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EVALUATION OF ACTIVE DRIVING ASSISTANCE SYSTEMS

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ABSTRACT

Active driving assistance (ADA) systems are becoming increasingly popular across vehicles of various price points. Currently available ADA systems are classified by SAE International®[1] as a Level 2 partial driving automation feature, meaning that constant driver supervision is required. To understand the progression of ADA system performance, AAA has evaluated these systems within a variety of closed-course and naturalistic scenarios since 2018. Building upon previous work, three popular vehicles equipped with an ADA system were evaluated by simulating various scenarios involving a simulated cyclist or passenger vehicle in a closed-course environment.

Research Questions:

1. How do vehicles equipped with ADA systems perform when encountering a possible collision with another passenger vehicle?
    a. Slow lead vehicle moving in the lane ahead of test vehicle
    b. Oncoming vehicle within travel lane of test vehicle
2. How do vehicles equipped with ADA systems perform when encountering a possible collision with a cyclist?
    a. Cyclist traveling in the lane ahead of test vehicle
    b. Cyclist crossing travel lane of test vehicle

Key Findings:

1. How do vehicles equipped with ADA systems perform when encountering a possible collision with another passenger vehicle?
    a. For a slow lead vehicle moving in the lane ahead, no collisions occurred among a total of 15 test runs.
    b. For an oncoming vehicle within the travel lane, a collision occurred during all 15 test runs. One test vehicle significantly reduced speed prior to collision on each run, while the other two did not intervene on any runs.
2. How do vehicles equipped with ADA systems perform when encountering a possible collision with a cyclist?
    a. For a cyclist traveling in the lane ahead of the test vehicle, no collisions occurred among a total of 15 test runs.
    b. For a cyclist crossing the travel lane of the test vehicle, a collision occurred for 5 out of 15 test runs.

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[1] Society of Automotive Engineers

CONTENTS

I. INTRODUCTION

Active driving assistance (ADA) systems continue to receive significant attention in terms of further development and consumer interest. These systems provide sustained lateral and longitudinal vehicle control, defined by SAE standard J3016 [1] as a Level 2 partial driving automation system. Until higher levels of autonomy are available to the public, ADA systems represent the most advanced driver assistance system.

Consumers are faced with a myriad of manufacturer names developed for marketing purposes; these sometimes confusing names can cause the capability of current ADA systems to be overestimated. Regardless of manufacturer, all ADA systems require continuous driving supervision in all driving environments. In 2018, a survey conducted by AAA found that 40 percent of Americans expect ADA systems with names like Autopilot or Pilot Assist to have the ability to drive the car by itself [2], indicating a discrepancy between consumer understanding and reality.

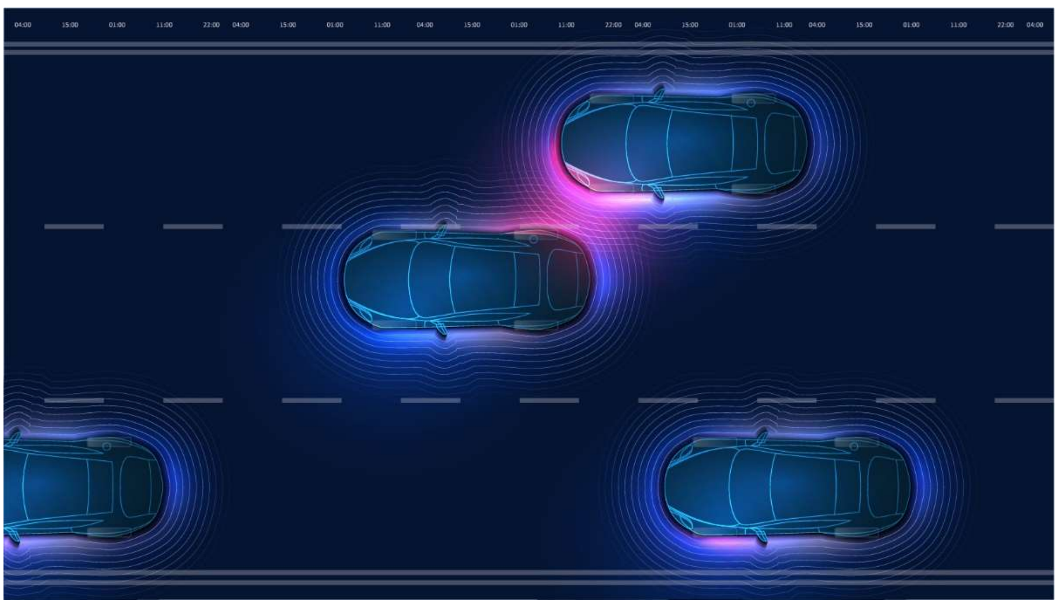

Figure 1: Active driving assistance systems are increasingly common in new vehicles Image Source: AAA

AAA recently characterized the performance of direct and indirect driver monitoring systems as they represent a primary means of mitigating ADA system misuse. Specifically, **direct** driver monitoring systems include a driver-facing camera. Systems utilizing only steering wheel input are referred to as an **indirect** driver monitoring system. Direct systems were found to be more effective at mitigating driver disengagement relative to indirect systems; however, all evaluated systems allowed some degree of disengagement depending on the specific scenario [3]. While the driver must remain attentive and maintain vehicle control at all times, it is nonetheless important to understand how ADA systems respond to possible collisions in the absence of adequate driver intervention. The purpose of this research is to assess the performance of ADA systems when encountering critical situations involving another passenger vehicle or cyclist.

II. BACKGROUND

According to the National Highway Traffic Safety Administration (NHTSA), there were an estimated 38,680 fatalities in motor vehicle traffic crashes during 2020. This corresponds to a fatality rate of 1.37 fatalities per 100 million vehicle miles traveled (VMT). This represents a 7.2 percent increase as compared to the 36,096 fatalities reported in 2019 [4]. Additionally, this is the highest projected number of motor vehicle fatalities since 2007.

While much attention has been justifiably focused on concerns such as overestimation of system capability, intentional misuse, and design characteristics that may lull drivers into a sense of complacency, ADA systems also have the potential to enhance highway driving safety and convenience. Iterative refinement of these systems will also contribute to the development of higher levels of autonomy and improve the performance of safety critical ADAS such as automatic emergency braking (AEB). The Insurance Institute of Highway Safety (IIHS) has previously found that current vehicles with AEB exhibited a 56 percent reduction in front-to-rear crashes with injuries compared to vehicles without the technology [5]. It can be expected that future development and increased market penetration of ADAS will contribute to additional reductions in motor vehicle crash rates over time.

ADA systems are standard or optional within 34 percent of 2020 model year vehicles. Based on previous AAA research, it is essential that additional development continues with particular focus on lane-centering performance on curved roadways, critical edge-case scenarios, and the human-machine interface to include robust mitigation of driver inattention and/or misuse. Due to increased availability over the past few years, an ADA system in a new vehicle could represent the first exposure to ADAS for many drivers. According to CCC Intelligent Solutions Inc., more than 54 percent of those who own a vehicle with ADAS believe that certain features can increase the chance of an accident and 70 percent have actually turned an ADAS feature off [6]. System performance must be consistent and reliable to facilitate widespread acceptance of current ADAS and higher levels of autonomy in the future.

AAA previously found ADA systems struggled with simulated highway situations on the closed-course including the following:

- Encountering a disabled vehicle partially in the roadway
- Lead vehicle changing lanes to reveal a stationary vehicle ahead

The purpose of this work is to evaluate additional critical scenarios that may be reasonably encountered in a highway environment. Recent AAA research provides potential distraction times allowed by current driver monitoring systems. When considered simultaneously, ADA system performance described herein can illustrate potential consequences when driver disengagement is combined with imperfect ADA system performance in the context of suddenly arising edge-case scenarios within a naturalistic environment.

All evaluated scenarios involve either a simulated passenger car or cyclist. Three popular vehicles equipped with ADA systems were selected for evaluation; these vehicles were utilized for driver monitoring research immediately preceding closed-course testing. Detailed test methodology is provided in the full research report available at the AAA NewsRoom.

The scope of primary research within this work exclusively focuses on vehicles equipped with ADA systems capable of SAE Level 2 operation within highway environments. Additional functionalities outside of this scope were not evaluated. A detailed description of SAE Driving Automation System Levels has been provided in AAA various research reports. For more information, refer to Section 2.1 of the Evaluation of Active Driving Assistance Systems research report on the AAA NewsRoom [7].

III. VEHICLE SELECTION METHODOLOGY

AAA researchers utilized industry sources and information from owner's manuals to verify test vehicles were equipped with an ADA system. To be characterized as a Level 2 system by SAE J3016, an ADA system must provide sustained lateral *and* longitudinal vehicle motion control within its operational design domain. Sales data and vehicle MSRP were considered to ensure that the test vehicles were a representative mix of popular models across various price points.

Additionally, the following criteria were utilized for vehicle selection:

- The ability for a system to function at speeds up to 70 mph
- Inclusion of domestic and import original equipment manufacturers (OEMs)
- Variety of manufacturers (only one vehicle per manufacturer will be tested)
- The vehicle model was not previously evaluated in 2020

Based on the preceding requirements, the following vehicles were selected for testing:

- 2021 Hyundai Santa Fe with "Highway Driving Assist"
    - Software Version: TM_FL.USA.S5W_M.V005.001.201120
    - Firmware Version: TMFL.USA.301.201012.MICOM.D

- 2021 Subaru Forester with "EyeSight®"
    - Software Version: Rel_UA.19.36.70

- 2020 Tesla Model 3 with "Autopilot"
    - Software Version: v10.2 (2021.4.18.2 6c676ce09ea5)

IV. TEST EQUIPMENT AND RESOURCES

A. *Vehicle Dynamics Equipment*

1. *Oxford Technical Solutions (OxTS) RT3000 V2 with RT-Range Hunter or RT3000 V3 with Integrated RT-Range Functionality*

Each vehicle was outfitted with either an OxTS RT3000 v2 with an RT-Range Hunter or a RT3000 with integrated RT-Range functionality. These instruments were utilized to capture test and target vehicle kinematic information and process vehicle-to-vehicle measurements relative to the vehicle under test. The RT3000 units interfaced with a site-installed base station to incorporate real-time kinematics (RTK) technology. The RT-Range interfaced with targets via XLAN.

While the OxTS RT3000 V3 is capable of measuring data at a frequency of 250 Hz, all measurements were captured at a rate of 100 Hz.

Position Accuracy	0.01 m
Velocity Accuracy	0.01 m/s
Roll & Pitch Accuracy	0.03°
Heading Accuracy	0.1°
Slip Angle Accuracy	0.15°
Output Data Rate	100 Hz

Figure 2: OxTS RT3000 specifications Image Source: AAA

Forward Range	0.03 m RMS
Lateral Range	0.03 m RMS
Resultant Range	0.03 m RMS
Forward Velocity	0.02 m/s RMS
Lateral Velocity	0.02 m/s RMS
Resultant Velocity	0.02 m/s RMS
Resultant Yaw Angle	0.1° RMS
Lateral Distance to Lane	0.02 m RMS

Figure 3: OxTS RT-Range Hunter specifications Image Source: AAA

2. Futek LAU220 Pedal Force Sensor

Each vehicle was equipped with a brake pedal force sensor to verify no braking intervention was applied during closed-course testing.

Rated Output (RO)	2mV/V
Nonlinearity	± 0.25% of RO
Hysteresis	± 0.25% of RO
Nonrepeatability	± 0.10% of RO
Off Center Loading	± 1% or better @

Figure 4: Futek LAU220 specifications Image Source: AAA

3. DEWESoft CAM-120 Cameras with CAM-BOX2 Distribution Box

Each vehicle was equipped with one camera facing the instrument cluster to monitor the activation state of the ADA system. Additionally, one camera was mounted to each side of the vehicle to monitor positioning relative to lane markers. Video from all cameras was captured at a rate of 45 Hz.

Image Sensor	Sony ICX618
Sensor Type	CCD
FPS	120 FPS @ 640x480
Dynamic Range	32 dB autogain function
Shutter Time	58 ns-60 s (autoshutter function)

Figure 5: DEWESoft CAM-120 specifications Image Source: AAA

4. DEWESoft CAN-2 Interface

Test vehicles were equipped with a CAN interface to capture data from OxTS instrumentation. Vehicle kinematics and range data were captured at a rate of 100 Hz and time-synced with pedal force measurements and video.

5. Data Logging Equipment

Test vehicles were either equipped with a DEWESoft DEWE-43 or SIRIUS® slice data logger to log pedal force measurements at a rate of 2000 Hz. Each data logger was equipped with anti-aliasing filters to attenuate frequencies above the Nyquist frequency.

6. DRI Low Profile Robotic Vehicle (LPRV) with DRI Soft Car 360®

The robotic vehicle is a hardened, satellite guided, self-propelled, low-profile vehicle, which serves as a dynamic platform for the DRI Soft Car. The LPRV has a top speed of 50 mph and a maximum deceleration rate of 0.8 G. The positions of the vehicle under test and LPRV are measured continually using differential GPS with RTK correction. Kinematic data relating to the vehicle under test is broadcast to the LPRV via wireless LAN. This information in conjunction with pre-loaded time-space trajectories (one each for the vehicle under test and LPRV) allow the LPRV to arrive at predefined locations relative to the vehicle under test in a repeatable manner.

Additionally, data from the LPRV was processed by the OxTS RT-Range Hunter to calculate LRPV kinematics relative to the vehicle under test (vehicle under test acts as a non-Newtonian reference frame).

Longitudinal Acceleration	**+0.11 G, -0.8 G**
Lateral Acceleration	**± 0.8 G**
Path Following Accuracy	**0.05 m**
Position Measurement Accuracy	**0.02 m**

Figure 6: DRI Low Profile Robotic Vehicle specifications Image Source: AAA

Figure 7: DRI Low Profile Robotic Vehicle Image Source: AAA

The Soft Car 360® is calibrated to be representative of a small passenger vehicle relevant to automotive sensors including radar and cameras. The hatchback model was utilized for testing; its length, width and height are 158 in, 67 in, and 56 in, respectively.

7. 4activeSystems FBsmall Robotic Platform and 4activeBS-adult Cyclist Target

The FBsmall robotic platform is utilized for dynamic test scenarios involving vulnerable road users (VRUs) i.e. pedestrians, cyclists, and motorcycles. The platform is designed according to Euro NCAP and ISO specifications with integrated dual antenna GNSS/IMU and full synchronize mode with the vehicle under test to allow for consistent run-to-run target positioning. The positions of the vehicle under test and FBsmall are measured continually using differential GPS with RTK correction. Kinematic data relating to the vehicle under test is broadcast to the FBsmall via wireless LAN. Data from the FBsmall was processed by the OxTS RT-Range Hunter to calculate FBsmall kinematics relative to the vehicle under test (vehicle under test acts as a non-Newtonian reference frame).

The 4activeBS-adult is the official Euro NCAP cyclist target and represents an average European adult male on a standard bike. The target includes rotating wheels with realistic micro Doppler spread and other signal characteristics with respect to radar, lidar, camera and infrared sensors.

Figure 8: 4activeFBsmall platform with 4activeBS-adult cyclist target Image Source: AAA

The height, wheel diameter and wheelbase of the bicycle is 47.2 in, 27.6 in, and 48.4 in, respectively. The height, shoulder width and torso angle of the cyclist is 70.9 in, 19.7 in, and 10°, respectively.

B. Test Facility

All closed-course testing was conducted on a surface street at the AAA Northern California, Nevada and Utah–operated GoMentum Station proving ground in Concord, California. GoMentum Station is utilized by automated vehicle developers and suppliers for testing, validation, and safety research.

All testing was conducted on a dry asphalt surface free of visible moisture. The surface was straight and flat, free of potholes and other irregularities that could cause significant variations in the trajectory of the test vehicle. The testing area was approximately 0.7 miles long and consisted of a two-lane roadway divided down the middle by a dashed white line. The width of each dashed white line segment was 7 inches with a uniform spacing of 17 feet 2 inches between segments.

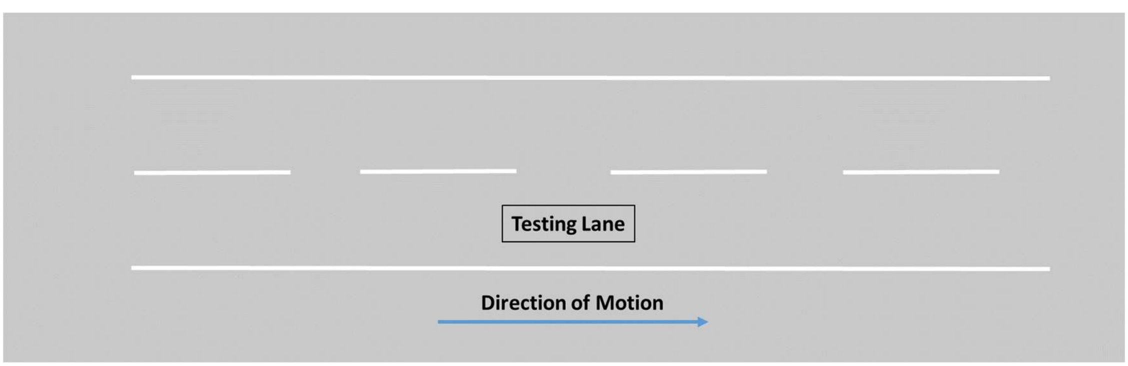

Figure 9: Illustration of testing surface Image Source: AAA

Each individual lane was marked by a solid white line on the lateral side and the previously described dashed white line on the medial side with a nominal lane width of 10 feet. This lane width is representative of typical roadways (excluding interstates and limited-access expressways with a nominal width of 12 feet) in both urban and rural areas within the United States.

V. VEHICLE PREPARATION

All vehicles were procured directly from manufacturers or specialty rental fleets. Vehicles provided by the manufacturer were verified by the OEM to be suitable for testing. To ensure the proper functioning of the ADA system, all test vehicles were serviced at Los Angeles–area dealerships to include a four-wheel alignment and recalibration of the ADA system before commencing naturalistic testing. Each dealership provided documentation to ensure ADA systems were calibrated according to manufacturer specifications.

All test vehicles were verified to be equipped with an ADA system with integrated driver monitoring. Systems were verified to be enabled and free of modifications. The odometer reading of all test vehicles was between 200 and 7,000 miles at the start of testing.

Additionally, vehicles were inspected to verify testing suitability according to the following checklist:

- No warning lights illuminated
- All system components free of damage and unaffected by any technical service bulletins and/or recalls
- Any stored diagnostic trouble codes were resolved and cleared
- All fluid reservoirs filled to at least the minimum indicated levels
- Tires inflated to placard pressure following stabilization at ambient temperature in a shaded environment

Before the start of each testing day, the areas surrounding the image and radar sensors on all test vehicles were cleaned to ensure optimal system operation.

VI. INQUIRY 1: HOW DO VEHICLES EQUIPPED WITH ADA SYSTEMS PERFORM WHEN ENCOUNTERING A POSSIBLE COLLISION WITH ANOTHER PASSENGER VEHICLE?

A. Objective

Evaluate the performance of ADA systems in the context of situations involving a potential collision with another passenger vehicle.

B. Methodology

In sections herein, “target vehicle” refers to the simulated lead or oncoming vehicle. To allow for full characterization of ADA system performance, the simulated vehicle previously described in Section IV.A.6 was utilized.

For the each of the test scenarios, the following data were collected and utilized to characterize system performance according to parameters within Figure 10:

- ADA system status and warning indicators (via video recording)
- Longitudinal velocity and acceleration for test and target vehicles

- Longitudinal and lateral position of target vehicle relative to test vehicle
- Calculated time-to-collision (TTC)

Five test runs were performed for each test vehicle per test scenario. Detection is considered to have occurred at the instant that a notification of a vehicle ahead is visible on the test vehicle's instrument cluster. Automatic braking is considered to have occurred once the test vehicle's longitudinal deceleration exceeds 0.1 G.

Parameter	Unit	Description
Detection Distance	ft	Longitudianal distance between the front of the test vehicle and rear of the target vehicle when the ADA system indicated the presence of the target vehicle
Detection Time-to-Collision	s	Time-to-collision associated with the detection distance
Braking Distance	ft	Longitudinal distance between the front of test vehicle and rear of the target vehicle when test vehicle deceleration reached 0.1 G
Braking Time-to-Collision	s	Time-to-collision associated with the braking distance
Average Deceleration	G	Average deceleration from braking initiation to the end of the braking event
Maximum Deceleration	G	Maximum deceleration from braking initiation to the end of the braking event
Impact Speed	mph	Test vehicle speed at first contact with the target vehicle (if applicable)
Separation Distance	ft	Final longitudinal distance between the test vehicle and the target vehicle at the end of the braking event (if no impact occurred)
Note: The end of the braking event is defined as either the moment of impact between the test vehicle and the target vehicle or the moment when the test vehicle successfully avoided a collison.		

Figure 10: Performance parameters for simulated vehicle tests Image Source: AAA

$$TTCa = \frac{-v_r - \sqrt{v_r^2 - 2a_{LV}r}}{a_{LV}}$$

Figure 11: TTC with lead vehicle acceleration Image Source: AAA

Figure 11 provides the TTC equation utilized within the following sections, where v_r is the relative velocity, a_{LV} is the lead vehicle acceleration, and r is the longitudinal separation distance.

1. Slow lead vehicle in the lane ahead of test vehicle

Slow or stopped traffic is frequently encountered in highway environments. In many cases, traffic ahead will suddenly slow or stop with minimal warning. It is essential that ADA systems respond to this common occurrence in a controlled and consistent manner. Previous AAA research found during naturalistic evaluations that all test vehicles generally performed well in terms of longitudinal vehicle control. For detailed test methodology and findings, please refer to Section 7 of the Evaluation of Active Driving Assistance Systems research report [7]. However, due to the naturalistic testing environment, test drivers may have intervened prior to ADA system action for abrupt changes in traffic flow and/or large speed differentials with traffic ahead.

To initiate a test run, the lead vehicle accelerated to 20 mph and traveled within the lane at steady-state speed for at least 10 seconds at a minimum of 1700 feet ahead of the test vehicle. At this point, the test vehicle was accelerated to 55 mph within the lane and the ADA system was engaged at this speed. After system engagement, the test driver provided no throttle or brake pedal application and only provided minimal steering wheel input if requested by the system to maintain ADA system engagement. Because the test driver applied no acceleration input once the system was engaged, the actual test speed was controlled by the ADA system and may be marginally higher or lower than 55 mph. As the test vehicle approached the target vehicle from behind, no driver intervention was applied until contact was made with the target vehicle (if contact occurred) or the test vehicle successfully mitigated a collision.

2. Oncoming vehicle within travel lane of test vehicle

Highways throughout the United States commonly consist of two-lane highways with oncoming traffic in the adjacent lane with no dividing barrier. In this environment, oncoming vehicles could enter the opposite lane of travel for reasons including passing, distraction, driver error, and/or impairment. The potential of a head-on collision represents a critical situation as this type of crash is among the most severe due to the underlying physics associated with increased impact speeds; death or severe debilitating injuries are common consequences. The purpose of this test is to characterize the ability of an ADA system to respond to this type of situation in the absence of adequate intervention by the driver.

To simulate an imminent head-on collision resulting from a distracted or impaired driver, the simulated vehicle previously described in Section IV.A.6 was placed in the middle of the roadway such that its lateral centerline was approximately located over the dashed white line separating the two travel lanes. The speed of the test vehicle and simulated oncoming vehicle was 25 mph and 15 mph, respectively. It is acknowledged that these speeds are significantly lower than commonly encountered speeds on rural two-lane highways. Due to constraints related to the potential of significant vehicle damage and maximum impact speed for the target vehicle, common speed limits (up to 55 mph) were not simulated. However, researchers theorize that evaluated speeds represent a best-case scenario in which ADA systems will have more time to respond in comparison to a similar situation with higher speeds seen in a naturalistic environment.

To initiate a test run, the oncoming vehicle accelerated to 15 mph and traveled at steady-state speed for the entirety of the test. The test vehicle was accelerated to 25 mph within the lane and the ADA system was engaged at this speed. Both vehicles reached steady-state speed with a minimum of 1000 feet of longitudinal separation distance. After system engagement, the test driver provided no throttle or brake pedal application and only provided minimal steering wheel input if requested by the system to maintain ADA system engagement. Since the test driver applied no acceleration input once the system was engaged, the actual test speed was determined by the ADA system and may be marginally higher or lower than 25 mph. As the test vehicle approached the target vehicle, no driver intervention was applied until contact was made with the target vehicle (if contact occurred) or the test vehicle successfully mitigated a collision.

C. Test Results

1. Slow lead vehicle in the lane ahead of test vehicle

Overall System Performance			
Test Vehicle	Detected Target Vehicle	Applied Brakes	Impacted Target Vehicle
Hyundai Santa Fe	5/5	5/5	0/5
Subaru Forester	5/5	5/5	0/5
Tesla Model 3	5/5	5/5	0/5
Note: Results are presented as the number of occurrences out of five total test runs per test vehicle.			

Figure 12: General ADA system performance observations Image Source: AAA

All test vehicles successfully detected the target vehicle, decelerated to avoid impact and matched the speed of the target vehicle. Figure 12 provides overall results pertaining to detection, braking, and impact phases. All test vehicles performed consistently; zero impacts occurred among a total of fifteen test runs.

Hyundai Santa Fe								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	370.1	7.39	336.2	6.81	0.148	0.302	NA	47.0
2	386.4	7.61	346.6	6.95	0.141	0.281	NA	46.2
3	382.0	7.56	337.2	6.78	0.143	0.261	NA	44.0
4	380.3	7.48	345.0	6.89	0.140	0.262	NA	46.4
5	381.7	7.47	345.6	6.85	0.142	0.259	NA	45.7
Avg	**380.1**	**7.50**	**342.1**	**6.86**	**0.143**	**0.273**	**NA**	**45.9**

Figure 13: Hyundai Santa Fe run level results Image Source: AAA

For each of the five test runs, the Hyundai Santa Fe detected the lead vehicle and applied the brakes consistently in terms of longitudinal distance. These distances provide adequate separation between vehicles and sufficient notification to the driver that the ADA system detects the slow lead vehicle. Additionally, the average and maximum decelerations were consistent in terms of magnitude. Observed magnitudes are characteristic of gradual deceleration, which would enhance passenger comfort.

For all test runs, the test vehicle matched the speed of the lead vehicle and maintained a safe following distance.

Subaru Forester								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	284.9	5.50	242.2	4.78	0.204	0.384	NA	32.7
2	278.6	5.36	239.8	4.68	0.205	0.421	NA	32.4
3	284.6	5.51	250.1	4.91	0.193	0.365	NA	36.3
4	265.0	5.09	223.0	4.36	0.220	0.420	NA	30.5
5	295.9	5.71	253.0	4.94	0.187	0.376	NA	32.8
Avg	**281.8**	**5.43**	**241.6**	**4.73**	**0.202**	**0.393**	**NA**	**33.0**

Figure 14: Subaru Forester run level results Image Source: AAA

For each of the five test runs, the Subaru Forester detected the lead vehicle and applied the brakes consistently in terms of longitudinal distance. These distances provide adequate separation between vehicles and sufficient notification to the driver that the ADA system detects the slow lead vehicle. Additionally, the average and maximum decelerations were consistent in terms of magnitude. Average deceleration magnitudes are characteristic of gradual deceleration, which would enhance passenger comfort.

For all test runs, the test vehicle matched the speed of the lead vehicle and maintained a safe following distance.

Tesla Model 3								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	319.8	6.58	288.3	6.16	0.150	0.333	NA	42.1
2	314.1	6.60	280.5	6.12	0.154	0.384	NA	42.0
3	302.2	6.44	281.9	6.15	0.150	0.369	NA	42.1
4	334.0	6.90	285.4	6.22	0.151	0.374	NA	42.1
5	302.1	6.40	287.1	6.19	0.151	0.366	NA	41.8
Avg	**314.5**	**6.58**	**284.6**	**6.16**	**0.151**	**0.365**	**NA**	**42.0**

Figure 15: Tesla Model 3 run level results Image Source: AAA

For each of the five test runs, the Tesla Model 3 detected the lead vehicle and applied the brakes consistently in terms of longitudinal distance. These distances provide adequate separation between vehicles and sufficient notification to the driver that the ADA system detects the slow lead vehicle. Additionally, the average and maximum decelerations were consistent in terms of magnitude. Average deceleration magnitudes are characteristic of gradual deceleration, which would enhance passenger comfort. However, instantaneous maximum decelerations are moderately abrupt and indicative of some modest "jerking" during the braking event.

For all test runs, the test vehicle matched the speed of the lead vehicle and maintained a safe following distance.

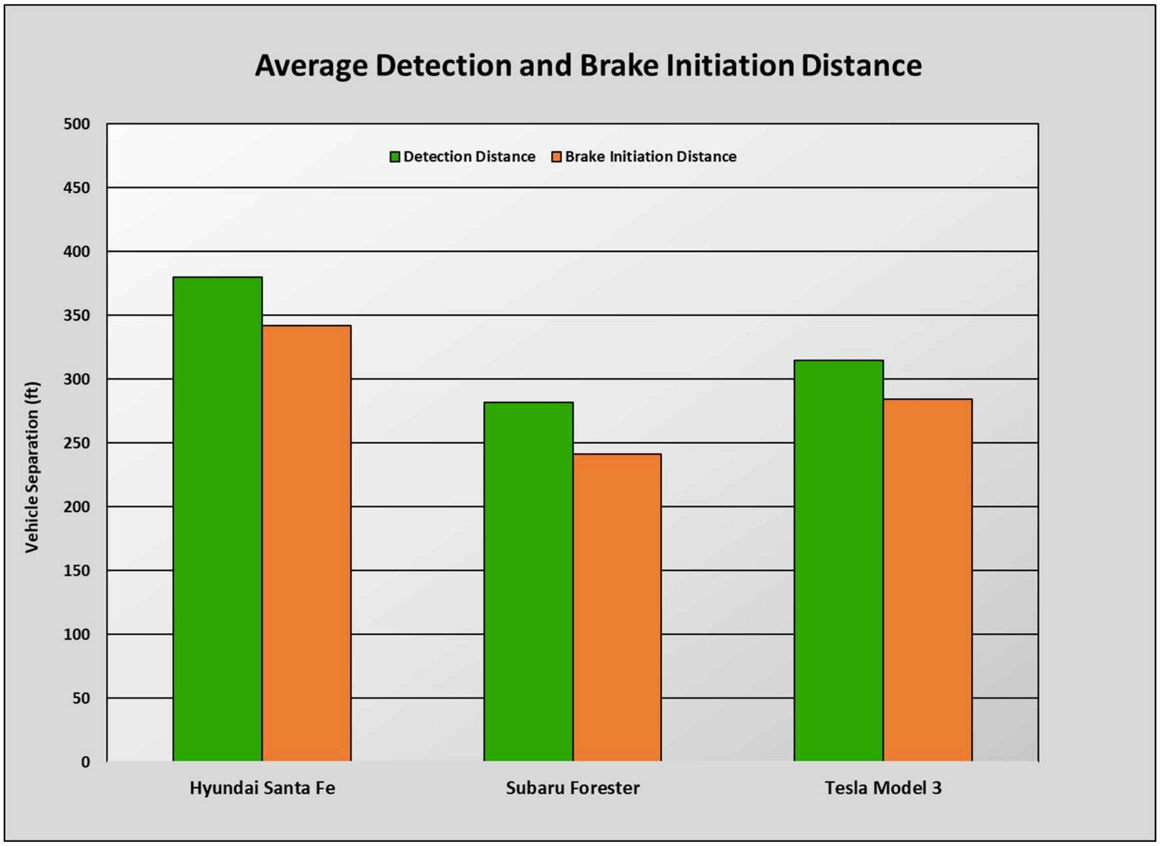

Figure 16: Average detection and braking initiation distances Image Source: AAA

Figure 16 illustrates average detection and braking initiation distances for each test vehicle. None of the vehicles provided an AEB warning for any test runs, indicating that ADA systems appropriately responded to the target vehicle. Of the three test vehicles, the Subaru Forester detected the slow-moving lead vehicle and initiated braking the latest, resulting in more aggressive braking relative to the other test vehicles. However, each ADA system appropriately decelerated the test vehicle at a gradual rate before following the target vehicle at a safe distance.

2. Oncoming vehicle within travel lane of test vehicle

Overall System Performance			
Test Vehicle	Detected Simulated Vehicle	Applied Brakes	Impacted Simulated Vehicle
Hyundai Santa Fe	0/5	0/5	5/5
Subaru Forester	0/5	0/5	5/5
Tesla Model 3	5/5	5/5	5/5
Note: Results are presented as the number of occurrences out of five total test runs per test vehicle.			

Figure 17: General ADA system performance observations Image Source: AAA

Figure 17 provides overall results pertaining to detection, braking, and impact phases. All test vehicles impacted the simulated vehicle for each of the five test runs. Additionally, each test vehicle performed consistently across test runs in terms of target vehicle detection and associated braking.

Hyundai Santa Fe								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	NA	NA	NA	NA	NA	NA	24.9	NA
2	NA	NA	NA	NA	NA	NA	25.0	NA
3	NA	NA	NA	NA	NA	NA	25.1	NA
4	NA	NA	NA	NA	NA	NA	25.0	NA
5	NA	NA	NA	NA	NA	NA	25.0	NA
Avg	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**25.0**	**NA**

Figure 18: Hyundai Santa Fe run level results Image Source: AAA

For each of the five test runs, the Hyundai Santa Fe failed to detect the approaching target vehicle partially in the travel lane. Consequently, no braking was applied and impact occurred without speed reduction for each test run. Consistent failure to mitigate the collision with the target vehicle indicates the incapability of the ADA system to adequately respond to this scenario absent driver intervention.

Subaru Forester								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	NA	NA	NA	NA	NA	NA	25.7	NA
2	NA	NA	NA	NA	NA	NA	25.5	NA
3	NA	NA	NA	NA	NA	NA	26.1	NA
4	NA	NA	NA	NA	NA	NA	25.5	NA
5	NA	NA	NA	NA	NA	NA	25.4	NA
Avg	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**25.6**	**NA**

Figure 19: Subaru Forester run level results Image Source: AAA

For each of the five test runs, the Subaru Forester failed to detect the approaching target vehicle partially in the travel lane. Consequently, no braking was applied and impact occurred without speed reduction for each test run. Consistent failure to mitigate the collision with the target vehicle indicates the incapability of the ADA system to adequately respond to this scenario absent driver intervention.

Tesla Model 3								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	317.0	6.26	161.7	3.32	0.260	0.522	0.9	NA
2	315.8	6.23	170.6	3.45	0.301	0.504	2.1	NA
3	316.5	6.23	165.3	3.37	0.245	0.480	2.6	NA
4	324.2	6.39	168.9	3.43	0.242	0.471	2.6	NA
5	313.2	6.17	159.2	3.26	0.314	0.455	3.2	NA
Avg	**317.3**	**6.26**	**165.1**	**3.37**	**0.273**	**0.486**	**2.3**	**NA**

Figure 20: Tesla Model 3 run level results Image Source: AAA

For each of the five test runs, the Tesla Model 3 detected the approaching target vehicle and applied the brakes consistently in terms of longitudinal distance. For all test runs, the ADA system significantly reduced the impact speed; the average test vehicle speed was 2.3 mph.

While the average detection distance was 317.3 feet, braking initiation did not occur for another 2.89 seconds, on average. This differs from the slow-moving lead vehicle scenario, during which braking was initiated 0.42 seconds after detection, on average. The significant delay between detection and braking suggests uncertainty by the ADA system in how to respond.

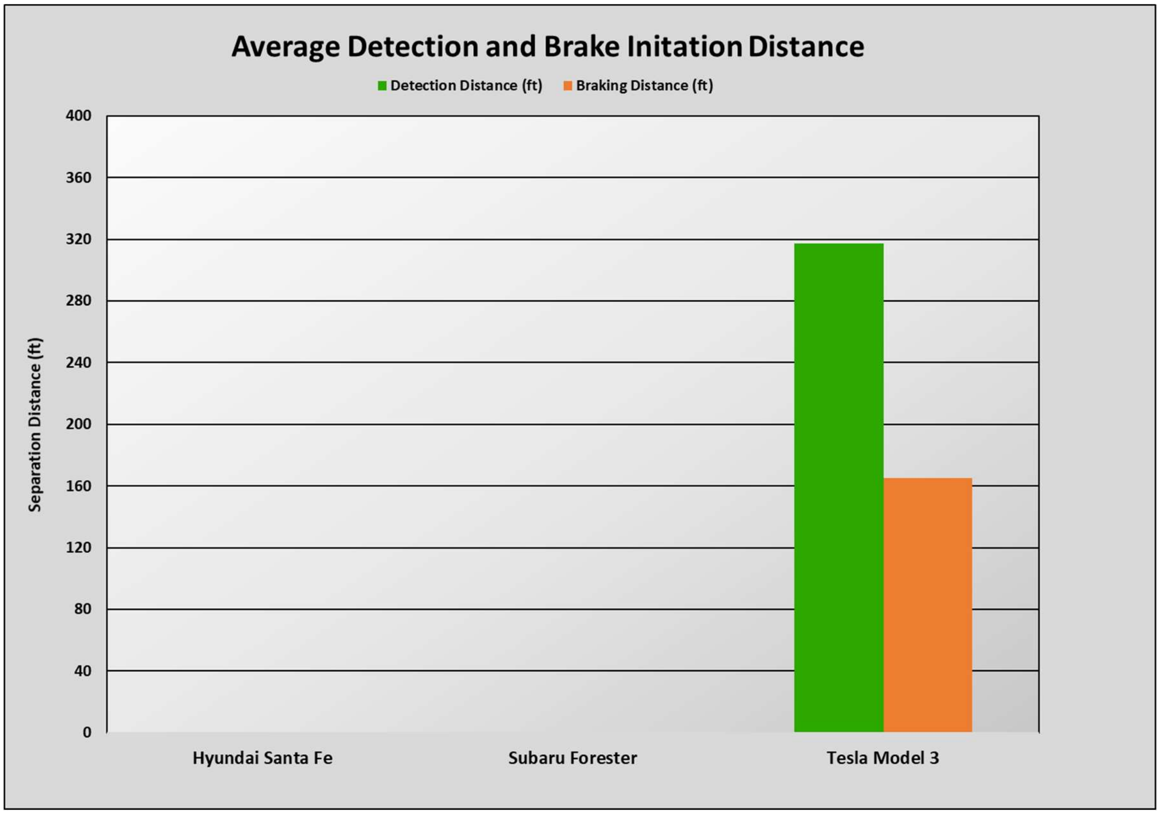

Figure 21: Average detection and braking initiation distances Image Source: AAA

As illustrated in Figure 21, two out of three test vehicles failed to indicate detection of the approaching vehicle or initiate braking for any of the five test runs. This finding suggests that the task of detecting and mitigating impending collision with an oncoming vehicle in the driving lane presents a significant challenge for ADA systems in general.

D. Discussion

Each evaluated ADA system consistently detected and initiated braking in response to a slow lead vehicle. Additionally, all vehicles matched the speed of the lead vehicle and maintained a safe following distance. This validates that the findings of earlier studies in which the adaptive cruise control (ACC) functionality of ADA systems performed well in the naturalistic environment.

For a slow oncoming vehicle within the travel lane of the test vehicle, two of three evaluated ADA systems failed to initiate braking in response to this critical situation. However, the Tesla Model 3 detected the oncoming vehicle and initiated braking in response to the imminent collision for each of the five test runs resulting in a significantly decreased impact speed.

These scenarios involving potential collisions with another passenger vehicle suggest that evaluated ADA systems are more effective at consistently responding to a typical scenario such as a slow-moving lead vehicle as opposed to an edge-case scenario involving an oncoming vehicle within the travel lane. It is important to note that the oncoming vehicle test was performed at unrealistically low vehicle speeds; at higher speeds characteristic of rural two-lane highways, it is unlikely that evaluated ADA systems would provide meaningful mitigation in the absence of driver intervention.

Based on these findings, further refinement of ADA systems to adequately respond to edge-case emergency scenarios is necessary. It is acknowledged that sudden changes in lateral direction at speed can introduce significant safety concerns. In lieu of sudden directional changes effected by the ADA system, enhanced early detection of emergency situations in conjunction with an effective warning protocol could provide drivers with more time to apply appropriate steering input.

VII. INQUIRY 2: HOW DO VEHICLES EQUIPPED WITH ADA SYSTEMS PERFORM WHEN ENCOUNTERING A POSSIBLE COLLISION WITH A CYCLIST?

A. Objective

Evaluate the performance of ADA systems in the context of situations involving a potential collision with a cyclist.

B. Methodology

For the each of the test scenarios, the following data were collected and utilized to characterize system performance according to parameters within Figure 22:

- ADA system status and warning indicators (via video recording),
- Longitudinal velocity and acceleration for test and target vehicles
- Longitudinal and lateral position of target vehicle relative to test vehicle
- Calculated time-to-collision (TTC)

Five test runs were performed for each test vehicle per test scenario. Detection is considered to have occurred at the instant that a notification of a vehicle ahead is visible on the test vehicle's instrument cluster. Automatic braking is considered to have occurred once the test vehicle's longitudinal deceleration exceeds 0.1 G.

Parameter	Unit	Description
Detection Distance	ft	Longitudinal distance between the front of test vehicle and the cyclist target when the ADA system indicated the presence of the cyclist target
Detection Time-to-Collision	s	Time-to-collision associated with the detection distance
Braking Distance	ft	Longitudinal distance between the front of the test vehicle and the cyclist target when test vehicle deceleration reached 0.1 G
Braking Time-to-Collision	s	Time-to-collision associated with the braking distance
Average Deceleration	G	Average deceleration from braking initiation to the end of the braking event
Maximum Deceleration	G	Maximum deceleration from braking initiation to the end of the braking event
Impact Speed	mph	Test vehicle speed at first contact with the cyclist target (if applicable)
Separation Distance	ft	Minimum longitudinal distance between the test vehicle and the cyclist target (if no impact occurred). For the crossing cyclist scenario, longitudinal distance once the rear wheel of the cyclist target clears the left corner of the test vheicle (if no impact occurred).
Note: The end of the braking event is defined as either the moment of impact between the test vehicle and the cyclist target or the moment when the test vehicle sucessfully avoided a collison.		

Figure 22: Performance parameters for cyclist target tests Image Source: AAA

$$TTCa = \frac{-v_r - \sqrt{v_r^2 - 2a_{LV}r}}{a_{LV}}$$

Figure 23: TTC with lead vehicle acceleration Image Source: AAA

Figure 23 provides the TTC equation utilized within the following sections, where v_r is the relative velocity, a_{LV} is the lead vehicle acceleration, and r is the longitudinal separation distance.

1. Cyclist traveling in the lane ahead of test vehicle

Drivers often have to share roadways lacking a dedicated bicycle lane with cyclists. In this scenario, vehicles will commonly approach a cyclist moving in the same direction at a significantly slower speed relative to automobile traffic. Depending on the width of the roadway, vehicles may pass with only a few feet of lateral clearance. As of September 2021, 35 states and the District of Columbia have enacted laws that require motorists to leave at least 3 feet of lateral clearance when passing a bicyclist [8].

According to NHTSA's National Center for Statistics and Analysis, 846 cyclists were killed and approximately 49,000 were injured in motor vehicle crashes in 2019 [9]. As cyclists are afforded the same privileges to non-limited access roadways as motor vehicles, it is important to understand ADA system performance in the context of interactions with this type of vulnerable road user (VRU).

The purpose of this test is to characterize ADA system performance when approaching a cyclist in the travel lane moving in the same direction as automotive traffic. The cyclist target previously described in Section IV.A.7 was utilized to simulate a cyclist traveling within the travel lane of the approaching test vehicle. The simulated cyclist was placed 1 foot to the left of the solid white lane marker on the right side of the travel lane and traversed at a steady-state speed of 15 mph. Lateral position within the travel lane was maintained throughout the test and steady-state speed was reached before a test run was initiated. To initiate a test run, the test vehicle was accelerated to 45 mph within the lane and the ADA system was engaged at this speed. A minimum of 500 feet separated the cyclist target and test vehicle at the moment of ADA system engagement. After system engagement, the test driver provided no throttle or brake pedal application and only provided minimal steering wheel input if requested by the system to maintain ADA system engagement. Since the test driver applied no acceleration input once the system was engaged, the actual test speed was determined by the ADA system and may be marginally higher or lower than 45 mph. As the test vehicle approached the target vehicle, no driver intervention was applied until contact was made with the target vehicle (if contact occurred) or the test vehicle successfully mitigated a collision.

2. *Cyclist crossing travel lane of test vehicle*

Four-way intersections are commonly encountered on non-limited access highways and within urban environments. As the design domain of most ADA systems include this environment, it is important to understand system performance in the context of perpendicular crossing situations involving other vehicles and VRUs.

The cyclist target previously described in Section IV.A.7 was utilized to simulate a cyclist crossing the travel lane of the test vehicle. The longitudinal center of the cyclist target was placed 100 feet to the right of the travel lane centerline (relative to approaching test vehicle). To initiate a test run, the test vehicle was accelerated to 25 mph within the lane and the ADA system was engaged at this speed. A minimum of 700 feet separated the cyclist target and test vehicle at the moment of ADA system engagement. As the test vehicle approached the cyclist target, the test driver provided no throttle or brake pedal application and only provided minimal steering wheel input if requested by the system to maintain ADA system engagement.

Since the test driver applied no acceleration input once the system was engaged, the actual test speed was determined by the ADA system and may be marginally higher or lower than 25 mph. It is acknowledged that this speed is significantly slower than typical speed limits on unrestricted four-lane highways; higher speeds were not evaluated due to design limitations relating to maximum impact speed for the cyclist target. However, it is expected that system performance would be adversely influenced by higher test speeds due to reduced available response time.

The cyclist target accelerated to 9.4 mph within 1.5 seconds once the test vehicle was within 290 feet in the longitudinal direction; the target adjusted its speed such that any impact would occur along the lateral centerline of the test vehicle (50 percent offset relative to the front right corner). If the test vehicle rapidly decelerated before impact, the impact point will be greater than 50% offset. This is a consequence of sudden speed reduction and does not constitute an invalid test run. The test driver did not apply the brakes until the vehicle successfully avoided a collision or until contact was made. Additionally, the test driver would apply steering input immediately after impact to avoid driving over the cyclist target, if necessary.

C. Test Results

1. Cyclist traveling in the lane ahead of test vehicle

Overall System Performance			
Test Vehicle	Detected Cyclist Target	Applied Brakes	Impacted Cyclist Target
Hyundai Santa Fe	5/5	5/5	0/5
Subaru Forester	5/5	5/5	0/5
Tesla Model 3	5/5	5/5	0/5
Note: Results are presented as the number of occurrences out of five total test runs per test vehicle.			

Figure 24: General ADA system performance observations Image Source: AAA

All test vehicles successfully detected the simulated cyclist and decelerated the vehicle to avoid impact with the cyclist target. Additionally, none of the test vehicles attempted to pass the cyclist target. Figure 24 provides overall results pertaining to detection, braking, and impact phases. While no impacts occurred among a total of fifteen test runs, there is some nuance associated with ADA system performance in totality.

Hyundai Santa Fe Detailed Results								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	240.1	5.62	218.8	5.19	0.150	0.384	NA	35.1
2	282.1	5.68	274.2	5.58	0.100	0.424	NA	39.1
3	125.1	2.86	115.1	2.64	0.364	0.618	NA	15.7
4	80.7	1.85	67.6	1.56	0.588	1.725	NA	0.0
5	296.3	6.73	266.0	6.15	0.092	0.435	NA	36.0
Avg	**204.8**	**4.55**	**188.3**	**4.22**	**0.259**	**0.717**	**NA**	**25.2**

Figure 25: Hyundai Santa Fe run level test results Image Source: AAA

For each of the five test runs, the Hyundai Santa Fe detected the cyclist target and initiated braking in response. For three of five test runs, detection and braking initiation distances provide enough separation distance to sufficiently notify the driver that the ADA system detects the cyclist target. Additionally, the average and maximum decelerations for these test runs were consistent in terms of magnitude. Average deceleration magnitudes are characteristic of gradual deceleration, which would enhance passenger comfort. However, instantaneous maximum decelerations are moderately abrupt and indicative of some modest "jerking" during the braking event.

For test runs three and four within Figure 25, the AEB system was activated as indicated by a notification within the instrument cluster. This corresponds with significantly reduced detection and braking initiation distances. For test run four, the longitudinal separation distance was zero. The front of the vehicle was roughly aligned with the longitudinal centerline of the cyclist target when the test vehicle matched the cyclist target's speed. Impact did not technically occur due to the lateral position of the cyclist target; there was 3.2 inches of lateral separation distance between the right side of the test vehicle and the cyclist target. While this is not considered an impact, this observed lateral clearance would likely prove hazardous in a naturalistic environment and additionally violates cyclist clearance laws previously described.

For test runs characterized by AEB activation, the test vehicle became unnecessarily close to the cyclist target. This suggests that the ADA system is challenged to consistently respond to a cyclist traveling in a parallel direction within the travel lane.

Subaru Forester Detailed Results								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	193.9	4.38	177.5	4.04	0.181	0.490	NA	26.5
2	177.1	4.02	149.5	3.47	0.203	0.561	NA	24.7
3	160.1	3.60	150.3	3.39	0.219	0.656	NA	24.8
4	163.2	3.69	144.7	3.29	0.248	0.422	NA	23.5
5	140.0	3.20	114.4	2.71	0.299	0.484	NA	20.5
Avg	**166.9**	**3.78**	**147.3**	**3.38**	**0.230**	**0.523**	**NA**	**24.0**

Figure 26: Subaru Forester run level test results Image Source: AAA

For each of the five test runs, the Subaru Forester detected the cyclist target and applied the brakes in response. For test runs one through four within Figure 26, detection and braking initiation distances provide enough separation distance to sufficiently notify the driver that the ADA system detects the cyclist target. Additionally, the average and maximum decelerations throughout these test runs were generally consistent in terms of magnitude. Average deceleration magnitudes are characteristic of gradual deceleration, which would enhance passenger comfort. However, instantaneous maximum decelerations are moderately abrupt and indicative of some "jerking" during the braking event. For test runs one through four, the test vehicle matched the speed of the cyclist target and maintained a safe following distance.

Test run five was noticeably later in terms of detection and braking initiation; the detection TTC of 3.20 seconds was later than the braking initiation TTC for test runs one through four. While the test vehicle matched the cyclist target speed with a minimum of 20.5 feet of longitudinal separation distance, system performance was noticeably diminished relative to test runs one through four.

Tesla Model 3 Detailed Results								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	302.6	6.87	262.9	6.29	0.107	0.379	NA	40.8
2	267.2	6.24	224.1	5.36	0.116	0.592	NA	40.6
3	322.4	7.63	299.7	7.20	0.085	0.436	NA	41.3
4	264.9	6.51	251.1	6.22	0.112	0.548	NA	41.0
5	316.4	7.40	273.1	6.56	0.101	0.492	NA	41.4
Avg	**294.7**	**6.93**	**262.2**	**6.32**	**0.104**	**0.490**	**NA**	**41.0**

Figure 27: Tesla Model 3 run level test results Image Source: AAA

For each of the five test runs, the Tesla Model 3 detected the cyclist target and applied the brakes in response. Detection and braking initiation distances provide enough separation distance to sufficiently notify the driver that the ADA system detects the cyclist target. Additionally, the average and maximum decelerations were consistent in terms of magnitude. Average deceleration magnitudes are characteristic of gradual deceleration, which would enhance passenger comfort. However, instantaneous maximum decelerations are moderately abrupt and indicative of some modest “jerking” during the braking event.

For all test runs, the test vehicle matched the speed of the cyclist target and maintained a safe following distance.

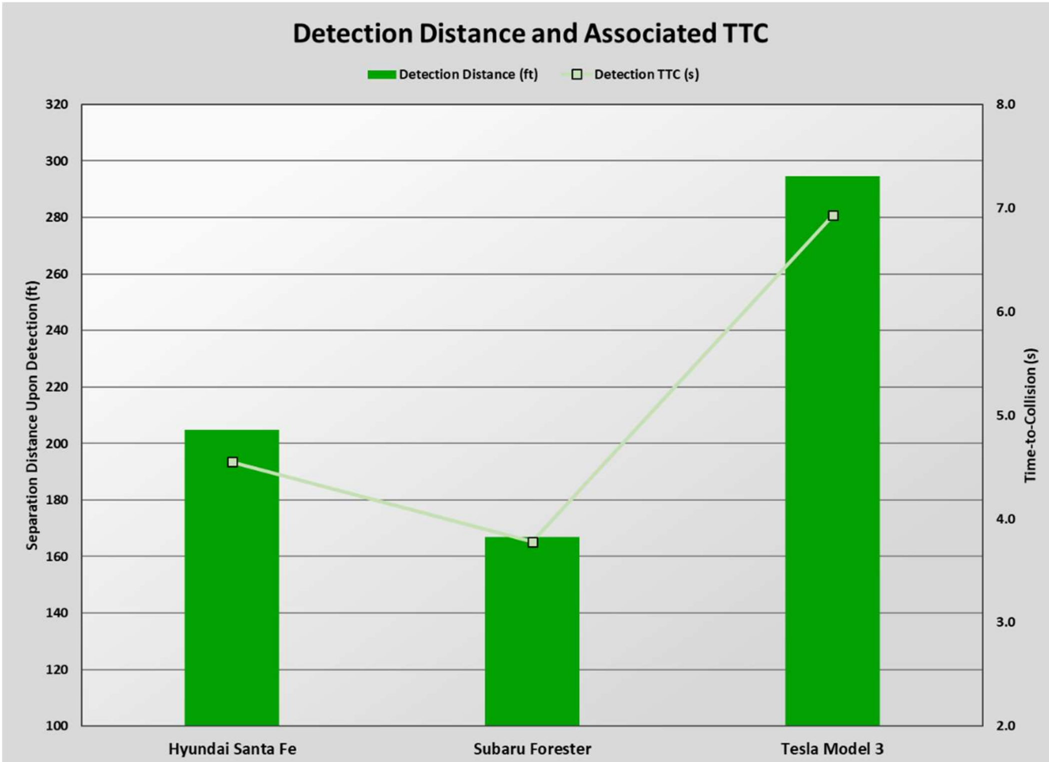

Figure 28: Average detection distance and associated TTC for all test vehicles Image Source: AAA

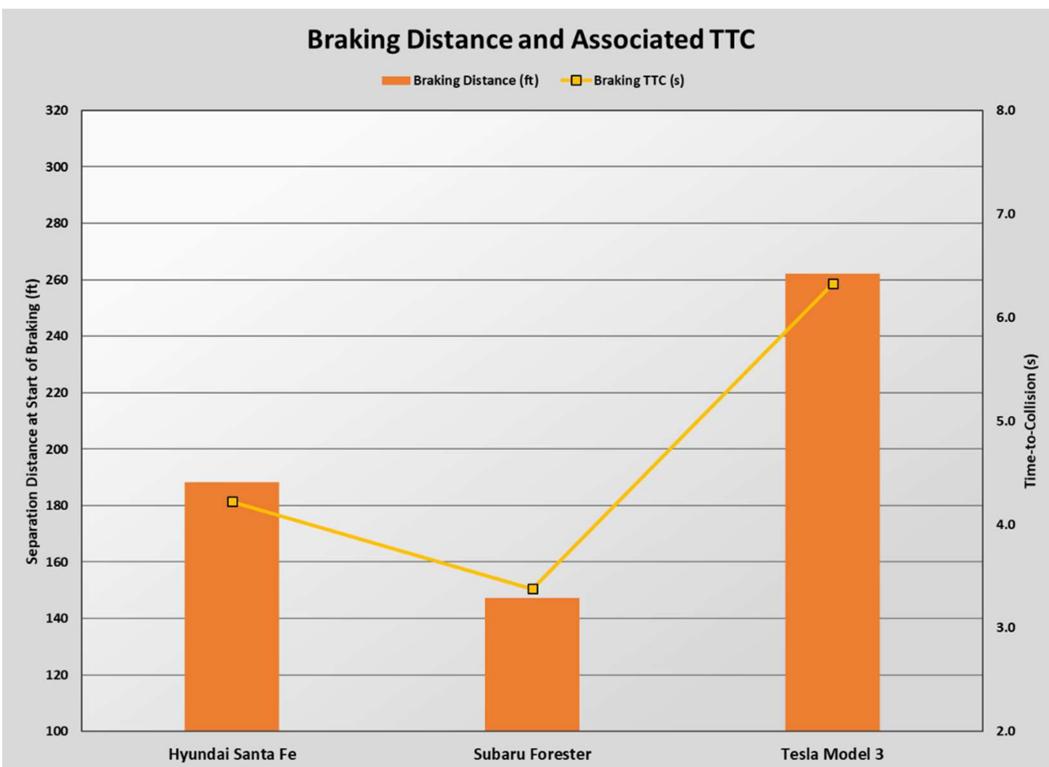

Figure 29: Average braking distance and associated TTC for all test vehicles Image Source: AAA

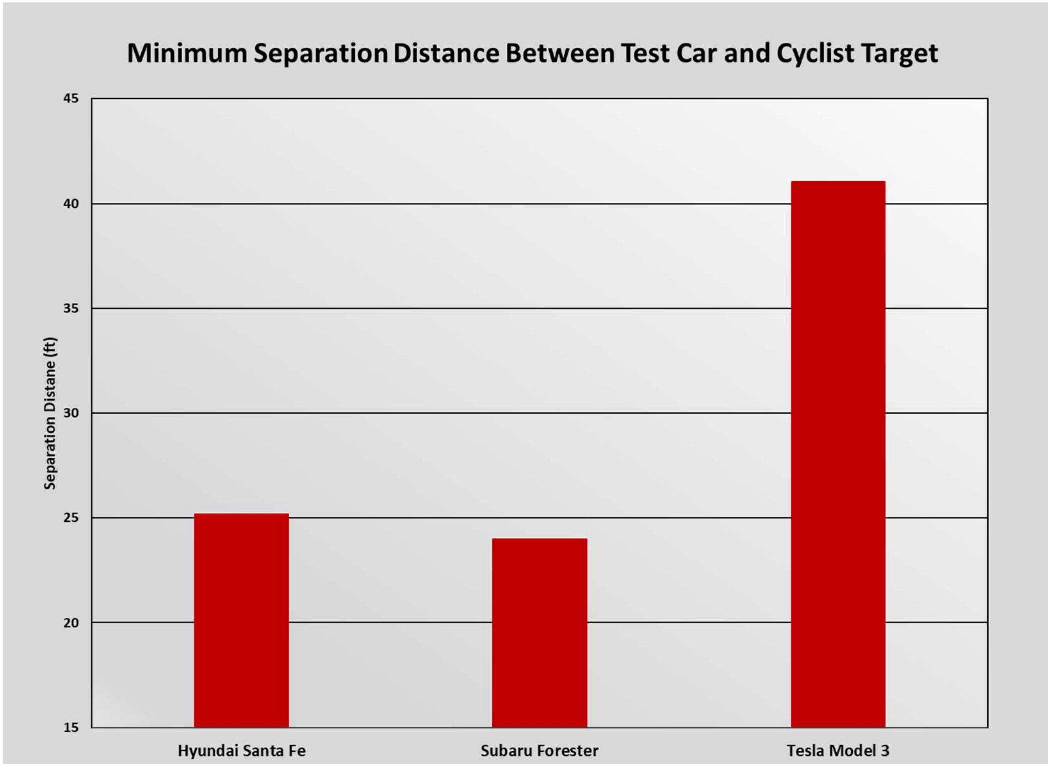

Figure 30: Average final separation distance for all test vehicles Image Source: AAA

Figures 28 and 29 illustrate average distances and associated TTC for detection and braking initiation phases. Figure 30 illustrates the average minimum longitudinal separation distance between the test vehicle and cyclist target.

2. Cyclist crossing travel lane of test vehicle

Overall System Performance			
Test Vehicle	**Detected Simulated Vehicle**	**Applied Brakes**	**Impacted Simulated Vehicle**
Hyundai Santa Fe	5/5	5/5	0/5
Subaru Forester	0/5	0/5	5/5
Tesla Model 3	5/5	5/5	0/5
Note: Results are presented as the number of occurrences out of five total test runs per test vehicle.			

Figure 31: General ADA system performance observations Image Source: AAA

Figure 31 provides overall results pertaining to detection, braking, and impact phases. Two out of three test vehicles avoided a collision with the cyclist target for all test runs. However, the AEB system activated for all ten test runs characterized by no impact. While this observation does not imply negative ADA system performance, it is important to note that AEB activation was responsible for collision avoidance rather than ACC braking. This is to be expected due to the nature of the test scenario.

Hyundai Santa Fe								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	29.16	0.788	30.98	0.846	0.799	1.350	NA	3.47
2	29.78	0.821	31.25	0.853	0.819	1.167	NA	4.96
3	30.34	0.830	30.34	0.830	0.833	1.481	NA	4.22
4	29.23	0.803	30.32	0.830	0.795	1.308	NA	2.85
5	30.44	0.829	30.44	0.829	0.804	1.210	NA	3.20
Avg	**29.79**	**0.814**	**30.67**	**0.838**	**0.810**	**1.303**	**NA**	**4.22**

Figure 32: Hyundai Santa Fe run level test results Image Source: AAA

For each of the five test runs, the Hyundai Santa Fe detected the cyclist target and initiated emergency braking in response. All test runs were consistent in terms of detection and braking initiation distances. Additionally, the final separation distance is consistent among the five test runs. This indicates repeatable capability of the AEB system to respond to a perpendicular crossing cyclist at this specific test speed.

It is noteworthy that there is no delay between detection and subsequent emergency braking. In all test runs, the criteria for braking initiation had been met prior to or simultaneous to an emergency braking alert being provided within the instrument cluster. In test runs characterized by detection alerts provided after braking initiation, this is likely explained by limitations relating to instrument cluster refresh rate and/or camera refresh rate of 45 Hz versus 100 Hz for vehicle dynamics measurement equipment.

Subaru Forester								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	NA	NA	NA	NA	NA	NA	26.1	0.00
4	NA	NA	NA	NA	NA	NA	23.5	0.00
5	NA	NA	NA	NA	NA	NA	26.0	0.00
Avg	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**25.20**	**0.00**

Figure 33: Subaru Forester run level test results Image Source: AAA

Three test runs are reported within Figure 33. For these test runs, the Subaru Forester failed to provide any detection alert or initiate any braking in response to the cyclist target.

Minor technicalities were uncovered in post-processing related to test driver operation during the second and third test runs (in sequential order). Specifically, the test driver touched the brake pedal with an approximate TTC of 0.50 and 0.35 seconds for test runs two and three, respectively. While these runs do not meet established acceptance criteria, it is noteworthy that no detection alerts or automatic braking were provided at any point during these test runs, which are separately detailed in Figure 34.

Subaru Forester								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
2	NA	NA	NA	NA	NA	NA	17.0	0.00
3	NA	NA	NA	NA	NA	NA	20.9	0.00
Avg	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**19.0**	**0.00**

Figure 34: Subaru Forester disqualified run level test results Image Source: AAA

System operation was verified after the first test run via a test AEB event utilizing the simulated vehicle previously described in Section IV.A.6 as a stationary target. No system abnormalities were noted.

Tesla Model 3								
Run #	Detection Distance (ft)	Detection TTC (s)	Braking Distance (ft)	Braking TTC (s)	Avg Decel. (G)	Max Decel. (G)	Impact Speed (mph)	Separation Distance (ft)
1	42.18	1.162	37.11	1.023	0.541	1.035	NA	0.36
2	43.61	1.205	35.96	1.025	0.549	0.997	NA	0.31
3	44.12	1.224	37.27	1.041	0.577	0.931	NA	1.71
4	46.23	1.280	37.93	1.055	0.581	0.980	NA	1.75
5	45.24	1.257	38.40	1.067	0.573	0.902	NA	2.22
Avg	**44.28**	**1.226**	**37.33**	**1.042**	**0.564**	**0.969**	**NA**	**1.27**

Figure 35: Tesla Model 3 run level test results Image Source: AAA

For each of the five test runs, the Tesla Model 3 detected the cyclist target and initiated emergency braking in response. For test runs three through five, the final separation distance was consistent. For test runs one and two, the final separation distance was noticeably shorter. While no impacts occurred for any test runs, the presence of two distinct “groups” of final separation distances suggest possible ambiguity with ADA system response throughout the entire braking event at this specific test speed.

This observation does not imply adverse performance relating to cyclist target detection and emergency braking in response. All test runs were consistent in terms of detection and braking initiation distances, indicating repeatable capability to detect and respond appropriately to an impeding collision.

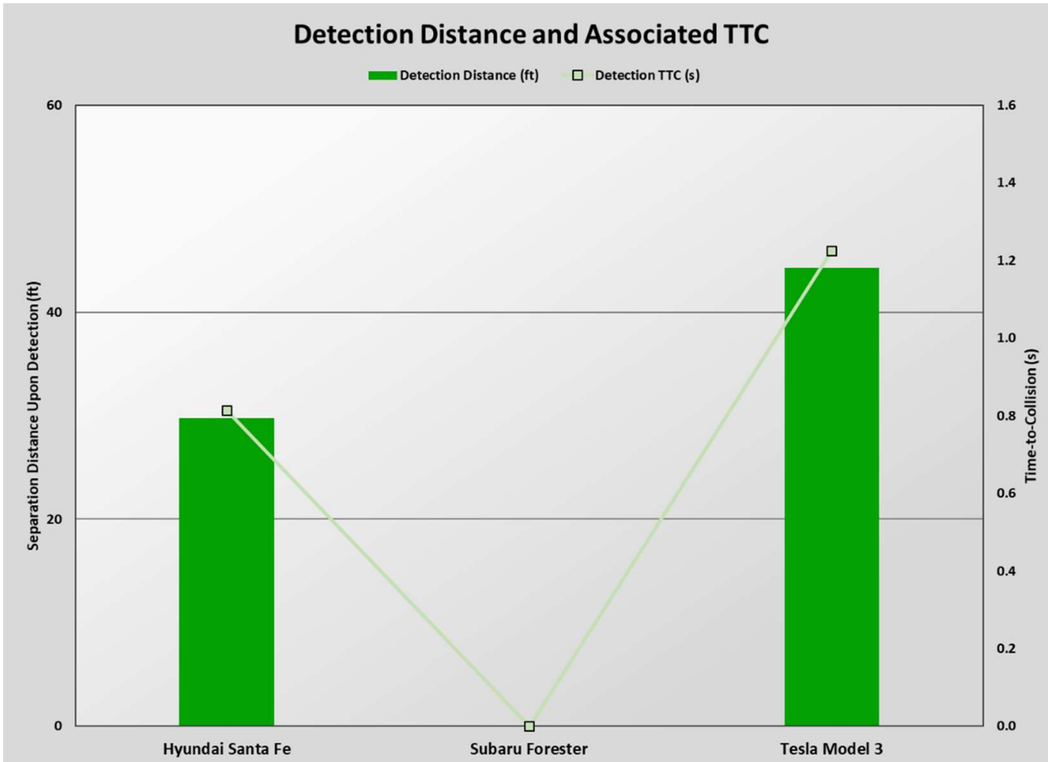

Figure 36: Average detection distance and associated TTC for all test vehicles Image Source: AAA

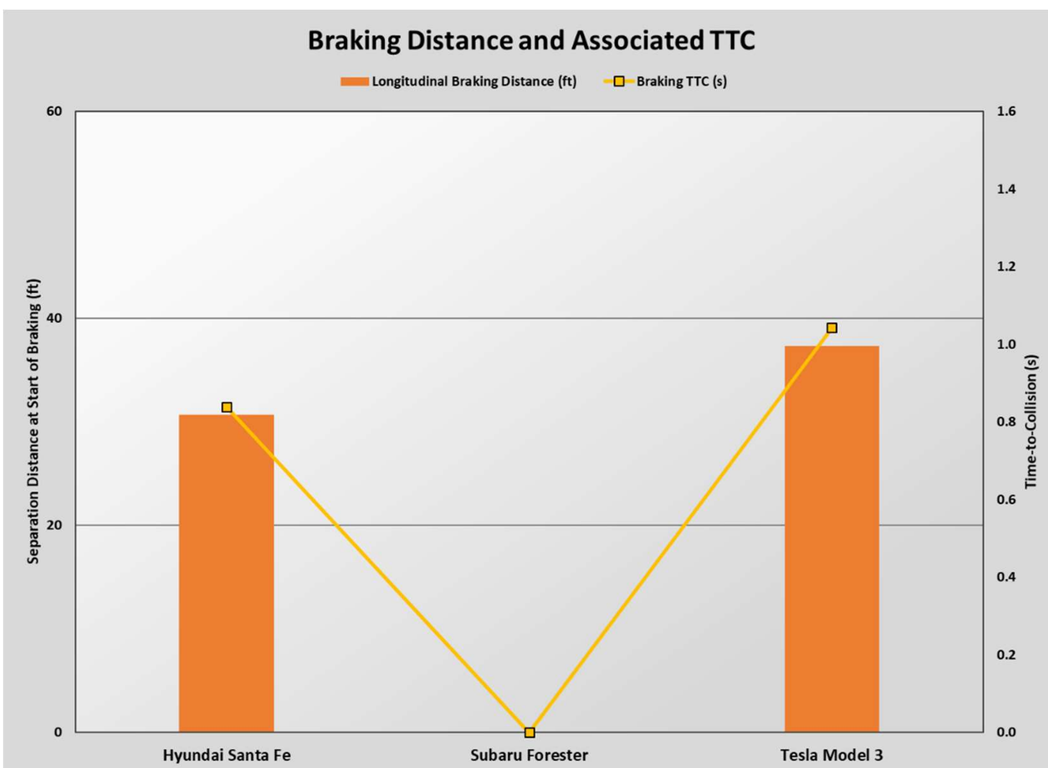

Figure 37: Average braking distance and associated TTC for all test vehicles Image Source: AAA

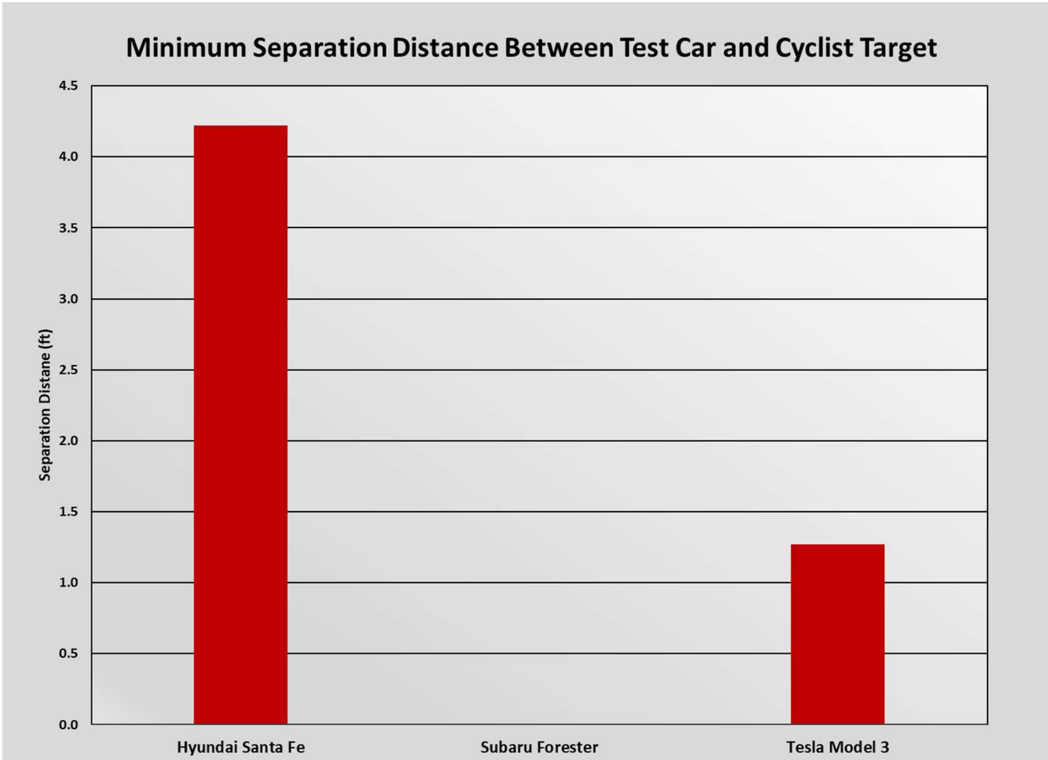

Figure 38: Average minimum separation distance and associated TTC for all test vehicles Image Source: AAA

Figures 36 and 37 illustrate average distances and associated TTC for detection and braking initiation phases. Figure 38 illustrates the average minimum longitudinal separation distance between the test vehicle and cyclist target.

D. Discussion

Each evaluated ADA system consistently detected and initiated braking in response to a simulated cyclist traveling ahead of the test vehicle within the travel lane. In aggregate, emergency braking occurred for two out of fifteen test runs. While these findings are encouraging, ADA system performance among two out of three test vehicles was less consistent relative to the detection of a slow lead passenger vehicle within the travel lane as described within Section VI.C.1. This suggests that the detection of a cyclist moving in a parallel direction is more challenging in general than the detection of another passenger vehicle within the travel lane.

For a cyclist crossing the travel lane of the test vehicle, two out of three test vehicles detected the cyclist and initiated emergency braking in response. For these test vehicles, a collision was avoided for all ten test runs in aggregate. While this is a promising result, the observation that one of three test vehicles failed to detect the cyclist target for any test runs once again suggest that edge-case emergency scenarios are more challenging for ADA systems in general.

VIII. CONCLUSIONS

In general, evaluated ADA systems performed consistently in response to slow-moving lead vehicles including a simulated passenger vehicle and adult cyclist. These scenarios generally evaluate the ACC component of ADA systems, which is designed to detect vehicles ahead and adjust speed to maintain an appropriate following distance. For leading passenger vehicle and adult cyclist scenarios, a collision was avoided for all thirty test runs, in aggregate. This is an encouraging finding and supports previous AAA research concluding that the ACC component of ADA systems are well-developed and perform according to expectations for typical closed-course scenarios and naturalistic driving environments.

For evaluated scenarios involving a simulated oncoming vehicle within the travel lane or a crossing cyclist, the performance of evaluated ADA was significantly diminished, on average. Specifically, AAA researchers consider these scenarios to be representative of emergency edge-case situations during which other drivers or VRUs act unexpectedly, resulting in atypical but not unrealistic challenges to the ADA system. While performance varied among evaluated ADA systems, collisions were more frequent relative to lead vehicle scenarios. Among a total of thirty runs, a collision occurred during twenty test runs, in aggregate.

While the refinement of publicly available ADA systems continues to improve, drivers must remain engaged in the driving task at all times. All test vehicles impacted a simulated passenger car and/or adult cyclist multiple times during closed-course evaluations. This general observation reinforces the need for robust camera-based driver monitoring systems to be integrated within ADA systems. Unexpected and atypical circumstances outside of ADA system capabilities can quickly materialize; possibly resulting in a hazardous situation without prompt driver intervention.

IX. KEY FINDINGS

1. How do vehicles equipped with ADA systems perform when encountering a possible collision with another passenger vehicle?
    a. For a slow lead vehicle moving in the lane ahead, no collisions occurred among a total of 15 test runs.
    b. For an oncoming vehicle within the travel lane, a collision occurred during all 15 test runs. One test vehicle significantly reduced speed prior to collision on each run, while the other two did not intervene on any runs.
2. How do vehicles equipped with ADA systems perform when encountering a possible collision with a cyclist?
    a. For a cyclist traveling in the lane ahead of the test vehicle, no collisions occurred among a total of 15 test runs.
    b. For a cyclist crossing the travel lane of the test vehicle, a collision occurred for 5 out of 15 test runs.

X. SUMMARY RECOMMENDATIONS

1. **Currently available ADA systems are not capable of sustained vehicle operation without constant driver supervision; it is imperative the driver maintain situational awareness at all times.**
2. Automakers should focus on refining ADA system performance in the context of edge-case scenarios involving other passenger vehicles and VRUs.

3. Integrate a robust camera-based driver monitoring component within ADA systems to encourage continual driver engagement.

XI.REFERENCES

[1] SAE International, "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles," 04 2021.

[2] American Automobile Association, "AAA NewsRoom," 14 11 2018. [Online]. Available: https://newsroom.aaa.com/2018/11/americans-misjudge-partially-automated-driving-systems-ability-based-upon-names/. [Accessed 14 10 2021].

[3] American Automobile Association, "Effectiveness of Driver Monitoring Systems," 2022.

[4] National Highway Traffic Safety Administration, "2020 Fatality Data Show Increased Traffic Fatalities During Pandemic," 3 June 2021. [Online]. Available: https://www.nhtsa.gov/press-releases/2020-fatality-data-show-increased-traffic-fatalities-during-pandemic. [Accessed 16 Febuary 2022].

[5] Insurance Institute for Highway Safety, "Real-world benefits of CA technologies," 2020. [Online]. Available: https://www.iihs.org/media/259e5bbd-f859-42a7-bd54-3888f7a2d3ef/shuYZQ/Topics/ADVANCED%20DRIVER%20ASSISTANCE/IIHS-real-world-CA-benefits.pdf. [Accessed 12 1 2022].

[6] CCC Intelligent Solutions Inc., "CCC Releases Research on Driver Sentiment on ADAS Features Included in Newer Vehicles," 10 8 2021. [Online]. Available: https://ir.cccis.com/news/news-details/2021/CCC-Releases-Research-on-Driver-Sentiment-on-ADAS-Features-Included-in-Newer-Vehicles/default.aspx. [Accessed 2022 January 12].

[7] American Automobile Association, "Evaluation of Active Driving Assistance Systems," 2020.

[8] National Conference of State Legislatures, "Safely Passing Bicyclists Chart," 10 9 2021. [Online]. Available: https://www.ncsl.org/research/transportation/safely-passing-bicyclists.aspx. [Accessed 16 2 2022].

[9] NHTSA's National Center and Statistics and Analysis, "Overview of Motor Vehicle Crashes in 2019," NHTSA, Washington DC, 2020.