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16. Abstract

The research described in this report used lead vehicle stopped (LVS), lead vehicle moving (LVM), and lead vehicle decelerating (LVD) test scenarios to evaluate the automatic emergency braking (AEB) performance of six light vehicles. LVS tests were also used to study the effect of regenerative braking system settings, adaptive cruise control (ACC) settings, and ambient lighting on the AEB performance of these vehicles.

Crash avoidance summaries are provided where applicable. For test trials that concluded with the subject vehicle contacting the principal other vehicle, relative impact speeds are provided.

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1.0 TEST OBJECTIVES

The National Highway Traffic Safety Administration (NHTSA) research described in this report used three test scenarios to evaluate the automatic emergency braking (AEB) performance of six light vehicles. Additionally, one scenario was used to study the effect of regenerative braking system settings, adaptive cruise control (ACC) settings, and ambient lighting on the AEB performance of these vehicles.

2.0 TEST METHODOLOGY

The subject vehicle (SV) brakes were not manually applied during any test described in this report. Any SV speed reductions were only the result of the SV automatically responding to the driving situation and the contribution of regenerative braking, where applicable.

2.1 Test Maneuvers

Although certain test parameters differ, the core rear-end pre-crash scenarios used for the tests described in this report were defined in a Notice of Proposed Rulemaking published on June 12, 2023 (NHTSA, 2023):

Lead Vehicle Stopped (LVS): The SV approaches a stationary lead vehicle located in the forward path of the SV. The lead vehicle is also known as the principal other vehicle (POV).

Lead Vehicle Moving (LVM): The SV approaches a slower-moving POV traveling at a constant speed in the forward path of the SV.

Lead Vehicle Decelerating (LVD): After a short period of the SV following a POV in its forward path with a constant speed and headway, the lead vehicle is braked to a stop using a constant deceleration.

2.2 Test Speed, SV-to-POV Headway, and POV Deceleration

Table 1 presents a summary of the nominal SV and POV test speeds, SV-to-POV headways, and POV decelerations used for each test scenario discussed in this report. As shown in Table 1, only LVS tests were used during the AEB evaluations performed with varying regenerative braking and ACC settings. Additionally, only LVS tests were performed in the dark ambient lighting (≤0.2 lux) condition.

Note: To help differentiate the speed reduction attributable to regenerative braking from that achieved by AEB alone, the test matrix shown in Table 1 nominally required regenerative braking be manually set to "off" for all tests where its operation was not of specific interest. This was not possible for some vehicles; the actual settings used are explained in greater detail in Sections 2.7.1 and 2.7.3.2.

2.3 Accelerator Pedal Release Timing

For all tests, the SV accelerator pedal was released within 500 ms from when the auditory FCW alert was presented. If an FCW alert was not presented during a trial, the test speed was maintained until an impact with the POV occurred.

Table 1. NHTSA's 2023 Light Vehicle AEB Test Matrix

Test Scenario	Test Speeds (km/h)		Headway (m)	POV Decel. (g)	FCW Setting	ACC Setting	Regen. Braking Setting	Lighting Conditions
	SV	POV						
 Lead Vehicle Stopped (LVS)	10,40,50,60,70,80	0	--	--	Near	n/a	Off	Daylight
	10,40,50,60,70,80	0	--	--	Near	n/a	Off	Dark (≤0.2 lux)
	10,40,50,60,70,80	0	--	--	Near	n/a	Low, High	Daylight
	10,40,50,60,70,80	0	--	--	Near	Near, Mid, Far	Off	Daylight
 Lead Vehicle Moving (LVM)	70,80	20	--	--	Near	n/a	Off	Daylight
 Lead Vehicle Decelerating (LVD)	50,80	50,80 (same as SV)	12	0.5	Near	n/a	Off	Daylight

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

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

2.5 Use of Repeated Test Trials

Subject vehicle speed was iteratively increased from lowest to highest for each scenario and, for the work described in this report, a series of five trials per scenario/speed combination were nominally specified. However, if an SV-to-POV impact occurred during the first trial of the series, and the SV speed reduction at the time of the impact was less than 50 percent, then no additional trials were performed for that series or test scenario. Also, if a total of three impacts were observed during the within-series repeat sequence, the test series was terminated, and no further trials were performed for the test scenario. These provisions were used to help mitigate the potential for repeated SV-to-POV impacts, particularly those associated with high relative velocities, from damaging the SV, GVT, and/or other test equipment.

2.6 Test Validity Criteria

The tests described in this report were performed within the test tolerances described in Appendix Table A1.

2.7 Test Vehicles

This section includes SV and POV descriptions and/or driver-configurable settings relevant to the AEB evaluations described in this report. Subject vehicle weight ratings and as-tested weights are available in Appendix Table A2.

2.7.1 Subject Vehicles

The six SVs evaluated for the work described in this report are listed in Table 2. Descriptions of the available FCW, ACC, and regenerative braking settings for each vehicle are also available in Table 2.

Table 2. Subject Vehicles and Related AEB Systems.

Vehicle	AEB System		Other Available Settings		
	Name	Speed Range (km/h)	FCW	ACC	Regenerative Braking
2023 BMW iX xDrive50 AWD; EV	Forward Collision Mitigation	5 to 250 km/h[1] (3 to 155 mph)	Off, Early, Medium, Late[2]	Close[3], Medium[3], Far[3]	Low[4,5], average, or high[5] (in drive mode D) or B[6]
2023 Ford F-150 Lightning Super Crew Cab; 145-in. wheelbase; 4X4; EV	Pre-Collision Assist	5 to 130 km/h[7] (3 to 81 mph)	Blue, Yellow, Red[2]	Closest[3], Close[3], Medium, Far[3]	One Pedal Drive on[5] or off[4,5]
2023 Hyundai Ioniq 5 Limited AWD; EV	Forward Collision-Avoidance Assist	10 to 100 km/h[8] (6 to 62 mph)	Normal, Late[2]	Distance 1[3], 2[3], 3, 4[3]	Level 0[4], 1[5], 2, 3, i-Pedal[5]
2024 Mazda CX-90 Turbo S AWD	Smart Brake Support (SBS) forward drive detection	4 to 160 km/h (2.5 to 99 mph)	Early, Normal, Late[2]	Extremely short[3], Short[3], Medium, Long[3]	N/A
2023 Nissan Pathfinder SL AWD	Automatic Emergency Braking (AEB) with Pedestrian Detection	5 to 80 km/h[9] (3 to 50 mph)	On[2] or off	Short[3], Middle[3], Long[3]	N/A
2023 Toyota Corolla Hybrid XLE FWD sedan	Pre-Collision System (PCS)	5 to 180 km/h (3 to 110 mph)	Earlier, Default, Later[2]	Short[3], Medium[3], Long, Extra long[3]	N/A

[1]Owner's manual indicates that at speeds above approximately 210 km/h (130 mph) "only a brief brake intervention will occur" (Bayerische Motoren Werke, 2022).

[2]FCW setting used for all tests described in this report.

[3]Setting used for ACC-based tests.

[4]Regenerative brake settings used for nominal daylight and dark tests. Although maximum regenerative braking was present when "One Pedal Drive" was enabled, some regenerative braking was still present when the mode was switched off.

[5]Setting used for regenerative braking-based tests.

[6]Owner's manual states that "The degree of the deceleration depends on the selector lever position, the energy recovery setting and the driving situation." When driving with the drive mode selector in "D" the manual indicates that regenerative braking strength is adjustable (low, average, or high) and adaptive, and that drive mode "B" provides high regenerative braking with "very pronounced" deceleration (Bayerische Motoren Werke, 2022).

[7]Vehicle manufacturer specification provided in response to the NHTSA NCAP annual vehicle information request.

[8]Owner's manual indicates a number of factors can affect the operation speed range of the system. The maximum speed, which is stated to be possible if the vehicle is equipped with front corner radars, is provided in Table 2 (Hyundai Motor America, 2022).

[9]Owner's manual states the AEB system will not function when a stationary lead vehicle is approached at speeds over approximately 80 km/h (50 mph) (Nissan North America, Inc., 2023).

2.7.2 SV Brake Conditioning

Before the AEB performance of a given SV was evaluated, its respective brake pads and rotors were burnished according to the Laboratory Test Procedure for FMVSS 135 Light Vehicle Brake Systems (NHTSA, 2005)[1].

2.7.3 SV-Specific Settings

2.7.3.1 Forward Collision Warning

If the vehicle was equipped with a driver-configurable FCW (i.e., an ability to have the FCW alert presented at different time-to-collision values), the "nearest" setting was used; that which provided the shortest SV-to-POV headway at the time of the alert was used.

2.7.3.2 Regenerative Braking

The BMW iX, Ford F-150 Lightning, and Hyundai Ioniq 5 were fully electric vehicles equipped with driver-configurable regenerative braking system settings. With the exception of the tests specifically intended to examine the effect of regenerative braking on AEB performance, regenerative braking was either switched off (Hyundai Ioniq 5) or to a setting intended to minimize the amount of speed reduction produced between the time the SV driver released the accelerator pedal and the onset of braking automatically produced by the SV (BMW iX and Ford F-150 Lightning).

For the tests intended to evaluate the effect of regenerative braking on AEB performance, the settings that provided the least and highest deceleration in response to the SV driver releasing the accelerator pedal were used with one exception. In the case of the BMW iX, the combination of drive mode "D" and the "high" regenerative brake system setting was used. According to the BMW iX owner's manual, drive mode "B" would have been expected to realize even higher deceleration (Bayerische Motoren Werke, 2022). Since the BMW iX tests produced crash avoidance during each of the 30 trials performed in drive mode D with high regenerative braking, additional tests performed in drive mode B were deemed unnecessary for the exploratory research tests described in this report.

Note: Although the Toyota Corolla (a gasoline electric hybrid) was also equipped with a regenerative braking system, it was not equipped with driver-configurable regenerative braking system settings.

2.7.3.3 Adaptive Cruise Control

To quantify the effect of ACC on AEB performance, a series of tests using three ACC settings per SV was used. For the SVs with three available settings (i.e., those corresponding to the farthest, middle, and closest SV-to-POV headways), each was used. For the SVs that had four available settings, the "middle" setting was taken to be the second closest headway increment (setting 2 as shown in Figure 1). Figure 1 summarizes the ACC settings used for the tests described in this report (shown in green).

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[1] The Ford F-150 Lighting referenced in this report had a gross vehicle weight rating (GVWR) of 3810 kg (8400 lbs.). Although FMVSS No. 105 applies to this vehicle, it was still burnished using the process defined in FMVSS No. 135 test procedure. Although there are differences between the brake burnish procedures defined in the respective test procedures, these differences are not believed to have affected the overall findings of the research.

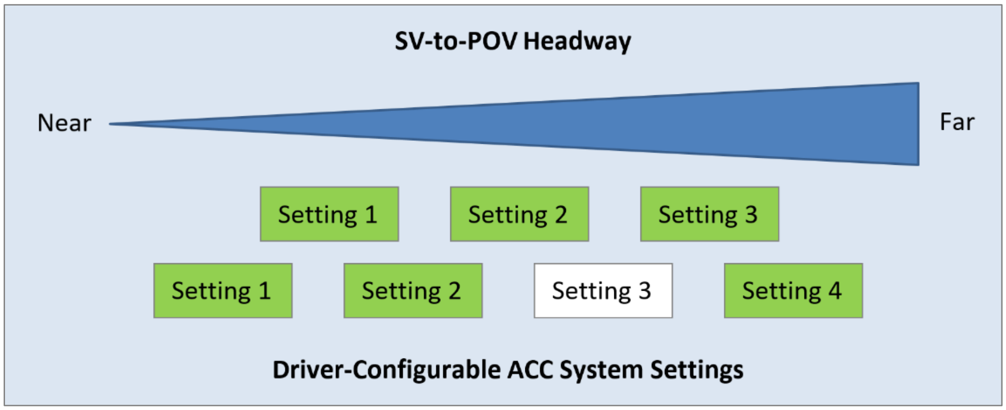

Figure 1. Driver-configurable settings used to evaluate the effect of ACC on AEB performance.

2.7.4 Principal Other Vehicle (POV)

An AB Dynamics (ABD) Global Vehicle Target (GVT) Revision G was used as the POV for all tests described in this report. This vehicle test device was secured to an ABD GST 120 robotic platform, as shown in Figure 2.

Figure 2. ABD GVT revision G vehicle test device secured to an ABD GST 120 robotic platform.

2.8 Test Equipment and Instrumentation

The equipment and instrumentation used to perform the tests is summarized in Appendix Tables A3 and A4. The robotic steering controller described in these tables is shown in Figure 3. With the exception of the tests performed with ACC, the SV test driver manually controlled all accelerator pedal inputs. For tests where an FCW alert was observed, the SV driver was also responsible for releasing the accelerator pedal in response to the alert.

Figure 3. Robotic steering controller.

2.9 Ambient Conditions

The ambient conditions observed during all trials described in this report were within the following parameters:

- The ambient temperature was between 7°C (45°F) and 40°C (104°F).
- The maximum wind speed was generally no greater than 10 m/s (22 mph).[2]
- The environment was free of inclement weather comprised of, but not limited to, rain, snow, hail, fog, smoke, ash, or other particulates.
- During daylight hours (expect for when the dark ambient lighting tests were performed since the ambient lighting was required to be ≤0.2 lux).
- The tests were not conducted with the SV and POV oriented into the sun during very low sun angle conditions (where the sun is oriented 15 degrees or less from horizontal).
- In an area void of overhead signs, bridges, or other significant structures over or near the testing site.
- No vehicles, obstructions, or stationary objects were within one lane width of either side of the SV path.

[2] A limited number of trials were performed with wind gusts that exceeded 10 m/s. However, the SV yaw rate measured during these trials was always withing the acceptable range defined in Appendix Table A1.

3.0 TEST RESULTS

3.1 Crash Avoidance and Relative Impact Speeds

Tables 3 through 10 provide an overall summary of the work described in this report. Trials where crash avoidance was observed are highlighted in green and labeled “CA”. Trials highlighted in red indicate an SV-to-POV contact was observed, and the relative impact speed is shown.

3.2 Nominal Condition

The nominal condition included LVS, LVM, and LVD tests performed in daylight conditions, manual SV speed modulation (i.e., no ACC), and with regenerative braking set to either “off” (where possible) or the minimum level. Results from the nominal condition tests are shown in Tables 3, 4, and 5.

3.2.1 LVS Performance

With the exception of the BMW iX, the per-vehicle AEB performance in the LVS scenario was largely consistent. For the remaining five vehicles, crash avoidance was observed up to a certain threshold speed; a speed where crash avoidance was either no longer observed or where both crash avoidance and mitigation both occurred within the same test speed series.

- The Toyota Corolla achieved crash avoidance during each of the five trials performed for each of the six test speeds.

- The Mazda CX-90 achieved crash avoidance for each trial performed at a speed of 60 km/h or less. However, each test performed at the next speed increment of 70 km/h resulted in SV-to-POV impact speeds of 20.7 to 22.4 km/h.

- The Ford F-150 Lightning, Hyundai Ioniq 5, and Nissan Pathfinder each achieved crash avoidance for all trials performed at a speed of 50 km/h or less. However, the manner in which each vehicle responded to the next speed increment (i.e., 60 km/h) varied.

    - The Ford F-150 Lightning avoided the POV during 2 of the 5 trials performed from 60 km/h, but three trials concluded with SV-to-POV impact speeds between 11.1 to 16.8 km/h.

    - The Hyundai Ioniq 5 impacted the POV during each of the three trials performed. Impact speeds ranged from 1.0 to 2.8 km/h.

    - The Nissan Pathfinder was unable to reduce its speed by ≥50 percent during the first trial performed at 60 km/h (an SV-to-POV impact at a speed of 34.9 km/h was observed), so only one test was performed at that speed.

- Unlike the other vehicles, the BMW iX impacted the POV during at least one trial for each of the test series performed at 10, 40, and 50 km/h. Since no FCW alert or AEB intervention occurred during each trial for which an impact occurred, and it was unclear if or when another impact would occur at the higher speeds (i.e., speeds capable of imposing significant damage to the SV and/or GVT), no additional LVS tests were performed with the vehicle in the nominal condition.

3.2.2 LVM Performance

Two SV speeds (70 and 80 km/h) and one POV speed (20 km/h) were used to evaluate AEB performance in the LVM test scenario. Prior to the speed reduction produced from the driver releasing the accelerator pedal or AEB braking, these conditions produced relative speeds of 50 and 60 km/h, respectively. Although the LVM AEB performance was largely consistent for a given SV, the SV response to the LVM vs. LVS scenario, for the same relative velocity, varied.

- The BMW iX, Hyundai Ioniq 5, and Toyota Corolla achieved crash avoidance during each of the five trials performed for both test speeds.
    - These results demonstrate improved consistency for the BMW iX (only crash avoidance was observed during the LVM tests) and capability for the Hyundai Ioniq 5 (crash avoidance was achieved with relative velocity of 60 km/h during the LVM trials, whereas impacts were observed during LVS tests performed with the same speed differential).
- For the Ford F-150 Lightning, SV-to-POV impacts were observed during each of the three LVM tests performed with a relative speed of 60 km/h. Impacts were observed during 3 of the 5 LVS trials performed with the same speed differential.
- The crash avoidance capability of both the Mazda CX-90 and Nissan Pathfinder was observed to be less than that recorded during the LVS tests.
    - Although crash avoidance was achieved during each LVS trial performed with the Mazda CX-90 at 60 km/h, LVM tests performed with the same relative speed produced an impact during 1 of the 5 trials.
    - Whereas the Nissan Pathfinder achieved crash avoidance during all LVS trials performed at 50 km/h, SV-to-POV impacts occurred during 3 of the 4 LVM trials performed with the same relative speed.

3.2.3 LVD Performance

Two SV and POV speed combinations were used for the LVD tests described in this report, 50 and 80 km/h. Whereas crash avoidance was generally observed for the 50 km/h tests (the exception being during 1 of 5 trials performed within the respective Hyundai Ioniq 5 and Nissan Pathfinder test series), only the BMW iX and Toyota Corolla were able to avoid the POV during at least some of the 80 km/h trials.

- The BMW iX avoided the POV during each of the LVD tests performed at 80 km/h.
- The Toyota Corolla avoided the POV during 2 of the 5 LVD tests performed at 80 km/h.

3.3 Effect of Dark Ambient Lighting

The only external illumination present during the dark ambient lighting tests was from the lower beams of the SV headlamps. That said, to be compliant with the specifications defined in ISO 19206-3 (International Organization for Standardization, 2021), the GVT incorporates reflective elements visible from the rear and oblique aspects to simulate taillights, brake light reflectors, bumper reflectors, and a rear license plate (AB Dynamics, 2023). The GVT used for the research described in this report was not equipped with external illumination (e.g., functional taillights); an optional feature that is permissible in ISO 19206-3.

Results from the dark ambient lighting tests are shown in Table 6. Recalling that only the LVS test scenario was used for these tests, the crash avoidance results observed during the dark ambient tests were largely consistent with those produced during the LVS tests performed in daylight.

- The dark versus day crash avoidance results observed for a given LVS test speed were identical or nearly identical for the Hyundai Ioniq 5, Mazda CX-90, Nissan Pathfinder, and Toyota Corolla. Where SV-to-POV impacts occurred, the impact speeds were very close among these vehicles.
    - For the Hyundai Ioniq 5, the ranges of impact speeds during the 60 km/h dark and day trials were 3.7 to 4.2 km/h and 1.0 to 2.8 km/h, respectively.
    - For the Mazda CX-90, the range of impact speeds observed during the 70 km/h tests performed during the day was nearly within that produced during the dark tests. The dark and day impact speed ranges were 20.8 to 26.9 km/h and 20.7 to 22.4 km/h, respectively.
    - The Nissan Pathfinder had one SV-to-POV impact during the dark tests performed at 10 km/h, whereas no impacts occurred during the day at that speed. However, the rest of the dark tests were largely consistent with those observed during day testing. In both lighting conditions, the SV AEB was unable to reduce speed by at least 50 percent before impacting the POV during first trial performed at 60 km/h. An impact at 30.6 km/h was observed during the dark tests versus 34.9 km/h in the daylight condition.
- Results from the dark tests performed with Ford F-150 Lightning were similar to those observed during the day. In both lighting conditions, SV-to-POV impacts only occurred during the respective 60 km/h test series. However, there were no instances of crash avoidance during the dark tests (crash avoidance occurred twice during the daylight tests at that speed), and the average impact speeds during the dark tests (23.7 km/h) was 78.2 percent greater than that of the tests performed in daylight (13.3 km/h).
- Dark versus daylight results from the BMW iX were the most disparate of the vehicles tested, largely due to the previously mentioned inconsistency of the daylight tests.
    - Tests performed at 10 and 40 km/h during the day produced at least one SV-to-POV impact for each speed condition, and no FCW or AEB response was observed during the trials which concluded with an impact. Conversely, crash avoidance was observed during each dark trial performed at the same speeds.
    - One SV-to-POV impact was observed within each test series performed at 50 km/h. However, no FCW or AEB response was observed during the test performed during daylight whereas a late and limited response was observed during the dark test (an impact speed of 44.2 km/h occurred during the dark test).

- One test was performed at 60 km/h in the dark ambient condition, whereas no similar test was performed during daylight. Although an FCW and AEB response occurred during this trial, an impact speed of 54.6 km/h was observed. No additional LVS tests were performed at 60 km/h to avoid potential damage to the SV, GVT, and/or other test equipment.

3.4 Effect of Regenerative Brake System Settings

Results from the AEB tests performed with regenerative braking set to the lowest and highest settings (as described in Section 2.7.3.2) are shown in Tables 7 and 8, respectively. Only the LVS test scenario was used for these tests. Overall, the effect of regenerative brake setting on the vehicle's ability to achieve crash avoidance during an AEB test performed at a given speed varied by SV.

Note: The crash avoidance and relative impact speed summaries shown in Table 7 are identical to the nominal condition results shown in Table 3 for the BMW iX, Ford F-150 Lightning, and Toyota Corolla. Regenerative braking could not be turned off entirely for the BMW iX and Ford F-150 Lightning. Although the Toyota Corolla was equipped with a regenerative brake system, it was not adjustable.

- For the BMW iX, use of the highest regenerative brake setting allowed the vehicle to realize crash avoidance during each of the five trials performed for each of the six test speeds. FCW and AEB activated during each trial performed at each speed when the highest regenerative brake setting was used. This is in contrast to the tests performed with the lowest regenerative brake setting, where at least one SV-to-POV impact occurred during the respective 10, 40, and 50 km/h test series due to AEB non-activation.

- Ford F-150 Lightning tests performed with the lowest and highest regenerative brake settings both achieved crash avoidance during each of the five respective trials performed at 10, 40, and 50 km/h. When the lowest regenerative brake setting was used, the vehicle avoided the POV during 2 of the 5 trials performed from 60 km/h. For the remaining three trials, the average impact speed was 13.3 km/h. When the highest regenerative brake setting was used, an SV-to-POV impact occurred during each of the three trials performed at 60 km/h and the average impact speed was 14.3 km/h; 7.5 percent higher than the average impact speed produced when the lowest regenerative brake setting was used.

- Hyundai Ioniq 5 tests performed with the lowest and highest regenerative brake settings both achieved crash avoidance during each of the five respective trials performed at 10, 40, and 50 km/h. However, when the test speed was increased to 60 km/h, crash avoidance was only observed during tests performed with the highest regenerative brake setting (during 4 of the 5 trials performed in that test series). For the one 60 km/h trial that resulted in an SV-to-POV impact, an impact speed of 1.3 km/h was observed. When the lowest regenerative brake setting was used, each 60 km/h trial resulted in an SV-to-POV impact and an average impact speed of 1.9 km/h.

  When highest regenerative brake setting was used with a test speed of 70 km/h, an SV-to-POV impact was observed during each of the three trials performed with the Hyundai Ioniq 5. The average impact speed of these trials was 16.4 km/h.

3.5 Effect of Adaptive Cruise Control Settings

Results from the AEB tests performed with ACC set to the nearest, middle, and farthest settings are shown in Tables 9, 10, and 11, respectively. Only the LVS test scenario was used for these tests.

It was not possible to perform the AEB evaluations with ACC and a test speed of 10 km/h. The ACC initialization threshold ranged from approximately 20 to 30 km/h for the vehicles evaluated in this study.

The use of ACC (any setting) allowed the BMW iX, Ford F-150 Lightning, Hyundai Ioniq 5, and Nissan Pathfinder to realize crash avoidance from higher speeds than achieved with AEB alone.

The BMW iX, Ford F-150 Lightning, Hyundai Ioniq 5, and Toyota Corolla achieved crash avoidance for all trials performed with each combination of test speed and ACC setting. This was also achieved for the Nissan Pathfinder when the closest and middle ACC settings were used, however with the farthest setting a 2.3 km/h SV-to-POV impact occurred during the first trial of the respective 80 km/h test series (crash avoidance was achieved during the four subsequent trials performed in this series).

The Mazda CX-90 achieved crash avoidance for all trials performed with each ACC setting during tests performed at 40, 50, and 60 km/h. However, SV-to-POV impacts were observed during each of the three 70 km/h trials performed using each ACC setting. The average impact speed associated with each ACC setting was nearly identical at 23.8, 25.3, and 26.3 km/h for the closest, middle, and farthest settings, respectively. The impact speed ranges from the tests performed with each ACC setting overlapped.

Table 3. LVS Test Results Crash Avoidance and Relative Impact Speed Summary (Nominal Condition).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 10 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	9.6	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 40 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	39.2	CA	CA	CA	CA	CA
	3	40.3	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 50 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	49.4	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 60 km/h POV = 0 km/h	1	--[1]	12.0	1.0	CA	34.9	CA
	2	--[1]	CA	2.5	CA	--[1]	CA
	3	--[1]	16.8	2.8	CA	--[1]	CA
	4	--[1]	CA	--[1]	CA	--[1]	CA
	5	--[1]	11.1	--[1]	CA	--[1]	CA
SV = 70 km/h POV = 0 km/h	1	--[1]	--[1]	--[1]	21.8	--[1]	CA
	2	--[1]	--[1]	--[1]	20.7	--[1]	CA
	3	--[1]	--[1]	--[1]	22.4	--[1]	CA
	4	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	5	--[1]	--[1]	--[1]	--[1]	--[1]	CA
SV = 80 km/h POV = 0 km/h	1	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	2	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	3	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	4	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	5	--[1]	--[1]	--[1]	--[1]	--[1]	CA

[1]Test not performed due to previously observed SV-to-POV contact.

CA = Crash Avoidance

Table 4. LVM Test Results Crash Avoidance and Relative Impact Speed Summary (Nominal Condition).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 70 km/h POV = 20 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	20.9	CA
	3	CA	CA	CA	CA	17.4	CA
	4	CA	CA	CA	CA	13.2	CA
	5	CA	CA	CA	CA	--[1]	CA
SV = 80 km/h POV = 20 km/h	1	CA	17.4	CA	CA	--[1]	CA
	2	CA	17.2	CA	9.4	--[1]	CA
	3	CA	22.8	CA	CA	--[1]	CA
	4	CA	--[1]	CA	CA	--[1]	CA
	5	CA	--[1]	CA	CA	--[1]	CA

[1]Test not performed due to previously observed SV-to-POV contact.

CA = Crash Avoidance

Table 5. LVD Test Results Crash Avoidance and Relative Impact Speed Summary (Nominal Condition).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 50 km/h POV = 50 km/h POV decel = 0.5g SV-to-POV headway = 12 m	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	20.3	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	4.0	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 80 km/h POV = 80 km/h POV decel = 0.5g SV-to-POV headway = 12 m	1	CA	12.6	15.2	21.5	27.1	CA
	2	CA	12.2	13.9	--[1]	--[1]	5.1
	3	CA	12.2	13.7	--[1]	--[1]	CA
	4	CA	--[1]	--[1]	--[1]	--[1]	2.9
	5	CA	--[1]	--[1]	--[1]	--[1]	2.5

[1]Test not performed due to previously observed SV-to-POV contact.

CA = Crash Avoidance

Table 6. LVS Test Results Crash Avoidance and Relative Impact Speed Summary (Dark Ambient Lighting).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 10 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	3.0	CA
	5	CA	CA	CA	CA	CA	CA
SV = 40 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 50 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	44.2	CA	CA	CA	CA	CA
SV = 60 km/h POV = 0 km/h	1	54.6	22.8	3.7	CA	30.6	CA
	2	--[1]	24.6	4.2	CA	--[1]	CA
	3	--[1]	23.7	4.2	CA	--[1]	CA
	4	--[1]	--[1]	--[1]	CA	--[1]	CA
	5	--[1]	--[1]	--[1]	CA	--[1]	CA
SV = 70 km/h POV = 0 km/h	1	--[1]	--[1]	--[1]	21.3	--[1]	CA
	2	--[1]	--[1]	--[1]	20.8	--[1]	CA
	3	--[1]	--[1]	--[1]	26.9	--[1]	CA
	4	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	5	--[1]	--[1]	--[1]	--[1]	--[1]	CA
SV = 80 km/h POV = 0 km/h	1	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	2	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	3	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	4	--[1]	--[1]	--[1]	--[1]	--[1]	CA
	5	--[1]	--[1]	--[1]	--[1]	--[1]	CA

[1]Test not performed due to previously observed SV-to-POV contact.

CA = Crash Avoidance

Table 7. LVS Test Results Crash Avoidance and Relative Impact Speed Summary (Lowest Regen. Brake Setting).

Test Conditions	Trial #	2023 BMW iX xDrive50[1]	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid[1]
SV = 10 km/h POV = 0 km/h	1	CA	CA	CA	--[3]	--[3]	CA
	2	9.6	CA	CA	--[3]	--[3]	CA
	3	CA	CA	CA	--[3]	--[3]	CA
	4	CA	CA	CA	--[3]	--[3]	CA
	5	CA	CA	CA	--[3]	--[3]	CA
SV = 40 km/h POV = 0 km/h	1	CA	CA	CA	--[3]	--[3]	CA
	2	39.2	CA	CA	--[3]	--[3]	CA
	3	40.3	CA	CA	--[3]	--[3]	CA
	4	CA	CA	CA	--[3]	--[3]	CA
	5	CA	CA	CA	--[3]	--[3]	CA
SV = 50 km/h POV = 0 km/h	1	CA	CA	CA	--[3]	--[3]	CA
	2	CA	CA	CA	--[3]	--[3]	CA
	3	CA	CA	CA	--[3]	--[3]	CA
	4	49.4	CA	CA	--[3]	--[3]	CA
	5	CA	CA	CA	--[3]	--[3]	CA
SV = 60 km/h POV = 0 km/h	1	--[2]	12.0	1.5	--[3]	--[3]	CA
	2	--[2]	CA	2.2	--[3]	--[3]	CA
	3	--[2]	16.8	2.1	--[3]	--[3]	CA
	4	--[2]	CA	--[2]	--[3]	--[3]	CA
	5	--[2]	11.1	--[2]	--[3]	--[3]	CA
SV = 70 km/h POV = 0 km/h	1	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	2	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	3	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	4	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	5	--[2]	--[2]	--[2]	--[3]	--[3]	CA
SV = 80 km/h POV = 0 km/h	1	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	2	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	3	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	4	--[2]	--[2]	--[2]	--[3]	--[3]	CA
	5	--[2]	--[2]	--[2]	--[3]	--[3]	CA

[1]The lowest regenerative brake setting was the same used for the nominal condition; [2]Test not performed due to previously observed SV-to-POV contact; [3]Test not performed, vehicle not equipped with regenerative braking or regenerative braking is not configurable.

CA = Crash Avoidance

Table 8. LVS Test Results Crash Avoidance and Relative Impact Speed Summary (Highest Regen. Brake Setting).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 10 km/h POV = 0 km/h	1	CA	CA	CA	--[2]	--[2]	--[2]
	2	CA	CA	CA			
	3	CA	CA	CA			
	4	CA	CA	CA			
	5	CA	CA	CA			
SV = 40 km/h POV = 0 km/h	1	CA	CA	CA			
	2	CA	CA	CA			
	3	CA	CA	CA			
	4	CA	CA	CA			
	5	CA	CA	CA			
SV = 50 km/h POV = 0 km/h	1	CA	CA	CA			
	2	CA	CA	CA			
	3	CA	CA	CA			
	4	CA	CA	CA			
	5	CA	CA	CA			
SV = 60 km/h POV = 0 km/h	1	CA	15.6	CA			
	2	CA	16.1	1.3			
	3	CA	11.3	CA			
	4	CA	--[1]	CA			
	5	CA	--[1]	CA			
SV = 70 km/h POV = 0 km/h	1	CA	--[1]	16.4			
	2	CA	--[1]	14.9			
	3	CA	--[1]	18.0			
	4	CA	--[1]	--[1]			
	5	CA	--[1]	--[1]			
SV = 80 km/h POV = 0 km/h	1	CA	--[1]	--[1]			
	2	CA	--[1]	--[1]			
	3	CA	--[1]	--[1]			
	4	CA	--[1]	--[1]			
	5	CA	--[1]	--[1]			

[1]Test not performed due to previously observed SV-to-POV contact; [2]Test not performed, vehicle not equipped with regenerative braking or regenerative braking is not configurable.

CA = Crash Avoidance

Table 9. LVS Test Results Crash Avoidance and Relative Impact Speed Summary (Closest ACC Setting).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 10 km/h POV = 0 km/h	1	--[1]	--[1]	--[1]	--[1]	--[1]	--[1]
	2						
	3						
	4						
	5						
SV = 40 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 50 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 60 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 70 km/h POV = 0 km/h	1	CA	CA	CA	26.4	CA	CA
	2	CA	CA	CA	25.9	CA	CA
	3	CA	CA	CA	19.2	CA	CA
	4	CA	CA	CA	--[2]	CA	CA
	5	CA	CA	CA	--[2]	CA	CA
SV = 80 km/h POV = 0 km/h	1	CA	CA	CA	--[2]	CA	CA
	2	CA	CA	CA	--[2]	CA	CA
	3	CA	CA	CA	--[2]	CA	CA
	4	CA	CA	CA	--[2]	CA	CA
	5	CA	CA	CA	--[2]	CA	CA

[1]Test not performed, speed below ACC minimum speed threshold; [2]Test not performed due to previously observed SV-to-POV contact.

CA = Crash Avoidance

Table 10. LVS Test Results Crash Avoidance and Relative Impact Speed Summary (Middle ACC Setting).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 10 km/h POV = 0 km/h	1	--[2]	--[2]	--[2]	--[2]	--[2]	--[2]
	2						
	3						
	4						
	5						
SV = 40 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 50 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 60 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 70 km/h POV = 0 km/h	1	CA	CA	CA	22.3	CA	CA
	2	CA	CA	CA	27.6	CA	CA
	3	CA	CA	CA	25.9	CA	CA
	4	CA	CA	CA	--[1]	CA	CA
	5	CA	CA	CA	--[1]	CA	CA
SV = 80 km/h POV = 0 km/h	1	CA	CA	CA	--[1]	CA	CA
	2	CA	CA	CA	--[1]	CA	CA
	3	CA	CA	CA	--[1]	CA	CA
	4	CA	CA	CA	--[1]	CA	CA
	5	CA	CA	CA	--[1]	CA	CA

[1]Test not performed due to previously observed SV-to-POV contact; [2]Test not performed, speed below ACC minimum speed threshold.

CA = Crash Avoidance

Table 11. LVS Test Results Crash Avoidance and Relative Impact Speed Summary (Farthest ACC Setting).

Test Conditions	Trial #	2023 BMW iX xDrive50	2023 Ford F-150 Lightning	2023 Hyundai Ioniq 5	2024 Mazda CX-90	2023 Nissan Pathfinder	2023 Toyota Corolla Hybrid
SV = 10 km/h POV = 0 km/h	1	--[2]	--[2]	--[2]	--[2]	--[2]	--[2]
	2						
	3						
	4						
	5						
SV = 40 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 50 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 60 km/h POV = 0 km/h	1	CA	CA	CA	CA	CA	CA
	2	CA	CA	CA	CA	CA	CA
	3	CA	CA	CA	CA	CA	CA
	4	CA	CA	CA	CA	CA	CA
	5	CA	CA	CA	CA	CA	CA
SV = 70 km/h POV = 0 km/h	1	CA	CA	CA	29.5	CA	CA
	2	CA	CA	CA	24.7	CA	CA
	3	CA	CA	CA	24.7	CA	CA
	4	CA	CA	CA	--[1]	CA	CA
	5	CA	CA	CA	--[1]	CA	CA
SV = 80 km/h POV = 0 km/h	1	CA	CA	CA	--[1]	2.3	CA
	2	CA	CA	CA	--[1]	CA	CA
	3	CA	CA	CA	--[1]	CA	CA
	4	CA	CA	CA	--[1]	CA	CA
	5	CA	CA	CA	--[1]	CA	CA

[1]Test not performed due to previously observed SV-to-POV contact; [2]Test not performed, speed below ACC minimum speed threshold.

CA = Crash Avoidance

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APPENDIX A. SUPPLEMENTAL TABLES

Test parameters, acceptable ranges, and assessment ranges are described in Table A1.

The subject vehicle front and rear axle weight ratings (GAWR), gross vehicle weight ratings (GVWR), and as-tested weights are shown in Table A2.

A description of the test equipment, its location in the SV and POV, and respective weight is described in Table A3.

Sensor descriptions and specifications of the instrumentation used to perform the tests described in this report is described in Table A4.

Table A1. Test Parameter Tolerances.

Parameter	Acceptable Range	Assessment Interval (For Valid Test Conduct)	Scenario		
			LVS	LVM	LVD
SV speed	Nominal ± 1.6 km/h	From TTC = 5.0 seconds to FCW onset	✓	✓	✓
POV speed	Nominal ± 1.6 km/h	From TTC = 5.0 seconds until POV deceleration = 0.05g		✓	✓
SV yaw rate	± 1 degree	From TTC = 5.0 seconds to FCW onset	✓	✓	✓
SV path deviation	± 0.3 meters	From TTC = 5.0 seconds to FCW onset	✓	✓	✓
POV placement	± 0.3 meters	From TTC = 5.0 seconds to EOT*	✓		
POV path deviation	± 0.3 meters	From TTC = 5.0 seconds to EOT*		✓	✓
SV-to-POV path deviation	± 0.3 meters	From TTC = 5.0 seconds to FCW onset	✓	✓	✓
POV brake onset threshold	POV deceleration = 0.05g	≥ 3 seconds after test validity assessment is initiated			✓
POV deceleration onset	Nominal ± 10%	Within 1.25 ± 0.25 s after POV brake onset			✓
POV average deceleration magnitude	Nominal ± 10%	From 1.5 seconds after POV brake onset until (1) impact or (2) 250 ms before the POV has stopped			✓
SV accelerator release threshold	Accelerator position ≤ 5%	From FCW onset + 0.5 seconds to EOT*	✓	✓	✓
SV initial brake temperature (front axle)	65 to 100 deg Celsius	At TTC = 5.0 seconds	✓	✓	✓

*EOT = end of test. For the LVS scenario, this occurs when either (1) the SV impacts the POV, or (2) 1 second after the SV has stopped. For the LVM scenario, this occurs when either (1) the SV impacts the POV, or (2) 1 second after the SV first falls below that of the POV. For the LVD scenario, this occurs when either (1) the SV impacts the POV, or (2) 1 second after the SV has stopped.

Table A2. Subject Vehicle Weight Information.

Vehicle	GAWR		GVWR	Weight As Tested[1]		Total Weight As Tested[1]
	Front	Rear		Front	Rear	
2023 BMW iX xDrive50 AWD; EV	1530 kg (3373 lbs.)	1770 kg (3902 lbs.)	3115 kg (6867 lbs.)	1300 kg (2867 lbs.)	1488 kg (3280 lbs.)	2788 kg (6147 lbs.)
2023 Ford F-150 Lightning Super Crew Cab; 4X4; 145-in. wheelbase; EV	1787 kg (3940 lbs.)	2177 kg (4800 lbs.)	3810 kg (8400 lbs.)	1638 kg (3610 lbs.)	1614 kg (3559 lbs.)	3252 kg (7169 lbs.)
2023 Hyundai Ioniq 5 Limited AWD; EV	1280 kg (2822 lbs.)	1370 kg (3020 lbs.)	2540 kg (5600 lbs.)	1136 kg (2504 lbs.)	1203 kg (2653 lbs.)	2339 kg (5157 lbs.)
2024 Mazda CX-90 Turbo S AWD	1273 kg (2806 lbs.)	1651 kg (3640 lbs.)	3109 kg (6854 lbs.)	1242 kg (2739 lbs.)	1238 kg (2729 lbs.)	2480 kg (5468 lbs.)
2023 Nissan Pathfinder SL AWD	1335 kg (2943 lbs.)	1530 kg (3373 lbs.)	2676 kg (5900 lbs.)	1205 kg (2657 lbs.)	1045 kg (2303 lbs.)	2250 kg (4960 lbs.)
2023 Toyota Corolla Hybrid XLE Sedan	1050 kg (2315 lbs.)	971 kg (2140 lbs.)	1844 kg (4065 lbs.)	892 kg (1966 lbs.)	677 kg (1492 lbs.)	1569 kg (3458 lbs.)

[1]Fully fueled, instrumentation, driver, in-vehicle experimenter(s).

Table A3. Test Equipment Description, Location, Weight.

Equipment Description	Equipment Used	Typical Location	Nominal Weight
Data Acquisition System (DAS)	Internally developed comprised of a NUC, PEAK modules, ethernet switch, laptop, and power converters	SV rear cargo area (e.g., trunk)	DAS ≈ 15 kg (32 lbs.) External batteries ≈ 23 to 29 kg (50 to 64 lbs.)
Integrated Inertial Measurement Unit and GPS (SV)	Oxford Technical Solutions (OxTS) RT 3000 series, NovAtel high precision antenna, FreeWave industrial radio and antenna	Antennas mounted to the roof of the SV. IMU/GPS securely positioned in the SV rear cargo area. GPS acquisition and ancillary equipment installed/secured in the SV rear cargo area.	RT 3000 ≈ 4 kg (8 lbs.) FreeWave ≈ 1 kg (3 lbs.)
Integrated Inertial Measurement Unit and GPS (POV)	OxTS RT 3000 series and antenna	Antenna mounted to the POV. IMU/GPS securely positioned within the POV near the center of the unit. GPS acquisition and ancillary equipment securely positioned within the POV.	≈ 4 kg (8 lbs.)
Programmable Driving Robot	AB Dynamics (ABD) SR15 steering robot, electronics box, battery box, and communications antenna.	Antenna mounted to the roof of the SV. Driving robot is connected to the steering wheel and windshield. The robot controller electronics box and batteries are typically secured in the SV rear cargo area.	Steering robot ≈ 5 kg (11 lbs.) Robot controller electronics box ≈ 12 kg (27 lbs.) Battery box ≈ 18 kg (39 lbs.) Antenna ≈ 4 kg (8 lbs.)
Sound Acquisition System	DBX equalizer, Xenyx mixing console, and microphone	Equalizer and mixing board positioned in the SV near the center of the vehicle, just behind the front seats. Microphone positioned near alert speakers.	≈ 5 kg (11 lbs.)
Vehicle-to-vehicle range receiver *(wireless communication between the SV and POV)*	OxTS RT Range, ABD communications antenna, driver displays	Antenna mounted to the roof of the SV. Ancillary equipment secured in the SV rear cargo area.	RT Range ≈ 2 kg (4 lbs.) Display boxes ≈ 2 kg (4 lbs.)
Vehicle-to-vehicle range transmitter *(wireless communication between the SV and POV)*	ABD communications antenna	Antenna mounted to the POV. Ancillary equipment secured within the POV.	≈ 0.5 kg (1 lb.)

Table A4. Sensor Descriptions and Specifications.

Type	Output	Range	Resolution	Accuracy
Longitudinal Speed Sensor	SV and POV longitudinal speed	0.1 – 241 km/h (0.1 – 150 mph)	0.05 km/h (0.031 mph)	± 0.25% of full scale range
Rate Sensor	SV yaw rate	± 100 deg/s	0.01 deg/s	± 0.05% of full scale range
SR Torque	SV steering controller torque	0 – 15 N-m (0 – 11 lb-ft)	1.5 N-m (± 1.1 lb-ft)	± 1.5 N-m (± 1.1 lb-ft)
Accelerometer	SV and POV longitudinal deceleration	± 10g	0.01g	± 0.01% of full scale range
Position Sensor (String Potentiometer)	SV brake pedal position	0 – 20.3 cm (0 – 8 in.)	0.03 mm (0.001 in.)	± 0.3 mm (± 0.01 in.)
Position Sensor (String Potentiometer)	SV throttle position	0 – 100 percent (normalized)	0.1 percent	± 0.1 percent
Differential GPS	Longitudinal position of SV and POV	N/A	1 mm (0.04 in.)	± 10 mm (± 0.4 in.)
Vehicle Dimensional Measurements	Location of SV and POV GPS antennas; SV and POV centerlines; front-most SV bumper position; rear-most POV bumper position.	N/A	1 mm (0.04 in)	± 1 mm (± 0.04 in)
SV-to-POV Static Range	Distance between POV and rear-most POV bumper position.	N/A	1 mm (0.04 in.)	± 10 mm (± 0.4 in.)
Microphone	Frequency and Intensity of FCW alert	20 Hz – 20 kHz; 0 – 112 dB	-33 dB at 1 kHz	N/A
FARO	SV and POV measuring	N/A	1,200,000 points per second	± 0.065 mm (± 0.003 in)