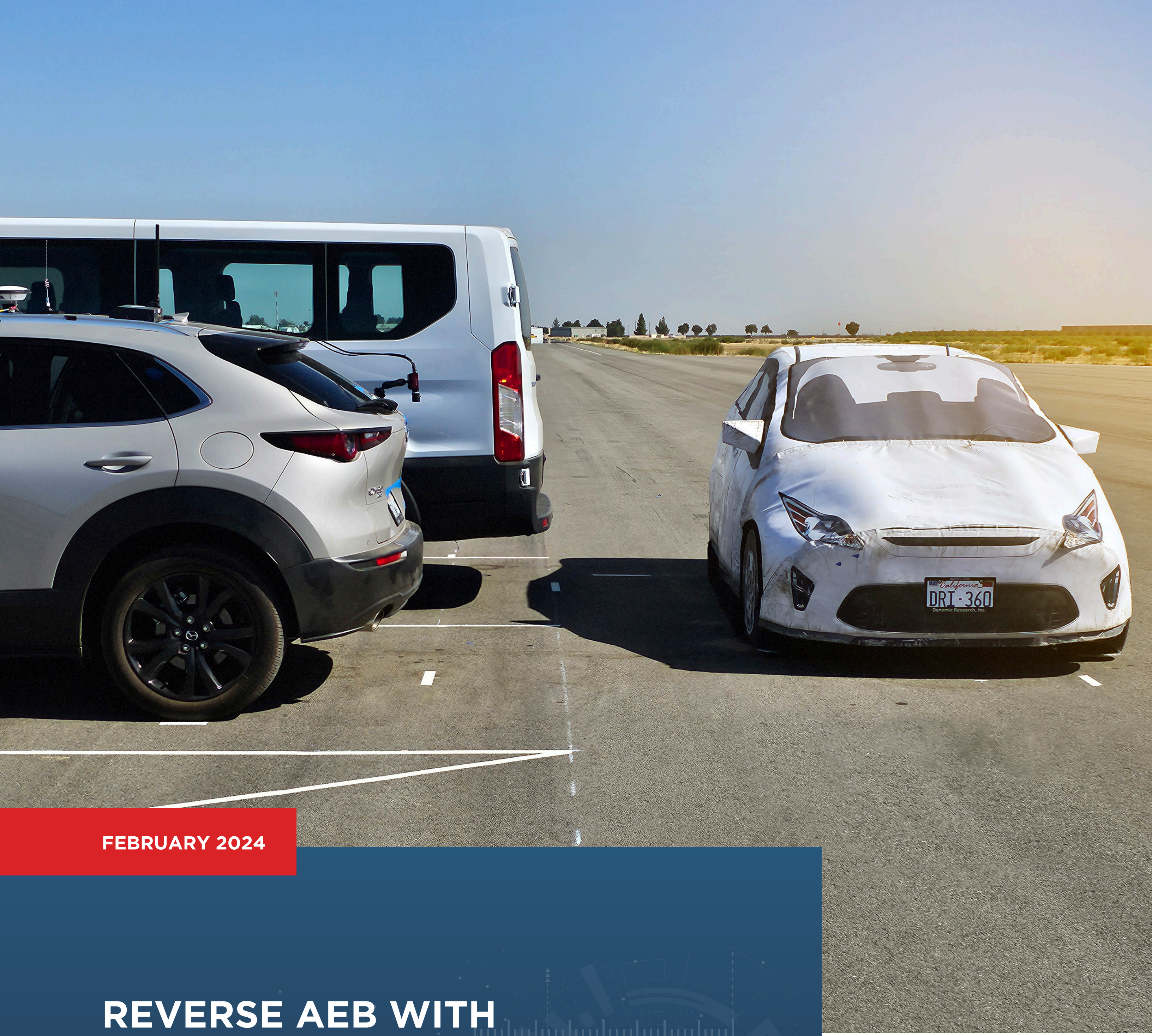

FEBRUARY 2024

REVERSE AEB WITH REAR CROSS TRAFFIC ALERT

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ABSTRACT

Reverse automatic emergency braking (AEB) and rear cross traffic warning (RCTW) systems have been shown to significantly reduce rear-end collisions; they are the most effective type of ADAS currently available on consumer vehicles in terms of property damage liability reductions [1]. Some reverse AEB systems include rear cross traffic mitigation and can not only detect rear cross traffic but automatically apply brakes in response.

AAA conducted primary research in a closed-course environment to understand the performance of reverse AEB systems with rear cross traffic mitigation in challenging scenarios involving perpendicular and angled traffic in the presence of a large blocking vehicle. Additionally, systems were evaluated in a simulated static child pedestrian scenario. Four popular 2023 model year vehicles equipped with reverse AEB with rear cross traffic mitigation were evaluated within this research. Only reverse AEB systems with the ability to detect and automatically brake for rear cross traffic were eligible for testing.

Research Questions:

1. How do evaluated reverse AEB systems with rear cross traffic mitigation perform when backing out of a parking space into path of oncoming vehicle with an adjacent parked vehicle obstructing view?
2. How do evaluated reverse AEB systems perform when encountering a static simulated child pedestrian behind the vehicle?

Key Findings:

1. In aggregate, evaluated reverse AEB systems with rear cross traffic mitigation automatically applied brakes in 26 of 40 (65%) of test runs and successfully prevented collision with the subject vehicle in only 1 of 40 total test runs (2.5%).
2. In the stationary child pedestrian test scenario, evaluated reverse AEB systems automatically applied brakes in 15 of 20 test runs (75%) and prevented collision with the target in 10 of 20 test runs (50%).

GLOSSARY

Blocking Vehicle: In the tests performed in this study, it is the vehicle parked in the adjacent space to the test vehicle for the purpose of obstructing the view of vehicles approaching from the side behind the test vehicle. Specifically, a 2023 Ford Transit passenger van was utilized.

Child Pedestrian Target: Refers to the target used to simulate a child pedestrian for the purpose of collision tests.

Rear Cross Traffic Warning (RCTW): Vehicle system that detects vehicles approaching from the side at the rear of the vehicle while in reverse gear and alerts the driver.

Reverse Automatic Emergency Braking (Reverse AEB): Vehicle system that detects potential collisions while in reverse gear and automatically brakes to avoid or lessen the severity of impact.

Reverse AEB with Rear Cross Traffic Mitigation: Reverse AEB system that includes the ability to detect and apply brakes for vehicles approaching from the side at the rear of the vehicle, as opposed to only detecting obstructions directly behind the vehicle.

Subject Vehicle: Refers to target that was used to simulate an approaching vehicle for the purpose of collision tests. Specifically, a DRI Low Profile Robotic Vehicle (LPRV) with DRI Soft Car 360® was utilized.

Test Vehicle: Refers to the vehicle under evaluation during the tests performed in this study.

Vulnerable Road User (VRU): A non-motorist road user, such as a pedestrian or bicyclist.

CONTENTS

I. INTRODUCTION

Rear cross traffic warning (RCTW) systems have been available on passenger vehicles for the past decade, and over the years these systems have become commonplace across vehicle segments and price points. Reverse automatic emergency braking (reverse AEB) can mitigate or prevent collisions with pedestrians, cyclists or stationary objects; in recent years it has become integrated with RCTW systems in some vehicles to mitigate or prevent backing collisions with traffic approaching from the side of the backing vehicle.

The Highway Data Loss Institute analyzed insurance data for 2015–2018 Subaru vehicles and 2014–2015 General Motors vehicles with and without reverse AEB. Overall, vehicles with reverse AEB exhibited a 28 percent decrease in property damage liability claims and a 10 percent decrease in collision claims; this was reported to be the largest reduction in claims among all other ADAS features analyzed [2]. It could be hypothesized that newer iterations of reverse AEB combined with RCTW would be more effective than systems found in 2014–2018 model year vehicles, possibly resulting in greater reductions in liability and collision claims among newer vehicles equipped with the technology.

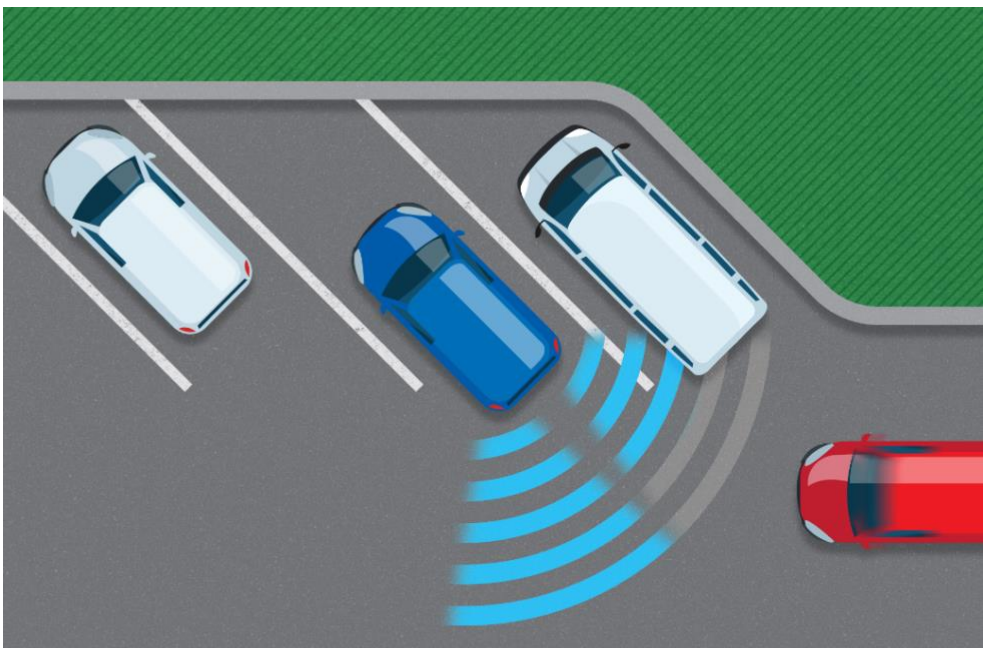

Figure 1: Reverse AEB with rear cross traffic mitigation can be beneficial in challenging backing scenarios. Image Source: AAA

While reverse AEB has been shown to reduce property damage and collision claims, its effect on personal injury and fatality rates have been small compared to other ADAS like front AEB due to the lower speeds typical of backing collisions between vehicles. However, there is still a potential safety benefit of reverse AEB for vulnerable road users (VRUs) such as cyclists and pedestrians.

The purpose of this research is to understand the performance of reverse AEB with rear cross traffic mitigation in the context of backing scenarios involving a large vehicle blocking the sight line. Additionally, a scenario involving a simulated child pedestrian is evaluated.

II. BACKGROUND

ADAS of various types have exploded in popularity over the past several years. As an example, recent AAA research evaluating ADAS repair costs found that a 2018 Nissan Rogue S came standard with four ADAS features, while a 2023 Nissan Rogue S now comes standard with seventeen ADAS features. ADAS encompasses a wide range of safety and convenience enhancements; sustained or temporary control of a vehicle's lateral or longitudinal direction is not required. For example, traffic sign recognition is a type of ADAS that does not affect the vehicle's trajectory but falls under the driver assistance umbrella.

Overall, the rapid rise of ADAS prevalence has significantly benefitted safety on the Nation's roadways. This is especially true for active safety features such as automatic emergency braking. While consumer sentiment towards fully autonomous vehicles has suffered in recent years, AAA found that 60 percent of U.S. drivers would "definitely" or "probably" want these systems in their next car purchase [3].

As previously discussed, reverse AEB was reported to be the most effective ADAS in terms of property damage liability claim reductions, while injury and fatality reductions were less pronounced than that of front AEB. Backing collisions usually happen between vehicles at a significantly lower speed resulting in a lower injury and fatality rate relative to collisions that may be mitigated by front AEB. However, children are particularly susceptible to back-over incidents in driveways and parking lots.

NHTSA estimates that every year, there are approximately 210 fatalities and 15,000 injuries caused by backover collisions [4]. Of those fatalities, approximately 31 percent are children under five years old. In addition to vehicle-to-vehicle collisions, it is important to evaluate the effectiveness of these systems in preventing or mitigating collisions with pedestrians, especially children. As these systems continue to become more commonplace, good performance in the context of vulnerable road user (VRU) avoidance has the potential to significantly decrease the occurrence of back-over incidents.

The child pedestrian scenario simulated within this work uses a stationary child pedestrian target. This scenario represents a realistic situation in which a child could be standing behind a backing vehicle with both the child and vehicle driver being unaware of their surroundings. Additionally, a stationary child is potentially more challenging for reverse AEB systems to detect than a moving child due to their size and lack of motion (adding to ambiguity for object detection and classification).

In the context of collision avoidance with vehicles and pedestrians, reverse AEB with rear cross traffic mitigation could significantly benefit drivers in challenging scenarios where visibility is occluded. While it is recommended that drivers turn and look behind them when backing out of a parking space, the presence of large vehicles in adjacent spaces can make it nearly impossible to see approaching traffic. It is acknowledged that simulated vehicle conflicts within this research are challenging due to radar and/or ultrasonic wave obstructions effected by the blocking vehicle. However, reverse AEB with rear cross traffic mitigation would be most beneficial in this type of situation where a driver would also be blocked from seeing approaching traffic.

III. VEHICLE SELECTION & PREPARATION

A. ADAS Requirements

This study is intended to evaluate reverse automatic emergency braking (reverse AEB) systems that utilize rear cross traffic mitigation. This functionality may be referred to by manufacturers separately as "rear cross traffic intervention" or similar, but for the purposes of this study is defined as a function of the reverse AEB system in accordance with the terminology provided in SAE J3063 [5]. Vehicles tested in this study were required to have systems that are intended by the manufacturer to automatically brake the vehicle while driving in reverse to avoid collisions. Further, the systems were required to function for obstructions directly behind the vehicle as well as for vehicles approaching from the side (rear cross traffic).

B. Test Vehicle Selection Process

Industry sources were used to produce a list of 2023 vehicle models that were likely to have available reverse AEB systems with rear cross traffic mitigation. For consistency of size and shape among test vehicles, it was determined that all test vehicles would be small to medium SUVs due to the popularity of these categories as determined by vehicles in operation (VIO) and the availability of models with appropriate reverse AEB systems.

Once identified, models and trims were confirmed via owner's manuals, manufacturer media, or direct communication with the manufacturer to have available reverse AEB systems meeting the requirements described in the previous section. Once the above criteria were applied, vehicle selection was determined primarily by availability due to limited selection. No more than one vehicle was selected from a single manufacturer.

C. Test Vehicles

1) 2023 Hyundai Tucson Hybrid Limited AWD

2) 2023 Lexus RX 350 Premium

3) 2023 Mazda CX-30 2.5 Turbo AWD Premium Plus Package

4) 2023 Volkswagen Tiguan 2.0T SEL R-Line

D. Test Vehicle Preparation

Once specific test vehicles were acquired, presence of the required reverse AEB system with rear cross traffic mitigation was confirmed by the vehicle's user-interface and owner's manual.

Test vehicles were inspected and confirmed to be in as-new operating condition with no check-engine lights or similar indications of malfunction. Tires were confirmed to be damage free, have adequate tread depth, and be at the manufacturer prescribed pressure.

Prior to testing, each test vehicle with the exception of the Volkswagen Tiguan was taken to an appropriate dealership where front-end alignments and ADAS sensor calibrations were performed per manufacturer specification. The Volkswagen Tiguan was provided by the manufacturer directly from the factory, and alignment and calibrations were not necessary per the provider.

IV. TEST EQUIPMENT AND RESOURCES

A. Vehicle Dynamics Equipment

1) Oxford Technical Solutions (OxTS) RT3000 V2 with RT-Range Hunter

Each vehicle was outfitted with an OxTS RT3000 v2 with an RT-Range Hunter. These instruments were utilized to capture test and subject 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 the dynamic soft car via XLAN. 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 that no braking intervention was applied by the test driver during test runs.

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

Test vehicles were equipped with one camera mounted to the side of the vehicle facing the rear and one camera mounted high on the rear of the vehicle facing downward in order to verify impacts during test runs.

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) 1080p Webcams

Two webcams with 1080p resolution and a frame rate of 12 Hz were utilized to capture visual alerts in the instrument cluster and/or center stack.

5) 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.

6) 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.

B. Test Subjects and Blocking Vehicle

1) 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 allows 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® served as the subject vehicle and is designed to be representative of a small passenger vehicle relevant to automotive sensors including radar, cameras, and ultrasonic sensors. The hatchback model was utilized for testing; its length, width and height are 158 in, 67 in, and 56 in, respectively.

2) 4activePA Child Pedestrian Target

The articulated child pedestrian target is designed to be representative of a typical 7-year-old and is intended for use in either dynamic or static test scenarios. The body height and width are 45 inches and 12 inches, respectively. As the child pedestrian target was stationary throughout the entirety of the test scenario, the subject was placed atop the 4activeSB "surfboard" platform to maintain upright stature, adding 1 inch to the total height.

3) Ford Transit Passenger Van

A 2023 Ford Transit passenger van was utilized as a "blocking" vehicle; it was parked in the adjacent parking space on the same side as the approaching subject vehicle. The blocking vehicle was selected to represent large vehicles such as trucks, vans, and SUVs that can significantly impair visibility when backing and interfere with radar and/or ultrasonic waves emitted by the RCTW system. The regular length, short roof height version was utilized; its length, width (excluding mirrors), and height are 219.9 in, 81.3 in, and 82.2 in, respectively.

C. Test Facility

All closed-course testing was conducted on roadways specifically designed for standardized ADAS testing on the grounds of Minter Field Airport in Shafter, California.

All test scenarios were conducted on a vehicle dynamics pad comprised of dry asphalt 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 and subject vehicles. For each scenario, parking spaces in either a perpendicular or angled orientation relative to the approaching subject vehicle were created with reflective pavement tape (parking space dimensions are provided in Section V.B.1 and Section V.B.2). The marked parking spaces were the only road markings present in the testing area. Besides the blocking vehicle, there were no obstructions present between the rear of the test vehicle and the approaching subject vehicle.

V. INQUIRY #1: HOW DO EVALUATED REVERSE AEB SYSTEMS PERFORM WHEN BACKING OUT OF A PARKING SPACE INTO PATH OF ONCOMING VEHICLE WITH AN ADJACENT PARKED VEHICLE OBSTRUCTING VIEW?

A. Objective

Evaluate the performance of reverse AEB systems with rear cross traffic mitigation in the context of mitigating or preventing a collision when backing out of a perpendicular or angled parking space with a large blocking vehicle present.

B. Methodology

In sections herein, “subject vehicle” refers to the dynamic soft car. To allow for full characterization of reverse AEB with rear cross traffic mitigation, the low-profile robotic vehicle (LPRV) previously described in Section IV.B.1 was utilized.

For each of the test scenarios, the following data were collected and utilized throughout the entirety of each test run to verify validity and characterize system performance according to parameters within Figure 8:

- RCTW and AEB warning indicators (via video recording)
- Longitudinal velocity and acceleration for test and subject vehicles
- Longitudinal and lateral position of subject vehicle relative to test vehicle

Parameter	Unit	Description
RCTW	N/A	Visual notification indicating the presence of rear cross traffic
Rear AEB Applied	N/A	Activation of AEB as defined by longitudinal acceleration equaling zero
Braking Distance	ft	Longitudinal distance between the rear of the test vehicle and right side of the subject vehicle when test vehicle deceleration reached zero
Impact Occurrence	N/A	Impact as defined by the test and subject vehicle making contact at any point during the test run
Separation Distance	ft	Final longitudinal distance between the test vehicle and the subject vehicle at the end of the braking event (if no impact occurred)
Speed Reduction at Impact	mph	Speed reduction calculated by subtracting the final speed at impact from the initial speed when the longitudinal acceleration equaled zero
Impact Speed	mph	Speed of the test vehicle at the point when the test and subject vehicles make contact
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 8: Performance parameters for parking lot scenarios. Image Source: AAA

Due to limitations pertaining to the frame rate for the in-vehicle cameras utilized, a maximum error of approximately 4.5 inches is possible for reported longitudinal distances associated with visual RCTW and AEB alerts. Therefore, the in-vehicle video was used to determine whether RCTW and AEB alerts occurred, but not to determine precise timing of alerts. For both test scenarios, automatic braking is considered to have occurred at the instant longitudinal acceleration equals zero.

Prior to test execution, a speed trace was collected for each test vehicle in which the test vehicle was placed in reverse and the brake pedal was released, allowing the vehicle to roll backwards with no throttle or brake input. These traces were utilized to determine timing of brake pedal release for test scenarios such that the test vehicle would impact the subject vehicle at the proper location (specific impact points are described in following subsections) in the case that reverse AEB does not activate. During test runs, an audible cue was used to signal the test driver to release the brake pedal at the moment at which the reversing characteristics of the test vehicle would result in a collision at the designated impact point (with no reverse AEB intervention).

To initiate each test run, the test vehicle was positioned in the prescribed position within the parking space, put in reverse gear, and held in place with the brake pedal by the test driver. The subject vehicle then approached in a simulated near lane with respect to the test vehicle at a steady-state speed of 15 mph; this speed was reached a minimum of 200 feet from the right side of the test vehicle.

When the audible cue sounded, the test driver released the brake pedal and applied no further pedal input until after either a collision occurred or AEB activation brought the test vehicle to a stop. After each run, data was reviewed to ensure the test driver did not inadvertently apply pressure to the brake pedal until one of these two conditions were met and that the prescribed collision orientation as shown in the following sections was achieved. Additionally, the subject vehicle must maintain steady-state speed with a tolerance of ± 1 mph until collision occurs or the test vehicle comes to a stop. For each test vehicle, five test runs for each test scenario were performed.

1) Backing Out of a Perpendicular Parking Space with Cross Traffic and Adjacent Parked Vehicle

At the start of each test run, the test and blocking vehicles were positioned in marked parking spaces according to dimensions provided in Figure 9. Throughout its approach, the medial centerline of the subject vehicle was 6 feet from the rear of the blocking vehicle (dimension D in figure 9).

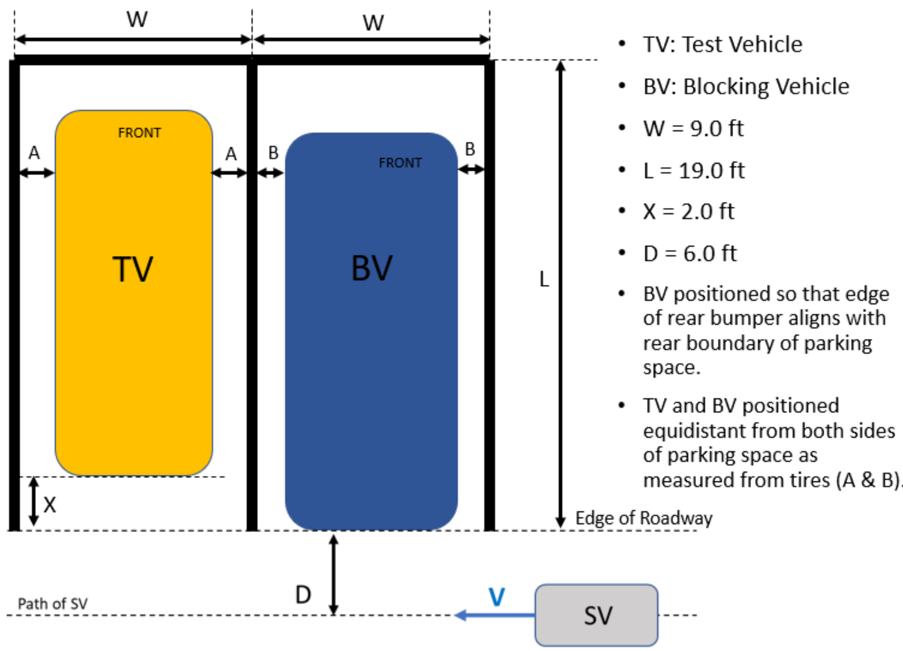

Figure 9: Visual depiction of perpendicular backing scenario at start of test (not to scale). Image Source: AAA

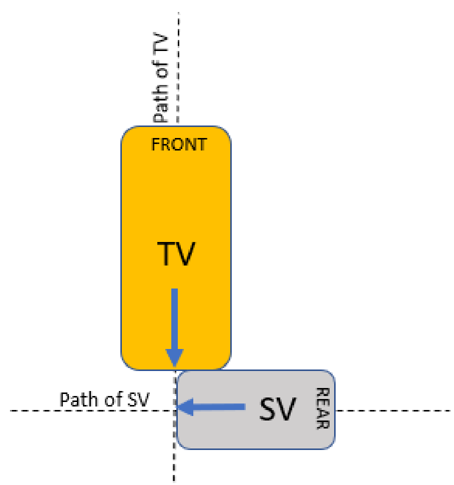

Figure 10: Impact point of test and subject vehicles (not to scale). Image Source: AAA

As illustrated in Figure 10, if reverse AEB does not activate, the test vehicle will impact the side of the subject vehicle with the midpoint of the rear bumper of the test vehicle aligning with the front plane of the subject vehicle.

2) Backing Out of an Angled Parking Space with Cross Traffic and Adjacent Parked Vehicle

At the start of each test run, the test and blocking vehicles were positioned in marked parking spaces according to dimensions provided in Figure 11. Throughout its approach, the medial centerline of the subject vehicle was 6 feet from the rear of the blocking vehicle.

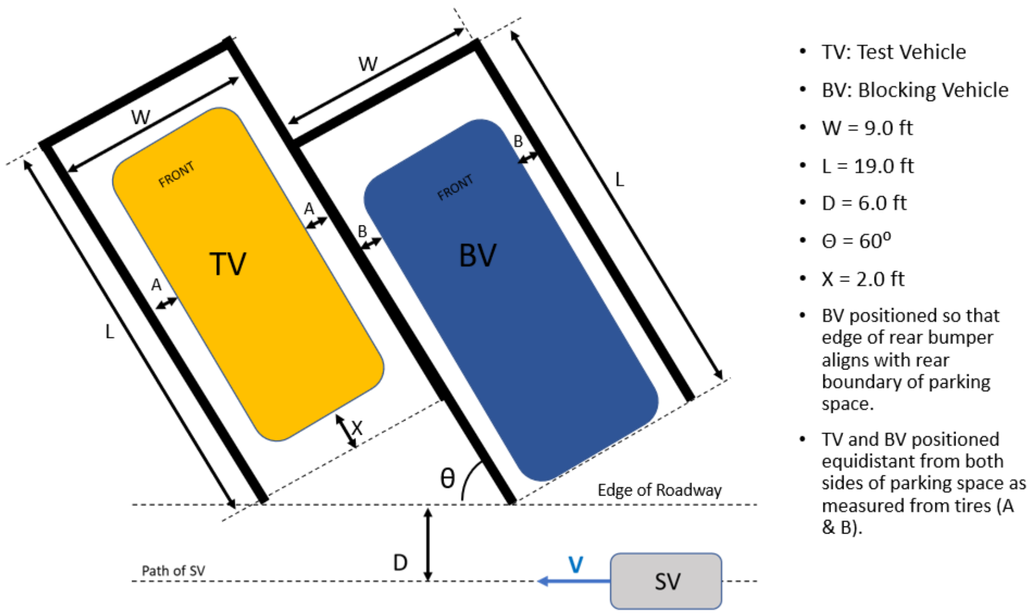

Figure 11: Visual depiction of angled backing scenario at start of test (not to scale). Image Source: AAA

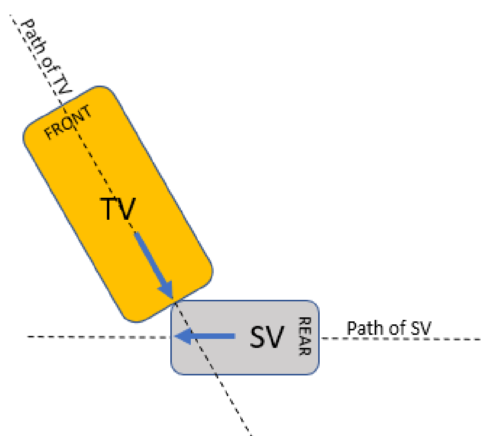

Figure 12: Impact point of test and subject vehicles (not to scale). Image Source: AAA

As illustrated in Figure 12, if reverse AEB does not activate, the center of the rear bumper on the test vehicle will contact the front right corner of the subject vehicle.

C. Test Results

1) Hyundai Tucson

Perpendicular Parking Cross-Traffic Test Results - Hyundai Tucson						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	Y	0.30	Y	NA	0.00	2.64
Y	Y	0.19	Y	NA	0.16	2.37
Y	Y	0.49	Y	NA	0.27	2.15
Y	Y	0.10	Y	NA	0.02	2.44
Y	Y	0.28	Y	NA	0.09	2.42

Figure 13: 2023 Hyundai Tucson run-level results for perpendicular test scenario. Image Source: AAA

In the perpendicular parking rear cross traffic scenario, a rear cross traffic warning was provided and reverse AEB activated in all five test runs (Figure 13). However, impact was made with the subject vehicle on all five test runs. Reverse AEB activations were late, which resulted in minimal speed reductions prior to impact.

Angled Parking Cross-Traffic Test Results - Hyundai Tucson						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
N	N	NA	Y	NA	0.00	3.27
Y	Y	0.66	Y	NA	0.02	3.22
Y	Y	0.38	Y	NA	0.07	3.13
Y	Y	1.51	Y	NA	0.40	2.77
Y	Y	0.43	Y	NA	0.16	3.02

Figure 14: 2023 Hyundai Tucson run-level results for angled test scenario. Image Source: AAA

In the angled parking scenario, a rear cross traffic warning was provided and reverse AEB activated on four of five test runs (Figure 14). Impact was made with the subject vehicle on all five test runs. Similar to the perpendicular parking scenario, reverse AEB activations were late and speed reductions prior to impact were minimal.

2) Lexus RX

Perpendicular Parking Cross-Traffic Test Results - Lexus RX						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	Y	0.28	Y	*NA*	0.20	2.57
Y	Y	0.22	Y	*NA*	0.11	2.51
Y	Y	0.21	Y	*NA*	0.04	2.48
Y	Y	-0.14	Y	*NA*	0.00	2.73
Y	Y	-0.14	Y	*NA*	0.00	2.73

Figure 15: 2023 Lexus RX run-level results for perpendicular test scenario. Image Source: AAA

In the perpendicular parking scenario, the Lexus RX provided rear cross traffic warning and activated reverse AEB in all five test runs (Figure 15). However, impact was made with the subject vehicle in each test run. Reverse AEB activations began very late, with two activations beginning after impact had been made with the subject vehicle. As such, reductions to impact speed were minimal.

Angled Parking Cross-Traffic Test Results - Lexus RX						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	N	*NA*	Y	*NA*	0.00	2.91
Y	N	*NA*	Y	*NA*	0.00	3.02
Y	N	*NA*	Y	*NA*	0.00	2.82
N	N	*NA*	Y	*NA*	0.00	2.91
Y	N	*NA*	Y	*NA*	0.00	3.00

Figure 16: 2023 Lexus RX run-level results for angled test scenario. Image Source: AAA

In the angled parking scenario, the Lexus RX provided a rear cross traffic warning on four of five test runs, but reverse AEB did not activate for any of the test runs (Figure 16).

3) Mazda CX-30

Perpendicular Parking Cross-Traffic Test Results - Mazda CX-30						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	Y	0.38	Y	*NA*	0.22	2.44
N	Y	0.68	Y	*NA*	1.16	1.43
Y	N	*NA*	Y	*NA*	0.00	2.84
Y	Y	0.29	Y	*NA*	0.89	1.79
Y	Y	0.40	Y	*NA*	1.12	1.54

Figure 17: 2023 Mazda CX-30 run-level results for perpendicular test scenario. Image Source: AAA

In the perpendicular parking scenario, the Mazda CX-30 provided a rear cross traffic warning on four of the five test runs and activated reverse AEB on four of the five test runs. However, impact was made with the subject vehicle on all five test runs. In the four test runs in which reverse AEB activated, speed reductions before impact varied significantly.

Angled Parking Cross-Traffic Test Results - Mazda CX-30						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	Y	3.42	Y	*NA*	1.34	1.95
Y	Y	3.26	Y	*NA*	1.16	2.01
Y	N	*NA*	Y	*NA*	0.00	3.29
*NA**	N	*NA*	Y	*NA*	0.00	3.29
Y	Y	3.15	Y	*NA*	1.21	1.97

* Due to equipment malfunction, rear cross-traffic alert could not be confirmed for this test run.

Figure 18: 2023 Mazda CX-30 run-level results for angled test scenario. Image Source: AAA

In the angled parking scenario, the Mazda CX-30 provided a rear cross traffic warning on four test runs, with the alert unable to be confirmed on the fifth due to equipment malfunction. Reverse AEB activated on three of five test runs, but impact was made with the subject vehicle on all five test runs. In the test runs when it activated, reverse AEB began earlier than for the perpendicular scenario, resulting in more significant speed reductions prior to impact, on average.

4) Volkswagen Tiguan

Perpendicular Parking Cross-Traffic Test Results - Volkswagen Tiguan						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	N	*NA*	Y	*NA*	0.00	2.42
Y	Y	0.88	Y	*NA*	1.01	1.23
Y	Y	1.59	N	0.93	2.10	*NA*
Y	Y	0.84	Y	*NA*	2.16	0.10
Y	N	*NA*	Y	*NA*	0.00	2.48

Figure 19: 2023 Volkswagen Tiguan run-level results for perpendicular test scenario. Image Source: AAA

For the Volkswagen Tiguan, rear cross traffic warning was provided in all five test runs of the perpendicular parking scenario (Figure 19). Reverse AEB activated on three of five test runs, and impact was made with the subject vehicle in four of five test runs. In the one test run in which impact did not occur, reverse AEB began significantly earlier than other reverse AEB activations.

Angled Parking Cross-Traffic Test Results - Volkswagen Tiguan						
RCTW Provided?	Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	Y	3.04	Y	*NA*	1.86	1.01
Y	Y	3.68	Y	*NA*	2.33	0.47
Y	N	*NA*	Y	*NA*	0.00	2.93
Y	N	*NA*	Y	*NA*	0.00	2.95
Y	N	*NA*	Y	*NA*	0.00	2.95

Figure 20: 2023 Volkswagen Tiguan run-level results for angled test scenario. Image Source: AAA

For the angled parking scenario, a rear cross traffic warning was provided in all five test runs and reverse AEB activated in two of the five test runs (Figure 20). Impact was made in all five test runs. In the two test runs during which reverse AEB activated, speed was reduced significantly prior to impact.

VI. INQUIRY #2: HOW DO EVALUATED REVERSE AEB SYSTEMS PERFORM WHEN ENCOUNTERING A STATIC SIMULATED CHILD PEDESTRIAN BEHIND THE VEHICLE?

A. Objective

Evaluate the performance of reverse AEB systems in preventing or mitigating a collision involving a child standing behind the vehicle.

B. Methodology

In sections herein, “child pedestrian” refers to the simulated child pedestrian target described in Section IV.B.2.

The following data were collected and utilized throughout the entirety of the test run to verify validity and characterize system performance according to parameters within Figure 21:

- RCTW and AEB warning indicators (via video recording)
- Longitudinal velocity and acceleration for test vehicle
- Position of test vehicle relative to stationary child pedestrian

Parameter	Unit	Description
Rear AEB Applied	N/A	Activation of AEB as defined by longitudinal acceleration equaling zero
Braking Distance	ft	Longitudinal distance between the rear of the test vehicle and the pedestrian target when test vehicle deceleration reached zero
Impact Occurrence	N/A	Impact is defined as the test vehicle and pedestrian target making contact at any point during the test run
Separation Distance	ft	Final longitudinal distance between the test vehicle and the pedestrian target at the end of the braking event (if no impact occurred)
Speed Reduction at Impact	mph	Speed reduction calculated by subtracting the final speed at impact from the initial speed when the longitudinal acceleration equaled zero
Impact Speed	mph	Speed of the test vehicle at the point when the test and pedestrian target make contact
Note: The end of the braking event is defined as either the moment of impact between the test vehicle and pedestrian dummy or the moment when the test vehicle successfully avoided a collison.		

Figure 21: Performance parameters for child pedestrian scenario. Image Source: AAA

Due to limitations pertaining to the frame rate for the in-vehicle cameras utilized, a maximum error of approximately 4.5 inches is possible for reported longitudinal distances associated with visual RCTW and AEB alerts. Therefore, the in-vehicle video was used to determine whether RCTW and AEB alerts occurred, but not to determine precise timing of alerts. Automatic braking is considered to have begun at the first instant during the backing maneuver that longitudinal acceleration was measured as zero or positive without brake pedal application.

1) Stationary Child Pedestrian

At the start of each test run, the test vehicle and child pedestrian target were positioned according to dimensions provided in Figure 22. Throughout its approach, the child pedestrian target was in line with the medial plane of the test vehicle. Parking space dimensions and test vehicle orientation within the parking space are identical to dimensions provided in Section V.B.1.

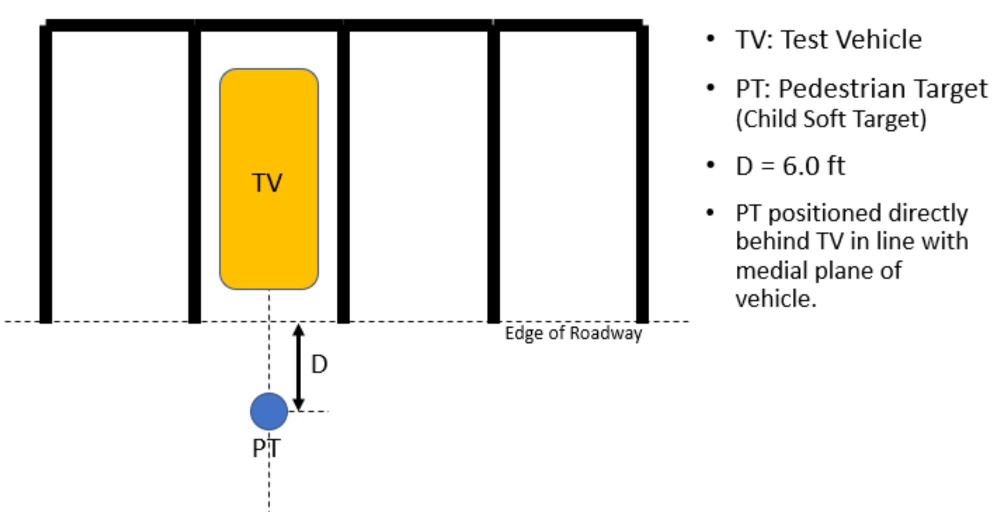

Figure 22: Impact point of test vehicle and child pedestrian (not to scale). Image Source: AAA

Prior to each test run, the test vehicle and child pedestrian target were positioned according to the diagram in Figure 22. The test vehicle was then put into reverse and held in place using the brake pedal by the test driver. The driver then released the brake pedal with the steering wheel centered; no further pedal input was applied until either the reverse AEB system brought the vehicle to a stop or collision with the child pedestrian target occurred (whichever occurred first). For each test vehicle, a total of five test runs were performed.

C. Test Results

1) Hyundai Tucson

Stationary Child Pedestrian Test Results - Hyundai Tucson					
Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	2.65	N	1.84	2.68	*NA*
Y	2.61	N	1.77	2.66	*NA*
Y	2.50	N	1.70	2.71	*NA*
Y	2.45	N	1.70	2.59	*NA*
Y	2.57	N	1.74	2.71	*NA*

Figure 23: 2023 Hyundai Tucson run-level results for child pedestrian test scenario. Image Source: AAA

The Hyundai Tucson automatically applied the brakes and prevented impact for all five test runs (Figure 23). Results were consistent with the vehicle coming to a stop at least 1.7 feet from the target for each test run.

2) Lexus RX

Stationary Child Pedestrian Test Results - Lexus RX					
Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	3.02	N	2.16	2.39	*NA*
Y	3.10	N	2.18	2.37	*NA*
Y	3.04	N	2.15	2.39	*NA*
Y	3.07	N	2.17	2.39	*NA*
Y	2.94	N	1.98	2.39	*NA*

Figure 24: 2023 Lexus RX run-level results for child pedestrian test scenario. Image Source: AAA

The Lexus RX automatically applied the brakes and prevented impact for all five test runs (Figure 24). Results were consistent with the vehicle coming to a stop approximately two feet or more from the target for each test run.

3) Mazda CX-30

Stationary Child Pedestrian Test Results - Mazda CX-30					
Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	-4.39	Y	*NA*	0.00	3.31
Y	-4.87	Y	*NA*	0.00	3.15
N	*NA*	Y	*NA*	0.00	3.24
N	*NA*	Y	*NA*	0.00	3.24
N	*NA*	Y	*NA*	0.00	3.20

*Due to equiment malfunction, parking obstruction alert could not be confirmed for this test run.

Figure 25: 2023 Mazda CX-30 run-level results for child pedestrian test scenario. Image Source: AAA

The Mazda CX-30 automatically applied the brakes for two of five test runs (Figure 25). However, both reverse AEB activations occurred after impact already occurred with the child pedestrian target. Impact occurred for all five test runs, with no speed reduction prior to impact.

4) Volkswagen Tiguan

Stationary Child Pedestrian Test Results - Volkswagen Tiguan					
Rev AEB Applied?	Rev AEB Start Distance (ft)	Impacted Target?	Separation Distance (ft)	Speed Reduction at Impact (mph)	Impact Speed (mph)
Y	-0.34	Y	*NA*	0.00	3.04
Y	-0.43	Y	*NA*	0.00	3.04
N	*NA*	Y	*NA*	0.00	3.04
N	*NA*	Y	*NA*	0.00	3.04
Y	-0.01	Y	*NA*	0.00	3.02

Figure 26: 2023 Volkswagen Tiguan run-level results for child pedestrian test scenario. Image Source: AAA

The Volkswagen Tiguan automatically applied the brakes in three of five test runs (Figure 26). However, all three reverse AEB activations occurred after impact already occurred with the child pedestrian target. Impact occurred for all five test runs, with no speed reduction prior to impact.

VII. DISCUSSION

A. How do evaluated reverse AEB systems perform when backing out of a parking space into path of oncoming vehicle with an adjacent parked vehicle obstructing view?

A total of 40 test runs were performed of the parking lot rear cross traffic scenarios—5 perpendicular and 5 angled parking orientation for each of the 4 test vehicles. These scenarios are intended to represent a driver backing out of a parking space with an adjacent parked vehicle obstructing their view and a vehicle approaching down the aisle.

In aggregate, rear cross traffic warnings were provided on 36 test runs (90%), reverse AEB was activated on 26 test runs (65%), and the test vehicle impacted the subject vehicle on 39 of the 40 test runs (97.5%). Results were slightly better for the perpendicular parking orientation with one prevented collision and reverse AEB activations on 85% of test runs, compared to only 45% for the angled orientation.

Aggregate Results for Parking Cross Traffic Tests			
	RCTA Provided?	Reverse AEB Applied?	Impacted Target?
Perpendicular Parking	19 95.0%	17 85.0%	19 95.0%
Angled Parking	17* 89.5%	9 45.0%	20 100.0%
Combined Parking	36** 92.3%	26 65.0%	39 97.5%

*Of 19 runs . Equipment malfunction prevented verification of RCTA for one run.

*Of 39 runs. Equipment malfunction prevented verification of RCTA for one run.

Figure 27: Aggregate results of parking cross traffic test scenarios. Image Source: AAA

In test runs where reverse AEB did activate (26 of the 40 runs), the effects of automatic braking were highly variable (Figures 27 and 28). In some instances, automatic braking resulted in the test vehicle stopping just slightly in the path of the subject vehicle, resulting in less severe impacts. In other cases, impact speed was reduced slightly but did not significantly affect the severity of the collision. In a number of cases, automatic braking did not begin until after impact had already occurred with the subject vehicle.

Impact of Reverse AEB in Parking Tests (when activated)			
	Avg Peak Speed (mph)	Avg Impact Speed (mph)	Avg Speed Reduction (mph)
Perpendicular Parking	2.54	1.97	0.56
Angled Parking	3.12	2.17	0.95

Figure 28: Average effect of reverse AEB for all activations within parking cross traffic test scenarios. Image Source: AAA

The results suggest that these systems have difficulty in situations with obstructed views and minimal time to react before collision. However, situations where drivers must back out of a parking space without a clear view of oncoming vehicles is common and are the type of scenarios where these systems could provide significant benefit.

B. How do evaluated reverse AEB systems perform when encountering a static simulated child pedestrian behind the vehicle?

Altogether, reverse AEB systems were activated in 75% of test runs (15 of 20) and prevented collision with the subject vehicle in 50% of test runs (10 of 20). Results in the child pedestrian scenario were significantly more consistent than for the rear cross traffic scenario. Two of the test vehicles successfully activated reverse AEB and prevented collision for all of their test runs (10 runs combined). The other two test vehicles activated reverse AEB on only 5 of 10 combined runs, with all automatic brake activations occurring after impact with the target had already occurred.

Aggregate Results for Pedestrian Tests	
Reverse AEB Applied?	Impacted Target?
15 75.0%	10 50.0%

Figure 29: Aggregate results of child pedestrian test scenario. Image Source: AAA.

VIII. KEY FINDINGS

1. In the parking cross traffic test scenarios, evaluated reverse AEB systems automatically applied brakes in 26 of 40 (65%) of test runs and successfully prevented collision with the subject vehicle in only 1 of 40 total test runs (2.5%).
2. In the stationary child pedestrian test scenario, evaluated reverse AEB systems automatically applied brakes in 15 of 20 test runs (75%) and prevented collision with the target in 10 of 20 test runs (50%).

IX. RECOMMENDATIONS

Drivers should not rely on reverse AEB systems to prevent collisions when backing up. Even in the pedestrian scenario, with a stationary target and an unobstructed view throughout the test run, collision was only prevented on 50% of runs. Drivers should be fully aware of their surroundings, utilize backup cameras to enhance their awareness, and back up cautiously.

Additionally, drivers should understand how these safety features work and give them the best chance to provide benefit. These systems rely on sensors that are typically mounted on the rear bumper area of the vehicle. When backing up with an obstructed view, drivers should back up cautiously and pause once the rear of their vehicle has cleared the obstruction to allow for these sensors to detect cross traffic. This will give the system more time to detect a potential collision and bring the vehicle to a stop.

X. REFERENCES

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XI. APPROVALS

		Date	Signature
Group Manager, Automotive Research Center, ACSC	Megan McKernan		
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Director—AAA National	Greg Brannon		