopped Daytime Motorcycle Target Testing FCW Activation TTC (in seconds)

LVS – Daytime		**10 km/h**	**20 km/h**	**30 km/h**	**40 km/h**	**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	0.64	0.67	1.64	1.86	2.04	-	-	-
	Motorcycle	0.83	0.95	1.21	1.75	-	-	-	-
	Motorcycle 50%	0.80	1.01	1.23	1.44	1.67	-	-	-
	GVT + Motorcycle	0.00	1.00	1.11	1.75	-	-	-	-
	GVT + Motorcycle 50%	0.76	0.88	1.07	1.39	1.73	-	-	-
Honda Civic	GVT	1.20	1.51	1.86	2.23	2.38	-	-	-
	Motorcycle	1.40	1.47	1.66	1.20	1.72	1.86	1.86	-
	Motorcycle 50%	1.34	1.38	1.40	1.71	1.77	1.85	1.88	-
	GVT + Motorcycle	1.27	1.43	1.27	1.58	1.61	1.18	-	-
	GVT + Motorcycle 50%	1.05	3.85	1.39	1.34	-	-		-
Volvo S60	GVT	1.03	1.49	1.92	2.10	2.35	2.80	2.96	-
	Motorcycle	1.23	1.63	1.81	1.58	1.23	1.00	-	-
	Motorcycle 50%	1.17	1.46	1.82	2.09	2.32	1.75	0.54	-
	GVT + Motorcycle	0.45	-	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.00	-	-	-	-	-	-	-
Lexus NX	GVT	1.95	2.00	2.12	2.29	2.39	2.45	2.62	2.73
	Motorcycle	2.05	2.00	2.16	2.19	2.25	2.30	2.33	2.34
	Motorcycle 50%	1.85	1.93	2.12	2.05	2.12	1.77	2.36	2.34
	GVT + Motorcycle	3.29	1.22	-	-	-	-	-	-
	GVT + Motorcycle 50%	1.97	1.28	-	-	-	-	-	-
Tesla Model 3	GVT	1.29	1.61	2.27	2.63	3.11	3.03	2.85	-
	Motorcycle	1.15	1.53	-	-	-	-	-	-
	Motorcycle 50%	1.22	1.56	-	-	-	-	-	-
	GVT + Motorcycle	1.42	0.75	1.64	-	-	-	-	-
	GVT + Motorcycle 50%	0.99	-	-	-	-	-	-	-

Table 24. Summary of Lead Vehicle Stopped Daytime Motorcycle Target Testing Relative Impact Speed (in km/h)

LVS – Daytime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.00	0.00	0.00	0.00	9.94	-	-	-
	Motorcycle	0.00	0.00	0.00	25.56	-	-	-	-
	Motorcycle 50%	0.00	0.00	0.00	0.00	19.80	-	-	-
	GVT + Motorcycle	9.46	0.00	0.00	14.87	-	-	-	-
	GVT + Motorcycle 50%	0.00	0.00	0.00	0.00	18.65	-	-	-
Honda Civic	GVT	0.00	0.00	0.00	0.00	2.38	-	-	-
	Motorcycle	0.00	0.00	0.00	0.00	0.00	0.00	34.74	-
	Motorcycle 50%	0.00	0.00	0.00	0.00	0.00	0.00	25.85	-
	GVT + Motorcycle	0.00	0.00	0.00	0.00	0.00	11.66	-	-
	GVT + Motorcycle 50%	0.00	0.00	0.00	36.54	-	-	-	-
Volvo S60	GVT	0.00	0.00	0.00	0.00	0.00	0.00	17.86	-
	Motorcycle	0.00	0.00	0.00	0.00	0.00	16.70	-	-
	Motorcycle 50%	0.00	0.00	0.00	0.00	0.00	0.00	51.77	-
	GVT + Motorcycle	10.22	-	-	-	-	-	-	-
	GVT + Motorcycle 50%	10.84	-	-	-	-	-	-	-
Lexus NX	GVT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Motorcycle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.74
	Motorcycle 50%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.27
	GVT + Motorcycle	0.00	18.32	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.00	18.68	-	-	-	-	-	-
Tesla Model 3	GVT	0.00	0.00	0.00	0.00	0.00	0.00	20.20	-
	Motorcycle	0.00	13.25	-	-	-	-	-	-
	Motorcycle 50%	0.00	15.08	-	-	-	-	-	-
	GVT + Motorcycle	0.00	0.00	25.96	-	-	-	-	-
	GVT + Motorcycle 50%	10.08	-	-	-	-	-	-	-

LVS – Motorcycle Nighttime

For the LVS scenario with motorcycle target in nighttime conditions, Table 25 shows the AEB activation TTC, Table 26 shows the FCW activation TTC, and Table 27 shows the relative impact speed. Performance varied between vehicles for the four motorcycle target configurations and in relation to the GVT, similar to daytime conditions. For the Bronco, impact with the (centered) motorcycle configuration occurred at 50 km/h, which was higher than the SV speed where impact occurred with the GVT (40 km/h). Impact with the motorcycle 50 percent, GVT + motorcycle, and GVT + motorcycle 50 percent configurations occurred at SV speeds ranging from 10 km/h to 30 km/h. Impact with the GVT + motorcycle configuration at an SV speed of 10 km/h occurred without AEB or FCW activation. For the Civic, impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at an SV speed of 60 km/h, which was higher than the SV speed where impact occurred with the GVT (10 km/h). Impact with the GVT + motorcycle and GVT + motorcycle 50 percent configurations occurred at SV speeds of 20 and 40 km/h, with relative impacts speeds of 19.40 and 37.44 km/h. For the S60, impact with GVT, (centered) motorcycle, and motorcycle 50 percent configurations occurred at SV speeds ranging from 30 to 40 km/h, which were lower than daytime conditions (60 to 70 km/h). However, impact with the GVT + motorcycle and GVT + motorcycle 50 percent configurations occurred at an SV speed of 20 km/h, which was higher than daytime conditions (10 km/h). For the NX, impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at 80 km/h, similar to daytime conditions, with higher relative impact speeds. Impact with the GVT + motorcycle and GVT + motorcycle 50 percent configurations occurred at 50 km/h, which was higher than daytime conditions (20 km/h). For the Model 3, impact with the GVT, (centered) motorcycle, GVT + motorcycle, and GVT + motorcycle 50 percent configurations occurred at SV speeds that were higher than daytime conditions. Impact with the motorcycle 50 percent configuration occurred at an SV speed of 20 km/h, which was the same as daytime conditions.

Table 25. Summary of Lead Vehicle Stopped Nighttime Motorcycle Target Testing AEB Activation TTC (in seconds)

LVS – Nighttime		**10 km/h**	**20 km/h**	**30 km/h**	**40 km/h**	**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	0.32	0.35	0.51	0.00	-	-	-	-
	Motorcycle	0.73	0.67	0.58	0.67	0.00	-	-	-
	Motorcycle 50%	0.69	0.62	0.00	-	-	-	-	-
	GVT + Motorcycle	0.00	-	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.69	0.00	-	-	-	-	-	-
Honda Civic	GVT	0.00	-	-	-	-	-	-	-
	Motorcycle	0.72	0.64	0.84	0.91	0.89	0.93	-	-
	Motorcycle 50%	0.96	0.53	0.85	1.00	1.02	0.71	-	-
	GVT + Motorcycle	0.59	0.00	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.68	0.74	0.66	0.00	-	-	-	-
Volvo S60	GVT	0.41	0.56	0.00	-	-	-	-	-
	Motorcycle	0.28	0.55	0.66	-	-	-	-	-
	Motorcycle 50%	0.20	0.48	0.65	0.32	-	-	-	-
	GVT + Motorcycle	0.24	0.20	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.24	0.00	-	-	-	-	-	-
Lexus NX	GVT	0.80	0.72	0.82	1.00	1.18	1.27	1.25	1.25
	Motorcycle	0.84	0.71	0.79	1.03	1.12	1.13	1.08	0.46
	Motorcycle 50%	0.77	0.70	0.87	1.02	1.10	1.06	1.10	1.01
	GVT + Motorcycle	0.91	0.70	0.76	1.01	0.31	-	-	-
	GVT + Motorcycle 50%	0.76	0.66	0.63	1.04	0.23	-	-	-
Tesla Model 3	GVT	0.44	0.54	0.58	0.74	0.89	1.07	1.02	1.03
	Motorcycle	0.59	0.37	0.55	0.69	0.88	0.90	0.93	-
	Motorcycle 50%	0.17	0.00	-	-	-	-	-	-
	GVT + Motorcycle	0.53	0.61	0.61	0.00	-	-	-	-
	GVT + Motorcycle 50%	0.42	0.00	-	-	-	-	-	-

Table 26. Summary of Lead Vehicle Stopped Nighttime Motorcycle Target Testing FCW Activation TTC (in seconds)

LVS – Nighttime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.71	0.63	1.41	0.00	-	-	-	-
	Motorcycle	0.85	0.94	0.91	1.46	0.00	-	-	-
	Motorcycle 50%	0.81	0.90	0.33	-	-	-	-	
	GVT + Motorcycle	0.00	-	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.86	0.18	-	-	-	-	-	-
Honda Civic	GVT	1.06	-	-	-	-	-	-	-
	Motorcycle	1.09	1.28	1.63	1.47	1.50	1.54	-	-
	Motorcycle 50%	1.37	1.33	1.54	1.81	1.39	1.14	-	-
	GVT + Motorcycle	1.07	0.09	-	-	-	-	-	-
	GVT + Motorcycle 50%	1.12	1.28	1.11	-	-	-	-	-
Volvo S60	GVT	1.27	1.19	0.00	-	-	-	-	-
	Motorcycle	1.14	0.64	1.80	-	-	-	-	-
	Motorcycle 50%	1.09	1.41	0.80	0.43	-	-	-	-
	GVT + Motorcycle	1.14	0.13	-	-	-	-	-	-
	GVT + Motorcycle 50%	1.15	0.00	-	-	-	-	-	-
Lexus NX	GVT	1.84	1.99	2.18	2.25	2.42	2.42	2.67	2.55
	Motorcycle	1.88	1.95	2.07	2.12	2.24	2.24	2.18	1.01
	Motorcycle 50%	1.87	2.02	2.17	2.21	2.32	2.32	1.81	1.59
	GVT + Motorcycle	2.00	2.10	1.88	2.13	2.22	-	-	-
	GVT + Motorcycle 50%	1.87	2.04	2.17	2.17	2.25	-	-	-
Tesla Model 3	GVT	1.22	1.55	2.16	2.56	2.98	2.94	2.96	2.88
	Motorcycle	1.12	1.46	2.08	2.34	2.73	2.32	2.56	
	Motorcycle 50%	1.11	1.33	-	-	-	-	-	
	GVT + Motorcycle	1.31	1.41	1.41	1.92	-	-	-	
	GVT + Motorcycle 50%	1.17	1.40	-	-	-	-	-	-

Table 27. Summary of Lead Vehicle Stopped Nighttime Motorcycle Target Testing Relative Impact Speed (in km/h)

LVS – Nighttime		10 km/h	20 km/h	30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.00	0.00	0.00	39.49	-	-	-	-
	Motorcycle	0.00	0.00	0.00	0.00	49.28	-	-	-
	Motorcycle 50%	0.00	0.00	27.72	-	-	-	-	-
	GVT + Motorcycle	9.43	-	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.00	18.54	-	-	-	-	-	-
Honda Civic	GVT	9.76	-	-	-	-	-	-	-
	Motorcycle	0.00	0.00	0.00	0.00	0.00	7.34	-	-
	Motorcycle 50%	0.00	0.00	0.00	0.00	0.00	27.11	-	-
	GVT + Motorcycle	0.00	19.40	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.00	0.00	0.00	37.44	-	-	-	-
Volvo S60	GVT	0.00	0.00	29.05	-	-	-	-	-
	Motorcycle	0.00	0.00	8.21	-	-	-	-	-
	Motorcycle 50%	0.00	0.00	0.00	12.60	-	-	-	-
	GVT + Motorcycle	0.00	14.83	-	-	-	-	-	-
	GVT + Motorcycle 50%	0.00	19.19	-	-	-	-	-	-
Lexus NX	GVT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Motorcycle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	62.14
	Motorcycle 50%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.15
	GVT + Motorcycle	0.00	0.00	0.00	0.00	34.99	-	-	-
	GVT + Motorcycle 50%	0.00	0.00	0.00	0.00	38.41	-	-	-
Tesla Model 3	GVT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.37
	Motorcycle	0.00	0.00	0.00	0.00	0.00	0.00	20.63	-
	Motorcycle 50%	0.00	17.17	-	-	-	-	-	-
	GVT + Motorcycle	0.00	0.00	0.00	32.76	-	-	-	-
	GVT + Motorcycle 50%	0.00	17.14	-	-	-	-	-	-

CIB LVM

CIB LVM was tested in daytime conditions for bicycle and motorcycle targets and the results are provided in Section 3. LVM testing of bicycle target configurations was conducted with an SV speed range of 30 to 80 km/h. LVM testing of motorcycle target configurations was conducted with an SV speed range of 50 to 100 km/h. For all LVM testing, the POV (e.g., GVT, bicycle and motorcycle target configurations) speed was 20 km/h.

LVM Bicycle

For the LVM scenario with bicycle target in daytime conditions, Table 28 shows the AEB activation TTC, Table 29 shows the FCW activation TTC, and Table 30 shows the relative impact speed. Performance varied between vehicles for the two bicycle target configurations and in relation to the GVT. For the Bronco, impact with the (centered) bicycle configuration occurred at an SV speed of 70 km/h, which was lower than the SV speed where impact occurred with the GVT (80 km/h). However, impact with the bicycle 25 percent configuration occurred at a lower SV speed of 30 km/h, without AEB or FCW activation. For the Civic, impact with the

GVT and (centered) bicycle configuration occurred at an SV speed of 80 km/h, with lower relative impact speed for the (centered) bicycle configuration (16.42 km/h) than GVT (24.84 km/h). The Civic was the only vehicle tested where no impact occurred with the bicycle 25 percent configuration at an SV speed of 80 km/h. For the S60, no impact occurred with the GVT and (centered) bicycle configuration at an SV speed of 80 km/h. However, impact with the bicycle 25 percent configuration occurred at a lower SV speed of 30 km/h, without AEB activation. For the NX, no impact occurred with the GVT and (centered) bicycle configuration at an SV speed of 80 km/h. However, impact with the bicycle 25 percent configuration occurred at a lower SV speed of 50 km/h, without AEB activation. For the Model 3, no impact occurred with the GVT at an SV speed of 80 km/h. Impact with the (centered) bicycle and bicycle 25 percent configurations occurred at a lower SV speed of 60 km/hr, with AEB and FCW activations, and relative impact speeds of 9.86 and 15.48 km/h.

Table 28. Summary of Lead Vehicle Moving Bicycle Target Testing AEB Activation TTC (in seconds)

LVM – Bicycle		**30 km/h**	**40 km/h**	**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	0.50	0.69	0.73	0.92	0.92	0.84
	Bicycle	0.67	0.74	0.95	0.96	0.00	-
	Bicycle 25%	0.00	-	-	-	-	-
Honda Civic	GVT	0.62	0.64	0.78	0.83	1.00	1.03
	Bicycle	1.08	1.10	1.11	1.00	1.08	1.15
	Bicycle 25%	0.99	0.98	1.03	1.08	1.25	1.26
Volvo S60	GVT	0.54	0.75	0.91	1.19	1.29	1.29
	Bicycle	0.65	0.88	1.02	1.25	1.27	1.30
	Bicycle 25%	0.00	-	-	-	-	-
Lexus NX	GVT	0.78	0.69	0.84	1.05	1.23	1.32
	Bicycle	0.72	0.80	0.91	1.18	1.26	1.29
	Bicycle 25%	0.97	0.78	0.00	-	-	-
Tesla Model 3	GVT	0.30	0.37	0.50	0.75	0.91	1.05
	Bicycle	0.00	0.56	0.66	0.57	-	-
	Bicycle 25%	0.00	0.63	0.63	0.49	-	-

Table 29. Summary of Lead Vehicle Moving Bicycle Target Testing FCW Activation TTC (in seconds)

LVM – Bicycle		30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.63	1.55	1.94	2.33	2.35	2.32
	Bicycle	1.17	1.36	1.91	1.90	0.58	-
	Bicycle 25%	0.00	-	-	-	-	-
Honda Civic	GVT	1.22	1.24	2.09	2.43	2.56	2.57
	Bicycle	1.48	3.58	1.80	1.96	1.30	1.45
	Bicycle 25%	1.53	2.95	1.66	1.81	1.99	1.97
Volvo S60	GVT	1.30	2.02	1.84	2.31	2.56	2.62
	Bicycle	1.46	2.64	1.20	1.23	1.87	1.31
	Bicycle 25%	1.51	-	-	-	-	-
Lexus NX	GVT	1.93	2.02	2.14	2.28	2.35	2.47
	Bicycle	2.25	2.04	2.30	2.27	2.32	2.41
	Bicycle 25%	1.37	2.16	0.57	-	-	-
Tesla Model 3	GVT	1.68	2.56	3.91	3.06	3.09	3.00
	Bicycle	1.83	2.63	2.87	2.75	-	-
	Bicycle 25%	2.06	2.41	2.68	2.67	-	-

Table 30. Summary of Lead Vehicle Moving Bicycle Target Testing Relative Impact Speed (in km/h)

LVM – Bicycle		30 km/h	40 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Ford Bronco	GVT	0.00	0.00	0.00	0.00	0.00	26.68
	Bicycle	0.00	0.00	0.00	0.00	47.88	-
	Bicycle 25%	10.23	-	-	-	-	-
Honda Civic	GVT	0.00	0.00	0.00	0.00	0.00	24.84
	Bicycle	0.00	0.00	0.00	0.00	0.00	16.42
	Bicycle 25%	0.00	0.00	0.00	0.00	0.00	0.00
Volvo S60	GVT	0.00	0.00	0.00	0.00	0.00	0.00
	Bicycle	0.00	0.00	0.00	0.00	0.00	0.00
	Bicycle 25%	9.22	-	-	-	-	-
Lexus NX	GVT	0.00	0.00	0.00	0.00	0.00	0.00
	Bicycle	0.00	0.00	0.00	0.00	0.00	0.00
	Bicycle 25%	0.00	0.00	29.34	-	-	-
Tesla Model 3	GVT	0.00	0.00	0.00	0.00	0.00	0.00
	Bicycle	0.00	0.00	0.00	9.86	-	-
	Bicycle 25%	0.00	0.00	0.00	15.48	-	-

LVM Motorcycle

For the LVM scenario with motorcycle targets in daytime conditions, Table 31 shows the AEB activation TTC, Table 32 shows the FCW activation TTC, and Table 33 shows the relative impact speed. Performance varied between vehicles for the two (2) motorcycle target configurations and in relation to the GVT. For the Bronco, impact with the (centered) motorcycle configuration occurred at an SV speed of 70 km/h, which was lower than the SV speed where impact occurred with the GVT (80 km/h). Impact with the motorcycle 50 percent configuration occurred at a lower SV speed of 60 km/h, without AEB or FCW activation. For the Civic, impact with the GVT and motorcycle 50 percent configuration occurred at an SV speed of 80 km/h, with lower relative impact speed for the motorcycle 50 percent configuration (4.97

km/h) than GVT (24.84 km/h). Impact with the (centered) motorcycle configuration occurred at a higher SV speed of 90 km/h, with AEB and FCW activations, and relative impact speed of 48.13 km/h. For the S60, impact with the (centered) motorcycle configuration occurred at an SV speed of 90 km/h, which was lower than the SV speed where impact occurred with the GVT (100 km/h). Impact with the motorcycle 50 percent configuration occurred at a lower SV speed of 80 km/h, without AEB or FCW activation. The NX was the only vehicle tested where no impact occurred with the GVT at an SV speed of 100 km/h. Impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at a lower SV speed of 90 km/h, without AEB or FCW activation. For the Model 3, impact occurred with the GVT at an SV speed of 90 km/h. Impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at a lower SV speed of 80 km/hr, with AEB and FCW activations, and low relative impact speeds of 3.28 and 4.07 km/h.

Table 31. Summary of Lead Vehicle Moving Motorcycle Target Testing AEB Activation TTC (in seconds)

LVM – Motorcycle		**60 km/h**	**70 km/h**	**80 km/h**	**90 km/h**	**100 km/h**
Ford Bronco	GVT	0.92	0.92	0.84	-	-
	Motorcycle	0.88	0.31	-	-	-
	Motorcycle 50%	0.00	-	-	-	-
Honda Civic	GVT	0.83	1.00	1.03	-	-
	Motorcycle	1.21	1.16	1.26	0.51	-
	Motorcycle 50%	1.21	1.14	1.16	-	-
Volvo S60	GVT	1.19	1.29	1.29	1.17	1.23
	Motorcycle	1.25	1.33	1.28	0.00	-
	Motorcycle 50%	1.25	1.22	0.00	-	-
Lexus NX	GVT	1.05	1.23	1.32	1.40	1.54
	Motorcycle	1.13	1.28	1.30	0.00	-
	Motorcycle 50%	1.15	1.21	1.32	0.00	-
Tesla Model 3	GVT	0.75	0.91	1.05	1.06	-
	Motorcycle	0.74	0.91	0.96	-	-
	Motorcycle 50%	0.76	0.84	0.93	-	-

Table 32. Summary of Lead Vehicle Moving Motorcycle Target Testing FCW Activation TTC (in seconds)

LVM – Motorcycle		60 km/h	70 km/h	80 km/h	90 km/h	100 km/h
Ford Bronco	GVT	2.33	2.35	2.23	-	-
	Motorcycle	1.82	1.64	-	-	-
	Motorcycle 50%	0.00	-	-	-	-
Honda Civic	GVT	2.43	2.56	2.57	-	-
	Motorcycle	1.95	2.07	1.86	1.93	-
	Motorcycle 50%	1.96	2.08	2.26	-	-
Volvo S60	GVT	2.31	2.56	2.62	2.02	2.95
	Motorcycle	0.95	1.02	1.32	1.07	-
	Motorcycle 50%	0.99	1.28	0.00	-	-
Lexus NX	GVT	2.28	2.35	2.47	2.64	2.73
	Motorcycle	2.31	2.30	2.34	0.00	-
	Motorcycle 50%	2.21	2.29	2.37	0.00	-
Tesla Model 3	GVT	3.06	3.09	3.00	2.84	-
	Motorcycle	2.83	2.81	2.74	-	-
	Motorcycle 50%	2.71	2.64	2.70	-	-

Table 33. Summary of Lead Vehicle Moving Motorcycle Target Testing Relative Impact Speed (in km/h)

LVM – Motorcycle		60 km/h	70 km/h	80 km/h	90 km/h	100 km/h
Ford Bronco	GVT	0.00	0.00	26.68	-	-
	Motorcycle	0.00	39.92	-	-	-
	Motorcycle 50%	39.10	-	-	-	-
Honda Civic	GVT	0.00	0.00	24.84	-	-
	Motorcycle	0.00	0.00	0.00	48.13	-
	Motorcycle 50%	0.00	0.00	4.97	-	-
Volvo S60	GVT	0.00	0.00	0.00	0.00	8.50
	Motorcycle	0.00	0.00	0.00	68.83	-
	Motorcycle 50%	0.00	0.00	60.91	-	-
Lexus NX	GVT	0.00	0.00	0.00	0.00	0.00
	Motorcycle	0.00	0.00	0.00	65.05	-
	Motorcycle 50%	0.00	0.00	0.00	67.60	-
Tesla Model 3	GVT	0.00	0.00	0.00	13.10	-
	Motorcycle	0.00	0.00	3.28	-	-
	Motorcycle 50%	0.00	0.00	4.07	-	-

CIB LVD

CIB LVD was tested in daytime conditions for bicycle and motorcycle targets and the results are provided in sections 3.3.1 and 3.3.2, respectively. LVD testing of bicycle target configurations was conducted with an SV speed range of 10 to 30 km/h and a headway of 12 m. LVD testing of motorcycle target configurations was conducted with an SV speed range of 50 to 80 km/h and headways of 12 m and 40 m. For all LVD testing, the POV (e.g., GVT, bicycle and motorcycle target configurations) deceleration was 0.5g.

LVD Bicycle

For the LVD scenario with bicycle target in daytime conditions, Table 34 shows the AEB activation TTC, Table 35 shows the FCW activation TTC, and Table 36 shows the relative impact speed. Performance varied between vehicles for the two bicycle target configurations and in relation to the GVT. For the Bronco, impact with the GVT occurred at an SV speed of 30 km/h, with AEB and FCW activations, and relative impact speed of 8 km/h. Impact with the (centered) bicycle and bicycle 25% configurations occurred at SV speeds of 10 and 20 km/h, without AEB activation, and with relative impact speeds of 10 and 20 km/h. For the Civic, no impact occurred with the GVT and bicycle 25 percent configuration at the tested SV speeds from 10 to 30 km/h. Impact with the (centered) bicycle configuration occurred at an SV speed of 30 km/h, with AEB and FCW activations, and relative impact speed of 9.94 km/h. For the S60, impact with the (centered) bicycle and bicycle 25 percent configurations occurred at an SV speed of 30 km/h, with AEB and FCW activations, and with relative impact speeds of 20.05 and 13.03 km/h. For the NX, no impact occurred with the GVT and both bicycle target configurations at the tested SV speeds from 10 to 30 km/h. For the Model 3, no impact occurred with the GVT and both bicycle target configurations at the tested SV speeds from 10 to 30 km/h.

Table 34. Summary of Lead Vehicle Decelerating Bicycle Target Testing AEB Activation TTC (in seconds)

LVD - Bicycle		10 km/h	20 km/h	30 km/h
Ford Bronco	GVT	0.44	0.65	0.53
	Bicycle	0.00	-	-
	Bicycle 25%	0.57	0.00	-
Honda Civic	GVT	0.62	0.65	0.88
	Bicycle	0.70	0.85	0.51
	Bicycle 25%	0.68	0.82	0.59
Volvo S60	GVT	0.44	0.72	0.59
	Bicycle	0.25	0.62	0.28
	Bicycle 25%	0.29	0.66	0.38
Lexus NX	GVT	0.76	0.73	0.95
	Bicycle	0.74	0.83	1.04
	Bicycle 25%	0.91	0.94	1.08
Tesla Model 3	GVT	0.39	4.84	0.31
	Bicycle	0.59	5.03	0.60
	Bicycle 25%	0.56	5.20	0.28

Table 35. Summary of Lead Vehicle Decelerating Bicycle Target Testing FCW Activation TTC (in seconds)

LVD - Bicycle		10 km/h	20 km/h	30 km/h
Ford Bronco	GVT	0.70	0.84	0.73
	Bicycle	0.86	-	-
	Bicycle 25%	0.70	0.80	-
Honda Civic	GVT	1.11	1.31	1.78
	Bicycle	1.24	1.46	1.18
	Bicycle 25%	1.27	1.52	1.05
Volvo S60	GVT	1.25	1.42	2.91
	Bicycle	1.00	1.38	2.64
	Bicycle 25%	0.92	1.54	1.32
Lexus NX	GVT	1.88	2.26	3.02
	Bicycle	2.22	2.53	3.22
	Bicycle 25%	2.11	1.96	2.58
Tesla Model 3	GVT	1.20	5.40	1.06
	Bicycle	1.72	5.44	2.48
	Bicycle 25%	1.56	5.61	0.94

Table 36. Summary of Lead Vehicle Decelerating Bicycle Target Testing Relative Impact Speed (in km/h)

LVD - Bicycle		10 km/h	20 km/h	30 km/h
Ford Bronco	GVT	0.00	0.00	8.32
	Bicycle	10.22	-	-
	Bicycle 25%	0.00	19.55	-
Honda Civic	GVT	0.00	0.00	0.00
	Bicycle	0.00	0.00	9.94
	Bicycle 25%	0.00	0.00	0.00
Volvo S60	GVT	0.00	0.00	0.00
	Bicycle	0.00	0.00	20.05
	Bicycle 25%	0.00	0.00	13.03
Lexus NX	GVT	0.00	0.00	0.00
	Bicycle	0.00	0.00	0.00
	Bicycle 25%	0.00	0.00	0.00
Tesla Model 3	GVT	0.00	0.00	0.00
	Bicycle	0.00	0.00	0.00
	Bicycle 25%	0.00	0.00	0.00

LVD Motorcycle

For the LVD scenario with motorcycle targets in daytime conditions, Table 37 shows the AEB activation TTC, Table 38 shows the FCW activation TTC, and Table 39 shows the relative impact speed. Performance varied between vehicles for the two (2) motorcycle target configurations and in relation to the GVT at the two headways of 12 m and 40 m. For the Bronco at 12 m headway, impact with the GVT and both motorcycle configurations occurred at an SV speed of 50 km/h. AEB and FCW did not activate for the (centered) motorcycle and motorcycle 50 percent configurations at an SV speed of 50 km/h, resulting in higher relative impact speeds of 39.74 and 40.21 km/h, than the GVT (22.57 km/h). At 40 m headway, impact with the (centered) motorcycle and motorcycle 50 percent configurations also occurred at an SV speed of 50 km/h, with relative impact speeds of 27.97 and 22.39 km/h. For the Civic at 12 m headway, impact with the GVT and motorcycle 50 percent configurations occurred at an SV speed of 50 km/h, with relative impact speed for the motorcycle 50 percent configuration of 0.15 km/h, which was lower than the GVT (11.99 km/h). The (centered) motorcycle configuration was not tested at an SV speed of 50 km/h for the Civic due to contact at 40 km/h in a pre-test evaluation. At 40 m headway, impact with the (centered) motorcycle and motorcycle 50 percent configurations also occurred at an SV speed of 50 km/h, with relative impact speeds of 32.47 and 34.67 km/h. For the S60 at 12 m headway, impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at SV speeds of 50 and 60 km/h, which were lower than the GVT (70 km/h). At 40 m headway, impact with the GVT occurred at an SV speed of 80 km/h, with relative impact speed of 17.1 km/h. Impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at lower SV speeds of 50 and 60 km/h, without AEB activations. For the NX at 12 m headway, impact with the GVT and (centered) motorcycle configuration occurred at an SV speed of 70 km/h, with low relative impact speeds of 3.10 and 5.55 km/h. Impact with the motorcycle 50 percent configuration occurred at a lower SV speed of 60 km/h, with low relative impact speed of 3.26 km/h. At 40 m headway, the NX was the only vehicle tested where no impact occurred with the GVT and (centered) motorcycle at SV speeds from 50 to 80 km/h. However, impact with the motorcycle 50 percent configuration occurred at an SV speed of 50 km/h, with AEB and FCW activations, and relative impact speed of 34.31 km/h. For the Model 3 at 12 m headway, impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at SV speeds of 60 and 50 km/h, which was lower than the SV speed where impact occurred with the GVT (70 km/h). At 40 m headway, impact with the (centered) motorcycle and motorcycle 50 percent configurations occurred at an SV speed of 70 km/h, which was lower than the SV speed where impact occurred with the GVT (80 km/h). For the (centered) motorcycle and motorcycle 50 percent configurations at an SV speed of 70 km/h, AEB and FCW activated, and the relative impact speeds were 22.93 and 37.84 km/h.

Table 37. Summary of Lead Vehicle Decelerating Motorcycle Target Testing AEB Activation TTC (in seconds)

		12 m Headway					40 m Headway			
LVD - Motorcycle 12m		**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**		**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	0.82	-	-	-		0.94	0.92	-	-
	Motorcycle	0.00	-	-	-		0.65	-	-	-
	Motorcycle 50%	0.00	-	-	-		0.74	-	-	-
Honda Civic	GVT	1.17	-	-	-		1.02	0.74	-	-
	Motorcycle	-	-	-	-		0.56	-	-	-
	Motorcycle 50%	0.56	-	-	-		0.51	-	-	-
Volvo S60	GVT	1.34	1.11	1.46	-		1.21	1.11	1.80	1.42
	Motorcycle	0.50	-	-	-		0.00	-	-	-
	Motorcycle 50%	0.99	0.00	-	-		0.99	0.00	-	-
Lexus NX	GVT	1.25	1.85	1.92	-		1.24	1.37	1.46	1.45
	Motorcycle	1.39	2.00	1.24	-		1.20	1.31	1.39	1.44
	Motorcycle 50%	1.26	1.91	-	-		0.39	-	-	-
Tesla Model 3	GVT	2.28	1.09	1.29	-		1.90	1.12	1.10	0.75
	Motorcycle	2.40	1.15	-	-		2.57	1.10	0.95	-
	Motorcycle 50%	2.05	-	-	-		2.58	1.02	0.68	-

Table 38. Summary of Lead Vehicle Decelerating Motorcycle Target Testing FCW Activation TTC (in seconds)

		12 m Headway					40 m Headway			
LVD - Motorcycle 12m		**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**		**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	1.77	-	-	-		1.78	2.42	-	-
	Motorcycle	0.30	-	-	-		1.37	-	-	-
	Motorcycle 50%	0.11	-	-	-		1.22	-	-	-
Honda Civic	GVT	2.69	-	-	-		2.79	4.07	-	-
	Motorcycle	-	-	-	-		0.87	-	-	-
	Motorcycle 50%	1.05	-	-	-		0.75	-	-	-
Volvo S60	GVT	2.90	1.93	2.33	-		3.02	4.85	5.2	4.96
	Motorcycle	2.68	-	-	-		3.12	-	-	-
	Motorcycle 50%	2.89	2.92	-	-		3.16	5.07	-	-
Lexus NX	GVT	3.53	3.41	2.33	-		3.26	3.41	3.72	3.81
	Motorcycle	2.84	4.93	3.10	-		3.01	4.93	3.43	3.61
	Motorcycle 50%	2.47	2.81	-	-		2.52	-	-	-
Tesla Model 3	GVT	3.70	1.73	1.81	-		2.74	2.82	2.81	2.53
	Motorcycle	2.93	1.80	-	-		4.19	2.82	2.3	-
	Motorcycle 50%	3.83	-	-	-		4.35	2.87	2.65	-

Table 39. Summary of Lead Vehicle Decelerating Motorcycle Target Testing Relative Impact Speed (in km/h)

		12 m Headway					40 m Headway			
LVD - Motorcycle 12m		**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**		**50 km/h**	**60 km/h**	**70 km/h**	**80 km/h**
Ford Bronco	GVT	22.57	-	-	-		0.00	27.25	-	-
	Motorcycle	39.74	-	-	-		27.97	-	-	-
	Motorcycle 50%	40.21	-	-	-		22.39	-	-	-
Honda Civic	GVT	11.99	-	-	-		0.00	18.97	-	-
	Motorcycle	-	-	-	-		32.47	-	-	-
	Motorcycle 50%	0.15	-	-	-		34.67	-	-	-
Volvo S60	GVT	0.00	0.00	4.46	-		0.00	0.00	0.00	17.1
	Motorcycle	23.36	-	-	-		47.23	-	-	-
	Motorcycle 50%	0.00	39.38	-	-		0.00	56.7	-	-
Lexus NX	GVT	0.14	0.00	3.10	-		0.00	0.00	0.00	0.00
	Motorcycle	0.00	0.00	5.55	-		0.00	0.00	0.00	0.00
	Motorcycle 50%	0.00	3.26	-	-		34.31	-	-	-
Tesla Model 3	GVT	0.00	0.00	0.76	-		0.00	0.00	0.00	27.18
	Motorcycle	0.00	4.75	-	-		0.00	0.00	22.93	-
	Motorcycle 50%	19.94	-	-	-		0.00	0.00	37.84	-

BSI SV Lane Change Constant Headway

For the BSI scenarios, data were recorded to indicate if a blind spot detection system was triggered by the POV, if there was intervention in the form of steering action, if the SV deviated from its lane, and if a potential crash was avoided. Note that it is possible based on the force of steering intervention and time of intervention that not all of the indicated conditions happen in that sequence. Also, as previously indicated, crash avoidance was considered to have occurred not if a collision was avoided, but if the SV provided sufficient steering action in a timely manner to avoid coming within 6 inches of the surrogate. In pilot testing, because the surrogates were mounted on low-profile steering platforms, an actual collision could lead to significant damage to the platform and put the SV into potentially unsafe conditions. Therefore, after consultation with NHTSA, it was decided that the threshold for collision avoidance would be within 6 inches of the surrogate. The Lexus NX was unable to detect the motorcycle target in its blind spot during the constant headway lane change scenario at SV speeds from 40 to 80 km/h. The Tesla Model 3 was able to detect the motorcycle target in its blind spot during the constant headway lane change scenario, but did not intervene at SV speeds from 40 to 60 km/h, resulting in lane deviation and impact with the 2-wheeled POV target. The Volvo S60 was unable to detect the motorcycle target in its blind spot during the constant headway lane change scenario at SV speeds from 50 to 80 km/h.

Table 40. SV Lane Change Constant Headway

Vehicle	Speed (km/h)	POV	Blind Spot Detection	Blind Spot Intervention	Lane Deviation	Crash Avoidance
Lexus NX	40	GVT	Yes	No	Yes	No
		Motorcycle	No	No	No	No
	50	GVT	Yes	Yes	Yes	Yes
		Motorcycle	No	No	No	No
	60	GVT	Yes	No	Yes	No
		Motorcycle	No	No	No	No
	70	GVT	Yes	Yes	Yes	Yes
		Motorcycle	No	No	No	No
	80	GVT	Yes	Yes	Yes	Yes
		Motorcycle	No	No	No	No
Tesla Model 3	40	GVT	Yes	No	Yes	No
		Motorcycle	Yes	No	Yes	No
	50	GVT	Yes	No	Yes	No
		Motorcycle	Yes	No	Yes	No
	60	GVT	Yes	No	Yes	No
		Motorcycle	Yes	No	Yes	No
	70	GVT	Yes	Yes	Yes	Yes
		Motorcycle	Yes	Yes	Yes	Yes
	80	GVT	Yes	Yes	Yes	Yes
		Motorcycle	Yes	Yes	Yes	Yes
Volvo S60	40	GVT	Yes	No	Yes	No
		Motorcycle	Yes	No	Yes	No
	50	GVT	Yes	No	Yes	No
		Motorcycle	No	No	Yes	No
	60	GVT	Yes	No	Yes	No
		Motorcycle	No	No	Yes	No
	70	GVT	Yes	No	Yes	No
		Motorcycle	No	No	Yes	No
	80	GVT	Yes	No	Yes	No
		Motorcycle	No	No	Yes	No

The Tesla Model 3 was able to detect the bicycle target in its blind spot during the constant headway lane change scenario but did not intervene, resulting in lane deviation and impact with the 2-wheeled POV target. The Tesla Model 3 was the only vehicle tested in this scenario, as it was the only vehicle that explicitly indicated bicycle detection for its BSI system in the user manual.

Table 41. SV Lane Change Constant Headway Low Speed Bicycle

Vehicle	Speed (km/h)	POV	Blind Spot Detection	Blind Spot Intervention	Lane Deviation	Crash Avoidance
Tesla Model 3	20	Bicycle	Yes	No	Yes	No
	30	Bicycle	Yes	No	Yes	No
	40	Bicycle	Yes	No	Yes	No

BSI SV Lane Change Closing Headway

For the BSI SV Lane Change Closing Headway scenario, similar metrics were used to the Constant Headway scenario, with the addition of distances associated with detection and intervention. In this condition, the longitudinal distance at detection is given for the point at which the blind spot warning indicator was activated by the motorcycle surrogate. Where the cell is gray and filled with a dash, there was no observed blind spot warning. The Lexus NX was able to avoid contact with the motorcycle target at SV speeds from 40 to 70 km/h, with lane deviation occurring at an SV speed of 60 km/h. The Tesla Model 3 was unable to avoid contact with the motorcycle target at SV speeds from 40 to 70 km/h. The Volvo S60 was able to avoid contact with the motorcycle target only at a SV speed of 60 km/h.

Table 42. SV Lane Change Closing Headway

Vehicle	POV Speed (km/h)	SV Speed (km/h)	POV	Longitudinal Distance at Detection (m)	Longitudinal Distance at Intervention (m)	Lane Deviation	Crash Avoidance
Lexus NX	80	40	GVT	52.86	26.21	No	Yes
			Motorcycle	51.65	19.90	No	Yes
		50	GVT	39.37	20.24	No	Yes
			Motorcycle	39.63	16.99	No	Yes
		60	GVT	29.96	10.61	Yes	Yes
			Motorcycle	25.62	5.53	Yes	Yes
		70	GVT	11.17	5.32	Yes	Yes
			Motorcycle	11.21	5.59	No	Yes
Tesla Model 3[1]	80	40	GVT	1.70	-	Yes	No
			Motorcycle	-	-	Yes	No
		50	GVT	2.55	-	Yes	No
			Motorcycle	-3.13	-	Yes	No
		60	GVT	3.76	-	Yes	No
			Motorcycle	-0.89	-	Yes	No
		70	GVT	4.53	3.51	Yes	Yes
			Motorcycle	3.41	-	Yes	No
Volvo S60	80	40	GVT	40.80	-	Yes	No
			Motorcycle	31.83	-	Yes	No
		50	GVT	26.30	-	Yes	No
			Motorcycle	25.05	-	Yes	No
		60	GVT	18.05	-	Yes	No
			Motorcycle	17.56	2.58	Yes	Yes
		70	GVT	8.79	-	Yes	No
			Motorcycle	8.67	0.23	Yes	No

[1] Blind Spot detection is considered a blinking red target on the screen (first time the driver is actually notified), as opposed to visualization on the center console screen.

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Conclusions

The following research questions were identified at project onset:

1. How do ADAS crash avoidance systems from a variety of makes/models respond to motorcycles and bicycles in several crash conditions?
    a. Rear-end crashes (lead motorcycle or bicycle stopped, lead motorcycle or bicycle decelerating, and lead motorcycle or bicycle moving slower); and
    b. Lane change crashes (motorcycle and light vehicle traveling in the same direction)
2. How do the handling and driving characteristics of motorcycles affect test specifications (e.g., lane position and acceleration/braking characteristics)?
3. How do the results of the tests conducted with motorcycles and bicycles as POVs compare with tests conducted with a light vehicle as the POV?
4. How could the draft test procedures be adjusted to account for motorcycles and bicycles given the findings specific to the results of this study?

Sections 4.1 through 4.4 summarize the findings of this project as it relates to answering these questions.

Primary Research Question 1 Conclusions

A detailed summary of rear-end crash response to lead motorcycle or bicycle stopped, lead motorcycle or bicycle decelerating, or lead motorcycle or bicycle moving is provided for each vehicle in Figure 13 – Figure 17.

For each rear-end test scenario, performance varied across test vehicles in response to the motorcycle and bicycle target configurations. There were no scenarios where AEB performance was highly consistent across all test vehicles. When grouped by sensor type (camera-radar fusion or camera-only), there was also not an observable pattern about performance.

For the BSI scenarios, performance also varied across test vehicles. In addition, there were fewer vehicles tested in BSI scenarios than rear-end scenarios. These tests, however, demonstrated that detection and response to bicycle and motorcycle surrogates in a variety of lane change scenarios is possible, and the tests performed were able to characterize BSI system performance.

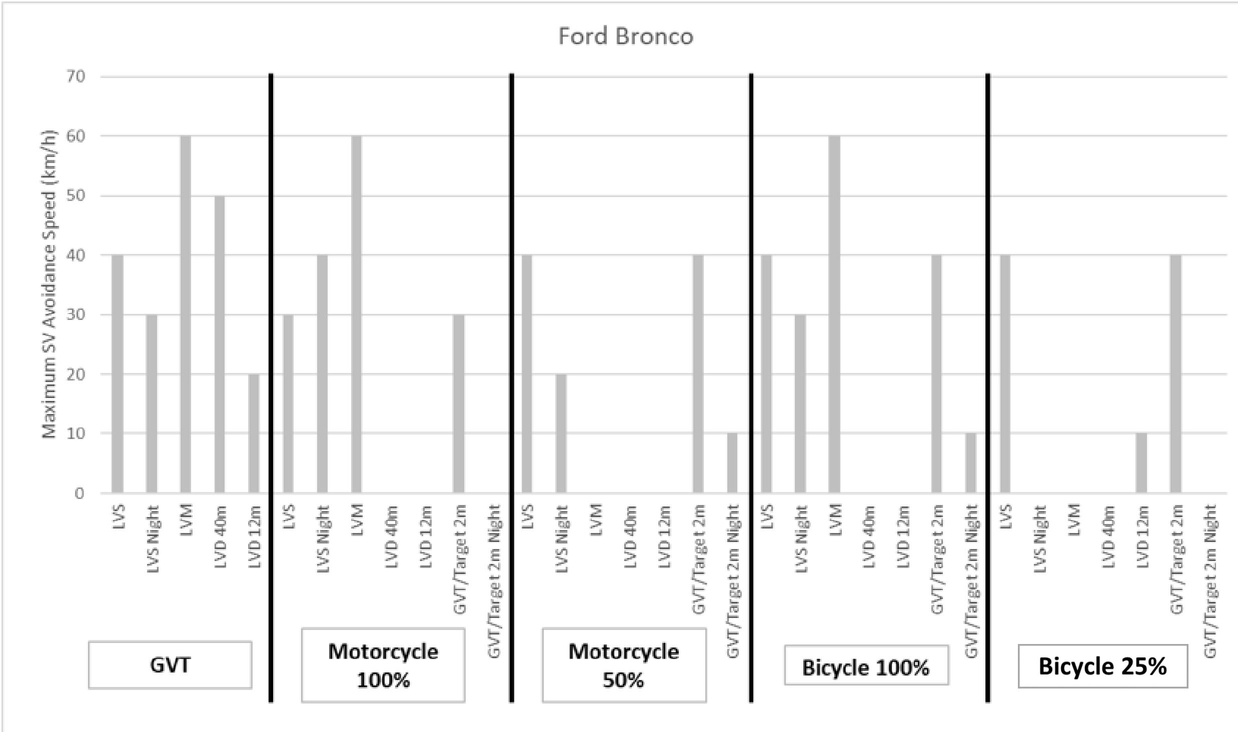

Figure 13. Ford Bronco Rear End Crash Maximum SV Avoidance Speed Summary

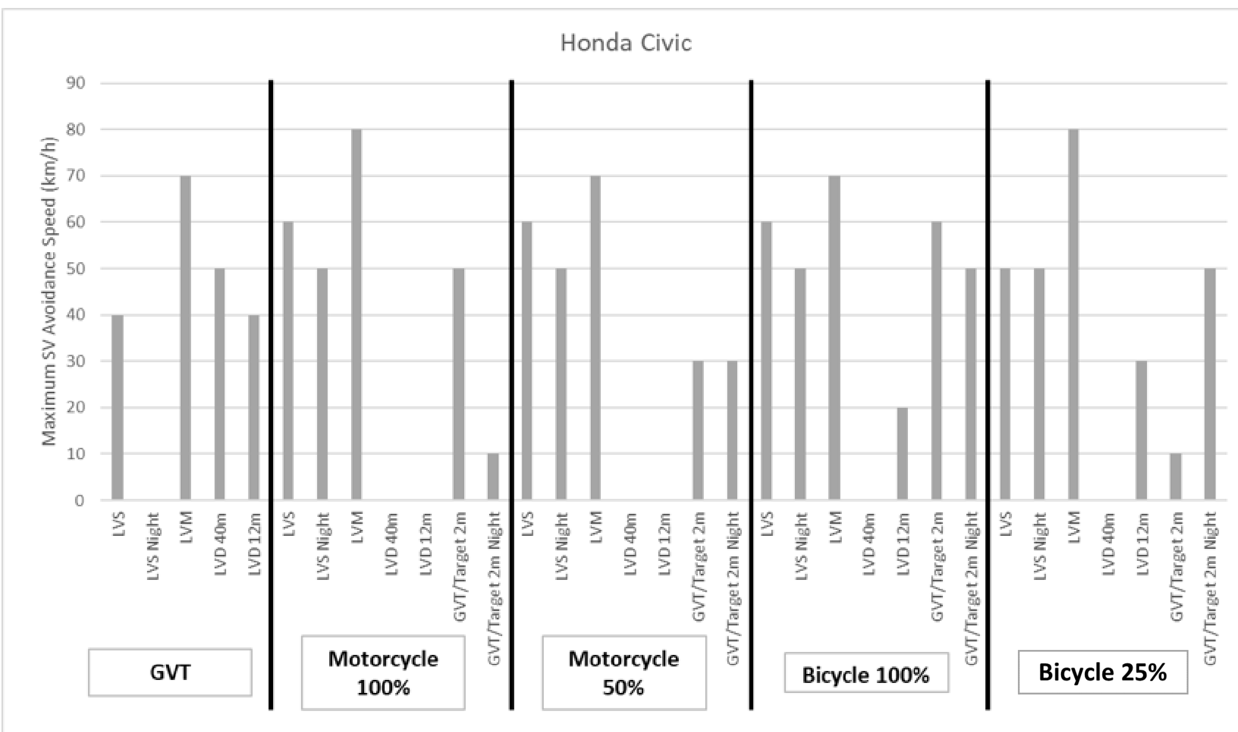

Figure 14. Honda Civic Rear End Crash Maximum SV Avoidance Speed Summary

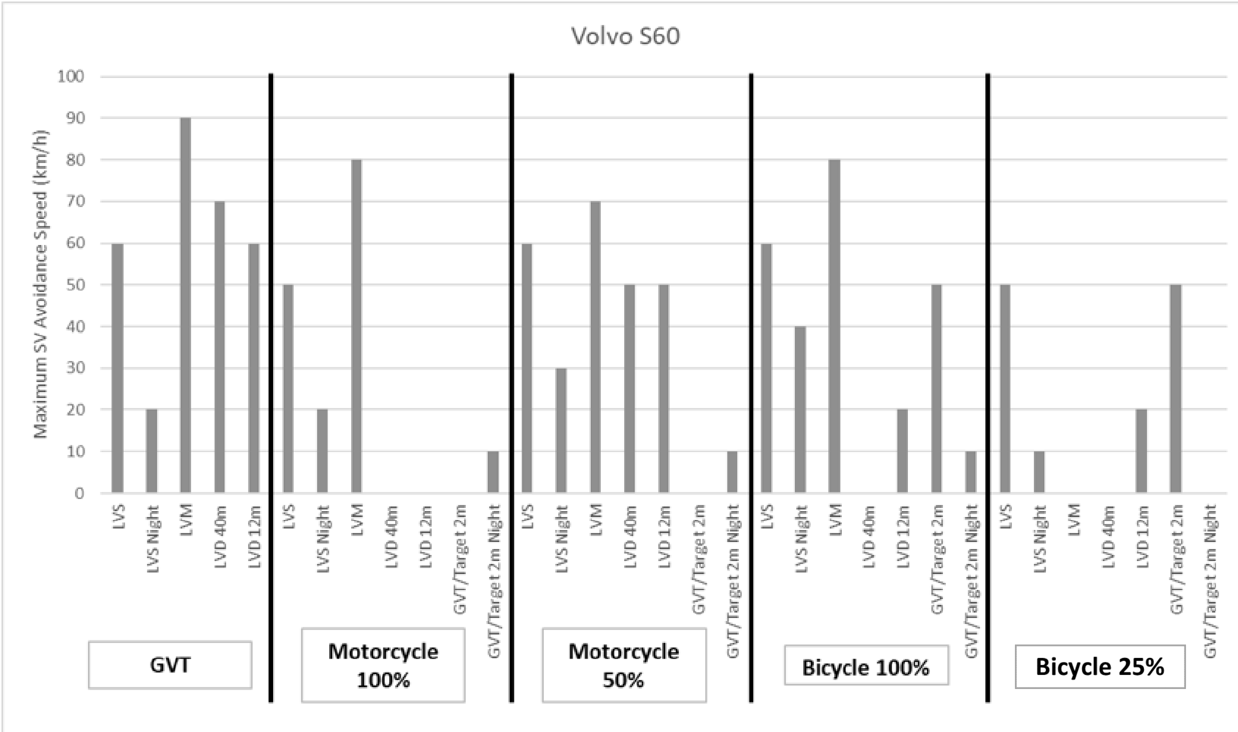

Figure 15. Volvo S60 Rear End Crash Maximum SV Avoidance Speed Summary

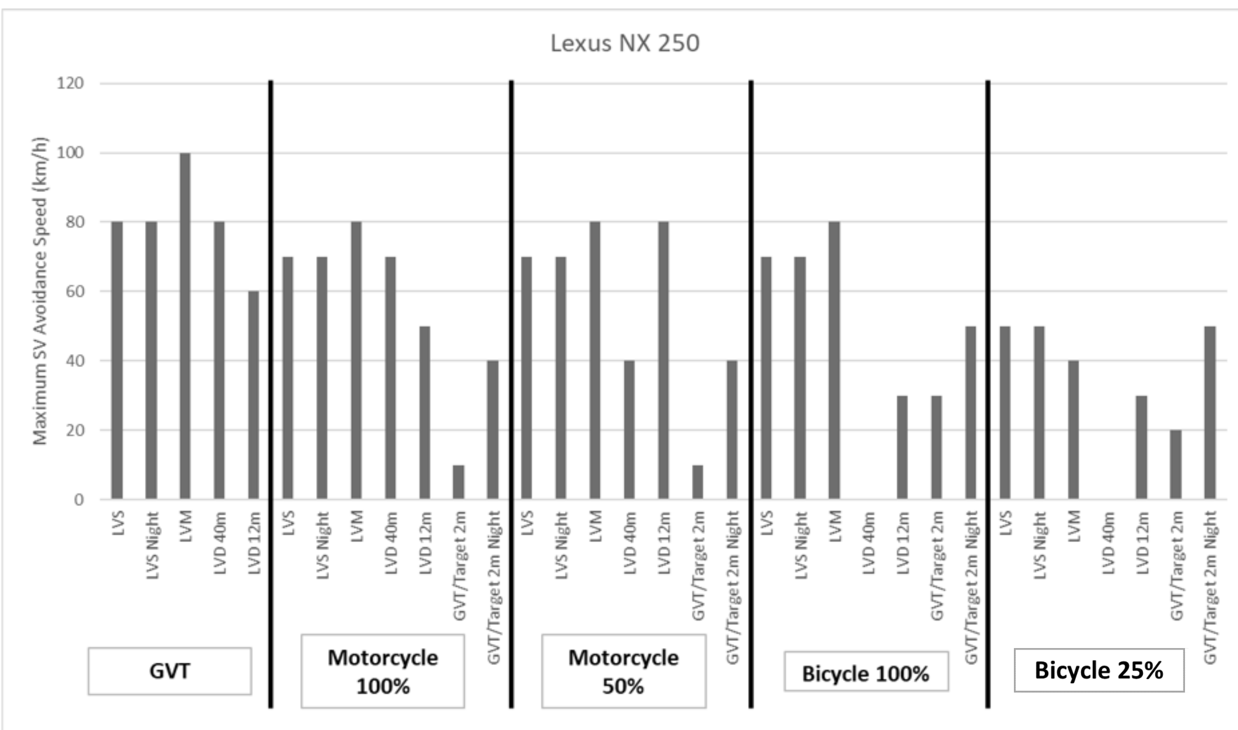

Figure 16. Lexus NX 250 Rear End Crash Maximum SV Avoidance Speed Summary

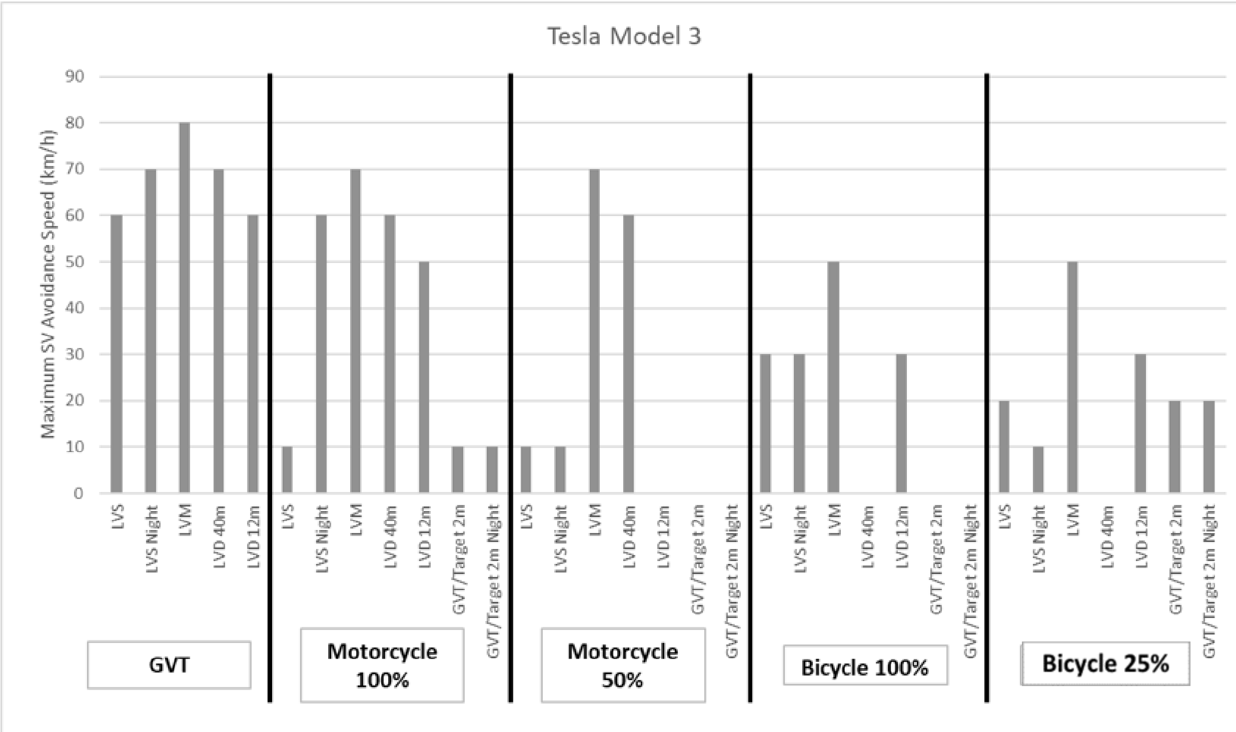

Figure 17. Tesla Model 3 Rear End Crash Maximum SV Avoidance Speed Summary

Primary Research Question 2 Conclusions

Motorcycles and bicycles have different physical characteristics from light vehicles, and also different performance characteristics. This project represented those differences through braking characteristics of motorcycles and bicycles (represented as 0.5g deceleration at all following headways) and the lane position of the motorcycle and bicycle surrogates when tested as POV (50% offset for motorcycles, and 25% offset for bicycles). Results shown in Table 43 indicate that lateral offset of the POV does affect performance for some systems tested, but there is no consistent pattern across test vehicles. For some vehicles and scenarios tested, an offset POV showed higher speed crash avoidance; in others, a centered POV showed higher speed crash avoidance. Overall, these results indicate that when testing motorcycle and bicycle POVs, offset can produce variability in system performance. In addition, consideration should be made when selecting test procedures that intend to realistically characterize motorcycle and bicycle POVs.

Table 43. Maximum SV Speed Avoidance (km/h) Comparison Table (Paired differences between offsets for the same scenario are highlighted in bold.)

		Max SV Avoidance Speed (km/h)				
Vehicle	**Scenario**	**GVT**	**Motorcycle 100%**	**Motorcycle 50%**	**Bicycle 100%**	**Bicycle 25%**
Lexus NX 250	LVS	80	70	70	**70**	**50**
	LVS Night	80	70	70	**70**	**50**
	LVM	100	80	80	**80**	**40**
	LVD 40m	80	**70**	**40**	-	-
	LVD 12m	60	**50**	**80**	30	30
	GVT/Target 2m	-	10	10	**30**	**20**
	GVT/Target 2m Night	-	40	40	50	50
Volvo S60	LVS	60	**50**	**60**	**60**	**50**
	LVS Night	20	**20**	**30**	**40**	**10**
	LVM	90	**80**	**70**	**80**	**0**
	LVD 40m	70	**0**	**50**	-	-
	LVD 12m	60	**0**	**50**	20	20
	GVT/Target 2m	-	0	0	50	50
	GVT/Target 2m Night	-	10	10	**10**	**0**
Honda Civic	LVS	40	60	60	**60**	**50**
	LVS Night	0	50	50	50	50
	LVM	70	**80**	**70**	**70**	**80**
	LVD 40m	50	0	0	-	-
	LVD 12m	40	0	0	**20**	**30**
	GVT/Target 2m	-	**50**	**30**	**60**	**10**
	GVT/Target 2m Night	-	**10**	**30**	50	50
Ford Bronco	LVS	40	**30**	**40**	40	40
	LVS Night	30	**40**	**20**	**30**	**0**
	LVM	60	**60**	**0**	**60**	**0**
	LVD 40m	50	0	0	-	-
	LVD 12m	20	0	0	**0**	**10**
	GVT/Target 2m	-	**30**	**40**	**40**	**40**
	GVT/Target 2m Night	-	0	10	**10**	**0**
Tesla Model 3	LVS	60	10	10	**30**	**20**
	LVS Night	70	**60**	**10**	**30**	**10**
	LVM	80	70	70	50	50
	LVD 40m	70	60	60	-	-
	LVD 12m	60	**50**	**0**	**30**	**30**
	GVT/Target 2m	-	**10**	**0**	**0**	**20**
	GVT/Target 2m Night	-	30	10	20	20

Primary Research Question 3 Conclusions

To serve as a comparison, in each scenario a GVT was used as POV in addition to the motorcycle and bicycle surrogates. This allowed direct comparison of response between GVT and motorcycle and bicycle surrogates. Performance varied for rear-end scenarios, with some vehicles responding differently to the GVT than the motorcycle or bicycle surrogates. As an example from the LVS daytime scenario (Tables 22–24), the Lexus NX avoided contact with the GVT at all test speeds up to 80 km/h and contacted the centered and 50 percent motorcycle target configurations at 80 km/h; the Civic avoided contact with the centered and 50 percent motorcycle target configurations at higher speeds (70 km/h) than the GVT (50 km/h). BSI testing results did not demonstrate a clear pattern, with crash avoidance responses being inconsistent across motorcycles and GVTs for the few vehicles tested. Ongoing testing at NHTSA continues to characterize blind spot intervention systems.

Primary Research Question 4 Conclusions

Results from these tests indicate that while no consistent patterns were observed across vehicles, for the rear-end scenarios, collision avoidance at speeds of 70 to 80 km/h was possible (reference Section 3 for complete graphs). This suggests that the speeds selected for testing were able to characterize performance in the system capabilities of the tested vehicles. Likewise, for BSI testing, crash avoidance was also demonstrated, suggesting that the speeds selected for testing were able to characterize performance in the system capabilities of the tested vehicles.

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Appendix A: Vehicle Information Sheets

<table>
<tr><th colspan="6">Vehicle Information</th></tr>
<tr><td colspan="2">Make</td><td colspan="4">Ford</td></tr>
<tr><td colspan="2">Model/Trim</td><td colspan="4">Bronco/Outer Banks</td></tr>
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<tr><td colspan="2">Engine Type/Displacement</td><td colspan="4">2.3L Inline 4-Cylinder Turbo EcoBoost</td></tr>
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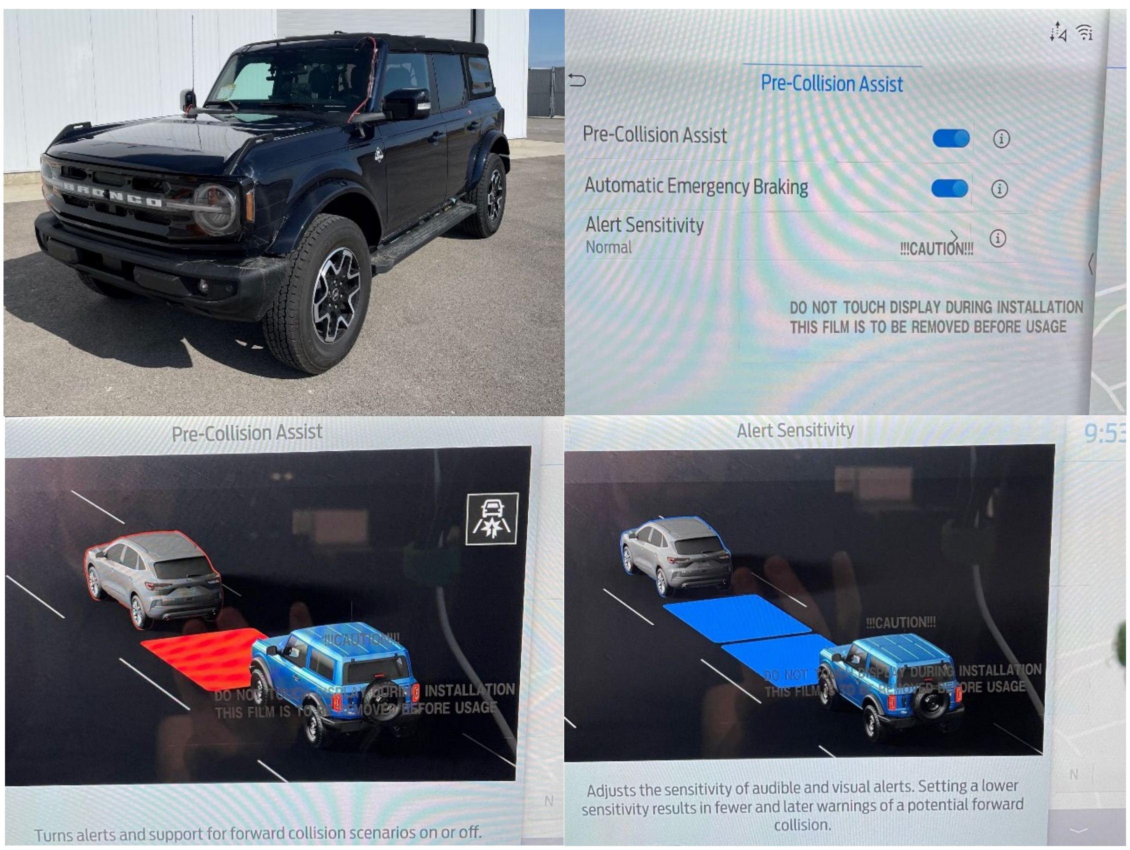

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<tr><td>Pre-Test Odometer Reading</td><td colspan="5">22 Miles</td></tr>
<tr><td>Date Vehicle Received</td><td colspan="5">2/11/22</td></tr>
<tr><td>Engine Type/Displacement</td><td colspan="5">2.0L 4-Cylinder</td></tr>
<tr><td>Fuel Type</td><td colspan="5">Unleaded 87</td></tr>
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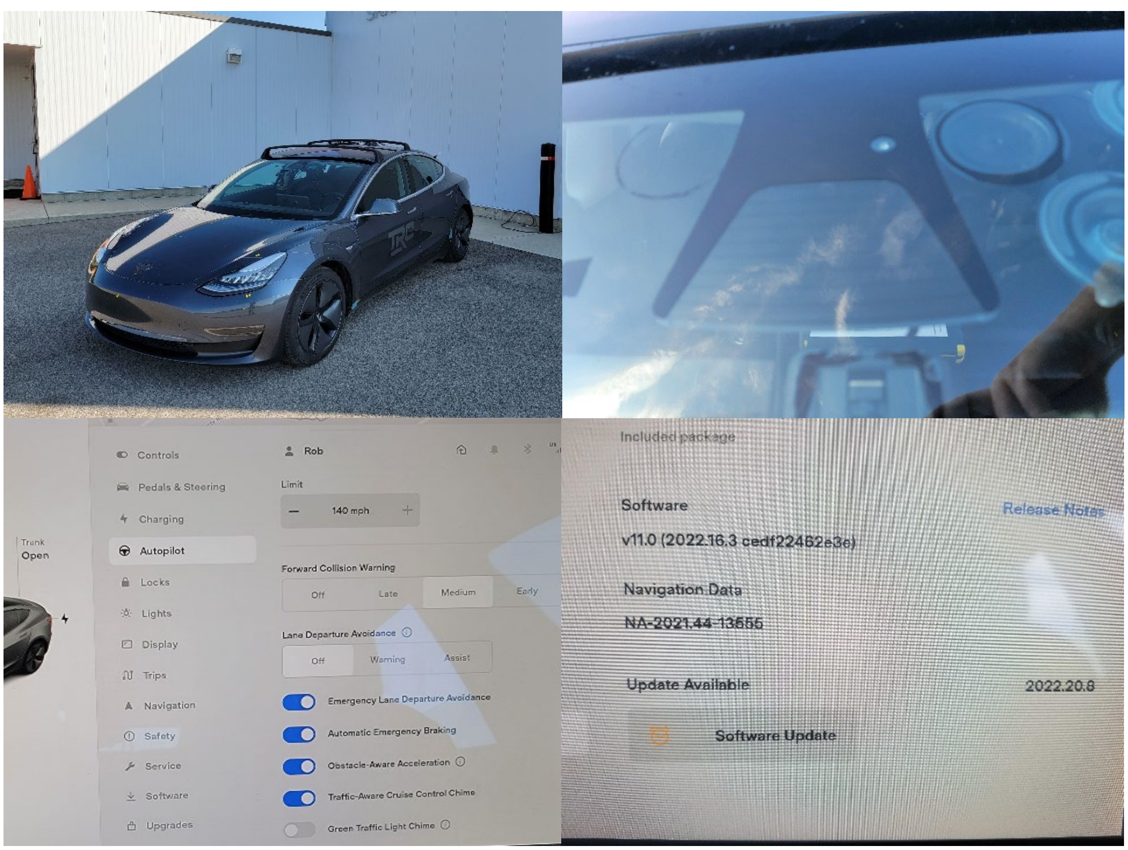

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Model/Trim	S60/Momentum
Body Style	Sedan
VIN	7JRA22TK8MG080346
Date of Manufacture	08/20
Exterior Color	Silver
Pre-Test Odometer Reading	27,236 Miles
Date Vehicle Received	5/9/22
Engine Type/Displacement	2.0L Inline 4-Cylinder Turbo
Fuel Type	Unleaded Premium
Transmission Type	8-Speed Automatic
Driveline Type (Rear, Front, or 4-Wheel Drive)	All Wheel Drive
Tire Size	235/45R18
Manufacturer/Tire Name	Continental/ProContact

Vehicle Weights (kg) From Placard	GVWR: 2281		Tire Pressure Recommendation from Placard (PSI)	LF: 36	RF: 36
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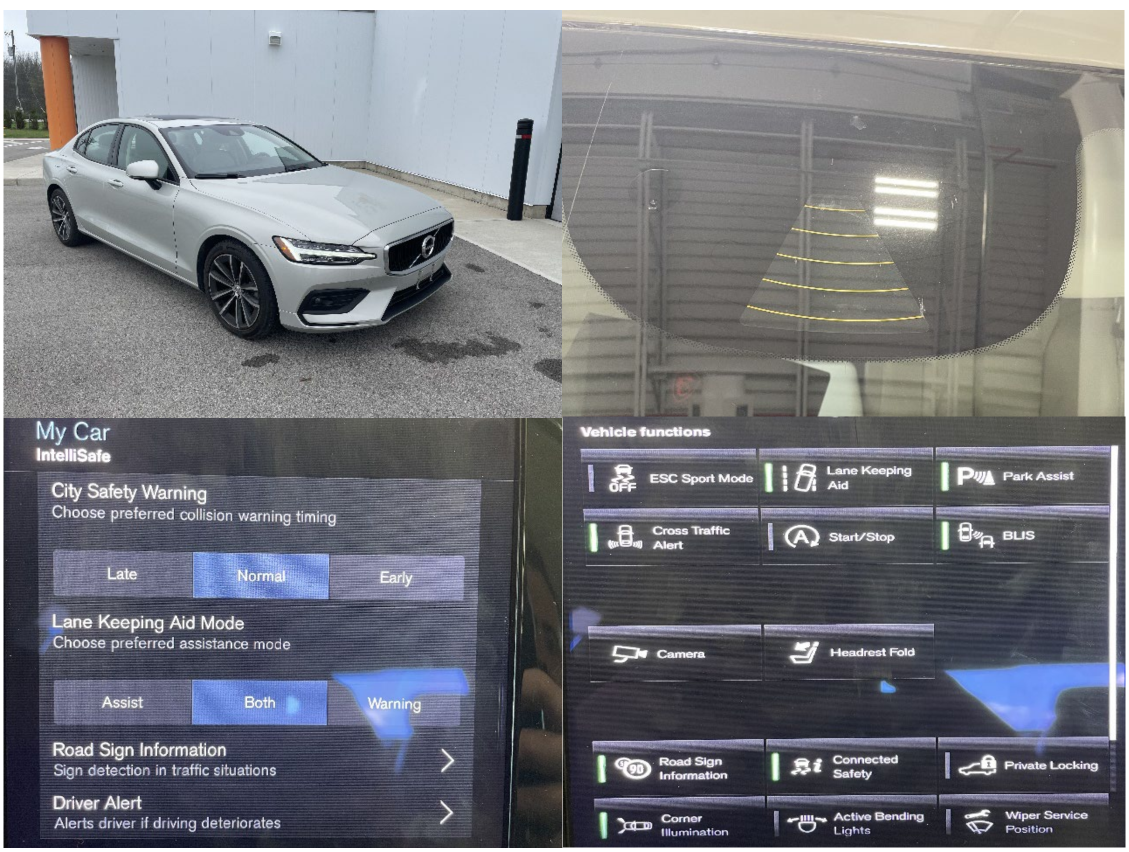

Vehicle Information	
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Model/Trim	NX250/FWD
Body Style	Sport Utility Vehicle
VIN	JTJADCAZ1N2001478
Date of Manufacture	01/22
Exterior Color	Dark Green
Pre-Test Odometer Reading	600 Miles
Date Vehicle Received	5/16/22
Engine Type/Displacement	2.5L Inline 4-Cylinder
Fuel Type	Unleaded 87
Transmission Type	8-Speed Automatic
Driveline Type (Rear, Front, or 4-Wheel Drive)	Front-Wheel Drive
Tire Size	235/60R18
Manufacturer/Tire Name	Bridgestone/Alenza A/S

Vehicle Weights (kg) From Placard	GVWR: 2,660		Tire Pressure Recommendation from Placard (PSI)	LF: 35	RF: 35
	GAWR(Front): 1,270	GAWR(Rear): 1,270		LR: 35	RR: 35

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October 2025

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