OCTOBER 2024

PROGRESSION OF AUTOMATIC EMERGENCY BRAKING TECHNOLOGY

NewsRoom.AAA.com

(this page intentionally left blank)

ABSTRACT

Automatic Emergency Braking (AEB) is an Advanced Driver Assistance System (ADAS) that utilizes sensors to detect imminent forward collisions with vehicles or other obstacles. When a potential collision is identified, and driver response is deemed insufficient, AEB automatically applies braking pressure to slow the vehicle or bring it to a complete stop, mitigating the severity of the impact or potentially avoiding the collision altogether. AEB is primarily designed to address forward-motion rear-end collisions, which in 2019, accounted for 32% of all auto accidents in the United States [1]. It functions most effectively at lower speeds, typically in stop-and-go traffic or highway cruising situations where a sudden slowdown might occur.

AEB systems have commonly relied on front-mounted, forward-looking vision systems; however, the industry has more recently begun to shift towards the deployment of a dual sensor approach, using radar and camera to continuously monitor the road ahead and assess potential hazards [2]. The data is gathered and subsequently processed by an onboard computer, which triggers automatic braking intervention when specific risk parameters are met. Studies by the National Highway Traffic Safety Administration (NHTSA) indicate that AEB can lower rear-end crashes by up to 49% [3].

Foreword:

AAA conducted primary research in a closed-course, simulated environment to evaluate the performance progression of AEB systems on vehicle model years between 2017 and 2024. AAA's research team added increased test speeds to the already planned test runs in an effort to determine how vehicles currently on the roadway perform at higher speeds.

Research Questions:

1. Has the functionality and performance of automatic emergency braking systems improved over the previous generation of technology?
2. How do vehicles currently on the road perform at higher speeds, such as 45 and 55 mph, which are not typically included in automatic emergency braking tests but may be encountered by motorists while driving?

Key Findings:

1. Late model (2024) vehicles tested were nearly twice as likely to avoid a collision as early model (2017, 2018) vehicles when tested at speeds up to 35 mph. Early model vehicles avoided collisions 51% of the time, compared to 100% for the late model vehicles.
2. At slower test speeds of 12 mph, the early model vehicles performed well and avoided 73% of collisions. When evaluated at slightly higher test speeds, this collision avoidance performance dropped to 47% at 25 mph and 33% at 35 mph. These results are in stark contrast to the late model group of test vehicles that were able to avoid a collision 100% of the time at speed ranges between 12 mph and 35 mph.
3. Vehicles that avoided a collision at lower test speeds of were evaluated at higher test speeds of 45 and 55mph. Three out of four vehicles evaluated were able to avoid a collision at 45 mph. The test speed was increased to 55 mph for those vehicles that avoided a collision at 45 mph. None of these remaining vehicles tested could avoid a collision, which resulted in either an aborted test run due to vehicle performance or an impact with the Softcar target vehicle.

GLOSSARY

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

Advanced Driver Assistance System (ADAS): A collection of technologies designed to enhance vehicle safety. The systems utilize a variety of sensors with software to assist drivers in the operation of their vehicles, aiming to reduce the likelihood of accidents caused by human error.

Vulnerable Road User (VRU): A person who uses the road without the protective shell of a motor vehicle, making them more susceptible to injury in the event of a collision. This category typically includes pedestrians, micromobility, cyclists, motorcyclists, and horse riders, as well as other individuals such as runners and construction workers.

Forward Collision Warning (FCW): An advanced driver assistance feature used to alert the driver of a potential hazard or vehicle in the roadway. Vehicles may use a visual alert in the center console, an audible beep, or haptic feedback to alert the driver of a potential collision.

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

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

Time-to-Collision (TTC): Time-to-collision is the instantaneous moment in time, measured in seconds, where the subject vehicle would impact the target vehicle based upon its current longitudinal separation distance and velocity. TTC is not an indicator of an actual collision but rather a parameter used in the evaluation of ADAS systems.

Edge Node Software Abstraction: The process of creating a simplified and generalized interface or layer that sits on top of the underlying hardware and software components of an edge node. This abstraction enables developers to interact with the edge node's functionalities without needing to understand the complexities of the hardware and low-level software operations.

CONTENTS

I. INTRODUCTION

Building on the deployment of anti-lock braking systems (ABS) and seatbelt pretensioners, Honda is recognized as developing the first commercial application of automatic emergency braking (AEB). In 2003, their collision mitigation brake system was launched on the Honda Inspire for the Japanese market, detecting a potential low-speed collision with a range of up to 100m (328ft) using a front-mounted radar [4]. Some original equipment manufacturers (OEMs), including Mercedes-Benz, launched similar systems around the same time; however, deployment was limited to premium vehicles and most commonly offered as an option. Over the following decade, AEB transitioned from a premium feature to a more widely available option across various models, with some OEMs taking the position to standardize the product range.

A key driver of AEB growth was a voluntary commitment made in 2016 by 20 automakers to equip all their vehicles with AEB by September 1, 2022, which was announced by the National Highway Traffic Safety Administration (NHTSA), the U.S. Department of Transportation (USDOT), and the Insurance Institute for Highway Safety (IIHS) in March 2016 [5].

AEB has since become a widely adopted safety feature, now present in 89% of all new vehicles sold in 2023 [2]. This widespread implementation has been primarily driven by the 2016 agreement and increasing competitive pressures. In 2029, new legislation will require vehicle manufacturers to make AEB standard in all new passenger cars and light trucks. According to the new Federal Motor Vehicle Safety Standard, FMVSS No.127, AEB is expected to save at least 360 lives and prevent more than 24,000 injuries annually [6].

Currently designed to prevent or mitigate forward collisions, especially at speeds between 2 mph and 50 mph, AEB systems are continuously evolving due to ongoing development and legislation. While current systems perform best at lower speeds, future versions will need to extend their effectiveness to higher-speed scenarios, providing additional protection on highways and expressways where collisions can be particularly severe. Starting in 2029, FMVSS No. 127 will mandate that all new passenger cars be capable of stopping to avoid contact with the vehicle in front of them at speeds up to 62 mph [6].

Historically reliant on either radar or windshield-mounted camera systems, AEB systems are starting to leverage greater levels of incumbent sensor fusion being deployed to support an entire range of (ADAS) features. The most common approach is to deploy long-range radar and monocamera sensors, which, in some cases, are integrated into a single unit. In 2023, 69% of passenger car models in the U.S. employ this approach for their ADAS sensor suite [2]. This multi-sensor approach is versatile to various weather and lighting conditions. It promises greater redundancy while improving the accuracy of object detection, including vulnerable road users (VRUs) and environmental perception, leading to more precise braking interventions. With increasing levels of autonomy, it is likely that Light Detection and Ranging (LiDAR) could be used alongside radar and camera sensors to further enhance the versatility and accuracy of the AEB system. However, penetration of LiDAR is currently limited to premium models in very low numbers, with widespread adoption unlikely before 2029.

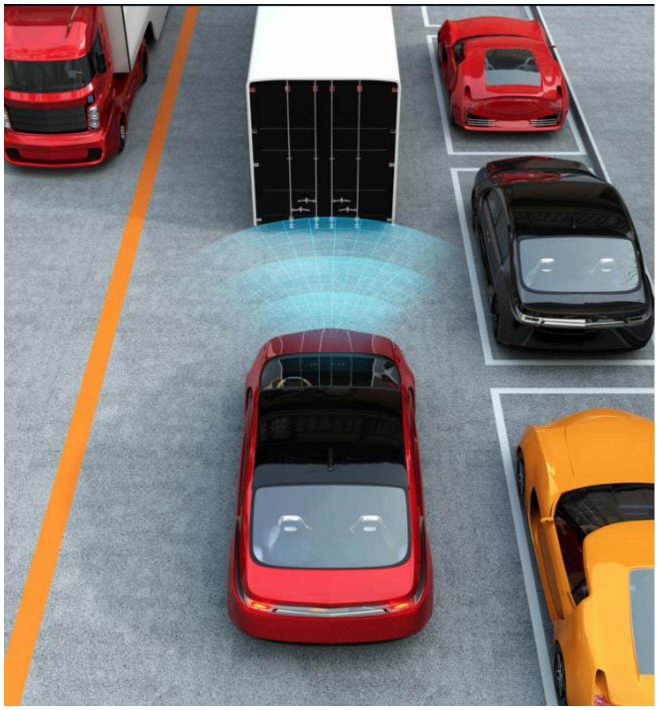

Figure 1: AEB can be beneficial in challenging scenarios where the driver's line-of-site is restricted and may reduce anticipation time for unexpected events. Image Source: SBD Automotive

As vehicles deploy more advanced electrical/electronic architecture that includes edge node software abstraction into centralized high-performance computers, advancement in machine learning and artificial intelligence will allow AEB systems to detect objects and classify them more effectively in real time. This could enable AEB to tailor braking responses to specific situations based on environmental context, vehicle type, and VRUs such as pedestrians and cyclists.

This report aims to assess the performance of older generation AEB technology in comparison to the current generation to determine if there is a measurable improvement. All testing focused on preventing forward-motion, rear-end collisions with a stationary vehicle at various speeds under identical test conditions

II. BACKGROUND

ADAS represents a growing segment in the automotive industry, encompassing a diverse range of technology-centric features designed to improve both driver convenience and safety outcomes. Unlike technologies aiming for full vehicle autonomy, ADAS functionalities do not involve taking sustained control of the vehicle's longitudinal or lateral direction. Many features, such as blind-spot warning and traffic-sign recognition, remain passive and do not take control of the vehicle; instead, they provide information or warning about potential hazards on the road. Passive ADAS features rely on the driver to interpret the information and take corrective action, whereas active features such as AEB will intervene to prevent a collision.

As regulatory bodies prepare the legislative framework and guidelines for mandating active safety features, OEMs are preemptively introducing new features as standard, and therefore penetration has been increasing year-on-year. The current trend is for safety-focused ADAS, such as automatic headlight dipping and collision avoidance systems, to become standard, partly due to regulatory pressure, but also to gain a competitive edge in terms of safety accreditation ratings. OEMs are deploying a richer and more diverse sensor suite to support a wider array of standard Society of Automotive Engineers (SAE) Level 0 ADAS features, including cameras, radar, and ultrasonics. Seeking a greater return on investment, this sensor suite can be leveraged to offer more advanced SAE convenience features as monetized options.

As an example, GMs Celestiq (MY2024) has a state-of-the-art sensor suite comprised of seven cameras, long-range radar, four short-range radars, a driver-facing infrared camera, LiDAR, and twelve ultrasonic sensors. This sensor suite will not only enable the basic SAE Level 0 safety features but also, with the inclusion of LiDAR, it is capable of SAE Level 2 and potentially Level 3 piloted driving (PD) [7].

The penetration rate of collision avoidance systems in the U.S. is rising rapidly, with AEB the most widely adopted technology, closely followed by pedestrian detection. With the sensor suite deployed to provide AEB as standard, OEMs are offering more advanced features, such as junction assist and evasive steering assist as options.

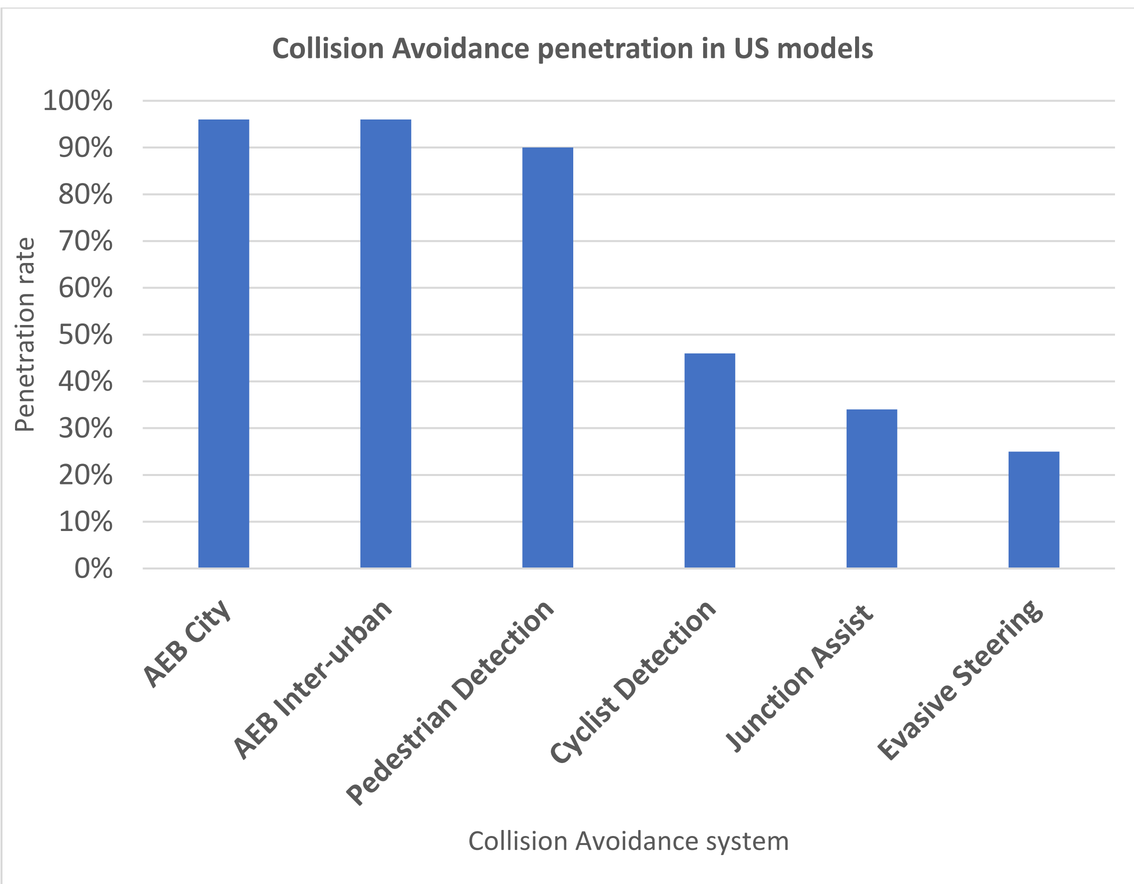

Figure 2: Collision avoidance feature penetration in 2023 models in the USA.

Source: 534 – ADAS Guide 2023 USA, SBD Automotive [7]

The USDOT has planned to invest $5 billion in research activities funded through the Bipartisan Infrastructure Law, also known as the Infrastructure Investment and Jobs Act. As a result, FMVSS No. 127 mandates that AEB will be fitted as standard from 2029, meaning that penetration for new vehicles will be at 100%. AEB has established itself as a valuable tool in preventing or mitigating collisions. Its effectiveness is well-documented, particularly in low-speed situations involving stop-and-go traffic, as evidenced in the 2019 study by the Intelligent Transportation Systems Joint Program Office, where it was found that low-speed AEB can reduce collisions by 38% [8] . However, ongoing evaluation remains important to ensure optimal performance across various scenarios, such as this evaluation conducted by AAA on AEB system performance.

The key area of AEB system capability is to detect and react to static objects. This could include situations where a driver encounters an unexpected obstacle on the road, such as a stalled vehicle or debris, or when a driver has an obstructed line-of-sight, restricting their ability to preempt an emergency stop scenario. Evaluating AEB performance in controlled scenarios helps assess its ability to bring the car to a complete stop or reduce its speed before impact in real-world scenarios.

III. VEHICLE SELECTION & PREPARATION

This study is intended to evaluate AEB systems on similarly equipped vehicles with differing generations of ADAS technology packages. Test vehicles were identified as having AEB systems as either standard or optional technology through secondary research.

A. Test Vehicle Selection Process

ADAS penetration data published by global automotive research firm SBD Automotive in their 2023 USA ADAS Guide [7] was used to define a list of 2024 vehicle models with AEB fitted as standard. For consistency of size and form factor, it was determined that all test vehicles would be mid-sized SUVs due to the popularity of the segment as determined by vehicles in operation and the availability of models with appropriate AEB systems fitted. Applying the criteria provided a list of models from several manufacturers; these were subsequently filtered to ensure that no more than one vehicle was selected from a single OEM, with the final list determined by the availability of 2017–2018 model year equivalents fitted with AEB.

B. ADAS and Vehicle Age Requirements

To ensure the selection of a previous generation of the technology, the team reviewed data from multiple years of SBD Automotive's ADAS Guide [7] . This methodology enabled the team to verify that the early model vehicles were sufficiently old to represent a previous generation. The team identified differences between vehicle systems by noting changes in Tier 1 ADAS suppliers, additional capabilities such as pedestrian detection, and new camera/radar hardware compared to the earlier version.

The Nissan Rogue was introduced with AEB technology in the U.S. in 2016, whereas the Jeep Grand Cherokee and Subaru Outback were introduced in 2014 and 2013, respectively.

Through this secondary research, it was determined that model year 2017–2018 vehicles would meet the testing requirements for the ***early model*** vehicles, and 2024 model-year vehicles would be utilized for the ***late model*** vehicle set.

C. Test Vehicles

	Model Year	Automaker	Model	Trim	VIN	Mileage at Testing	Tire Info	Tread Depth	Test Vehicle Weight (lbs)	AEB Fitment	Technology	Pedestrian Detection	Cyclist Detection
Early Models	2018	Subaru	Outback	Premium+ES	4S4BSAFC3J3272001	113,012	Bridgestone 225/65/R17	11/32nds	3,747	Opt.	Stereo Cameras	☐	☐
Early Models	2018	Nissan	Rogue	S	5N1AT2MT0JC717179	72,371	Hankook Dynapro 225/65/R17	11/32nds	3,569	Std.	Radar + Mono Camera	☑	☐
Early Models	2017	Jeep	Grand Cherokee	Trailhawk	1C4RJFLG3HC612543	80,378	Michellin 265/60/R18	11/32nds	5,128	Opt.	Radar + Mono Camera	☐	☐
Late Models	2024	Subaru	Outback	Touring	4S4BTGPDXR3195033	4,062	Yokohama 225/60/R18	11/32nds	3,961	Std.	Stereo Cameras	☑	☑
Late Models	2024	Nissan	Rogue	SV	5N1BT3BA8RC703814	2,179	Falken 235/60/R18	11/32nds	3,557	Std.	Radar + Mono Camera	☑	☑
Late Models	2024	Jeep	Grand Cherokee	Limited 4XE	1C4RJYB67RC146296	1,432	Michellin 265/60/R18	11/32nds	5,423	Std.	Radar + Mono Camera	☑	☑

Figure 3: Test Vehicle Detailed Information at Time of Testing.

The research team made significant efforts to procure early model test vehicles from the same model year. However, due to limitations of vehicle sourcing, a combination of 2017 and 2018 test vehicles had to be utilized. Secondary research confirmed that both the 2017 and 2018 Jeep Grand Cherokee models employed identical ADAS technology systems.

Figure 4: Progression of AEB Test Vehicle Line Up with Early and Late Model Vehicles. Image Source: AAA Inc.

D. Test Vehicle Preparation

Test vehicles were inspected and confirmed to be in working order with no check engine lights or warning messages on the dash. Early model test vehicles were taken to a dealership to have new tires, brakes, and rotors installed in addition to a complete brake system flush. The early model vehicles also had a computerized four-wheel alignment performed along with a software update to the latest version of ADAS software available from the dealership. Early model vehicles accumulated 500 miles of driving after the installation of new tires and brakes to ensure tires were properly broken in and ready for testing.

Late model test vehicles were also taken to their respective dealerships for a computerized four-wheel alignment and ADAS software update to the latest version available. Since the late model vehicles had low mileage, they did not receive new tires or brakes.

The tread depth of the tires was measured, and the vehicles were weighed using a calibrated digital four-wheel scale. Tire pressure for each vehicle was adjusted to the specifications on the vehicle placard using a calibrated gauge. Prior to testing and subsequent to the accumulation of at least 500 miles of on-road driving, the brakes of the early model test vehicles were bedded in with ten practice braking events from 50-to-0 mph. The brakes and vehicle were allowed to cool before testing was conducted.

IV. TEST EQUIPMENT AND RESOURCES

A. Vehicle Dynamics Equipment

1) Precision GPS with RTK Capability: 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 5: 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 6: OxTS RT-Range Hunter specifications. Image Source: AAA

2) Pedal Force Sensor: Each vehicle was equipped with a Futek LAU220 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 7: 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 front windshield to verify impact with the target vehicle and with a second camera to document lane position in relation to the right lane marker.

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 8: DEWESoft CAM-120 specifications. Image Source: AAA

4) 1080p Webcams: Webcams with 1080p resolution and a frame rate of 15 Hz were utilized to capture both the forward collision warning (FCW) alerts in the instrument cluster and verify impacts during tests runs by being mounted on the dash.

5) DEWESoft Sirius Datalogger and Other Data Logging Equipment: Test vehicles were equipped with a DEWESoft SIRIUS® slice data logger to log pedal force measurements at a rate of 1000 Hz in addition to the CANbus data from the Oxford Precision GPS. 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. Test data and videos are all time-synchronized utilizing the DEWESoft data logger so the files can be evaluated post-process.

Figure 9: Oxford Precision GPS and DEWESoft Data Logger Setup in Vehicle. Image Source: AAA Inc.

B. Static Target Vehicle

1) DRI Soft Car 360®: The Soft Car 360® served as the target vehicle and is designed to represent 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.

The Soft Car 360® was secured to a static test base to ensure repeatability between test runs and vehicles. Prior to testing each vehicle, the team re-zeroed the test vehicle to the static target vehicle at the start of the test series. The zero-calibration process enabled the team to create a point of collision and calculate the time-to-collision and other parameters used within this analysis.

Figure 10: Longitudinal distance zeroing process. Subject vehicle is moved forward until contact is made with the Soft Car 360®. This creates zero-point for distance and TTC calculations. **Image Source: AAA Inc.**

Figure 11: DRI Soft Car 360® on Static Base. **Image Source: AAA**

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.

Figure 12: Closed-course test facility with lane markers and Soft Car 360® positioned in lane. Image Source: AAA Inc.

Vehicle testing occurred on a closed-course dynamics test pad designed to replicate real-world scenarios, featuring solid lane markers on the right side and intermittent stripes on the left. Test vehicles had over 2,000 feet of runway, allowing drivers to reach target speeds and stabilize before detecting the target vehicle. The track surface was straight, flat, and free of potholes or other irregularities that could significantly affect the trajectory of the vehicles.

Figure 13: Aerial view of test track used for AEB evaluation. Image Source: Dynamic Research Inc.

V. INQUIRY #1: HAS THE FUNCTIONALITY AND PERFORMANCE OF AUTOMATIC EMERGENCY BRAKING SYSTEMS IMPROVED OVER THE PREVIOUS GENERATION OF TECHNOLOGY?

A. Objective

Examine how AEB systems perform in a static automatic emergency braking test scenario across early and late model test vehicles. The assessment involved testing the vehicles at three common speeds to evaluate the technology: 12 mph, 25 mph, and 35 mph.

B. Methodology

- Early and late model vehicles from the same automaker were evaluated back-to-back on the same day to eliminate any testing bias.
- Vehicles were driven on a closed-course roadway representing a standard two-lane divided road, separated by a dashed white line and solid lane markers on the outside.
- The DRI Soft Car 360® was positioned at the end of the course with the rear facing the subject vehicle, simulating a rear-end collision.
- The roadway provided a minimum of 2,000 feet of runway to stabilize test speeds for over 30 seconds.
- Drivers were instructed not to apply the brakes, relying on the activation of the AEB system to slow or stop the vehicle. A pedal load cell was mounted on the brake pedal to detect any instances where the driver applied the brakes.
- Drivers were instructed to apply the gas pedal to maintain steady-state speed until the vehicle received the forward collision warning (FCW). Once the FCW alert was displayed, the driver released the gas pedal and allowed the vehicle to complete the braking event.
- Any tests where the driver inadvertently applied the brakes or the vehicle speed exceeded the target speed range were considered invalid and were repeated.
- After each test run, vehicles underwent a key-on cycle to ensure readiness for the next test run.
- Standardized AEB testing speeds were as follows:
    - 12 mph (+/− 1 mph): 5 test runs
    - 25 mph (+/− 1 mph): 5 test runs
    - 35 mph (+/− 1 mph): 5 test runs

C. Test Results

The AAA engineering team evaluated the test results for each vehicle by playing back the precision GPS data that is time-synchronized to the video feed so they can identify when specific events occurred within an AEB event. The team was able to validate the entrance test speed, where the FCW took place and the time and distance when braking was initiated. Multiple cameras were also used to validate impact with the Soft Car 360® in addition to team members outside documenting the individual runs. Individual data was entered into the table format discussed below to enable side-by-side comparison of the test vehicles.

Camera Locations:

- AEB system activation on instrument cluster
- Forward facing on the dash (impact verification)
- Forward facing on the windshield (impact verification)
- Right front tire placement versus lane marker (test vehicle centering)

Figure 14: Data Analysis Software with Video and Data Overlay w/ FCW Alert. Image Source: AAA Inc.

The stopping distance (ft) shown in the table below indicates the calculated distance from the front bumper of the subject vehicle to the point of impact on the target vehicle (Soft Car 360®). Distances that are shown as positive indicate how close the subject vehicle came to hitting the target vehicle, whereas negative numbers (highlighted in red) indicate how far the subject vehicle traveled beyond the point of impact after hitting the target vehicle.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Early or Late Model Vehicle Under Test	Target vehicle speed- static AEB	Test run number 1-5	Actual vehicle speed in miles per hour prior to FCW warning	Y/N, was there an alert on the center console?	What was the longitudinal distance (feet) from target at time of the alert?	Time-to-Collision (seconds) at FCW activation	Y/N, were brakes applied by the vehicle.	Distance from target when automatic brake application started.	Distance from target when the vehicle came to a stop (if it did).	Time-to-Collision (seconds) at brake activation	Y/N, was impact made with the target?	Speed of test vehicle when impact with target occurred (if it did).

Figure 15: Test result matrix for AEB Test Run Data. Image Source: AAA Inc.

1) Test Scenario: 12 mph—Static Target:

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Jeep Early Model (2017)	12mph	Run1	11.68	Y	12.14	0.709	Y	8.06	-1.69	0.479	Y	6.31
		Run2	12.64	Y	15.62	0.842	Y	11.19	-0.77	0.610	Y	4.21
		Run3	12.33	Y	12.67	0.701	Y	7.99	-2.35	0.438	Y	7.09
		Run4	12.50	Y	12.60	0.697	Y	10.77	-0.43	0.590	Y	3.06
		Run5	12.70	Y	14.75	0.792	Y	10.66	0.13	0.570	N	0.00
Jeep Late Model (2024)	12mph	Run1	11.81	Y	12.62	0.728	Y	11.58	4.77	0.760	N	0.00
		Run2	11.55	Y	8.26	0.606	Y	11.24	4.78	0.666	N	0.00
		Run3	12.37	Y	13.63	0.751	Y	12.36	4.89	0.683	N	0.00
		Run4	12.46	Y	9.74	0.617	Y	12.67	5.35	0.691	N	0.00
		Run5	12.65	Y	13.94	0.751	Y	13.01	5.14	0.702	N	0.00

Figure 16: Jeep Grand Cherokee run-level results for 12-mph test scenarios. Image Source: AAA

The early and late model Jeep Grand Cherokee were evaluated at 12 mph to validate system performance at lower test speeds. The early model Jeep avoided a collision with the target vehicle in one out of five trials (20%), whereas the late model Jeep avoided a collision in all five trials.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Nissan Early Model (2018)	12mph	Run1	11.92	Y	20.02	1.145	Y	13.44	1.55	0.791	N	0.00
		Run2	12.45	Y	20.93	1.147	Y	15.66	1.69	0.872	N	0.00
		Run3	12.62	Y	22.92	1.239	Y	14.45	1.93	0.800	N	0.00
		Run4	12.26	Y	19.60	1.090	Y	14.42	2.03	0.816	N	0.00
		Run5	12.15	Y	20.23	1.134	Y	14.73	2.92	0.842	N	0.00
Nissan Late Model (2024)	12mph	Run1	11.60	Y	25.99	1.528	Y	14.03	6.15	0.829	N	0.00
		Run2	12.24	Y	27.21	1.515	Y	17.35	6.08	0.979	N	0.00
		Run3	12.48	Y	27.87	1.521	Y	18.61	5.20	1.040	N	0.00
		Run4	11.72	Y	24.32	1.414	Y	16.60	6.94	0.976	N	0.00
		Run5	11.99	Y	27.06	1.539	Y	18.16	5.27	1.057	N	0.00

Figure 17: Nissan Rogue run-level results for 12-mph scenarios. Image Source: AAA

At 12 mph, both the early and late model Nissan Rogue avoided a collision for each of their five respective trial runs. The late model Rogue performed slightly better than the early model when considering stopping distance to the target vehicle, which is measured at the front bumper. The late model Rogue averaged 5.9 feet at 12 mph, whereas the early model averaged 2.0 feet at the same speed.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Subaru Early Model (2018)	12mph	Run1	11.61	Y	29.76	1.748	Y	13.35	2.49	0.813	**N**	0.00
		Run2	12.10	Y	30.88	1.739	Y	13.23	2.28	0.784	**N**	0.00
		Run3	12.45	Y	31.20	1.708	Y	13.94	2.30	0.800	**N**	0.00
		Run4	11.35	Y	29.27	1.758	Y	11.23	2.73	0.729	**N**	0.00
		Run5	11.84	Y	30.23	1.741	Y	13.13	2.09	0.792	**N**	0.00
Subaru Late Model (2024)	12mph	Run1	11.59	Y	30.75	1.808	Y	14.68	3.83	0.906	**N**	0.00
		Run2	11.71	Y	30.86	1.799	Y	14.43	3.80	0.861	**N**	0.00
		Run3	12.12	Y	32.59	1.834	Y	14.31	4.10	0.836	**N**	0.00
		Run4	11.77	Y	30.99	1.797	Y	15.37	3.62	0.919	**N**	0.00
		Run5	12.78	Y	30.83	1.645	Y	15.47	4.50	0.868	**N**	0.00

Figure 18: Subaru Outback run-level results for 12-mph scenarios. Image Source: AAA

The early and late model Subaru Outback performed well at the 12 mph test scenario by avoiding a collision in all test runs. The late model vehicle performed slightly better when evaluating average stopping distance with a five-run average of 3.9 feet, compared to the 2.3 feet on the early model variant.

Figure 19: Late Model Subaru Outback braking at 12 mph. Image Source: AAA Inc.

2) Test Scenario: 25 mph—Static Target:

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Jeep Early Model (2017)	25mph	Run1	25.45	Y	41.135	1.102	Y	32.933	-2.396	0.887	Y	8.25
		Run2	25.18	Y	42.051	1.138	Y	32.093	-1.670	0.875	Y	7.02
		Run3	24.85	Y	42.388	1.163	Y	33.658	0.390	0.930	N	0.00
		Run4	24.74	Y	40.220	1.108	Y	32.247	-0.709	0.894	Y	4.18
		Run5	25.12	Y	42.421	1.152	Y	34.334	1.201	0.939	N	0.00
Jeep Late Model (2024)	25mph	Run1	25.41	Y	47.365	1.271	Y	33.957	5.344	0.914	N	0.00
		Run2	24.07	Y	38.668	1.095	Y	32.329	7.605	0.921	N	0.00
		Run3	24.72	Y	43.419	1.198	Y	33.268	5.430	0.919	N	0.00
		Run4	24.62	Y	43.612	1.206	Y	32.425	5.804	0.901	N	0.00
		Run5	25.79	Y	49.196	1.300	Y	35.594	6.572	0.943	N	0.00

Figure 20: Jeep Grand Cherokee run-level results for 25-mph test scenarios. Image Source: AAA

At a testing speed of 25 mph, the early model Jeep Grand Cherokee avoided a collision with the target vehicle in two out of five trials (40%), whereas the late model Jeep Grand Cherokee avoided a collision in all trials (100%). Despite the late model Jeep's strong performance in this evaluation, it has the shortest FCW alert distance among late model vehicles at 25 mph, averaging 44.4 feet, compared to 63.4 feet for the Nissan Rogue and 96.7 feet for the Subaru Outback.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Nissan Early Model (2018)	25mph	Run1	24.63	Y	57.625	1.596	Y	37.782	-3.615	1.055	Y	9.08
		Run2	25.66	Y	61.355	1.630	Y	38.793	-13.845	1.040	Y	12.75
		Run3	25.10	Y	57.959	1.585	Y	39.573	-14.629	1.085	Y	13.82
		Run4	24.38	Y	54.459	1.524	Y	41.949	-1.375	1.177	Y	5.95
		Run5	25.48	Y	59.711	1.597	Y	41.834	-4.997	1.131	Y	10.27
Nissan Late Model (2024)	25mph	Run1	25.30	Y	66.332	1.788	Y	61.138	5.262	1.652	N	0.00
		Run2	25.22	Y	62.313	1.684	Y	59.724	4.993	1.619	N	0.00
		Run3	24.60	Y	62.428	1.730	Y	59.905	3.986	1.664	N	0.00
		Run4	25.17	Y	64.052	1.735	Y	57.779	4.728	1.573	N	0.00
		Run5	25.26	Y	62.090	1.675	Y	60.607	5.036	1.639	N	0.00

Figure 21: Nissan Rogue run-level results for 25-mph scenarios. Image Source: AAA

The differences between early and late model vehicles can be clearly seen in this example. At 12 mph the early model Nissan Rogue was able to avoid a collision on all trials, whereas at the higher test speed of 25 mph, the early model vehicle avoided zero collisions and struck the target vehicle at an average speed of 10.4 mph. The late model Nissan Rogue performed well at 25 mph by avoiding a collision in all five trials.

Figure 22: Early Model Nissan Rogue impact at 25 mph. Image Source: AAA Inc.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Subaru Early Model (2018)	25mph	Run1	24.04	Y	89.255	2.531	Y	43.297	2.838	1.284	**N**	0.00
		Run2	24.67	Y	89.314	2.468	Y	43.366	2.087	1.249	**N**	0.00
		Run3	25.17	Y	94.882	2.571	Y	43.911	2.756	1.250	**N**	0.00
		Run4	24.95	Y	94.318	2.578	Y	44.993	2.388	1.283	**N**	0.00
		Run5	24.28	Y	88.163	2.476	Y	42.628	2.320	1.247	**N**	0.00
Subaru Late Model (2024)	25mph	Run1	25.21	Y	96.440	2.607	Y	45.535	6.020	1.268	**N**	0.00
		Run2	24.71	Y	95.548	2.636	Y	44.944	6.601	1.273	**N**	0.00
		Run3	25.23	Y	96.194	2.599	Y	45.965	7.077	1.272	**N**	0.00
		Run4	25.14	Y	98.944	2.683	Y	48.399	6.339	1.355	**N**	0.00
		Run5	24.98	Y	96.690	2.639	Y	48.760	6.834	1.362	**N**	0.00

Figure 23: Subaru Outback run-level results for 25-mph scenarios. Image Source: AAA

At 25 mph, both the early and late model Subaru Outback excelled in this test, avoiding collisions in all five of their respective trials. The late model Subaru Outback performed slightly better, with an average stopping distance of 6.5 feet compared to the early model's 2.4 feet.

3) Test Scenario: 35 mph—Static Target:

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Jeep Early Model (2017)	35mph	Run1	34.25	Y	69.436	1.382	Y	56.398	-56.535	1.127	Y	23.85
		Run2	34.81	Y	76.762	1.503	Y	57.395	-58.812	1.132	Y	24.56
		Run3	34.02	Y	69.446	1.397	Y	54.570	-56.581	1.105	Y	23.91
		Run4	34.95	Y	76.420	1.491	Y	56.453	-100.469	1.108	Y	25.19
		Run5	34.74	Y	74.885	1.470	Y	57.595	-57.680	1.138	Y	24.07
Jeep Late Model (2024)	35mph	Run1	34.39	Y	94.409	1.872	Y	55.784	6.175	1.120	N	0.00
		Run2	35.08	Y	98.199	1.909	Y	58.228	6.201	1.144	N	0.00
		Run3	35.46	Y	102.005	1.964	Y	61.024	7.753	1.184	N	0.00
		Run4	34.61	Y	100.289	1.972	Y	58.228	8.570	1.158	N	0.00
		Run5	35.34	Y	101.808	1.961	Y	59.928	6.522	1.166	N	0.00

Figure 24: Jeep Grand Cherokee run-level results for 35-mph test scenarios. Image Source: AAA

When the vehicles were tested at 35 mph, the differences between model variants became even more noticeable. The late model Jeep Grand Cherokee avoided a collision in 100% of the trials, whereas the early model Grand Cherokee avoided zero collisions and struck the target vehicle at an average speed of 24.3 mph. Starting at 35 mph, the early model vehicle only reduced its speed by 10.7 mph before impact, while the late model vehicle completely reduced its speed by 35 mph, avoiding a collision altogether.

Figure 25: Early Model Jeep Grand Cherokee impact at 35 mph. Image Source: AAA Inc.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Nissan Early Model (2018)	35mph	Run1	35.01	Y	98.159	1.912	Y	57.156	-44.623	1.121	Y	25.50
		Run2	35.50	Y	102.582	1.970	Y	57.444	-50.840	1.118	Y	25.70
		Run3	35.25	Y	101.129	1.955	Y	54.495	-107.943	1.076	Y	25.70
		Run4	35.05	Y	86.535	1.683	Y	53.825	-55.246	1.063	Y	25.59
		Run5	34.45	Y	97.310	1.925	Y	57.175	-45.659	1.152	Y	24.63
Nissan Late Model (2024)	35mph	Run1	34.92	Y	88.658	1.729	Y	90.200	4.593	1.755	N	0.00
		Run2	34.71	Y	95.177	1.869	Y	92.123	5.581	1.812	N	0.00
		Run3	34.79	Y	95.830	1.878	Y	92.264	5.066	1.813	N	0.00
		Run4	34.58	Y	94.308	1.859	Y	89.751	5.961	1.780	N	0.00
		Run5	35.81	Y	100.141	1.906	Y	97.516	5.489	1.858	N	0.00

Figure 26: Nissan Rogue run-level results for 35-mph test scenarios. Image Source: AAA

At 35 mph, the late model Nissan Rogue was able to avoid a collision 100% in all five trials, whereas the early model Rogue experienced a collision in all five trials. The early model Rogue hit the target vehicle at an average speed of 25.4 mph, which is only a speed reduction of 9.6 mph at this testing speed. The FCW detection distances for both models are similar, but the starting brake application distance is much later on the early model Rogue at 56.1 feet compared to 92.4 feet on the late model Rogue.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Subaru Early Model (2018)	35mph	Run1	34.32	Y	150.016	2.980	Y	92.615	4.075	1.881	N	0.00
		Run2	34.85	Y	151.312	2.961	Y	94.626	4.242	1.900	N	0.00
		Run3	34.75	Y	151.251	2.972	Y	95.413	3.540	1.916	N	0.00
		Run4	34.47	Y	152.418	3.015	Y	92.648	4.226	1.893	N	0.00
		Run5	34.95	Y	155.108	3.025	Y	94.836	2.904	1.907	N	0.00
Subaru Late Model (2024)	35mph	Run1	34.67	Y	159.701	3.140	Y	97.067	8.031	1.944	N	0.00
		Run2	34.78	Y	160.577	3.147	Y	97.717	7.651	1.948	N	0.00
		Run3	34.70	Y	161.690	3.177	Y	95.318	6.736	1.912	N	0.00
		Run4	35.32	Y	165.997	3.204	Y	98.612	6.263	1.942	N	0.00
		Run5	35.01	Y	161.591	3.157	Y	95.748	6.496	1.900	N	0.00

Figure 27: Subaru Outback run-level results for 35mph test scenarios. Image Source: AAA

At the higher testing speed of 35 mph, both early and late model variants for the Subaru Outback avoided a collision in 100% of all testing trials. When comparing the FCW alert timing and start of braking, both models are very similar in their approach to alerting the driver and automatically applying the brakes to avoid a collision.

4) Impact with Target Vehicles: AEB systems are intended to mitigate the severity of a crash or, in the best case, avoid a collision altogether. Avoiding a collision often depends on the vehicle's condition, such as tires and brakes, and external factors, such as pavement type and ambient weather conditions. Automakers design their vehicles to minimize the number of false positive FCW alerts while still providing adequate braking performance. Some manufacturers are more aggressive in their braking profiles to aid in preventing a collision, as seen in the following graphs.

Vehicle	Test Scenario	Run No.	Impact: Impact?	Impact: Speed (mph)	Test Scenario	Impact: Impact?	Impact: Speed (mph)	Test Scenario	Impact: Impact?	Impact: Speed (mph)
Jeep Early Model (2017)	12mph	Run1	Y	6.31	25mph	Y	8.25	35mph	Y	23.85
		Run2	Y	4.21		Y	7.02		Y	24.56
		Run3	Y	7.09		N	No Impact		Y	23.91
		Run4	Y	3.06		Y	4.18		Y	25.19
		Run5	N	No Impact		N	No Impact		Y	24.07
Nissan Early Model (2018)	12mph	Run1	N	No Impact	25mph	Y	9.08	35mph	Y	25.50
		Run2	N	No Impact		Y	12.75		Y	25.70
		Run3	N	No Impact		Y	13.82		Y	25.70
		Run4	N	No Impact		Y	5.95		Y	25.59
		Run5	N	No Impact		Y	10.27		Y	24.63
Subaru Early Model (2018)	12mph	Run1	N	No Impact	25mph	N	No Impact	35mph	N	No Impact
		Run2	N	No Impact		N	No Impact		N	No Impact
		Run3	N	No Impact		N	No Impact		N	No Impact
		Run4	N	No Impact		N	No Impact		N	No Impact
		Run5	N	No Impact		N	No Impact		N	No Impact

Impact Severity Legend	Speed Increments (mph)						
	No Impact	5	10	15	20	25	30

Figure 28: Early Model Vehicle Impact vs Test Speeds. Image Source: AAA Inc.

The early model test vehicles performed marginally well in regard to the standard test speeds, with the exception of the Subaru Outback, which avoided a collision in all fifteen test runs. The early model Jeep Grand Cherokee hit the target vehicle in 12 of 15 test runs (80% of the time), whereas the Nissan Rogue hit the target vehicle in 10 of 15 test runs (66% of the time). At the 35-mph test speed, the impact speed for the Nissan Rogue and Jeep Grand Cherokee were more severe averaging 25.42 and 24.32 mph, respectively.

Vehicle	Test Scenario	Run No.	Impact: Impact?	Impact: Speed (mph)	Test Scenario	Impact: Impact?	Impact: Speed (mph)	Test Scenario	Impact: Impact?	Impact: Speed (mph)
Jeep Late Model (2024)	12mph	Run1	N	No Impact	25mph	N	No Impact	35mph	N	No Impact
		Run2	N	No Impact		N	No Impact		N	No Impact
		Run3	N	No Impact		N	No Impact		N	No Impact
		Run4	N	No Impact		N	No Impact		N	No Impact
		Run5	N	No Impact		N	No Impact		N	No Impact
Nissan Late Model (2024)	12mph	Run1	N	No Impact	25mph	N	No Impact	35mph	N	No Impact
		Run2	N	No Impact		N	No Impact		N	No Impact
		Run3	N	No Impact		N	No Impact		N	No Impact
		Run4	N	No Impact		N	No Impact		N	No Impact
		Run5	N	No Impact		N	No Impact		N	No Impact
Subaru Late Model (2024)	12mph	Run1	N	No Impact	25mph	N	No Impact	35mph	N	No Impact
		Run2	N	No Impact		N	No Impact		N	No Impact
		Run3	N	No Impact		N	No Impact		N	No Impact
		Run4	N	No Impact		N	No Impact		N	No Impact
		Run5	N	No Impact		N	No Impact		N	No Impact

Impact Severity Legend	Speed Increments (mph)						
	No Impact	5	10	15	20	25	30

Figure 29: Late Model Vehicle Impact vs Test Speeds. Image Source: AAA Inc.

The late model test vehicles demonstrated exceptional performance in preventing collisions with the target vehicle, as no collisions occurred in all forty-five trials conducted at test speeds ranging from 12 mph to 35 mph. This is in stark contrast to the early model vehicles, which experienced 22 impacts under similar conditions.

Another way to evaluate system performance is by examining the number of collisions avoided. To calculate collisions avoided, subtract the number of impacts from the total number of trials at that speed, then divide that result by the total number of trials.

		AEB Collision Analysis								
Vehicle	Test Scenario	n- Impact	Collisions Avoided	Test Scenario	n- Impact	Collisions Avoided	Test Scenario	n- Impact	Collisions Avoided	Collisions Avoided All Speed
Jeep Early-2017	12mph	4	20%	25mph	3	40%	35mph	5	0%	Early Model Vehicles
Nissan Early-2018	12mph	0	100%	25mph	5	0%	35mph	5	0%	
Subaru Early-2018	12mph	0	100%	25mph	0	100%	35mph	0	100%	
Early Avg. Collisions Avoided	12mph	73%		25mph	47%		35mph	33%		51%
Jeep Late-2024	12mph	0	100%	25mph	0	100%	35mph	0	100%	Late Model Vehicles
Nissan Late-2024	12mph	0	100%	25mph	0	100%	35mph	0	100%	
Subaru Late-2024	12mph	0	100%	25mph	0	100%	35mph	0	100%	
Late Avg. Collisions Avoided	12mph	100%		25mph	100%		35mph	100%		100%

Figure 30: Impact Analysis by Vehicle Model Year. Image Source: AAA Inc.

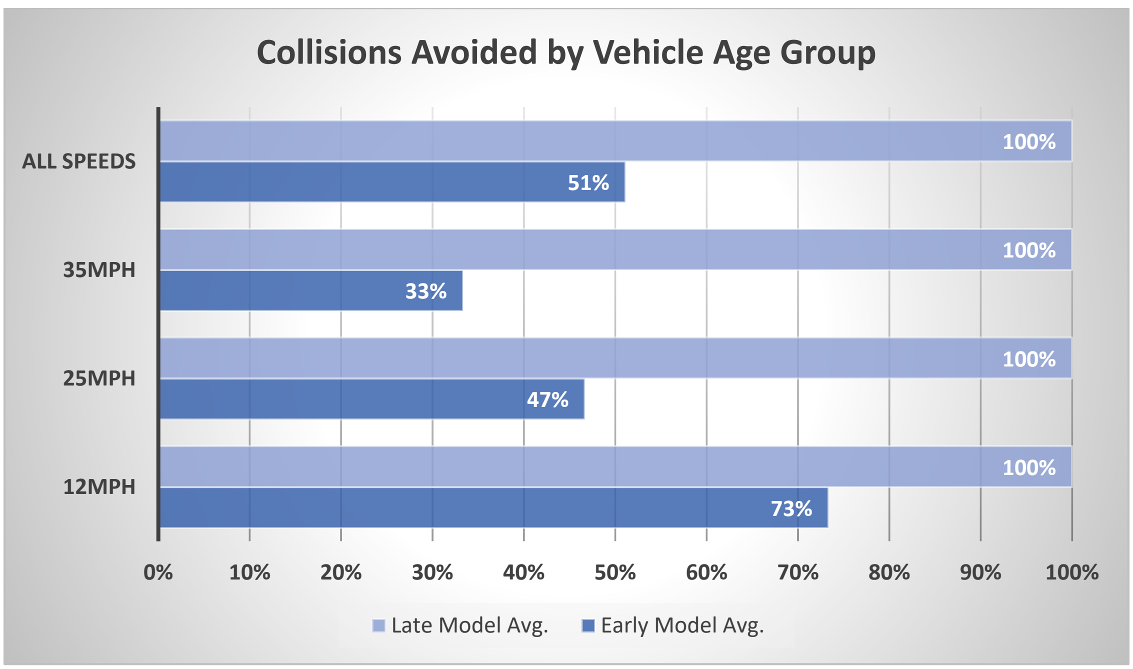

Figure 31: Standard speed collisions avoided by vehicle group. Image Source: AAA Inc.

The late model test vehicles avoided collisions 100% of the time (45 out of 45 test runs) at test speeds up to 35 mph, whereas the early model vehicles avoided collisions only 51% of the time (23 out of 45 test runs). At slower test speeds, the early model vehicles were able to avoid collisions 73% percent of the time at 12 mph and 47% of the time at 25 mph. Avoiding a collision is the preferred outcome, but if a collision is unavoidable, reducing the vehicle's speed at impact is crucial. All vehicles tested at standard speeds showed speed reductions that will lessen collision severity and mitigate the potential for occupant injury.

VI. HOW DO VEHICLES CURRENTLY ON THE ROAD PERFORM AT HIGHER SPEEDS, SUCH AS 45 AND 55MPH

Vehicles demonstrating satisfactory performance within the standard AEB testing speeds of 12 mph to 35 mph were subjected to incremental increases in testing speeds, progressing in 10 mph intervals until reaching the threshold of consistent collisions. To safeguard the vehicle from considerable damage, the test driver retained the discretion to abort a test run if the forward collision warning activated late or the vehicle's braking was deemed inadequate to avert a high-speed collision. Test setup remained the same as the standard speed trials, using a static Soft Car 360® target vehicle on a closed-course test facility with lane markers to simulate a normal roadway. Only vehicles that avoided a collision in the lower speed test runs of 35mph were evaluated at increased speeds. It should be noted that FMVSS 127 only requires fully automatic emergency braking to 50 MPH. The higher speeds noted in that standard integrate dynamic braking support to achieve crash avoidance and mitigation.

A. Test Results

1) Increased Speed Scenario: 45 mph—Static Target:

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Jeep Late Model (2024)	45mph	Run1	45.34	Y	148.773	2.241	Y	126.161	-1.299	1.897	Y	4.85
		Run2	45.47	Y	153.025	2.294	Y	124.380	-1.657	1.874	Y	2.35
		Run3	45.17	Y	153.970	2.322	Y	123.510	-1.099	1.878	Y	4.21
		Run4	45.43	Y	153.986	2.312	Y	125.988	-0.039	1.893	Y	0.20
		Run5	45.59	Y	153.143	2.292	Y	126.437	-1.280	1.894	Y	4.97

Figure 32: Jeep Grand Cherokee run-level results for 45-mph test scenarios. Image Source: AAA

At test speeds of 45 mph, the late model Jeep Grand Cherokee hit the target vehicle in all five trials, but the impact speed was relatively low, which would reduce the potential damage in a real collision.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Nissan Late Model (2024)	45mph	Run1	44.91	Y	124.820	1.895	Y	116.919	2.001	1.779	N	0.00
		Run2	45.06	Y	122.169	1.847	Y	121.509	1.854	1.838	N	0.00
		Run3	44.12	Y	119.708	1.850	Y	115.827	3.130	1.784	N	0.00
		Run4	45.16	Y	125.358	1.892	Y	118.740	0.164	1.797	N	0.00
		Run5	44.91	Y	119.439	1.813	Y	116.148	0.190	1.766	N	0.00

Figure 33: Nissan Rogue run-level results for 45-mph test scenarios. Image Source: AAA

In contrast, the late model Nissan Rogue avoided a collision in all five trials, albeit at very close stopping distances in relation to the target vehicle at less than two inches from the point of impact on run 4 and 5. Since this Nissan avoided a collision in all five trials, it was tested at the next higher speed of 55 mph.

Figure 34: Late Model Nissan Rogue 45-mph Run 4—Close Stop Event. Image Source: AAA Inc.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Subaru Early Model (2018)	45mph	Run1	44.42	Y	171.257	2.629	Y	135.617	3.120	2.108	**N**	0.00
		Run2	45.12	Y	184.810	2.793	Y	145.285	4.006	2.222	**N**	0.00
		Run3	44.78	Y	182.799	2.782	Y	147.454	2.963	2.267	**N**	0.00
		Run4	44.52	Y	180.945	2.771	Y	137.428	3.120	2.134	**N**	0.00
		Run5	45.41	Y	185.463	2.784	Y	158.241	3.648	2.397	**N**	0.00
Subaru Late Model (2024)	45mph	Run1	45.29	Y	247.051	3.718	Y	154.833	5.597	2.351	**N**	0.00
		Run2	45.14	Y	252.011	3.807	Y	150.584	5.344	2.313	**N**	0.00
		Run3	44.98	Y	252.861	3.832	Y	150.413	5.636	2.340	**N**	0.00
		Run4	44.52	Y	245.925	3.768	Y	145.686	5.827	2.283	**N**	0.00
		Run5	45.01	Y	245.577	3.720	Y	149.990	6.030	2.320	**N**	0.00

Figure 35: Subaru Outback run-level results for 45-mph test scenarios. Image Source: AAA

Both the early and late model Subaru Outback excelled in the AEB test scenarios at 45 mph by avoiding a collision in all ten trials and stopping the vehicle at an average of 3.37 feet from the target vehicle for the early model and 5.69 feet for the late model vehicle.

The subject vehicles that avoided a collision at 45 mph were evaluated at 55 mph under the same conditions. Only vehicles that avoided a collision in prior test runs were evaluated at the higher test speeds.

2) Increased Speed Scenario: 55 mph—Static Target:

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Nissan Late Model (2024)	55mph	Run1	55.14	N			N				NA[1]	
		Run2	55.13	N			N				NA[1]	
		Run3	NA	NA			NA					
		Run4	NA	NA			NA					
		Run5	NA	NA			NA					

TEST IMPACT NOTE[1]: Test Run Aborted Due to No FCW and No Automatic Braking

Figure 36: Nissan Rogue run-level results for 55-mph test scenarios. Image Source: AAA

At 55 mph, the late model Nissan Rogue was evaluated under the same conditions as the lower speed trials but failed to provide a forward collision warning (FCW) or automatically apply the braking, and as a result, the driver aborted the test run and swerved to avoid a high-speed collision with the target vehicle. The test was repeated after restarting the vehicle and cycling the power, and in the second trial, the vehicle again failed to provide an FCW alert or show any indication of braking, so the driver again had to swerve to avoid the target vehicle. After not responding with an alert or providing any indication of emergency braking, the 55-mph speed trials for the Nissan Rogue were ended after two attempts.

Vehicle	Test Scenario	Run No.	Vehicle Speed (mph)	Forward Collision Warning			Automatic Braking				Impact	
				Alert?	Long Dist (ft)	TTC (s)	Applied?	Start Dist (ft)	Stop Dist (ft)	TTC Start Brake (s)	Impact?	Speed (mph)
Subaru Early Model (2018)	55mph	Run1	55.10	Y	82.392	1.057	N				NA[1]	NA
		Run2	54.05	Y	78.891	1.026	N				NA[1]	NA
		Run3	54.80	Y	176.040	2.190	Y	171.220	-8.766	2.134	Y	15.43
		Run4	54.29	Y	159.596	2.003	Y	170.000	**NA**	2.116	NA[1]	NA
		Run5	55.32	Y	79.360	1.005	N				NA[1]	NA
Subaru Late Model (2024)	55mph	Run1	55.50	Y	280.075	3.452	Y	201.191	-4.610	2.484	Y	12.03
		Run2	55.22	Y	276.529	3.414	Y	107.769	-52.575	1.370	Y	28.30
		Run3	55.25	Y	271.969	3.356	Y	208.852	-2.329	2.593	Y	8.21
		Run4	54.63	Y	274.783	3.430	Y	151.276	-27.461	1.920	Y	20.98
		Run5	54.13	Y	123.163	1.585	Y	92.943	-51.959	1.204	Y	28.74

TEST IMPACT NOTE[1]: Test Run Aborted Due to Late FCW and No Automatic Braking

Figure 37: Subaru Outback run-level results for 55-mph test scenarios. Image Source: AAA

At 55 mph, the early model Subaru Outback provided a delayed FCW alert on three of the five trials by alerting on average at 80.21 feet from the target vehicle, which was roughly 100 feet shorter than the alert distance at 45 mph, which resulted in the driver aborting the test runs since there was insufficient distance to stop. In test run 3, the vehicle provided an alert at 176.04 feet and initiated braking, so the driver allowed the vehicle to automatically apply the brakes, which resulted in a collision at a speed of 15.43 mph. In test run four, the vehicle provided an alert at 159.59 feet but was applying the brakes at a low braking level, so the driver again decided to abort the test run. This concluded the testing of the early model Subaru Outback.

The late model Subaru Outback performed exceedingly well in lower speed trials but struggled to avoid a collision in all five of the tests at 55 mph. The late model Subaru also had the longest FCW detection distance of vehicles tested at 280.07 feet but failed to reduce speed sufficiently, which resulted in an average speed of impact of 19.65 mph with the target vehicle. In test run 5, the vehicle provided a delayed forward collision alert over 152.67 feet shorter than the average FCW detection distance of 275.83 feet, resulting in a collision at 28.74 mph.

Figure 38: Late Model Subaru Outback collision with Soft Car at 55 mph. Image Source: AAA Inc.

A summary of the vehicle performance at higher test speeds is shown below to illustrate FCW alerts, brake activation, and collision avoidance or collision speeds.

		Alert / Braking		Impact			Alert / Braking		Impact	
Vehicle	Test Scenario	FCW Alert	Auto Brake	Impact?	Speed (mph)	Test Scenario	FCW Alert	Auto Brake	Impact?	Speed (mph)
Jeep Late Model (2024)	45mph	Y	Y	Y	4.85	55mph	Not Tested Due to Impact at 45mph			
		Y	Y	Y	2.35					
		Y	Y	Y	4.21					
		Y	Y	Y	0.20					
		Y	Y	Y	4.97					
Nissan Late Model (2024)	45mph	Y	Y	N	No Impact	55mph	N	N	NA[1]	NA[1]
		Y	Y	N	No Impact		N	N	NA[1]	NA[1]
		Y	Y	N	No Impact		Testing Stopped Due to No Alert / Braking			
		Y	Y	N	No Impact					
		Y	Y	N	No Impact					
Subaru Early Model (2018)	45mph	Y	Y	N	No Impact	55mph	Y-Late	N	NA[1]	NA[1]
		Y	Y	N	No Impact		Y-Late	N	NA[1]	NA[1]
		Y	Y	N	No Impact		Y	Y	Y	15.43
		Y	Y	N	No Impact		Y	Y	NA[1]	NA[1]
		Y	Y	N	No Impact		Y-Late	N	NA[1]	NA[1]
Subaru Late Model (2024)	45mph	Y	Y	N	No Impact	55mph	Y	Y	Y	12.03
		Y	Y	N	No Impact		Y	Y-Late	Y	28.30
		Y	Y	N	No Impact		Y	Y	Y	8.21
		Y	Y	N	No Impact		Y	Y-Late	Y	20.98
		Y	Y	N	No Impact		Y-Late	Y-Late	Y	28.74

Impact Severity Legend	Speed Increments (mph)						
	No Impact	5	10	15	20	25	30

TEST IMPACT / SPEED NOTE[1]: Test Run Aborted Due to Late FCW or Limited Braking by Vehicle

Figure 39: Increased test speed overall performance matrix.

At 55 mph, the three remaining vehicles struggled with detecting the target vehicle and successfully applying the brakes in a consistent manner to avoid a collision. The late model Nissan Rogue was tested at 55 mph but failed to detect the static target vehicle in two consecutive trials. Since the vehicle did not provide a FCW, testing was stopped after two attempts.

The early model Subaru Outback was able to detect the target vehicle, but three out of five alerts were late based upon previous test outcomes, which resulted in the driver swerving to avoid hitting the target vehicle at high speeds. The late model Subaru Outback performed slightly better than the early model counterpart but failed to detect the target vehicle in one trial. The braking performance of the late model Subaru was also inconsistent as it applied AEB late in three out of five trials, which resulted in impact speeds greater than 20 mph. While the late model Subaru hit the target vehicle in all five trials, it should be noted that any mitigation of speed will help to reduce the severity of impact if this were an actual crash.

VII. DISCUSSION

AEB systems have shown considerable improvement based on the results of this evaluation. In standard test speeds, late model vehicles performed as good or better than early models in all speed trials. While the late model vehicles avoided a collision in the standard speed testing from 12 mph to 35 mph, it should be noted that the braking severity and FCW time varied greatly among the automakers tested.

A. Braking Severity

In addition to measuring key parameters such as vehicle speed and separation distance from the target vehicle, the data logger and GPS enabled the research team to measure the deceleration (g-force) of the vehicle throughout the entirety of the test run. G-force, or gravitational force, is the force exerted on the body due to acceleration or deceleration of the vehicle. In this report, a negative g-force value represents the force exerted during braking, indicating deceleration. Conversely, a positive g-force value would be experienced during acceleration, indicating an increase in speed. This measurement is crucial for understanding the vehicle's performance and the forces acting on it during various phases of the test.

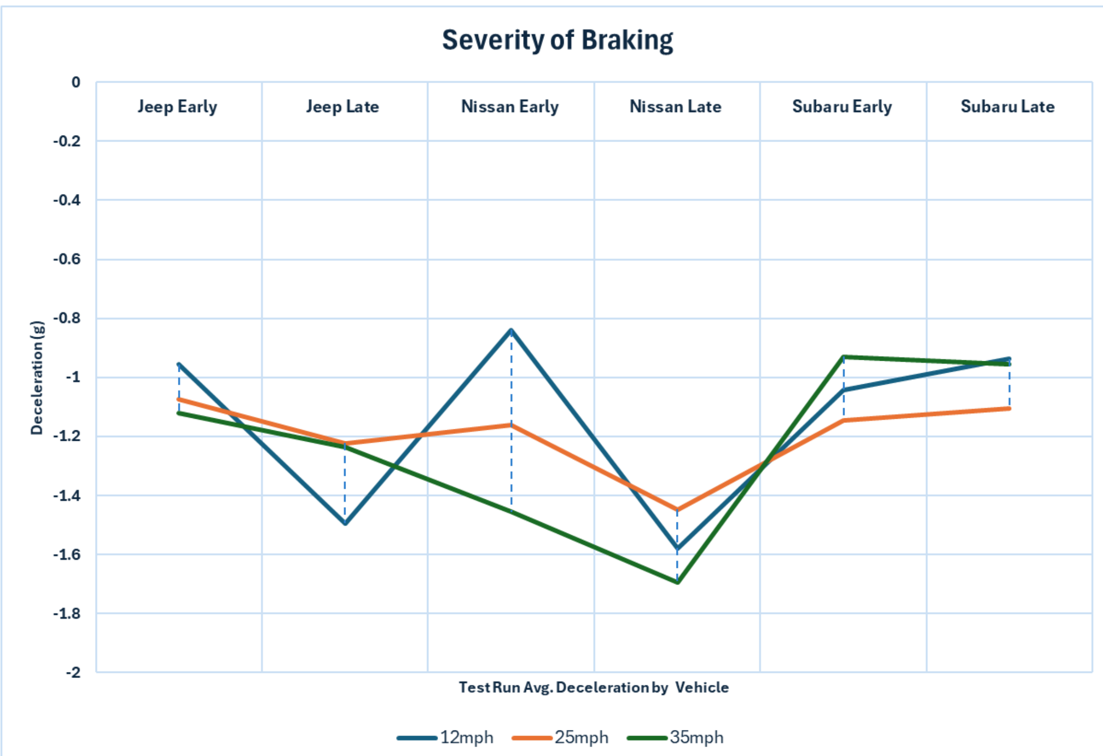

Figure 40: Severity of braking for vehicles under test at 12 mph, 25 mph, and 35 mph. Image Source: AAA Inc.

In the graph shown above, the maximum deceleration g-force observed at 12 mph, 25 mph, and 35 mph for the vehicles under test is depicted. The values represent the average maximum g-force from the five test runs. Moderate braking may be considered −0.2g to −0.4 g, while heavy braking often exceeds −1 g.

Comparing early and late model vehicles from each manufacturer reveals distinct differences in their braking characteristics. At slow speeds such as 12 mph, the early model Nissan Rogue experienced

−0.839 g and impacted the target vehicle, whereas the late model Nissan Rogue experienced −1.581 g and avoided the target vehicle. Avoiding a collision is ideal, but it should not be at the expense of nearly twice the g-force in braking.

The late model Jeep Grand Cherokee also experienced harsh braking of −1.494g at the 12-mph test speed, as braking didn't initiate until the vehicle was only 11.6 feet from the target vehicle. Initiating gradual braking at further distances would minimize the harsh braking felt by the motorist.

At higher test speeds of 35 mph, the late model Nissan Rogue experienced a maximum braking g-force of −1.69g compared to −0.96g for the Subaru Outback. The Subaru initiated gradual braking earlier and was able to gradually apply the brakes to avoid collision while mitigating harsh braking conditions.

B. Time-to-Collision and Driver Response Time

Time-to-collision (TTC) is a common metric in assessing ADAS, representing the theoretical duration between an alert or brake application and the projected moment of impact with the target vehicle. It is important to note that TTC does not confirm whether the vehicle indeed collided with the target, as there is a possibility for the tested vehicle to come to a stop before a collision occurs.

AEB systems frequently accompany FWC systems, which are designed to notify drivers of potential collisions. FCW systems, depending on vehicle setup, utilize audible, visual, or haptic alerts. In the following charts, is an analysis of the interval between the initiation of the FWC alert and the application of automatic braking by the vehicle. This difference in time reflects the window available for the driver to react and manually engage the brakes before automatic intervention takes effect, which is depicted as ***reaction time*** below.

Figure 41: Forward Collision Warning (FCW) Detecting Vehicle Example. Image Source: IIHS

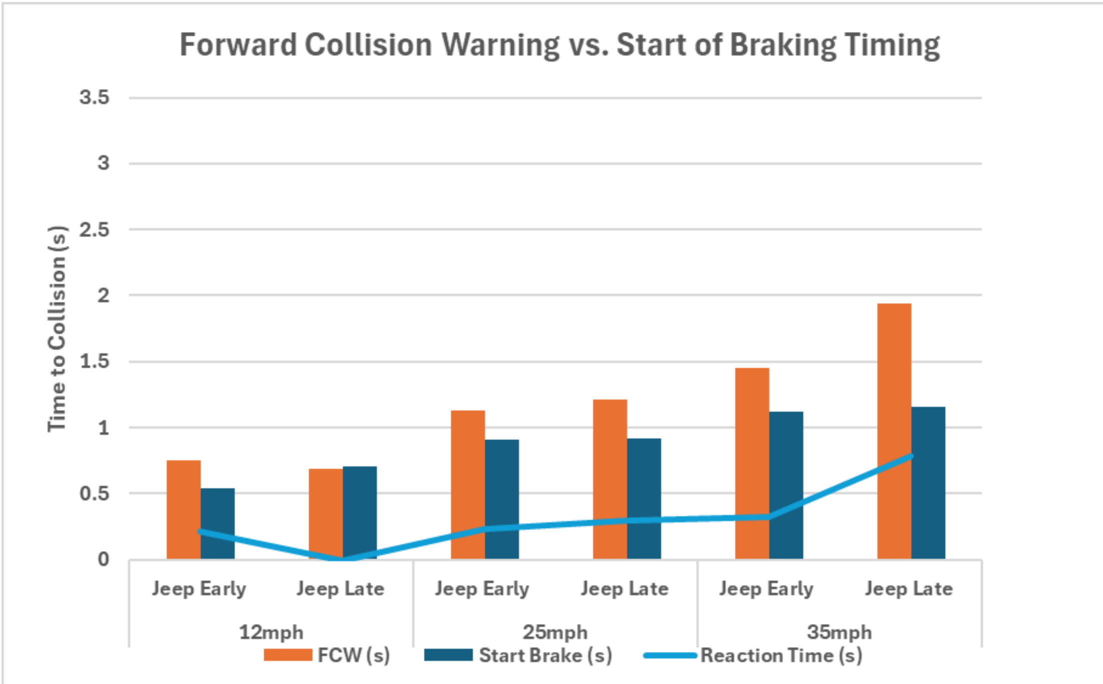

Figure 42: FCW to Brake Application—Jeep Grand Cherokee Early vs. Late Model. Image Source: AAA Inc.

The Jeep Grand Cherokee had the slowest FCW timing of any vehicle we tested at 0.74 seconds (TTC) for the early model and 0.69 seconds (TTC) for the late model at 12 mph, which is inadequate time for the driver to respond to the alert and act prior to a potential collision. At 35 mph, the late model Jeep Grand Cherokee shows a slight improvement in FCW over the early model variant with a 1.93 seconds (TTC) compared to the early model with 1.45 seconds (TTC).

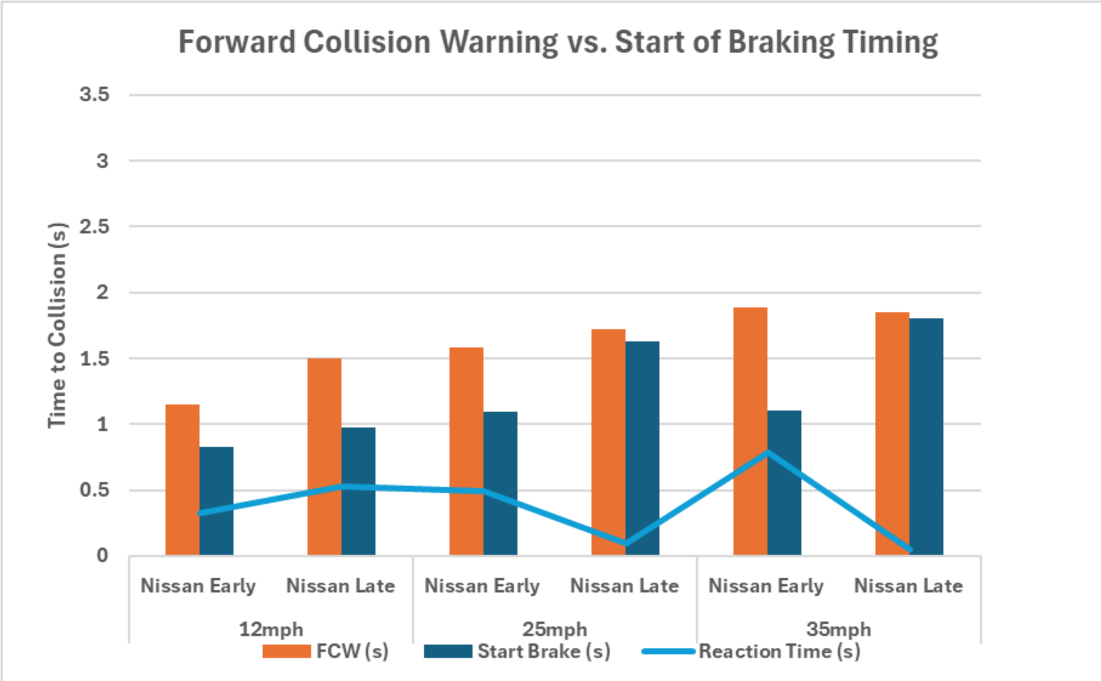

Figure 43: FCW to Brake Application—Nissan Rogue Early vs. Late Model. Image Source: AAA Inc.

The Nissan Rogue exhibits a distinct difference between its early and late model variants in terms of braking initiation. In the late model, braking at speeds of 25 mph and 35 mph begins almost simultaneously with the FCW alert to the driver. This timing leaves the driver insufficient time to react or brake on their own. While this approach may serve to notify the driver and potentially alter the speed, a more advanced FCW alert system would be preferable.

When analyzing FCW timing across various speeds, it was found that the forward collision warning at 35 mph, with a timing of 1.85 seconds (TTC), is only 0.34 seconds longer than the alert timing at 12 mph, which is 1.50 seconds.

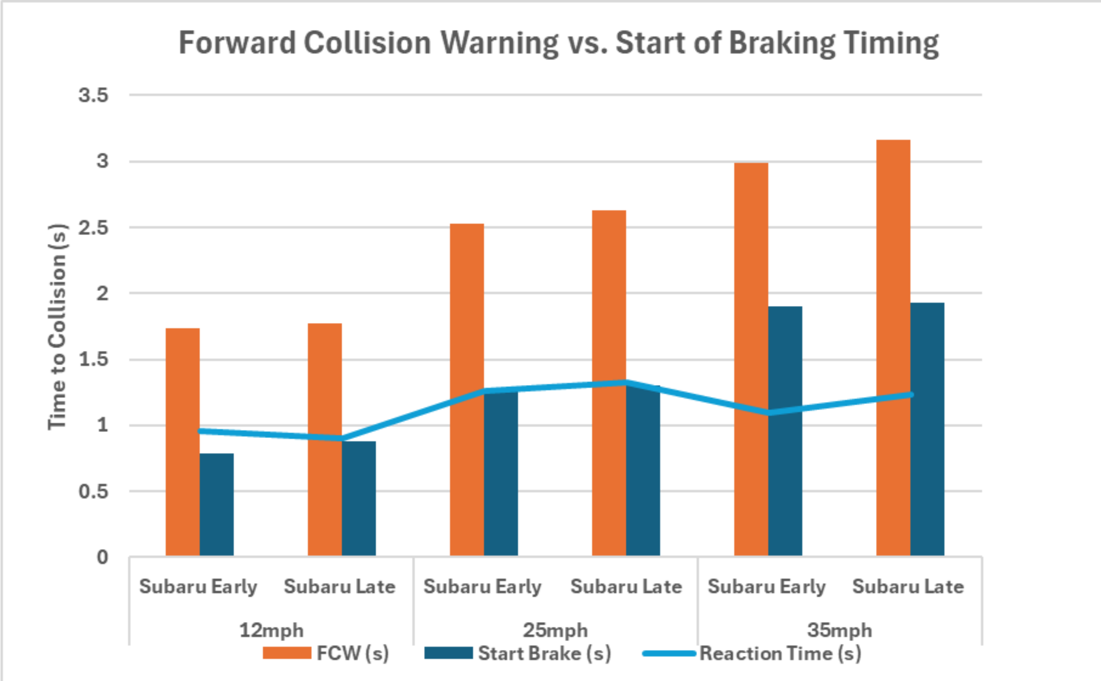

Figure 44: FCW to Brake Application—Subaru Outback Early vs. Late Model. Image Source: AAA Inc.

When comparing the early and late model Subaru Outback, researchers observed similar timing trends in both models across all three test speeds, with approximately 1 second between the FCW alert and brake activation. Specifically, at 35 mph, the late model Subaru provides an FCW alert at 3.16 seconds (TTC) and initiates braking just over a second later at 1.93 seconds (TTC). This design approach allows the driver time to respond to a potential collision and take action, rather than relying solely on the vehicle to prevent a collision.

VIII. KEY FINDINGS

1. Late model (2024) vehicles tested were nearly twice as likely to avoid a collision as early model (2017, 2018) vehicles when tested at speeds up to 35 mph. Early model vehicles avoided collisions 51% of the time, compared to 100% for the late model vehicles.
2. At slower test speeds of 12 mph, the early model vehicles performed well and avoided 73% of collisions. When evaluated at slightly higher test speeds, this collision avoidance performance dropped to 47% at 25 mph and 33% at 35 mph. These results are in stark contrast to the late model group of test vehicles that were able to avoid a collision 100% of the time at speed ranges between 12 mph and 35 mph.
3. Vehicles that avoided a collision at lower test speeds of were evaluated at higher test speeds of 45 and 55mph. Three out of four vehicles evaluated were able to avoid a collision at 45 mph. The test speed was increased to 55 mph for those vehicles that avoided a collision at 45 mph. None of these remaining vehicles tested could avoid a collision, which resulted in either an aborted test run due to vehicle performance or an impact with the Softcar target vehicle.

IX. RECOMMENDATIONS

AAA supports NHTSA's final ruling on AEB system performance (FMVSS 127) as it lays the foundation for safer roads and helps standardize this life-saving technology across the automotive industry. Our research indicates that the current generation of AEB technology can significantly enhance collision avoidance capabilities, though much progress is needed to ensure these systems are effective at higher speeds. Based on our findings, AAA also commends the industry for improving AEB system performance compared to previous generations, as these advancements have the potential to reduce the severity of collisions and save lives.

While there have been notable improvements in AEB systems over the last few years, drivers should not rely solely on this technology to avoid collisions or expect the vehicle to always brake in the event of a crash. External factors such as vehicle condition, road type, and ambient weather can all significantly impact the functionality of these systems

AEB technology offers significant benefits for motorist safety, particularly at lower and moderate speeds. Adopting AEB systems capable of higher speeds, enhancing FCW alerts, investing in high-speed safety research, and promoting public awareness can reduce the likelihood and severity of crashes. Achieving these safety goals requires collaborative efforts between automakers, regulatory bodies, safety organizations and consumers.

Based on the findings of this study, AAA recommends the following:

- ❖ **Adopt Advanced AEB Systems:** Automakers should prioritize the implementation of AEB technology compatible with higher speeds in all new vehicle models. These systems have proven highly effective in preventing collisions at lower to moderate speeds.
- ❖ **Enhance FCW Alerts:** Improved FCW systems that provide earlier alerts can give drivers more time to react, reducing reliance on AEB systems alone. This approach can lead to a more collaborative safety system where both the driver and the vehicle work together to avoid collisions.
- ❖ **Research and Development for High-Speed Scenarios:** Continued investment in research and development is necessary to enhance the performance of AEB systems at higher speeds. This includes refining sensor technologies, improving braking algorithms, and conducting extensive real-world testing to meet new regulatory standards and ensure safety at speeds above 45 mph.
- ❖ **Public Awareness and Training:** Educating drivers about the capabilities and limitations of AEB systems is crucial. Drivers should understand how these systems work and the importance of maintaining attentive driving practices, even in vehicles equipped with advanced safety features.
- ❖ **Regulatory Support and Training:** Government agencies should support the widespread adoption of AEB technology through regulations and driver education programs to ensure motorists understand the limitations of the technology. NHTSA, other relevant agencies, and automakers should collaborate more closely ensure the technology is effective at higher test speeds while balancing false positive alerts/activation that can hinder widespread acceptance.

X. REFERENCES

[1] NHTSA Crash Stats, "Traffic Safety Facts 2019, A Compilation of Motor Vehicle Crash Data," 2019. [Online]. Available: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813141. [Accessed 17 June 2024].

[2] SBD Automotive, "USA ADAS and Autonomy Forcast 2023," Ann Arbor, 2023.

[3] National Highway Traffic Safety Administration, "Partnership for Analytics Research in Traffic Safety," [Online]. Available: https://www.nhtsa.gov/parts-partnership-for-analytics-research-in-traffic-safety#:~:text=The%20study%20shows%20that%20vehicles,lighting%20conditions%20are%20not%20ideal.. [Accessed 10 June 2024].

[4] Honda Motor Company, "Honda Develops World's First 'Collision Mitigation Brake System'(CMS) for Predicting Rear-end Collisions and Controlling Brake Operations," 20 May 2003. [Online]. Available: https://global.honda/en/newsroom/news/2003/4030520-eng.html. [Accessed 9 June 2024].

[5] National Highway Traffic Safety Administration, "U.S. DOT and IIHS announce historic commitment of 20 automakers to make automatic emergency braking standard on new vehicles," 17 March 2016. [Online]. Available: https://www.nhtsa.gov/press-releases/us-dot-and-iihs-announce-historic-commitment-20-automakers-make-automatic-emergency. [Accessed 10 June 2024].

[6] National Highway Traffic Safety Administration, "NHTSA Finalizes Key Safety Rule to Reduce Crashes and Save Lives -FMVSS127," 29 April 2024. [Online]. Available: https://www.nhtsa.gov/press-releases/nhtsa-fmvss-127-automatic-emergency-braking-reduce-crashes. [Accessed 2 June 2024].

[7] SBD Automotive, "534 – ADAS Guide 2023 USA, SBD Automotive," 2023. [Online]. Available: https://www.sbdautomotive.com/reports/adas-%26-autonomy-guide.

[8] Intelligent Transportation Systems Joint Program Office, "Low speed autonomous emergency braking (AEB) can reduce rear-end crashes by 38 percent.," 6 June 2019. [Online]. Available: https://www.itskrs.its.dot.gov/2019-b01373#:~:text=Home%20%2F-,Low%20speed%20autonomous%20emergency%20braking%20(AEB)%20can%20reduce%20rear%2D,on%20real%2Dworld%20crash%20experience.. [Accessed 5 June 2024].

