Active Park Assist Draft Test Procedure Validation

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16. Abstract

The 13 test scenarios described in NHTSA's August 2019 draft research active park assist (APA) test procedure were used to evaluate the system performance of three passenger cars: a 2017 BMW 540i, a 2017 Tesla Model S 90D, and a 2018 Cadillac CT6. This report discusses the test results and provides a general assessment of the scenarios used. The August 2019 version of this draft test procedure is an update to that was originally published in April 2018.

The test scenarios were intended to emulate commonly encountered perpendicular and parallel parking scenarios. Two scenarios evaluated how the subject vehicle (SV) performed back-in parking maneuvers. Three scenarios tested the SV response to a pedestrian encroaching into the parking space while the vehicle performed the parking maneuver. Two scenarios examined the SV response to a following vehicle that stops and obstructs the SV path when it began to perform the parking maneuver. Finally, six scenarios were designed to see how the SV reacts to the driver performing a manual override of the steering, accelerator pedal, or brake pedal inputs as the SV performed the parking maneuver.

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Glossary

APA	active park assist
CW	clockwise
CCW	counterclockwise
DNMC	does not meet criteria
DRI	Dynamic Research, Inc.
GST	Guided Soft Target
GVT	Global Vehicle Target
LPRV	Low Profile Robotic Vehicle
MC	meets criteria
PED	surrogate pedestrian (test mannequin)
POV	principal other vehicle
PV	parked vehicle
SV	subject vehicle

Executive Summary

The primary objective of the work described in this report was to validate NHTSA's August 2019 active park assist (APA) draft research test procedure (NHTSA, 2019). This draft test procedure, which is an update to that previously published in April 2018 (NHTSA, 2018), was designed to objectively and effectively assess the performance of APA systems presently available on some light vehicles sold in the United States.

The draft test procedure defines 13 commonly encountered perpendicular and parallel parking test scenarios to assess APA system performance. Two scenarios evaluated how the subject vehicle (SV)performed back-in parking maneuvers. Three scenarios tested the SV response to a pedestrian encroaching into the parking space while the vehicle performed the parking maneuver. Two scenarios examined the SV response to a following vehicle that stops and obstructs the SV path when it began to perform the parking maneuver. Finally, 6 scenarios were designed to see how the SV reacts to the driver performing a manual override of the steering, accelerator pedal, or brake pedal inputs as the SV performed the parking maneuver.

Three vehicles equipped with APA were used for testing: a 2017 BMW 540i, a 2017 Tesla Model S 90D, and a 2018 Cadillac CT6. The APA systems in the 2017 BMW 540i and the 2017 Tesla Model S 90D control steering, brake, throttle, and gear selection. The APA system in the 2018 Cadillac CT6 controls steering, brake, and throttle, but the driver manually controls gear selection.

Five trials were performed for each scenario. The BMW 540i met all testing criteria in 38 out of 65 trials, the Tesla Model S met all testing criteria in 32 out of 55 trials, and the Cadillac CT6 met all testing criteria in 25 out of 65 trials. The testing verified that the most recent version of NHTSA's draft APA test procedure has the potential to effectively evaluate vehicles equipped with APA technology.

1. Introduction

Active park assist is an advanced driver assistance system designed to assist drivers with parallel or perpendicular parking. APA should identify viable parking spaces capable of fitting the driver's vehicle and maneuver the vehicle into the parking space without striking any obstacles (pedestrians, other vehicles, etc.) with minimal-to-no input from the driver. APA systems provide, at a minimum, automated steering control. The systems may also provide automated accelerator and brake application, as well as gear selection.

NHTSA developed the June 2019 draft APA test procedure (subsequently referred to simply as the "draft test procedure") for research purposes, and to provide a documented process by which system operation and effectiveness can be objectively assessed (NHTSA, 2019). This draft test procedure is an update to that originally published in April 2018 (NHTSA, 2018). Compared to the previous version, the August 2019 update features improved clarity, ease of test conduct, and general performability.[1]

This report details the track testing to validate the most recent version of the agency's draft test procedure. Test protocols, results, and conclusions are provided.

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[1] Specific details are provided in Section 3.

2. Test Protocol

2.1. Subject Vehicles

Results from three subject vehicles equipped with APA are described in this report.

1. 2017 BMW 540i
2. 2017 Tesla Model S 90D
3. 2018 Cadillac CT6

A brief overview of each vehicle's respective APA system is provided in **Table 2-1** and Sections 2.1.1, 2.1.2, and 2.1.3.

APA system capabilities vary by manufacturer and operating conditions, and are defined in the respective owners manuals. An overview of each system is provided in the following sections.

Table 2-1. Test Vehicles, Sensing Technologies, and APA Activation

Vehicle	Sensing Technology		APA Activation
	Ultrasonic	**Vision**	
2017 BMW 540i	4 sensors on front and rear bumpers and one mounted at each corner of the vehicle	Cameras located near interior mirror, front and rear bumper, and side mirrors	Press park assist button
2017 Tesla Model S 90D	4 sensors on front and rear bumpers and one mounted at each corner of the vehicle	Cameras located near interior mirror, front fenders, rear bumper, and each door pillar	Vehicle settings menu
2018 Cadillac CT6	4 sensors on front and rear bumpers and one mounted at each corner of the vehicle	Cameras located near interior mirror, front and rear bumper, and side mirrors	Press park assist button

2.1.1. 2017 BMW 540i

The 2017 BMW 540i is an all-wheel drive, 4-door passenger car equipped with APA and other active safety technologies. The APA system controls throttle, brake, steering, and gear selection during the parking maneuver (Bayerische Motoren Werke AG, 2017). To use the BMW 540i automatic parking feature, the driver presses the park assistance button, as shown in **Figure 2-1** on the following page.

Figure 2-1. BMW 540i park assistance button

Once activated, the system will scan for parking spaces large enough to accommodate the vehicle. When a suitable space is found, the vehicle alerts the driver to stop the vehicle with both an audible and visual alert. Once the driver responds to these alerts, the instructions displayed on the vehicle's infotainment system guide the driver through the parking process using the following notifications.

1. Activate turn signal to initiate parking maneuver

2. Reminder that it is the driver's responsibility to pay attention and intervene if necessary

3. Take hands off steering wheel and press parking assistance button

4. Release brake so vehicle can begin parking

For examples of these notifications, see **Appendix A.1**.

Once the APA system has completed the parking maneuver, it brings the vehicle to a stop and notifies the driver that the maneuver is complete.

2.1.2.   2017 Tesla Model S 90D

The 2017 Tesla Model S 90D is an all-wheel drive, 4-door passenger car equipped with APA and other active safety technologies. The APA system controls throttle, brake, steering, and gear selection during the parking maneuver. The Tesla Model S does not require the driver to press any buttons to activate the automatic parking feature; once enabled in a settings menu, the APA system remains enabled until it is de-activated. At low speeds, the system will scan for parking spaces large enough to accommodate the vehicle. When a suitable space is found, the APA system will alert the driver with a visual alert on the instrument cluster (Tesla Motors, Inc., 2018). Once the driver brings the vehicle to a stop in response to this alert, the instructions displayed on the vehicle's infotainment system guide the driver through the parking process using the following notifications.

1. Press "Start" button to initiate parking maneuver

2. Release brake so vehicle can begin parking

For examples of these notifications, see **Appendix A.2**.

Once the APA system has completed the parking maneuver, it brings the vehicle to a stop and notifies the driver that the maneuver is complete.

The software in the Tesla Model S was version v8.1 build 2018.10.4 at the time of testing.

2.1.3. 2018 Cadillac CT6

The 2018 Cadillac CT6 is an all-wheel drive, 4-door passenger car equipped with APA and other active safety technologies. The APA system controls throttle, brake, and steering during the parking maneuver, but the driver must manually operate the transmission shifter when prompted to do so. To use the Cadillac CT6 automatic parking feature, a driver begins by press the parking assist button, shown in **Figure 2-2**. Once activated, the system will scan for parking spaces large enough to accommodate the vehicle (General Motors LLC, 2017). When a suitable space is found, the APA system alerts the driver with both an audible and visual alert, also shown in **Figure 2-2**.

Figure 2-2. Cadillac CT6 automatic parking assist button and alert

Once the driver brings the vehicle to a stop and shifts into reverse in response to these alerts, the instructions displayed on the vehicle's infotainment system guide the driver through the parking process using the notifications below.

1. Automatic steering enabled and be prepared to brake – release steering wheel and brake
2. Alternating notifications to back up or drive forward – switch to respective gears, reverse or drive, as necessary

For examples of these notifications, see **Appendix A.3**.

Once the APA system has completed the parking maneuver, it brings the vehicle to a stop and notifies the driver that the maneuver is complete.

2.2. Test Targets and Parked Vehicles

The test targets and parked vehicles used in this program are described in the following sections.

2.2.1. Surrogate Pedestrian

A "static pedestrian" mannequin manufactured by 4activeSystems GmbH, of Traboch, Austria, was used as the surrogate pedestrian test mannequin, subsequently referred to as the PED, for all tests requiring a pedestrian. This PED is a 50th percentile adult male-sized static (non-articulating) posable mannequin designed to appear realistic to the sensors used by automotive safety systems and automated vehicles including radar (24 and 76-77 GHz), cameras, and lidar. Appropriate reflective characteristics are achieved by using specific treatments to the PED skin surfaces, clothing, and test apparatus. The PED is secured to a shallow platform (using magnets), which is accurately pulled along a pre-programmed path using closed loop control relative to the SV. If hit by the SV, the PED is typically pushed off and away from the platform, which is then pushed against the ground and stops as the test vehicle is driven over it. The PED can be repeatedly struck from any approach angle without harm to those performing the tests or the vehicles being evaluated. Reassembly and securing the PED back to top of the platform takes one person approximately 1 minute to complete. The PED and platform are shown in **Figure 2-3**.

Figure 2-3. 4activeSystems static pedestrian

2.2.2. Surrogate Vehicle

The Guided Soft Target (GVT), developed by Dynamic Research, Inc., was used as the principal other vehicle (POV) for the obstructing vehicle scenarios. The GST is comprised of two main parts, the Low Profile Robotic Vehicle (LPRV) shown in **Figure 2-4**, and the GVT shown in **Figure 2-5**. This system provides accurate closed loop control of the GST relative to the SV, and because it is strikeable from any

approach aspect it can be incorporated into nearly any pre-crash scenario. Multiple fail-safe measures are designed to ensure the safe operation of the GST.
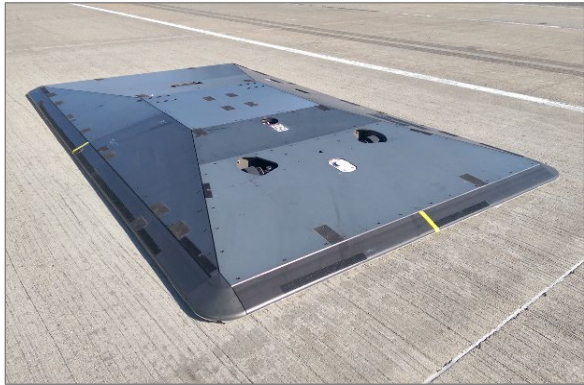
Figure 2-4. DRI GST LPRV

Figure 2-5. GVT atop of the LPRV

2.2.3.   *Parked Vehicles*

For all APA tests described in this report, actual parked vehicles[2] were positioned in the parking spaces adjacent to the desired SV parking space.

- 2008 Infiniti EX35: 182.0" (L) X 71.0" (W)

- 2016 Tesla Model S 85D: 196.0" (L) X 77.3" (W)

- 2017 BMW 540i: 194.6" (L) X 73.5" (W)

- 2017 Mercedes E300: 193.8" (L) X 72.9" (W)

- 2017 Tesla Model S 90D: 196.0" (L) X 77.3" (W)

- 2018 Cadillac CT6: 204.1" (L) X 74.0" (W)

2.3. **Test Scenarios and Assessment Criteria**

Brief descriptions of the scenarios, validity criteria, and evaluation criteria used for the tests described in this report are provided in sections 2.3.1 through 2.3.6; additional details can be found in NHTSA's APA draft research test procedure (NHTSA, 2018). All tests were performed with an approach speed of 6 mph (9.7 km/h). The approach and termination boundaries shown in **Figure 2-6** help define the validity period[3] for each test. The approach and termination boundaries are perpendicular to the approach lane. Validity

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[2] The test procedure specifies that PVs shall be between 175 to 197 in. (455 to 500 cm) long and 70 to 76 in. (178 to 193 cm) wide. While some of the PVs used for the tests described in this report did not fall within this range, it is not believed this confounded test results. This is because the PVs on either side of the SV's desired parking space were positioned in the spot based on their nearest sides being 1 ft (0.3 m) away from the near edge of the parking space lines. Therefore, the size of the SV's desired parking space was kept constant regardless of the size of the PVs.

[3] The validity period is an interval during which all test tolerances must be satisfied. More details are available in Section 2.3.5 of this report.

assessments for each test start one second before the SV crosses the approach boundary and the test is terminated if the rearmost part of the SV crosses the termination boundary.

Note: The test facilities available at the time of testing did not match the parking space measurements provided in the latest version of the draft APA test procedure (NHTSA, 2018). The perpendicular spaces were narrower than the 9 ft (2.7 m) width specification, and the approach lane used for the parallel scenarios was 10 ft (3.0 m) wide rather than 12 ft (3.7 m). The figures presented in this section reflect the measurements of the actual parking spaces used and, therefore, do not match those shown in the draft test procedure.

2.3.1. Active Park Assist Performance Assessment

The APA performance assessment tests are designed to evaluate how well an APA system performs an automated parking maneuver in both perpendicular and parallel parking spaces. The test layout geometry for the perpendicular and parallel scenarios are given in **Figures 2-6** and **2-7**, respectively.
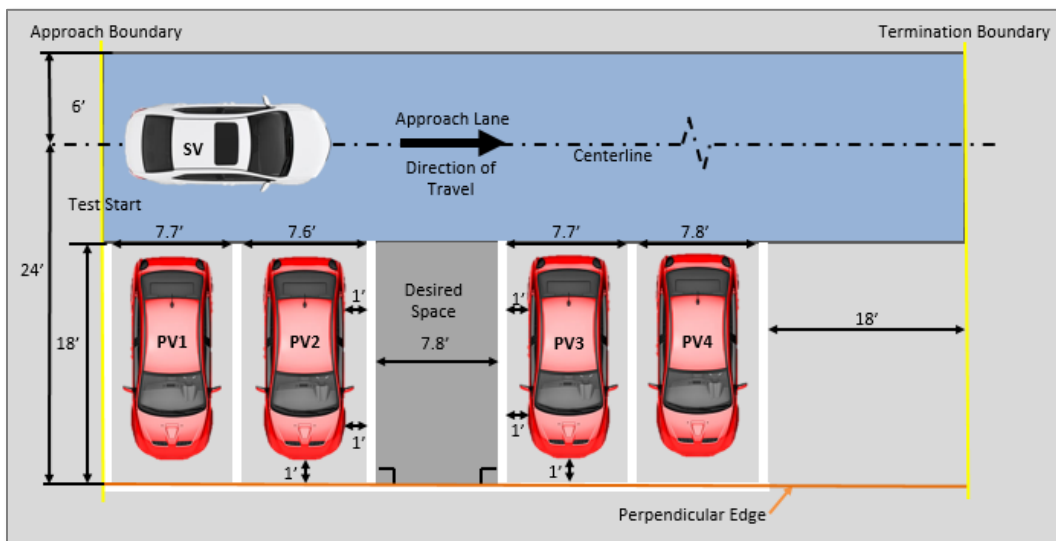
Figure 2-6. Perpendicular parking test layout
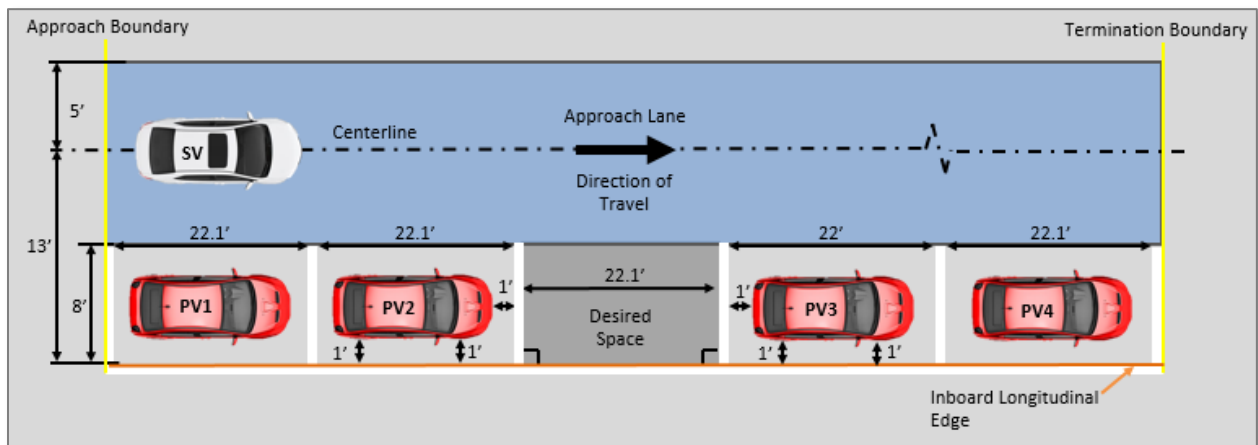
Figure 2-7. Parallel parking test layout

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2.3.2.   Encroaching Pedestrian Detection Assessment

The encroaching pedestrian tests are designed to evaluate how an APA system responds to a (simulated) pedestrian encroaching into the SV's desired parking space while the perpendicular or parallel parking maneuver is performed. The test layout geometry is given for perpendicular tests in **Figure 2-8**.
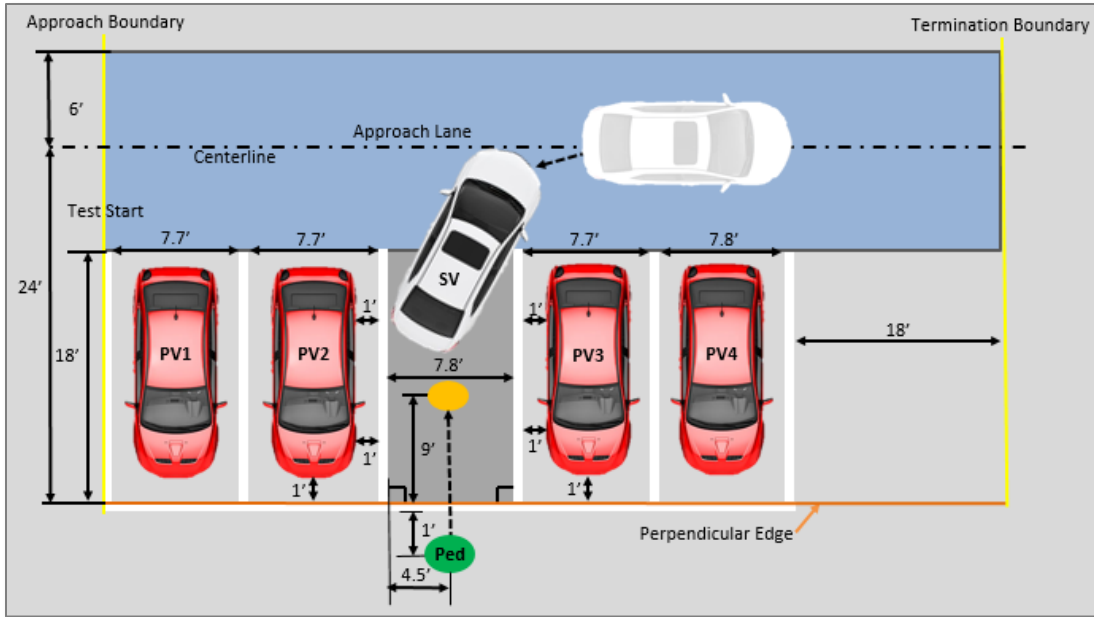
Figure 2-8. Perpendicular parking with encroaching pedestrian

Parallel tests are performed with the pedestrian encroaching into both the front and back of the parking space. The test layout geometry for the rear encroaching and front encroaching parallel tests are given in **Figures 2-9** and **2-10**, respectively.
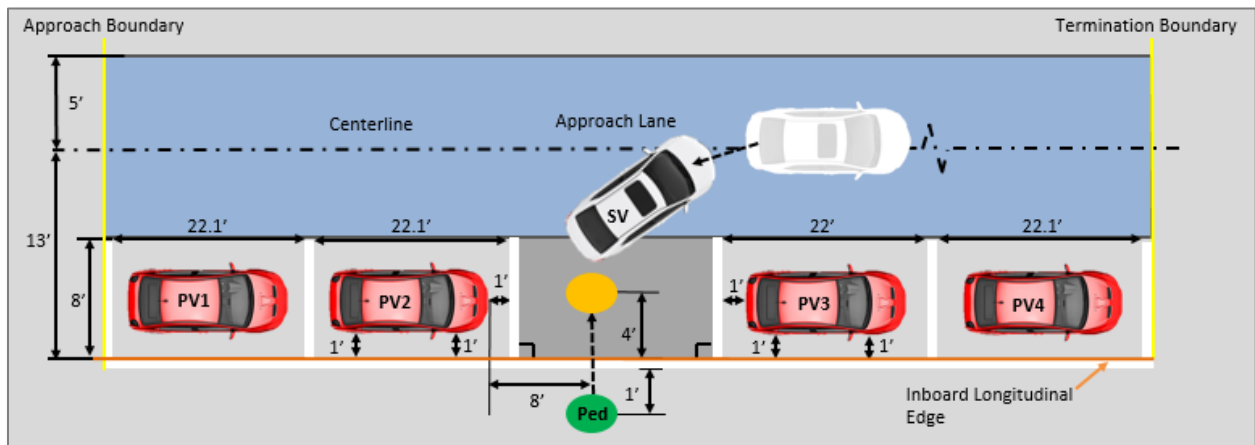
Figure 2-9. Parallel parking with rear encroaching pedestrian
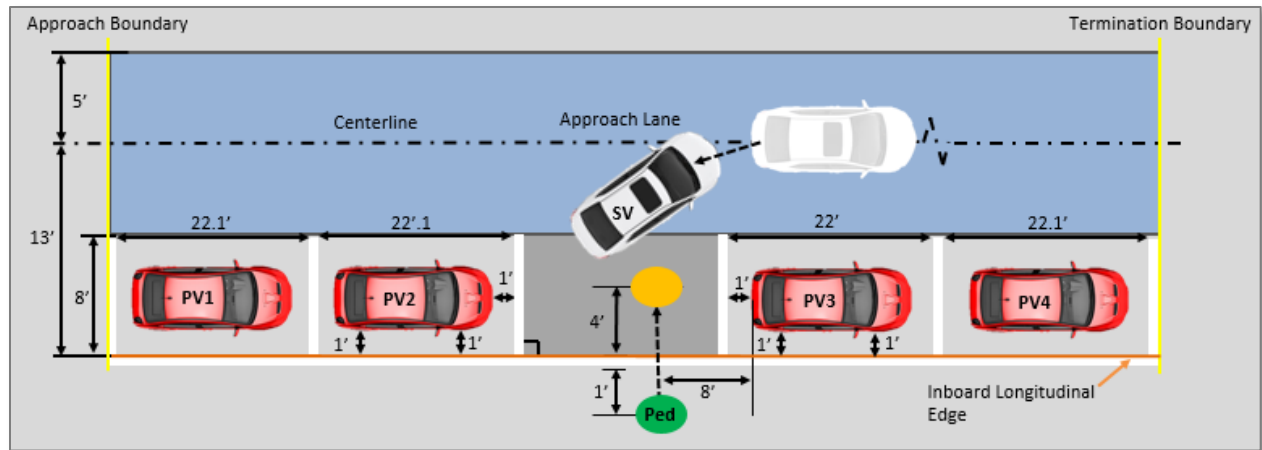
Figure 2-10. Parallel parking with front encroaching pedestrian

The encroaching PED path specifications were as follows.

- The path travelled by the PED shall be from 1 ft (0.3 m) outside of the desired SV space to a location 4 ft (1.2 m) from the inboard longitudinal edge line (parallel parking), or 9 ft (2.7 m) from the inboard perpendicular edge line (perpendicular parking).

- The lateral and longitudinal path tolerances of the PED shall be ±6 in (15 cm).

- The PED shall use the following nominal displacement profile: accelerate from rest to 3.5 mph (5.6 km/h) in 0.5 seconds, remain at 3.5 mph (5.6 km/h) for 0.47 seconds (parallel parking) or 1.45 seconds (perpendicular parking), then decelerate to a stop in 0.5 seconds.

- The overall time frame for achieving the total longitudinal displacement of the PED shall be 1.47±0.5 seconds for parallel tests or 2.45±0.5 seconds for perpendicular tests.

- The PED began moving within 1s after the SV first began to move backwards.

2.3.3. Obstructing Vehicle Detection Assessment

The obstructing vehicle detection assessment tests are designed to evaluate how an APA system responds to a driving scenario where a POV closely follows behind the SV that is looking for a vacant parking space. When the SV stops to begin the parking maneuver, the POV stops behind it, thereby blocking a clear path into the desired space. Tests performed in the obstructing vehicle scenario use perpendicular and parallel parking maneuvers. The test layout geometry is given in **Figures 2-11** and **2-12**.

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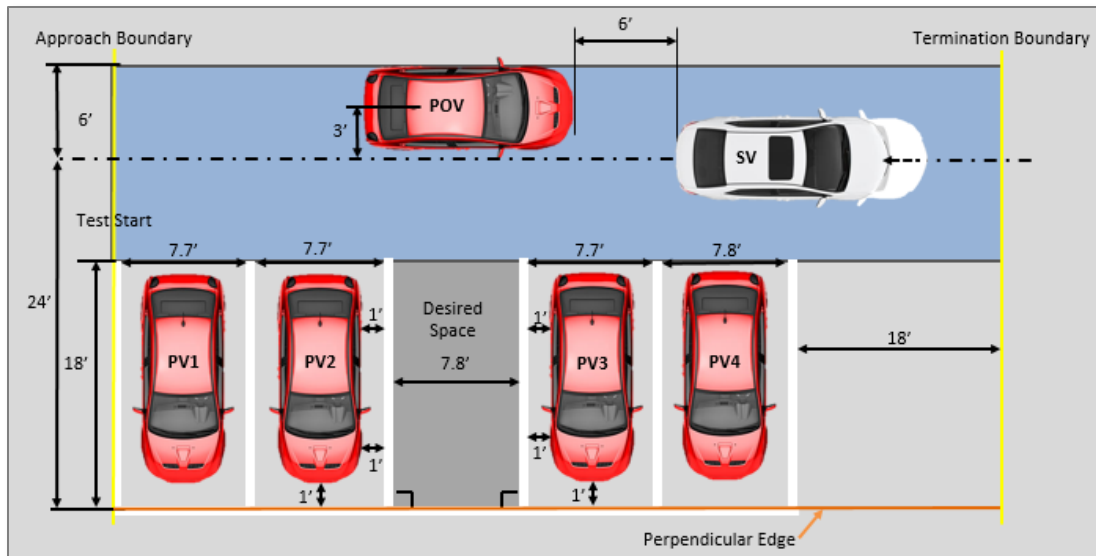
Figure 2-11. Perpendicular parking with obstructing vehicle test layout
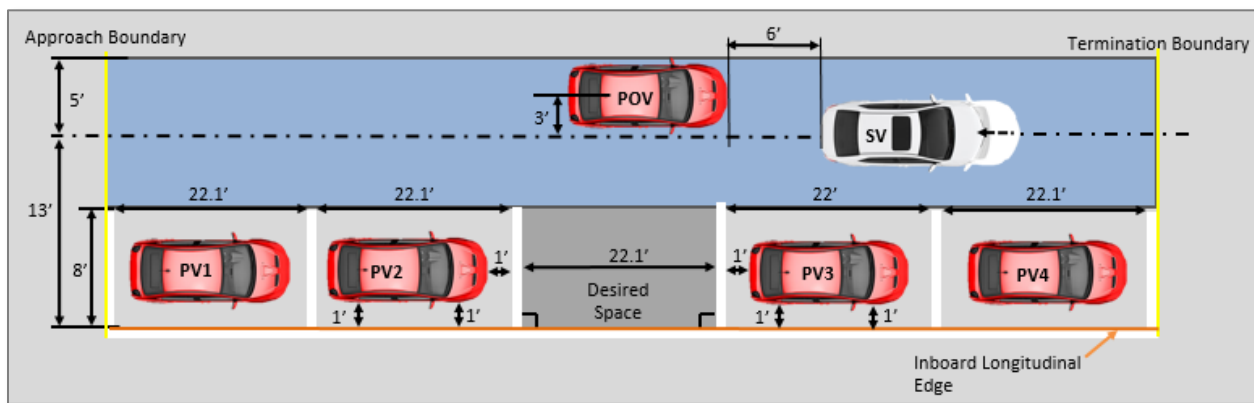
Figure 2-12. Parallel parking with obstructing vehicle test layout

2.3.4.   System Override Assessment

The system override assessment tests are designed to evaluate how an APA system responds to a manual driver input while the APA system is performing a perpendicular or parallel parking maneuver. For all system override assessment tests, the driver input occurs at the first clockwise (CW) steering action made by the APA system during the parking maneuver.

Three different types of override maneuvers are performed.

1. Steering override
2. Accelerator pedal override
3. Brake pedal override or manual timeouts

For the steering and accelerator pedal override assessments, the SV driver applies either a steering wheel torque or accelerator pedal input to see if the APA system will stop automatically in response to the driver input.

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If the APA system automatically controls braking during the parking maneuver, brake pedal override is performed. This involves the SV driver applying the brake pedal to see if the APA system will stop automatically in response to the driver input.

If the APA system does not automatically control braking during the parking maneuver, manual timeout assessments are performed. This involves the SV driver braking the vehicle to a complete stop and waiting to see if the APA system will time out after being stopped for longer than 5 seconds.

2.3.5. Validity Criteria

The validity criteria described in the draft APA test procedure were assessed for each test performed in this study. These criteria included test tolerances for the initial SV approach by the parking space, SV driver response times, and specific validity criteria for the individual tests.

SV lane position and speed test tolerances were confirmed from 1 second prior to the front most part of the SV crossing the approach boundary until either the onset of the SV driver's braking in response to receiving the parking space detection notification, or 1 second after the rearmost part of the SV crossed the termination boundary for all parking maneuvers.

During the approach:

- The SV remained in the center of the approach lane ± 1 ft (± 0.3 m); and
- The SV speed was 6 ± 1.0 mph (9.7 ± 1.6 km/h).

The SV driver's response time was confirmed for the following instances during a test.

- The accelerator pedal was released and SV driver decelerated to a stop within 5 seconds or before the rearmost part of the SV crossed the termination boundary.
- Driver initiated the automated parking function within 5 seconds of receiving the in-vehicle instructions.
- SV driver released manual control of any automated portions of the parking maneuver (gear selector, steering, brake pedal, and accelerator pedal inputs) within 5 seconds of being prompted to do so.
- The driver made gear selection changes within 3 seconds of a request.
- The driver made accelerator pedal and/or brake pedal applications within 2 seconds of a request.

A summary of the validity criteria checks for specific test scenarios follows.

- Encroaching pedestrian detection assessment
    - The PED achieved the desired longitudinal displacement in 1.47 ± 0.5 s for parallel tests and 2.45 ± 0.5 s for perpendicular tests.
    - The PED began moving within 1s after the SV first began to move backwards.
- Obstructing vehicle detection assessment
    - Until the SV came to a stop after detecting a parking space, the POV followed the SV at a lateral offset of 3 ft (0.9 m) ± 6 in (15 cm).
    - Experimenters were unable to maintain the desired constant longitudinal POV-to-SV headway of 6 ft (1.8 m) ±6 in (15 cm) while both vehicles were moving. However, the

final headway was within the draft APA test procedure specifications after both vehicles had come to a stop.[4]

- o The POV was stationary as the APA system performed the rest of the parking maneuver.

- System override assessment

  - o Steering, accelerator pedal, and brake pedal overrides were applied within 500 ms after the initial CW steering reversal was initiated.

2.3.6.   *Performance Criteria*

In addition to test validity criteria, vehicle performance criteria were analyzed. The full list of vehicle performance criteria is listed in Appendix B. For this report, only a select number of performance criteria are presented in the results section. These include the following.

- Time tolerance

  - o Systems with automated gear selection, brake, and throttle control must complete the parking maneuver within 45 second from the instant the SV driver first releases the brake pedal.

  - o Systems with manual gear selection, brake pedal, and/or accelerator pedal inputs must complete the parking maneuver within 60 seconds.

- Final parking position

  - o Perpendicular

    - The rearmost part of the SV shall be within 12 in. (0.3 m) of the inboard edge of the rear of the desired parking space.

    - The leftmost part of the SV shall be 12 or more inches (0.3 m) away from the rightmost part of PV2.

    - The rightmost part of the SV shall be 12 or more inches (0.3 m) away from the leftmost part of PV3.

  - o Parallel

    - The rightmost edge of the SV's right-side tires shall be within 12 inches from the inboard edge of the desired parking space.

    - The front most part of the SV must be 12 or more inches (0.3 m) away from the rearmost part of PV3.

    - The rearmost part of the SV must be 12 or more inches (0.3 m) away from the front most part of PV2.

- Encroaching pedestrian detection assessment

  - o If the APA system uses all automated inputs (steering, brake, throttle, and gear selector), the park assist system shall not allow the SV to strike the PED at any time.

  - o If the APA system uses manual inputs for brake, throttle, and/or gear selector:

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[4] To make sure that the POV was at the desired longitudinal range after the SV came to a stop, the SV-to-POV headway was programmed to be 9 ft (2.7 m) while the vehicles were moving.

- The park assist system shall instruct the driver how to avoid the PED during the parking maneuver; and

- Provided the SV driver responds to the requests within 2 seconds, the SV shall not strike any PV.

- Obstructing vehicle detection assessment
  - If the APA system uses all automated inputs (steering, brake, throttle, and gear selector), the park assist system shall not allow the SV to strike the POV at any time.
  - If the APA system uses manual inputs for brake, throttle, and/or gear selector:
    - The park assist system shall instruct the driver how to avoid POV during the parking maneuver; and
    - Provided the SV driver responds to the requests within 2 seconds, the SV shall not strike any PV.

- System override assessment
  - The park assist system shall automatically terminate the parking maneuver and bring the SV to a stop upon any manual input by the SV driver to the steering wheel, brake pedal, or accelerator.

2.4. Test Facility

All tests were performed on the Vehicle Dynamics Area at the Transportation Research Center in East Liberty, Ohio.

2.5. Measurement and Data Acquisition Systems

All sensor and video data was collected using the robotic operating system) installed on a laptop. Vehicle GPS position and inertial measurements were measured using RT3002 units manufactured by Oxford Technical Solutions, Ltd., of Oxforsdshire, UK (abbreviated as OxTS). This system uses real-time kinematic corrections to improve GPS accuracy to within 0.8 in. (2 cm). Relative distances and velocity between test actors were measured using an OxTS RT-Range S system.

3. Changes to the April 2018 Draft APA Test Procedure

Since the time of its release, there have been several changes made to the April 2018 draft APA test procedure (NHTSA, 2019) to improve clarity, ease of test conduct, and general performability. These changes are described in the revision history of the most current draft APA test procedure (i.e., the version used for the tests described in this report, unless noted) (NHTSA, 2018).

- Lowered the steady-state timing requirements on the approach to the parking space to be consistent with the timing criteria for the start of the validity period.

- Braking specifications changed from achieving a specific deceleration to stopping within 5 seconds of applying the brakes and before crossing the termination boundary, as specified deceleration was difficult to achieve at such low speeds.

- Pedestrian path changed from going 3 ft (0.9 m) into the spaces to going halfway into the spaces, so 9 ft (2.7 m) for perpendicular and 4 ft (1.2 m) for parallel, as the APA systems could still park in the perpendicular spaces when the pedestrian only went in 3 ft (0.9 m).

- Pedestrian location modified to start 1 ft (0.3 m) outside of the parking spaces rather than the 2 ft (0.6 m) used in the procedure due to a lack of space outside of the spaces.

- Termination boundary changed for the perpendicular test to be 4 spaces (36 ft, or 11 m) past desired space rather than two (18 ft, or 5.5 m), as this brought it closer to the distance used for parallel tests (44 ft, or 13.4 m).

- Override tests were modified so that all driver inputs occur on the first CW steering motion rather than the first CCW steering motion, which occurs after the first CW steering motion. The torque sensor used on the steering wheel for steering overrides provided enough torque when switching from CW to CCW steering that the vehicle would register it as driver input, causing the overrides to occur at the incorrect time.

4. Test Results

This section provides results from the APA parking performance, system override, encroaching pedestrian, and obstructing vehicle evaluations. Results from each vehicle, and the respective evaluation criteria, are presented in tabulated summaries.

4.1. Parking Performance

4.1.1. BMW 540i Parking Performance

Parking performance results for the BMW 540i are shown in **Table 4-1** for perpendicular parking and **Table 4-2** for parallel parking.

For the perpendicular tests, the proximity of SV rear bumper to the inboard edge of the rear parking space line exceeded the performance criteria maximum of 12 in. (0.3 m) in all five trials. One of these trials also exceeded the maximum time duration of 45 seconds. All five parallel trials met the performance criteria except that the right-side tires of the SV were more than 12 in. (0.3 m) from the line.

4.1.2. Tesla Model S Parking Performance

Parking performance results for the Tesla Model S are shown in **Table 4-3** for perpendicular parking and **Table 4-4** for parallel parking.

Of the five perpendicular trials performed, the vehicle did not detect the parking space during two, and exceeded the maximum time duration in the remaining three. Of these three tests, the proximity of the rear-most part of the Tesla Model S rear bumper to the inboard perpendicular edge defining the rear of the desired space was within the ≤12 in. (0.3 m) performance criteria during two. The Tesla Model S APA system required that the inboard longitudinal edge of the parking space shown in **Figure 2-7** be defined by a 4.6 in. (11.7 cm) high curb to enable automated parallel parking. With the curb in place, four of the trials met all performance criteria. During one trial, the proximity of the SV's front right tire to the inboard edge of the parking space line exceeded the performance criteria maximum of 12 in. (0.3 m).

4.1.3. Cadillac CT6 Parking Performance

Parking performance results for the Cadillac CT6 are shown in **Table 4-5** for perpendicular parking and **Table 4-6** for parallel parking.

In one perpendicular trial, the APA system was unable to park in the parking space, and the APA system did not detect the parking space during two perpendicular trials. The remaining two perpendicular trials met all the performance criteria stated in the draft test procedure. For parallel parking, in all five trials the proximity of the SV's right-side tires to the inboard edge of the parking space line exceeded the performance criteria maximum of 12 in. (0.3 m).

Table 4-1. BMW 540i Perpendicular Parking Performance Results

BMW 540i	Duration (s) (must be ≤ 45)	Front Left Tire to PV2 (must be ≥ 12 in.)	Rear Left Tire to PV2 (must be ≥ 12 in.)	Front Right Tire to PV3 (must be ≥ 12 in.)	Rear Right Tire to PV3 (must be ≥ 12 in.)	Rear Bumper to Line (must be ≤ 12 in.)
Test 1	57.7[1]	27.5 in. (69.9 cm)	26.8 in. (68.2 cm)	25.7 in. (65.3 cm)	24.4 in. (62.0 cm)	14.9 in. (37.7 cm)
Test 2	43.9	24.9 in. (63.2 cm)	27.9 in. (70.8 cm)	24.7 in. (62.8 cm)	27.1 in. (68.8 cm)	15.3 in. (38.7 cm)
Test 3	44.0	24.5 in. (62.2 cm)	27.1 in. (68.8 cm)	25.5 in. (64.7 cm)	27.5 in. (69.8 cm)	14.0 in. (35.7 cm)
Test 4	43.7	28.6 in. (72.5 cm)	23.0 in. (58.4 cm)	29.6 in. (75.2 cm)	23.5 in. (59.6 cm)	15.0 in. (38.1cm)
Test 5	44.5	24.3 in. (61.8 cm)	27.1 in. (68.8 cm)	25.5 in. (64.8 cm)	27.6 in. (70.2 cm)	14.8 in. (37.7 cm)
Average	46.8	26.0 in. (65.9 cm)	26.4 in. (67.0 cm)	26.2 in. (66.6 cm)	26.0 in. (66.1 cm)	14.8 in. (37.6 cm)
Standard Deviation	6.12	1.95 in. (4.94 cm)	1.93 in. (4.90 cm)	1.94 in. (4.93 cm)	1.93 in. (4.90 cm)	0.45 in. (1.14 cm)

[1] Exceeded the maximum time duration.

Table 4-2. BMW 540i Parallel Parking Performance Results

BMW 540i	Duration (s) (must be ≤ 45)	Front Right Tire to Line (must be ≤ 12 in.)	Rear Right Tire to Line (must be ≤ 12 in.)	Front Bumper to PV3 (must be ≥ 12 in.)	Rear Bumper to PV2 (must be ≥ 12 in.)
Test 1	29.4	25.8 in. (65.6 cm)	25.6 in. (64.9 cm)	34.8 in. (88.4 cm)	67.8 in. (172.2 cm)
Test 2	30.8	24.8 in. (62.9 cm)	23.8 in. (60.5 cm)	35.0 in. (88.9 cm)	67.5 in. (171.5 cm)
Test 3	28.7	26.0 in. (66.1 cm)	24.8 in. (62.9 cm)	34.9 in. (88.7 cm)	67.6 in. (171.7 cm)
Test 4	30.1	23.9 in. (60.8 cm)	23.0 in. (58.3 cm)	34.0 in. (86.3 cm)	68.5 in. (174.1 cm)
Test 5	30.2	25.0 in. (63.4 cm)	24.8 in. (63.0 cm)	36.2 in. (91.9 cm)	66.4 in. (168.6 cm)
Average	29.8	25.1 in. (63.8 cm)	24.4 in. (61.9 cm)	35.0 in. (88.9 cm)	67.6 in. (171.6 cm)
Standard Deviation	0.83	0.86 in. (2.17 cm)	1.0 in. (2.55 cm)	0.79 in. (2.00 cm)	0.77 in. (1.95 cm)

Table 4-3. Tesla Model S Perpendicular Parking Performance Results

Tesla Model S	Duration (s) (must be ≤ 45)	Front Left Tire to PV2 (must be ≥ 12 in.)	Rear Left Tire to PV2 (must be ≥ 12 in.)	Front Right Tire to PV3 (must be ≥ 12 in.)	Rear Right Tire to PV3 (must be ≥ 12 in.)	Rear Bumper to Line (must be ≤ 12 in.)
Test 1	N/A[1]	N/A[1]	N/A[1]	N/A[1]	N/A[1]	N/A[1]
Test 2	56.3[2]	23.5 in. (59.7 cm)	24.8 in. (63.0 cm)	25.4 in. (64.4 cm)	25.1 in. (63.8 cm)	10.2 in. (25.9 cm)
Test 3	52.4[2]	30.7 in. (78.1 cm)	25.4 in. (64.5 cm)	24.9 in. (63.2 cm)	18.0 in. (45.7 cm)	12.2 in. (31.0 cm)
Test 4	53.3[2]	25.6 in. (64.9 cm)	26.5 in. (67.4 cm)	23.7 in. (60.1 cm)	23.1 in. (58.6 cm)	7.1 in. (18.0 cm)
Test 5	N/A[1]	N/A[1]	N/A[1]	N/A[1]	N/A[1]	N/A[1]
Average	54.0	26.6 in. (67.6 cm)	25.6 in. (65.0 cm)	24.6 in. (62.6 cm)	22.1 in. (56.0 cm)	9.8 in (25.0 cm)
Standard Deviation	2.1	3.73 in. (9.47 cm)	0.87 in. (2.21 cm)	0.88 in. (2.24 cm)	3.68 in. (9.35 cm)	2.59 in. (6.58 cm)

[1] APA system did not detect the space.
[2] Exceeded the maximum time duration.

Table 4-4. Tesla Model S Parallel Parking Performance Results

Tesla Model S	Duration (s) (must be ≤ 45)	Front Right Tire to Line (must be ≤ 12 in.)	Rear Right Tire to Line (must be ≤ 12 in.)	Front Bumper to PV3 (must be ≥ 12 in.)	Rear Bumper to PV2 (must be ≥ 12 in.)
Test 1	33.4	12.8 in. (32.4 cm)	10.7 in. (27.3 cm)	35.4 in. (90.0 cm)	65.7 in. (166.8 cm)
Test 2	32.2	11.1 in. (28.3 cm)	9.7 in. (24.7 cm)	40.5 in. (102.8 cm)	60.7 in. (154.1 cm)
Test 3	32.4	11.4 in. (29.0 cm)	10.7 in. (27.1 cm)	40.2 in. (102.1 cm)	61.0 in. (154.9 cm)
Test 4	33.4	7.5 in. (19.0 cm)	7.7 in. (19.5 cm)	40.0 in. (101.7 cm)	61.2 in. (155.4 cm)
Test 5	34.6	11.5 in. (29.3 cm)	10.1 in. (25.6 cm)	37.4 in. (95.0 cm)	63.8 in. (161.9 cm)
Average	33.2	10.9 in. (27.6 cm)	9.8 in. (24.8 cm)	38.7 in. (98.3 cm)	62.4 in. (158.6 cm)
Standard Deviation	1.0	1.99 in. (5.06 cm)	1.24 in. (3.15 cm)	2.21 in. (5.61 cm)	2.19 in. (5.55 cm)

Table 4-5. Cadillac CT6 Perpendicular Parking Performance Results

Cadillac CT6	Duration (s) (must be ≤ 45)	Front Left Tire to PV2 (must be ≥ 12 in.)	Rear Left Tire to PV2 (must be ≥ 12 in.)	Front Right Tire to PV3 (must be ≥ 12 in.)	Rear Right Tire to PV3 (must be ≥ 12 in.)	Rear Bumper to Line (must be ≤ 12 in.)
Test 1	47.1	N/A	N/A	N/A	N/A	N/A[1]
Test 2	N/A	N/A	N/A	N/A	N/A	N/A[2]
Test 3	N/A	N/A	N/A	N/A	N/A	N/A[2]
Test 4	38.1	28.0 in. (71.1 cm)	28.1 in. (71.4 cm)	23.1 in. (58.6 cm)	22.4 in. (56.8 cm)	2.8 in. (7.1 m)
Test 5	38.2	26.1 in. (66.4 cm)	26.5 in. (67.3 cm)	24.7 in. (62.7cm)	24.2 in. (61.5 cm)	6.2 in. (15.9 m)
Average	38.1	27.1 in. (68.7 cm)	27.3 in. (69.4 cm)	23.9 in. (60.6 cm)	23.3 in. (59.2 cm)	4.5 in. (11.5 m)
Standard Deviation	0.07	1.31 in. (3.33 cm)	1.13 in. (2.87 cm)	1.13 in. (2.88 cm)	1.31 in. (3.34 cm)	2.43 in. (6.18 m)

[1] APA system was unable to park in the space after multiple attempts and then aborted the maneuver (therefore not included in average or standard deviation).
[2] APA system did not detect the space.

Table 4-6. Cadillac CT6 Parallel Parking Performance Results

Cadillac CT6	Duration (s) (must be ≤ 45)	Front Right Tire to Line (must be ≤ 12 in.)	Rear Right Tire to Line (must be ≤ 12 in.)	Front Bumper to PV3 (must be ≥ 12 in.)	Rear Bumper to PV2 (must be ≥ 12 in.)
Test 1	29.8	17.6 in. (44.7 cm)	17.0 in. (43.1 cm)	56.7 in. (144.1 cm)	36.9 in. (93.8 cm)
Test 2	30.2	16.0 in. (40.8 cm)	15.3 in. (38.8 cm)	65.8 in. (167.1 cm)	27.8 in. (70.7 cm)
Test 3	28.9	16.2 in. (41.2 cm)	16.1 in. (40.8 cm)	58.3 in. (148.1 cm)	35.4 in. (89.9 cm)
Test 4	30.0	15.4 in. (39.0 cm)	16.1 in. (40.8 cm)	56.6 in. (143.8 cm)	37.1 in. (94.3 cm)
Test 5	29.8	17.6 in. (44.6 cm)	15.5 in. (39.5 cm)	49.8 in. (126.5 cm)	43.8 in. (111.2 cm)
Average	29.7	16.6 in. (42.1 cm)	16.0 in. (40.6 cm)	57.5 in. (145.9 cm)	36.2 in. (92.0 cm)
Standard Deviation	0.48	0.99 in. (2.51 cm)	0.65 in. (1.65 cm)	5.69 in. (14.46 cm)	5.68 in. (14.43 cm)

4.1.4. Parking Performance Summary

A summary of the SV's ability to satisfy the parking performance criteria described in the draft APA test procedure, based on the test results described earlier in this section, is provided in **Table 4-7**.

Table 4-7. Parking Performance Summary

Vehicle	Trials Able to Satisfy Performance Criteria		
	Perpendicular	Parallel	Overall
BMW 540i	0/5	0/5	0/10
Tesla Model S	0/5	4/5[1]	4/10
Cadillac CT6	2/5	0/5	2/10

[1] Parallel parking required use of a curb to define the longitudinal edge of the parking space.

4.2. System Overrides

This section provides results of the system override assessments. For the tables in this section, trials that met all system override criteria are labelled MC for "met criteria," and trials that did not meet all system override criteria are labelled DNMC for "did not meet criteria."

Note that while all the SVs alerted the driver when a maneuver had been aborted due to a manual override, none displayed the language explicitly defined in the draft test procedure (i.e., that provided in Appendix B.6). Therefore, when the tables in this section indicate a test "met criteria," and the accompanying descriptions state that all performance criteria defined in the draft procedure were satisfied, the implication is that all criteria expect the post-abort alert notifications were satisfied.

4.2.1. BMW 540i System Overrides

Results of the BMW 540i APA override tests are shown in **Table 4-8**. For the steering and accelerator system override evaluations, all trials met the performance criteria defined in the draft test procedure. During the brake override trials, the BMW 540i APA system did not detect the parking space in three of the perpendicular trials. In the remaining two perpendicular trials, and in all five parallel trials, the APA system did not abort the parking maneuver upon brake application by the driver. The APA system allowed the driver to apply the brakes and come to a stop, after which the APA system then waited until the maneuver timed out before restoring control manual to the driver. Despite the BMW 540i essentially performing a manual timeout, it was evaluated with the brake override assessment since it automatically controls SV braking.

Table 4-8. BMW 540i System Override Results

BMW 540i	System Override Assessment (MC/DNMC)					
	Steering		Accelerator		Brake	
	Perpendicular	Parallel	Perpendicular	Parallel	Perpendicular	Parallel
Test 1	MC	MC	MC	MC	DNMC[1]	DNMC[1]
Test 2	MC	MC	MC	MC	DNMC[1]	DNMC[1]
Test 3	MC	MC	MC	MC	DNMC[2]	DNMC[1]
Test 4	MC	MC	MC	MC	DNMC[2]	DNMC[1]
Test 5	MC	MC	MC	MC	DNMC[2]	DNMC[1]

[1] The APA system did not abort the parking maneuver; it just waited and let the driver hold the brake until it timed out.

[2] The APA system did not detect the space.

4.2.2.   Tesla Model S System Overrides

Results of the Tesla Model S APA override tests are shown in **Table 4-9**. For the steering and brake override evaluations, all the trials met the performance criteria defined in the draft test procedure. During the accelerator override evaluation, the Tesla Model S APA system did not bring the vehicle to a stop when the driver pressed the accelerator pedal during any test trial. Instead, the vehicle accelerated in response to the driver's input, terminated the automated parking maneuver, and restored full manual control of the vehicle to the driver.

Table 4-9. Tesla Model S System Override Assessment Results

Tesla Model S	System Override Assessment (MC/DNMC)					
	Steering		Accelerator		Brake	
	Perpendicular	Parallel	Perpendicular	Parallel	Perpendicular	Parallel
Test 1	MC	MC	DNMC[1]	DNMC[1]	MC	MC
Test 2	MC	MC	DNMC[1]	DNMC[1]	MC	MC
Test 3	MC	MC	DNMC[1]	DNMC[1]	MC	MC
Test 4	MC	MC	DNMC[1]	DNMC[1]	MC	MC
Test 5	MC	MC	DNMC[1]	DNMC[1]	MC	MC

[1] SV did not bring vehicle to stop after accelerator was pressed; it let the vehicle accelerate and restored full control to driver.

4.2.3.   Cadillac CT6 System Overrides

Results of the Cadillac CT6 APA override tests are shown in **Table 4-10**. For the steering override evaluations, all the trials met the performance criteria defined in the draft test procedure. For the accelerator overrides, the APA system did not abort the parking maneuver upon accelerator application by

the driver. During each of the five trials performed, the APA system ignored the driver's accelerator pedal input and continued with the automated parking maneuver. For brake overrides, the Cadillac CT6 APA system did not abort the parking maneuver upon brake application by the driver. Although the vehicle stopped in response to the driver's brake application, the Cadillac CT6 APA system did not terminate the parking maneuver. Instead, the system remained suspended until the driver ended the test 5 seconds after the vehicle stopped (i.e., the test termination criteria specified in the draft APA test procedure).

Table 4-10. Cadillac CT6 System Override Results

| Cadillac CT6 | System Override Assessment (MC/DNMC) | | | | | |
| | Steering | | Accelerator | | Brake | |
	Perpendicular	Parallel	Perpendicular	Parallel	Perpendicular	Parallel
Test 1	MC	MC	DNMC[1]	DNMC[1]	DNMC[2]	DNMC[2]
Test 2	MC	MC	DNMC[1]	DNMC[1]	DNMC[2]	DNMC[2]
Test 3	MC	MC	DNMC[1]	DNMC[1]	DNMC[2]	DNMC[2]
Test 4	MC	MC	DNMC[1]	DNMC[1]	DNMC[2]	DNMC[2]
Test 5	MC	MC	DNMC[1]	DNMC[1]	DNMC[2]	DNMC[2]

[1] SV does not respond when accelerator is pressed.
[2] SV did not abort the parking maneuver, it just waited and let the driver hold the brake until it timed out.

4.2.4.   System Override Summary

The number of system override tests that met all the performance criteria specified in the APA draft test procedure are presented in **Table 4-11**. Overall totals per SV are also presented.

Table 4-11. System Override Summary

| Vehicle | Trials Able to Satisfy Performance Criteria (MC/Total) | | | | | | |
| | Steering | | Accelerator | | Brake | | Overall |
	Perpendicular	Parallel	Perpendicular	Parallel	Perpendicular	Parallel	
BMW 540i	5/5	5/5	5/5	5/5	0/5	0/5	20/30
Tesla Model S	5/5	5/5	0/5	0/5	5/5	5/5	20/30
Cadillac CT6	5/5	5/5	0/5	0/5	0/5	0/5	10/30

4.3. Encroaching Pedestrian Detection

This section provides results of the encroaching pedestrian detection tests. Using the labelling convention defined in Section 4.2, trials that met all encroaching pedestrian detection evaluation criteria are labelled MC, whereas those that did not are labelled DNMC.

4.3.1. BMW 540i Encroaching Pedestrian Detection

BMW 540i tests results are shown in **Table 4-12**. The BMW 540i avoided the pedestrian in all the perpendicular trials. However, the vehicle failed each perpendicular trial because its final parking position was halfway into the desired space (i.e., the front of the vehicle extended well into the approach lane) rather than alerting the driver and aborting the maneuver. In the parallel trials, the APA system did not detect the desired space in one of the rear encroaching trials and the SV came into contact with the edge of the PED's hand in one of the front encroaching trials. For the rest of the parallel trials, the APA system alerted the driver that it could not complete the maneuver due to the PED residing in path of vehicle's path (i.e., within the desired parking space) and then aborted.

Table 4-12. BMW 540i Encroaching Pedestrian Results

BMW 540i	Minimum Distance from SV to Pedestrian			MC/DNMC		
	Perpendicular	Parallel (Rear PED)	Parallel (Front PED)	Perpendicular	Parallel (Rear PED)	Parallel (Front PED)
Test 1	0.9 ft (28 cm)	N/A[1]	1.9 ft (58.1 cm)	DNMC[2]	DNMC[1]	MC
Test 2	0.9 ft (28 cm)	2.2 ft (68 cm)	< 0.1 ft (< 2 cm)	DNMC[2]	MC	MC[3]
Test 3	1.0 ft (31 cm)	2.2 ft (68 cm)	< 0.1 ft (< 2 cm)	DNMC[2]	MC	MC[3]
Test 4	0.9 ft (27 cm)	2.2 ft (67 cm)	1.7 ft (53.2 cm)	DNMC[2]	MC	MC
Test 5	1.1 ft (35 cm)	2.3 ft (70 cm)	0.0 ft (0 cm)	DNMC[2]	MC	DNMC[4]
Average	0.98 ft (29.8 cm)	2.24 ft (68.3 cm)	0.91 ft (27.8 cm)	--	--	--
Standard Deviation	0.11 ft (3.27 cm)	0.04 ft (1.26 cm)	1.06 ft (32.20 cm)	--	--	--

[2] The APA system did not detect the space.

[1] SV failed to abort the maneuver after it was unable to park in the desired space due to the presence of the PED.

[3] Although the SV came closer than 2 cm to the PED (the resolution of the PED position data was 2 cm), it was visually confirmed that no impact occurred.

[4] The SV came in contact with the edge of the PED's hand.

4.3.2. Tesla Model S Encroaching Pedestrian Detection

The Tesla Model S did not detect the desired space in two of the perpendicular trials, but avoided the pedestrian in all trials that the space was detected. The pedestrian was not positioned correctly for the front and rear encroaching parallel conditions so those results are not included in this analysis or the summary shown in **Table 4-13**. The vehicle failed all three perpendicular trials in which it did detect the space because its final parking position was halfway into the desired space (i.e., the front of the vehicle extended well into the approach lane) rather than alerting the driver and aborting the maneuver.

Table 4-13. Tesla Model S Encroaching Pedestrian Results

Tesla Model S	Minimum Distance from SV to Pedestrian			MC/DNMC		
	Perpendicular	Parallel (Rear PED)[2]	Parallel (Front PED)[2]	Perpendicular	Parallel (Rear PED)	Parallel (Front PED)
Test 1	1.2 ft (36.2 cm)	--	--	DNMC[1]	--	--
Test 2	1.1 ft (33.7 cm)	--	--	DNMC[1]	--	--
Test 3	N/A[3]	--	--	DNMC[3]	--	--
Test 4	1.0 ft (30.8 cm)	--	--	DNMC[1]	--	--
Test 5	N/A[3]	--	--	DNMC[3]	--	--
Average	1.10 ft (33.5 cm)	--	--	--	--	--
Standard Deviation	0.09 ft (2.70 cm)	--	--	--	--	--

[1] SV failed to abort the maneuver after it was unable to park in the desired space due to the presence of the PED.
[2] The PED was set up at incorrect locations within the parking space. Therefore, the results are not reported.
[3] The APA system did not detect the space.

4.3.3. Cadillac CT6 Encroaching Pedestrian Detection

The Cadillac CT6 did not detect the space in two of the perpendicular trials. In the other three perpendicular trials, the Cadillac CT6 was able to avoid the pedestrian. In these three trials, it also alerted the driver that it could not complete the maneuver and then aborted. In the rear encroaching parallel trials, the APA system did not detect the parking space in four trials, but avoided the pedestrian in the one trial that the APA system did detect the space. In the one rear encroaching parallel trial that the APA system detected the space, the system alerted the driver that it could not complete the maneuver and aborted the maneuver. The Cadillac CT6 did not detect the space in two of the front encroaching parallel trials, and struck the pedestrian in all three trials in which it did detect the space. Cadillac CT6 test results are shown in **Table 4-14**.

Table 4-14. Cadillac CT6 Encroaching Pedestrian Results

Cadillac CT6	Minimum Distance from SV to Pedestrian			MC/DNMC		
	Perpendicular	Parallel (Rear PED)	Parallel (Front PED)	Perpendicular	Parallel (Rear PED)	Parallel (Front PED)
Test 1	1.0 ft (29 cm)	N/A[1]	0.0 ft (0.0 cm)	MC	DNMC[1]	DNMC[2]
Test 2	N/A[1]	N/A[1]	N/A[1]	DNMC[1]	DNMC[1]	DNMC[1]
Test 3	1.1 ft (33 cm)	1.1 ft (34 cm)	0.0 ft (0.0 cm)	MC	MC	DNMC[2]
Test 4	1.0 ft (32 cm)	N/A[1]	N/A[1]	MC	DNMC[1]	DNMC[1]
Test 5	N/A[1]	N/A[1]	0.0 ft (0.0 cm)	DNMC[1]	DNMC[1]	DNMC[2]
Average	1.0 ft (31.3 cm)	1.1 ft (34 cm)	0.0 ft (0.0 cm)	--	--	--
Standard Deviation	0.07 ft (2.08 cm)	--	0.0 ft (0.0 cm)	--	--	--

[1] APA system did not detect the space.
[2] SV struck pedestrian.

4.3.4. Encroaching Pedestrian Detection Summary

A summary of the SV's ability to satisfy the obstructing vehicle detection performance criteria described in the draft APA test procedure, is provided in **Table 4-15**.

Table 4-15. Encroaching Pedestrian Detection Summary

Vehicle	Trials Able to Satisfy Performance Criteria			
	Perpendicular	Parallel (Rear Encroachment)	Parallel (Front Encroachment)	Overall
BMW 540i	0/5	4/5	4/5	8/15
Tesla Model S	0/5	--	--	0/5
Cadillac CT6	3/5	1/5	0/5	4/15

4.4. Obstructing Vehicle Detection

This section provides results of the obstructing vehicle detection tests. Using the labelling convention defined in Section 4.2, trials that met all obstructing vehicle detection evaluation criteria are labelled "MC," whereas those that did not are labelled "DNMC."

4.4.1. *BMW 540i Obstructing Vehicle Detection*

Results of the BMW 540i obstructing vehicle detection tests are shown in **Table 4-16**. In all trials, the BMW 540i met the performance criteria stated in the draft APA test procedure and aborted the maneuver to avoid the obstructing vehicle.

Table 4-16. BMW 540i Obstructing Vehicle Detection Results

BMW 540i	Distance Between SV and POV at Abort		MC / DNMC	
	Perpendicular	**Parallel**	**Perpendicular**	**Parallel**
Test 1	0.85 ft (25.9 cm)	1.05 ft (32.0 cm)	MC	MC
Test 2	1.05 ft (31.9 cm)	0.90 ft (27.3 cm)	MC	MC
Test 3	0.72 ft (21.8 cm)	0.92 ft (27.9 cm)	MC	MC
Test 4	0.90 ft (27.4 cm)	0.86 ft (26.3 cm)	MC	MC
Test 5	0.91 ft (27.6 cm)	0.87 ft (26.6 cm)	MC	MC
Average	0.88 ft (26.9 cm)	0.92 ft (28.0 cm)	--	--
Standard Deviation	0.12 ft (3.63 cm)	0.08 ft (2.31 cm)	--	--

4.4.2. *Tesla Model S Obstructing Vehicle Detection*

Results of the Tesla Model S obstructing vehicle detection tests are shown in **Table 4-17**. In all the perpendicular trials, and in one parallel trial, the APA system recognized the desired parking space but would not initiate the parking maneuver due to the presence of the obstructing vehicle. In the remaining four parallel trials, the APA system started the parking maneuver, but then aborted the maneuver to avoid the obstructing vehicle. In two of these four trials, the Tesla Model S met the performance criteria, while in the other two trials the APA system did not provide instructions to begin the parking maneuver within the allotted time of 5 seconds after the SV came to a stop.

Table 4-17. Tesla Model S Obstructing Vehicle Detection Results

Tesla Model S	Distance Between SV and POV at Abort		MC / DNMC	
	Perpendicular	Parallel	Perpendicular	Parallel
Test 1	6.11 ft (186.2 cm)	6.09 ft (185.6 cm)	MC (wouldn't let start)	MC (wouldn't let start)
Test 2	6.17 ft (188.0 cm)	0.74 ft (22.7 cm)	MC (wouldn't let start)	MC
Test 3	6.20 ft (188.9 cm)	0.77 ft (23.6 cm)	MC (wouldn't let start)	MC
Test 4	6.02 ft (183.4 cm)	0.89 ft (27.2 cm)	MC (wouldn't let start)	DNMC (late instructions)[1]
Test 5	5.66 ft (172.6 cm)	0.79 ft (24.2 cm)	MC (wouldn't let start)	DNMC (late instructions)[1]
Average	6.03 ft (183.8 cm)	1.86 ft (56.7 cm)	--	--
Standard Deviation	0.22 ft (6.61 cm)	2.37 ft (72.10 cm)	--	--

[1] The APA system took more than 5 seconds to issue instructions to begin the parking maneuver.

4.4.3. *Cadillac CT6 Obstructing Vehicle Detection*

Results of the Cadillac CT6 obstructing vehicle detection tests are shown in **Table 4-18**. In all trials except one perpendicular trial, the Cadillac CT6 met the performance criteria specified in the APA draft test procedure, and aborted the maneuver to avoid the obstructing vehicle. In one perpendicular trial, the APA system did not detect the desired parking space.

Table 4-18. Cadillac CT6 Obstructing Vehicle Detection Results

Cadillac CT6	Distance Between SV and POV		MC / DNMC	
	Perpendicular	Parallel	Perpendicular	Parallel
Test 1	0.47 ft (14.3 cm)	0.62 ft (18.9 cm)	MC	MC
Test 2	0.57 ft (17.4 cm)	0.56 ft (17.2 cm)	MC	MC
Test 3	0.30 ft (9.2 cm)	0.40 ft (12.1 cm)	MC	MC
Test 4	0.74 ft (22.6 cm)	0.53 ft (16.3 cm)	MC	MC
Test 5	N/A[1]	0.60 ft (18.2 cm)	DNMC[1]	MC
Average	0.52 ft (15.9 cm)	0.54 ft (16.5 cm)	-	-
Standard Deviation	0.18 ft (5.62 cm)	0.09 ft (2.67 cm)	-	-

[1] The APA system did not detect the space.

4.4.4. Obstructing Vehicle Detection Summary

A summary of the SV's ability to satisfy the obstructing vehicle detection performance criteria described in the draft APA test procedure is provided in **Table 4-19**.

Table 4-19. Obstructing Vehicle Detection Summary

Vehicle	Trials Able to Satisfy Performance Criteria		
	Perpendicular	Parallel	Overall
BMW 540i	5/5	5/5	10/10
Tesla Model S	5/5	3/5	8/10
Cadillac CT6	4/5	5/5	9/10

5. Summary and Conclusions

The work described in this report demonstrates that use of the tests described in the August 2019 version of NHTSA's draft APA test procedure (NHTSA, 2018) provide a potentially viable way by which to evaluate light vehicle APA performance for research purposes.

Of the three vehicles evaluated, the Tesla Model S was the only one to satisfy all performance criteria during a parallel parking trial, doing so in four of the five tests performed. However, unlike the other vehicles, the Tesla Model S required the presence of a curb for its APA system to operate. The Cadillac CT6 was the only SV to satisfy all performance criteria during the perpendicular parking evaluation, albeit only during the two trials where it could detect the desired space or park within 45 seconds.

The system override assessment concluded that each SV could satisfy the applicable performance criteria for at least one of the three override types, but not for all of them. The BMW 540i did not meet the criteria for brake overrides, the Tesla Model S did not meet the criteria for accelerator overrides, and the Cadillac CT6 did not meet the criteria for brake or accelerator overrides.

Each vehicle consistently avoided the rear encroaching pedestrian during parallel trials in which the parking space was detected. The rear encroaching pedestrian was also avoided during all perpendicular trials in which the parking space was detected; however, the final test outcome was vehicle dependent. While the Cadillac CT6 aborted the parking maneuver in response to pedestrian, the BMW 540i and Tesla Model S did not and simply parked ahead of it; therefore causing the front end of these two vehicles to extend well into the approach lane at the end of the parking maneuver. SV-to-pedestrian impacts were only observed during the front encroaching pedestrian parallel parking tests. In one front encroaching pedestrian trial the BMW 540i came in contact with the tip of the pedestrian's hand while the Cadillac CT6 struck the pedestrian in every front encroaching pedestrian trial.

In the obstructing vehicle detection tests, the APA systems appeared to respond in a similar manner regardless of whether a perpendicular or parallel parking maneuver was to be performed. Except for the two Tesla Model S trials that took longer than 5 seconds to provide instructions to the driver to begin the maneuver after the SV came to a stop and one Cadillac CT6 perpendicular trial in which the space was not detected, all trials performed satisfied the obstructing vehicle detection performance criteria.

Overall, the BMW 540i satisfied all applicable performance criteria during 38 of 65 trials, the Tesla Model S met all criteria in 32 out of 55 trials, and the Cadillac CT6 met all criteria in 25 out of 65 trials.

6. References

Bayerische Motoren Werke AG. (2017). *The BMW 5 Series Sedan. Owner's Manual.* Author.

General Motors LLC. (2017). *2018 Cadillac CT6* [Owner's manual]. Author.

National Highway Traffic Safety Administration. (2019). *Active park assist system confirmation test (working draft)*. Author.

National Highway Traffic Safety Administration. (2018, April). *Active park assist system confirmation test (working draft)*. Author.

Tesla Motors, Inc. (2018). *Model S Owner's Manual.* www.tesla.com/sites/default-/files/model_s_owners_manual_north_america_en_us.pdf

Appendix A

A.1 BMW 540i Notifications

Figure A-1. BMW 540i notification 1
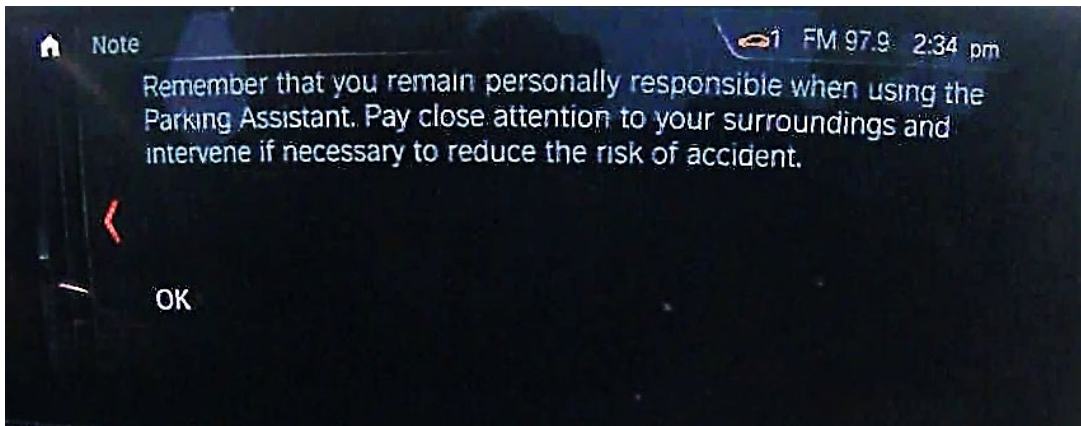

Figure A-2. BMW 540i notification 2

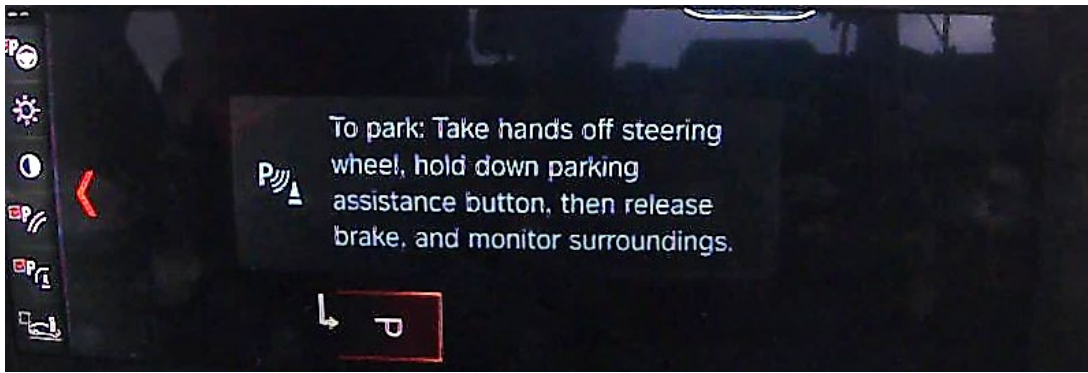**Figure A-3. BMW 540i notification 3**
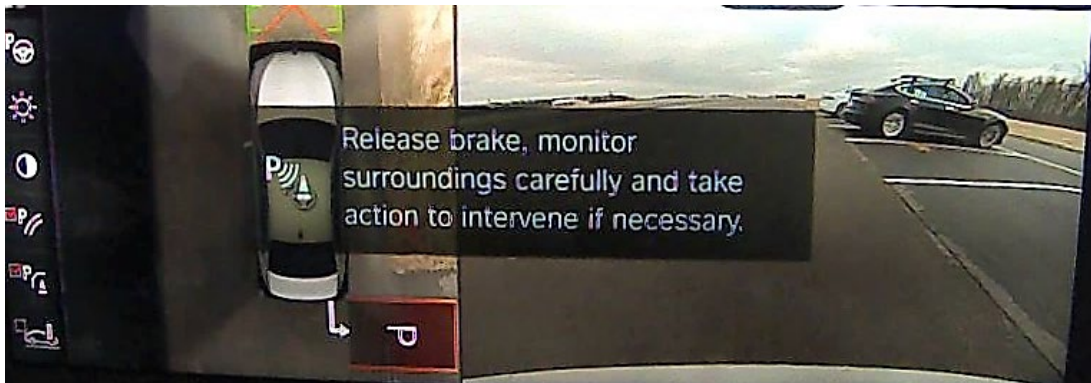
Figure A-4. BMW 540i notification 4

Figure A-5. BMW 540i notification 5

A.2 Tesla Model S Notifications

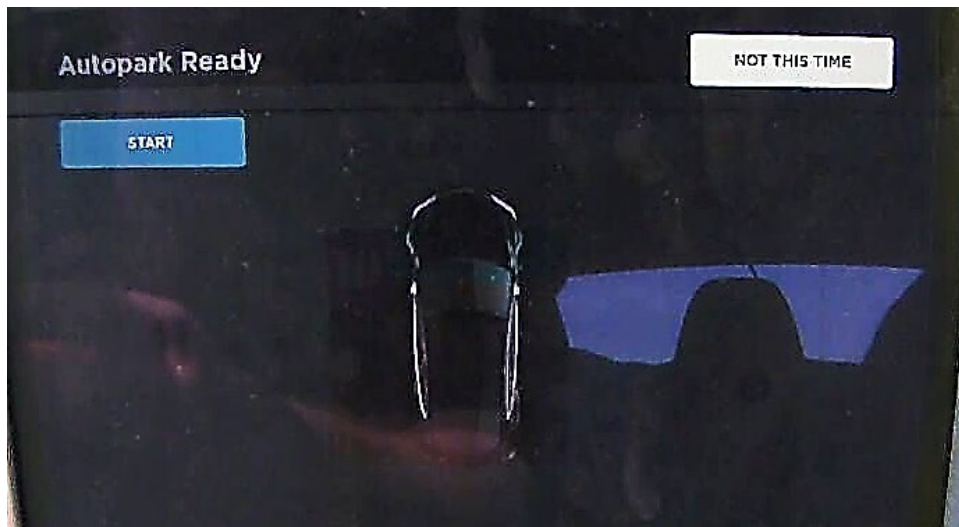**Figure A-6. Tesla Model S notification 1**

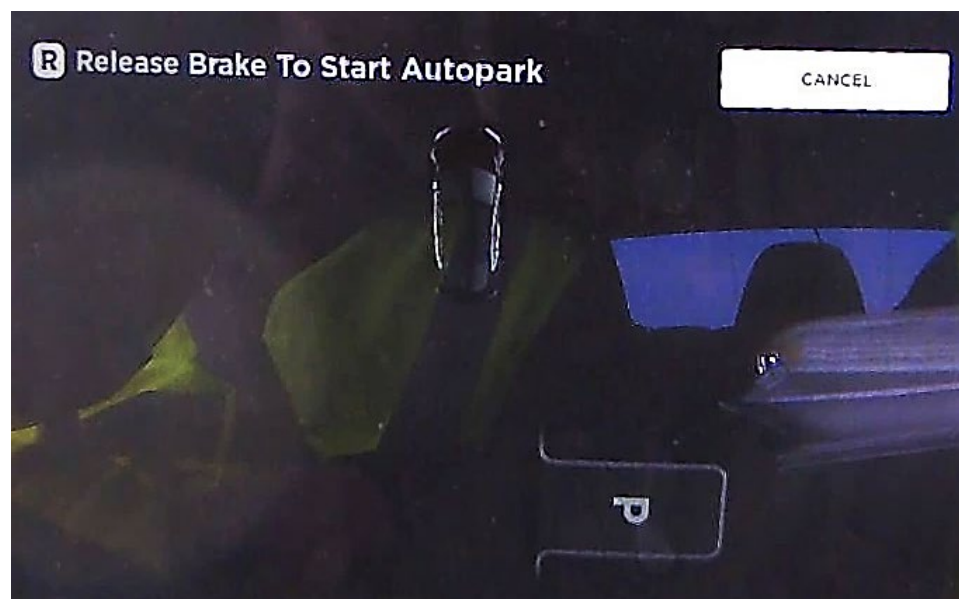**Figure A-7. Tesla Model S notification 2**

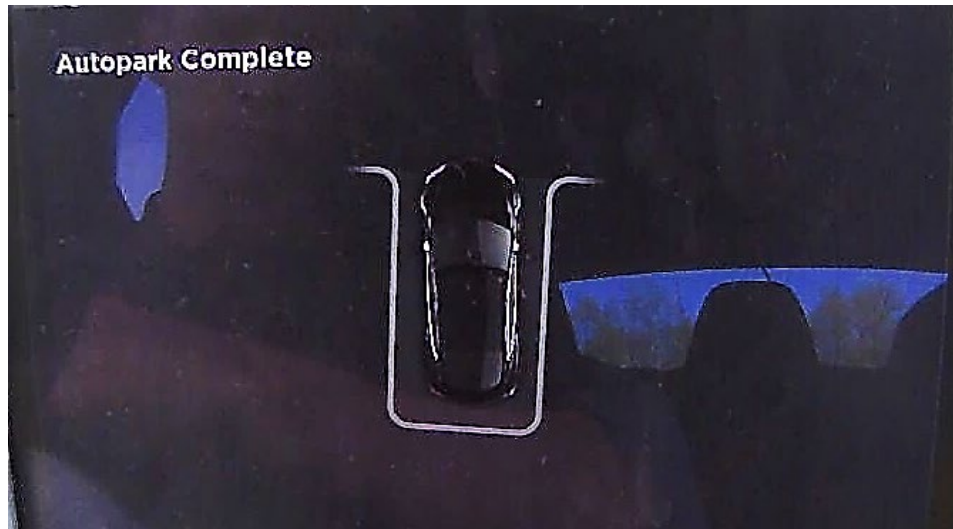**Figure A-8. Tesla Model S notification 3**

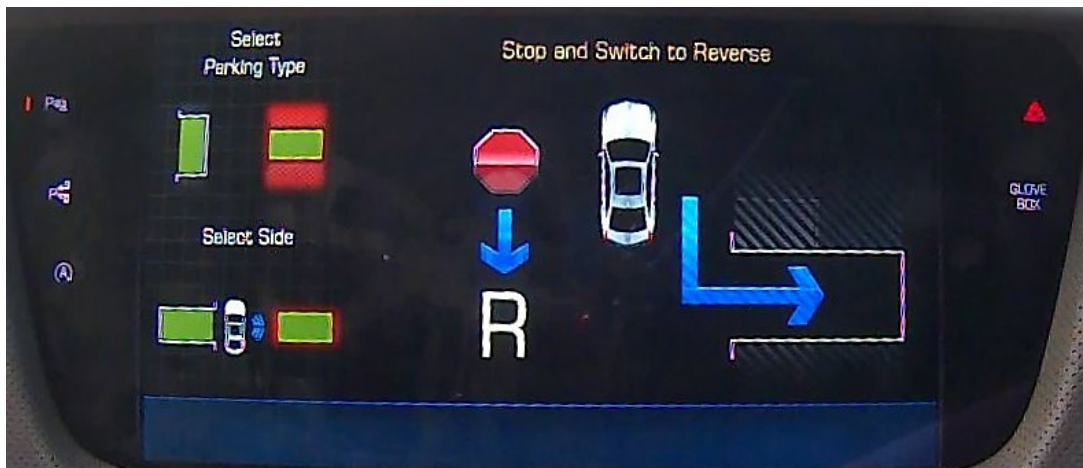**Figure A-9. Tesla Model S notification 4**

A.3 Cadillac CT6 Notifications

Figure A-10. Cadillac CT6 notification 1

Figure A-11. Cadillac CT6 notification 2

Figure A-12. Cadillac CT6 notification 3

Figure A-13. Cadillac CT6 notification 4

Appendix B

The following is a list of vehicle performance criteria defined within NHTSA's draft APA test procedure. It includes a list of APA system parking notification, time tolerance, final parking position, encroaching pedestrian detection assessment, obstructing vehicle detection assessment, and system override assessment specifications intended to facilitate objective, accurate, and repeatable system evaluations.

B.1 SV Parking Notifications

- APA systems must present a parking space detection notification before the rearmost part of the SV crosses the termination boundary.

- APA systems must present a notification to begin the parking function within 5 seconds of the vehicle coming to a complete stop.

- APA systems shall present in-vehicle instruction within 5 seconds after the SV driver has initiated the automated parking function.

- APA systems shall present instructions within 5 seconds after completion of the parking maneuver.

B.2 Time Tolerance

- Systems with automated gear selection must complete the parking maneuver within 45 second from the instant the SV driver first releases the brake pedal.

- Systems with manual gear selection, brake pedal, and/or accelerator pedal inputs must complete the parking maneuver within 60 seconds.

B.3 Final Parking Position

- Perpendicular

  - The rearmost part of the SV shall be within 12 in. (0.3 m) of the inboard edge of the rear of the desired parking space.

  - The leftmost part of the SV shall be 12 in. (0.3 m) or more away from the rightmost part of the second parked vehicle (PV2).

  - The rightmost part of the SV shall be 12 in. (0.3 m) or more away from the leftmost part of the third parked vehicle (PV3).

- Parallel

  - The rightmost edge of the SV's right-side tires shall be within 12 in. (0.3 m) from the inboard edge of the desired parking space.

  - The front most part of the SV must be 12 in. (0.3 m) or more away from the rearmost part of PV3.

  - The rearmost part of the SV must be 12 in. (0.3 m) or more away from the front most part of PV2.

B.4 Encroaching Pedestrian Detection Assessment

- If the APA system uses all automated inputs (steering, brake, throttle, and gear selector):
    - The park assist system shall not allow the SV to impact the PED at any time.
    - If the system cannot park, it shall terminate the maneuver.
- If the APA system uses manual inputs for brake, throttle, and/or gear selector:
    - The park assist system shall instruct the driver how to avoid the PED during the parking maneuver.
    - Provided the SV driver responds to the requests within 2 seconds, the SV shall not impact any PV.
    - If the system cannot park the SV due to the PED the SV shall terminate the maneuver.

B.5 Obstructing Vehicle Detection Assessment

- If the APA system uses all automated inputs (steering, brake, throttle, and gear selector):
    - The park assist system shall not allow the SV to impact the POV at any time.
    - If the system cannot park due to the POV's presence, it shall terminate the maneuver.
- If the APA system uses manual inputs for brake, throttle, and/or gear selector:
    - The park assist system shall instruct the driver how to avoid the PED during the parking maneuver.
    - Provided the SV driver responds to the requests within 2 seconds, the SV shall not impact any PV.
    - If the system cannot park the SV due to the PED the APA system shall terminate the maneuver.

B.6 System Override Assessment

- Each APA system override assessments shall be assessed within 500 ms after the first clockwise steering input is initiated.
- The steering wheel torque require to override the system shall be ≤ 20 ft·lbf (27 N·m).
- The accelerator pedal position required to manually override the system shall be ≤ 5 percent of the wide-open accelerator pedal position.
- For an automated braking system, the brake pedal position required to manually override the system shall be ≤ 5 percent of the fully applied brake pedal position. Here, fully applied brake pedal position occurs when a force of 112 lbf (500 N) is applied to the brake pedal.
- For a manual braking system, the driver manually applies force to the SV brake pedal, and brings the vehicle to a stop within 2 seconds. The APA system shall automatically terminate the parking maneuver once the SV has been stopped for > 5 seconds.
- For all system overrides, the APA system shall present the SV driver with the alert "Parking assist override initiated. Apply brakes to complete." After the driver applies the brakes, the APA system shall present the following alert: "Parking assist override complete. Manual driving restored."

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