FLIR

FUSED AEB WITH THERMAL CAN SAVE LIVES

A TEST SUMMARY FOR TESTING AGENCIES, AUTOMOTIVE MANUFACTURERS, AND TIER 1 SUPPLIERS

VSI Labs

Test conducted by VSI Labs for FLIR Systems

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EXECUTIVE SUMMARY

Improving AEB Effectiveness with Thermal Sensing Technology

CURRENT CONDITIONS

In 2019, vehicle accidents in the United States killed more than 6,000 pedestrians, the highest annual total ever recorded, and sent more than 100,000 to hospitals with injuries. 75% of the reported fatalities occurred at night.[1] In an ongoing effort to make roads safer, twenty automakers committed to the U.S. Congress that all newly manufactured cars and trucks will be equipped with AEB systems starting in 2022. However, today's Euro New Car Assessment Programme (NCAP) testing procedures do not include testing for common driving conditions such as driving in total darkness or with glare. The AAA exposed potential weaknesses in current AEB systems in day and night conditions in their October 2019 paper, Automatic Emergency Braking with Pedestrian Detection.[2]

To detect pedestrians, current AEB systems rely on either visible light cameras, radar or both. None currently use thermal cameras, which can detect a pedestrian much further than typical headlights can illuminate for a visible camera.

6,590

PEDESTRIAN DEATHS IN THE US IN 2019

OVER 100,000 WITH SEVERE INJURIES

TESTING THERMAL TECHNOLOGY IN AEB SYSTEMS

This paper tests the theory that adding thermal technology to today's radar and visible light technology can reduce pedestrian collisions in common driving conditions. A FLIR sponsored car using a fused AEB system combining thermal, radar, and visible light sensing with a convolutional neural network (CNN) tested against four commercially available cars with state of the art AEB systems.

Five test cases were developed based on Euro NCAP testing protocols. The tests included scenarios not currently in standard AEB positive detection testing. These are: daytime when pedestrians' clothes blend in with the background, daytime pedestrian in oversized clothing, nighttime driving, driving into sun glare, and nighttime child and adult pedestrian emerging from behind a parked car.

The results are compelling:

- The fused thermal AEB system was successful in 25 of 25 tests at effectively preventing pedestrian injury with only two instances where the vehicle contacted, but did not knock down the SPT (soft pedestrian target)
- The four commercially available AEB systems had positive performance in daytime tests (42 passed out of 50 tests). These systems did not perform well in the nighttime tests, striking the SPT in all but two test cases.
- There is an opportunity for automotive manufacturers, Tier 1 suppliers, government regulators, and automotive testing agencies to make AEB more reliable by expanding AEB compliance testing to include viable sensing technologies such as thermal sensing.

[1] https://www.ghsa.org/resources/news-releases/pedestrians20

[2] https://www.aaa.com/AAA/common/aar/files/Research-Report-Pedestrian-Detection.pdf

INTRODUCTION

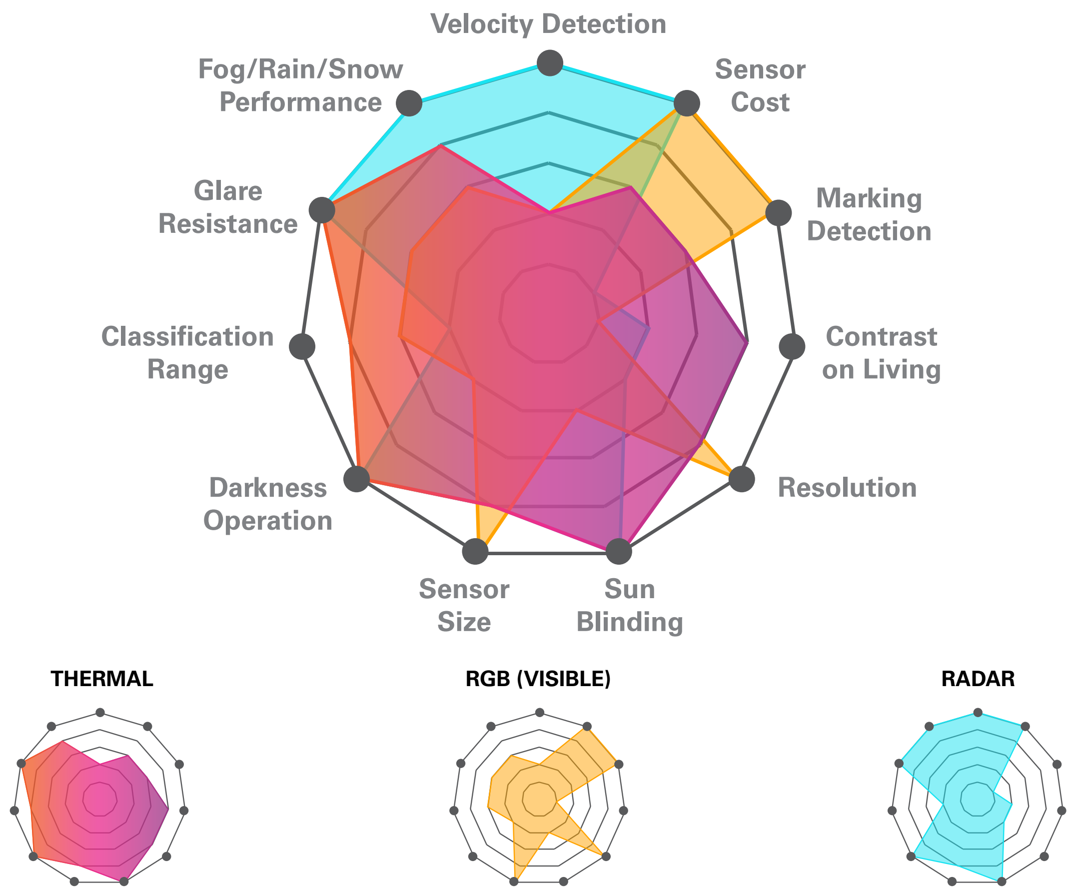
For several years, FLIR Systems, Inc. (FLIR) has been working with auto manufacturers and Tier 1 suppliers to assist in the development of cutting-edge ADAS and AV Systems with thermal Far Infrared (FIR) in the sensor suite. FLIR engaged VSI Labs (VSI) to develop and test the world's first fused AEB sensor suite that employed a thermal longwave infrared (LWIR) camera, a radar, a visible camera, and a convolutional neural network (CNN).

VSI incorporated this system into a 2018 Ford Fusion and tested it along with four 2019 vehicles deployed with then state of the art AEB systems. All tests were conducted at the American Center for Mobility (ACM) in Ypsilanti, Michigan. The tests were based on Euro New Car Assessment Programme (NCAP) positive detection tests with additional gap tests developed by VSI to represent common driving conditions such as darkness and sun glare. These gap tests represent conditions not currently tested by NCAP or other testing agencies. VSI designed the tests to include driving toward a soft pedestrian target (SPT) heated to mimic a human at 25 mph (40 kph). The FLIR premise was that current commercially available vehicle AEB systems would struggle to identify and react to a pedestrian target in dark and sun glare conditions and with completely bright or dark oversized clothing.

This paper describes VSI's testing methodology, procedures, and results.

SENSING TECHNOLOGIES FOR AEB

FLIR believes there is no single sensor that can enable a reliable Automatic Emergency Braking (AEB) system. It is only the fusing of a combination of sensors that will enable an AEB system to perform accurately in common driving conditions. As the results of the tests shown in this paper demonstrate, a combination of thermal, radar, and visible thermal sensors with pedestrian detection has the potential to do so.



AEB sensor performance and characteristics overlay map

Thermal image (top left), visible image, (bottom left), radar and thermal fusion top down view (right). This image is taken from a thermal video with a CNN detecting pedestrians. The corresponding radar points provide distance to the identified target.

METHODOLOGY

The most common pedestrian collisions occur when a pedestrian crosses a roadway perpendicular to a vehicle. Most Euro NCAP pedestrian AEB test cases emulate this type of scenario[3]. VSI based their test protocols on this perpendicular pedestrian crossing scenario, with the addition of five gap tests that include testing in darkness, sun glare, and alternate clothing a pedestrian may wear. The NCAP standards were followed in the daytime testing with dry road conditions, the temperature between 5° to 50° Celsius (41° to 122° Fahrenheit, daylight, and clear visibility. At night key NCAP procedures were followed to emulate the car perpendicular position with the addition of the nighttime, gap test features. To reduce the risk of damage to the vehicle or SPT with repeated collisions, each test case was repeated five times or until the vehicle under test (VUT) collided with the SPT a maximum of two times.

At the ACM, the VSI Ford Fusion with the fused thermal, radar and visible sensors was subjected to the Euro NCAP tests that commercially available cars pass during development and as part of a new car assessment program. The tests were administered by the ACM track staff. The VSI Ford Fusion passed all tests, the complete results can be found in Appendix II of this paper.

[3] M. Yanagisawa, E. Swanson, P. Azeredo, and W. Najm, "Estimation of potential safety benefits for pedestrian crash avoidance systems," National Highway Traffic Safety Administration, 2017.

COMMERCIALLY AVAILABLE VEHICLES WITH AEB

VSI selected four commercially available vehicles[4] with top AEB systems, to test alongside the VSI Ford Fusion test car that included the thermally fused AEB system. The vehicle models were:

2019 Tesla Model 3 with Autopilot™ 3.0
The 2019 Tesla Model 3 is an electric sedan with Autopilot 3.0. The Tesla's AEB system is based on three forward-facing cameras behind the windshield in the rearview mirror cutout and a 160-meter forward facing radar.

Learn more at Tesla Autopilot

2019 Toyota Corolla with Toyota Safety Sense™ 2.0
The 2019 Toyota Corolla is a four-door sedan with the Toyota Safety Sense 2.0 safety system that includes an integrated forward-facing visible camera and grille-mounted radar system designed to mitigate a collision with a preceding car or pedestrian. Safety Sense 2.0 is the latest generation ADAS package and claims improved detection in low-light conditions[5].

Learn more at Toyota Safety Sense 2.0

2019 Subaru Forester with Subaru EyeSight®
The 2019 Subaru Forest is a compact SUV equipped with Subaru EyeSight driver assist technology. The system is based on two forward-facing cameras mounted behind the windshield on either side of the rearview mirror.

Learn more at Subaru EyeSight

2019 BMW X7 with Mobileye®
The BMW X7 is a full-size SUV with Mobileye's TriCam4 module. The AEB system with pedestrian and cyclist detection is based on three forward-facing cameras with 28°, 52°, and 150° field of views.

Learn more at BMW Driver Assistance

VEHICLES TESTED AT ACM

	VSI - Ford Fusion	2019 Tesla Model 3	2019 Toyota Corolla	2019 Subaru Forester	2019 BMW X7
					
Thermal LWIR Camera	✓ FLIR ADK with Boson® (75° FOV)	✗	✗	✗	✗
Visible Camera	✓ FLIR Blackfly (75° FOV)	✓ 3 cameras (35°, 50°, 150° FOV)	✓ 1 camera (forward facing)	✓ 2 cameras (stereoscopic 25° FOV)	✓ 3 cameras (28°, 52°, 150° FOV)
Radar	✓ Delphi ESR	✓	✓	✗	✓

Five vehicles tested. Visible cameras noted in the chart account for the Forward Camera Modules (FCM) only.

[4] *All product and company names are trademarks™ or registered® trademarks of their respective holders. Use of any product or company trademark does not imply any affiliation with FLIR or VSI, or any endorsement by the mark owners.*

[5] *https://www.toyota.com/content/ebrochure/CFA_TSS_2.pdf*

AEB TEST SETUP

TEST FACILITY

The ACM offers a wide variety of infrastructure scenarios based on common real-world road conditions. To conduct the tests VSI used two ACM track locations, the six-lane by six-lane (6×6) intersection and the 214.5-meter (704-foot) tunnel with a radial curve.

The 6×6 intersection was used with an adult pedestrian target crossing the roadway unobstructed in daylight conditions and a child and an adult pedestrian target crossing the roadway when emerging from behind a parked car in dark conditions.

The tunnel with a radial curve was selected to emulate a real-world tunnel, found in a mountainous or dense urban environments, to test the effects of sudden change in illumination on visible cameras and radar when emerging from a dark tunnel. For this test, an adult pedestrian target crossed the roadway at the opening of the tunnel as the car exited into the harsh or blinding light.

6x6 is an intersection and an unobstructed space ideal for testing numerous traffic scenarios. Photo Credit: Google Earth

ACM Tunnel exit (Photo Credit: Google Earth)

ACM tunnel provides dynamic transition from dark to harsh lighting conditions

TEST EQUIPMENT

The ACM provided necessary test equipment and services for the AEB tests. The setup included one adult-sized and one child-sized heated, articulated Soft Pedestrian Target (SPT). The SPTs were the same SPTs regulators use in official NCAP testing of ADAS safety systems. These SPTs are manufactured by 4activeSystems™ and were modified to include heating and emulate human body temperatures for the FLIR infrared thermal camera. Motorized, articulated legs emulated walking. The ACM staff installed, operated, and managed the 4activeSystems SPTs and software throughout the tests.

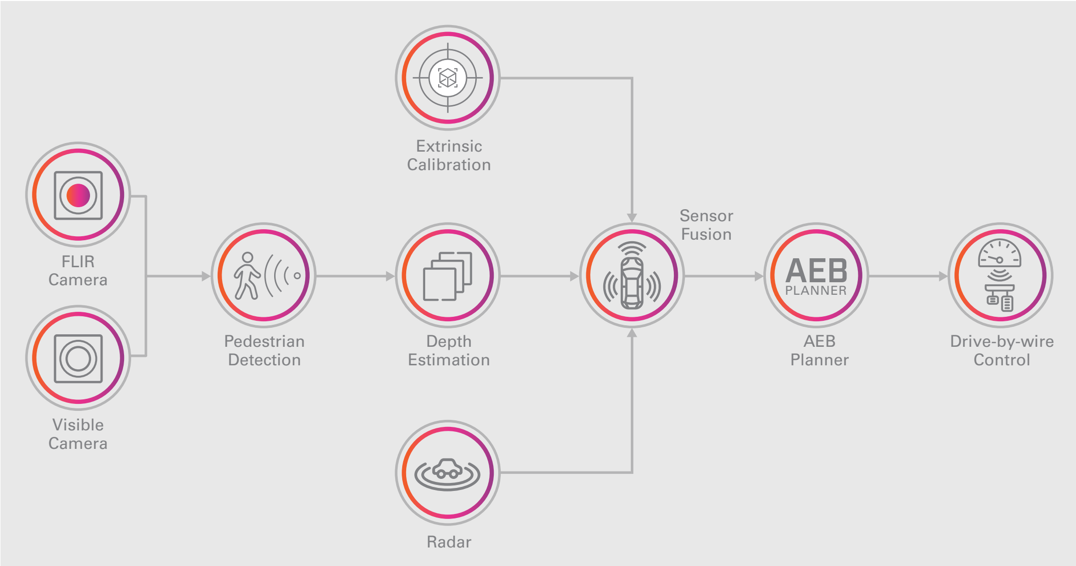
SPT (left) and human (right), both at approximately 97° Fahrenheit (35° Celsius)

The ACM staff mounted the SPTs on a moving platform that was attached to a belt. This belt was pulled by a software-controlled, motorized unit that uses vehicle roadway position data to trigger the SPT to cross in front of the vehicle at a precise time and speed per Euro NCAP testing protocols.

The ACM outfitted the test vehicles with additional equipment to ensure the SPT would be in the center of the vehicle path at impact if the car did not brake. The motorized control unit received 1 cm accurate position data wirelessly from OxTS RT30003 and OxTS RT-Range S units mounted on the vehicle under test (VUT).

TEST VEHICLE WITH THERMAL

VSI Labs maintains vehicles to test and demonstrate ADAS and AV componentry, including a 2018 Ford Fusion Research Vehicle with Thermal Enhanced AEB. VSI's open and modular software framework is designed to integrate sensors and applications safely and in a highly controllable fashion.



Thermal AEB System Map

The VSI Ford Fusion Hybrid includes the ADAS Kit from Dataspeed, providing by-wire interface control to steering, throttle, and braking. This configuration is well suited for ADAS and AV testing.

For this thermal AEB testing, VSI installed a FLIR thermal LWIR camera and a FLIR visible Blackfly BFLY-PGE-20E4C camera on the roof, and a Delphi/Aptiv ESR 2.5 radar, in the grille, as the external, forward-facing sensors. The visible camera/radar combination was tested with the thermal LWIR camera because most new vehicles include a forward camera and radar.

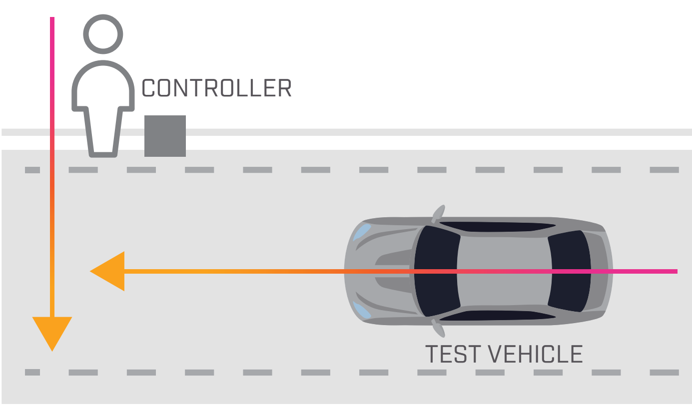
The VSI Ford Fusion research vehicle also used information from the Fusion's Controller Area Network (CAN bus) such as wheel speeds and steering wheel angle. The thermal LWIR camera, radar, and visible light camera interfaced to a computer in the vehicle. This ruggedized computer is often used for testing and evaluating ADAS and AV applications. It can process the associated algorithms that include a CNN to detect pedestrians. Finally, VSI software fused and tracked detections using the LWIR camera, visible light camera, and radar. The system detected and classified objects to determine whether to trigger an AEB event to avoid a pedestrian collision based on the vehicle speed and trajectory.

NOTE: During testing the thermal camera initiated all AEB events in the Ford Fusion and the visible camera, present for redundancy, did not contribute to an AEB event.

Click to learn more about the FLIR CNN training datasets.

ENSURING TESTING CONSISTENCY

For all tests, the ACM staff mounted the SPTs on a "surfboard" platform on a conveyer belt controlled by the 4activeSB unit, which can maintain a speed of 5 kph (3.10 mph), the average walking speed of an adult. The speed adjusted dynamically to ensure the SPT and vehicle crossed the desired collision point simultaneously. The 4activeSB controller and pedestrian target platform were set-up to the vehicle's right at a safe distance from the test lane's travel path and centerline, as illustrated in the below figure.



Controller, SPT, and vehicle configuration

The 4activeSB controller activated the SPT by using the SPT and the vehicle under test (VUT) speed and precise GPS coordinates. The VUT approach speed was 40 kph (25 mph), as defined in the 4active software. This information, combined with the timing of the VUT crossing the moving SPT path, allowed the controller to place the SPT along the lateral centerline of the vehicle as defined by NCAP. Before each test run, the SPT was reassembled if necessary and placed in the same starting position.

Before each vehicle test, ACM staff outfitted the car with OxTS hardware and ensured that the system was fully calibrated and working with the 4activeSB system. The ACM driver familiarized themselves with the vehicle to make sure they knew how to set the cruise control to the correct speed.

The precise test setup resulted in consistent, repeatable pedestrian motion throughout all tests performed, ensuring a fair comparison between the different systems presented in this paper.

Procedure

Here is the procedure used for each test case:

- Install and configure OxTS measurement device in VUT
- Verify the accuracy of the OxTS device and that data is recording
- Bring VUT up to 40 kph (25 mph) and set the cruise control
- Drive along the designated lane and direction
- The OxTS unit in the vehicle triggers the movement of the SPT at the correct time
- Driver allows the VUT to either run into the SPT or activate AEB
- If the vehicle collided with the SPT the driver could apply the brakes after the collision to bring the VUT to a stop

Each test was performed for each VUT to have five trials or until the VUT struck the SPT twice. ACM staff recorded data for every trial, including vehicle speed, vehicle acceleration, and distance to SPT (VRU Distance) over time. Using this data, VSI extracted the critical results for each trial for each test case. From this data, VSI can derive the following test metrics:

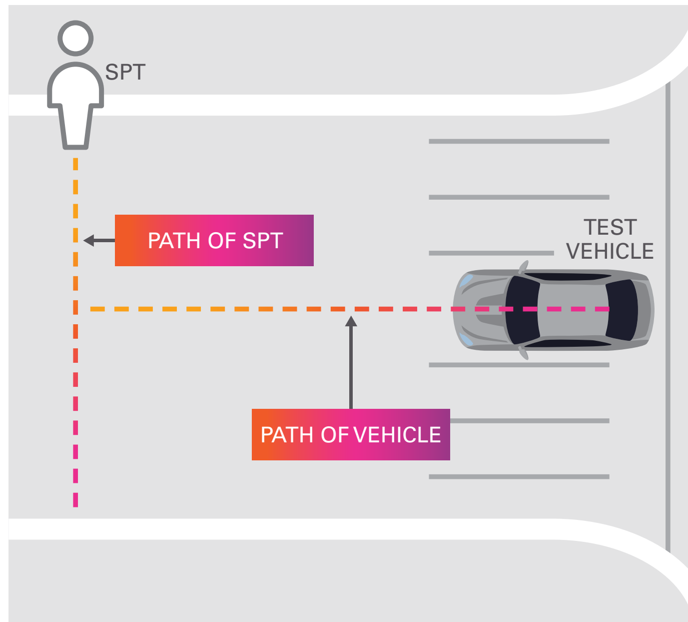
1. Initial braking distance: Longitudinal distance to the SPT when the test VUT initiates braking
2. Maximum deceleration: Deceleration in m/s^2 of VUT
3. Impact speed: Speed of VUT at impact if applicable
4. Speed reduction percent: Reduction in speed of VUT at impact if applicable
5. Final separation distance: Distance between SPT and stopped VUT if applicable

Additional data about the track conditions were manually collected every 30 minutes to comply with NCAP testing protocol—these measurements including wind speed, lighting, air temperature, and track surface temperature.

TESTS CASES

The AEB scenarios covered by the following tests are a combination of tests taken from Euro NCAP's AEB testing protocol and some non-standard gap tests designed by VSI with common real-world driving conditions. The gap tests intended to challenge current commercially available AEB systems and represent the conditions in which pedestrians are often injured or killed when struck by a vehicle.

All of the gap tests included SPT movement perpendicular to the car with the potential for braking and stopping before hitting the SPT or a collision, timed so the SPT strike with the vehicle would occur in the middle of the grille area.



Setup for the Ford Fusion NCAP tests.

NCAP Validation Tests (VSI Ford Only)

Three Euro NCAP VRU AEB tests were performed on the VSI thermal enhanced Ford Fusion: CPNA-50, CPNA-25, and CPLA-50. See the results in Appendix II of this paper. VSI conducted these tests to validate that an AEB system with thermal vision has reliable results during NCAP AEB tests. As noted previously, the SPTs were heated to match the temperature of a human pedestrian; the FIR camera can detect the SPT (and human pedestrians) in daylight or absolute darkness.

Since the commercially available vehicles were previously tested on the Euro NCAP standards, these vehicles were excluded from the three NCAP tests at ACM.

GAP TEST DESCRIPTION AND RESULTS

DAYTIME OVERSIZED CLOTHING OBSCURATION GAP TEST

The daytime Oversized Clothing Obscuration gap test examines AEB system performance when the human shape of the SPT is obscured by oversized clothing. This test was set-up like the NCAP CPNA-50 test, with one variation, the SPT was wearing a long coat that intersected with the midday sunshine on the SPT.

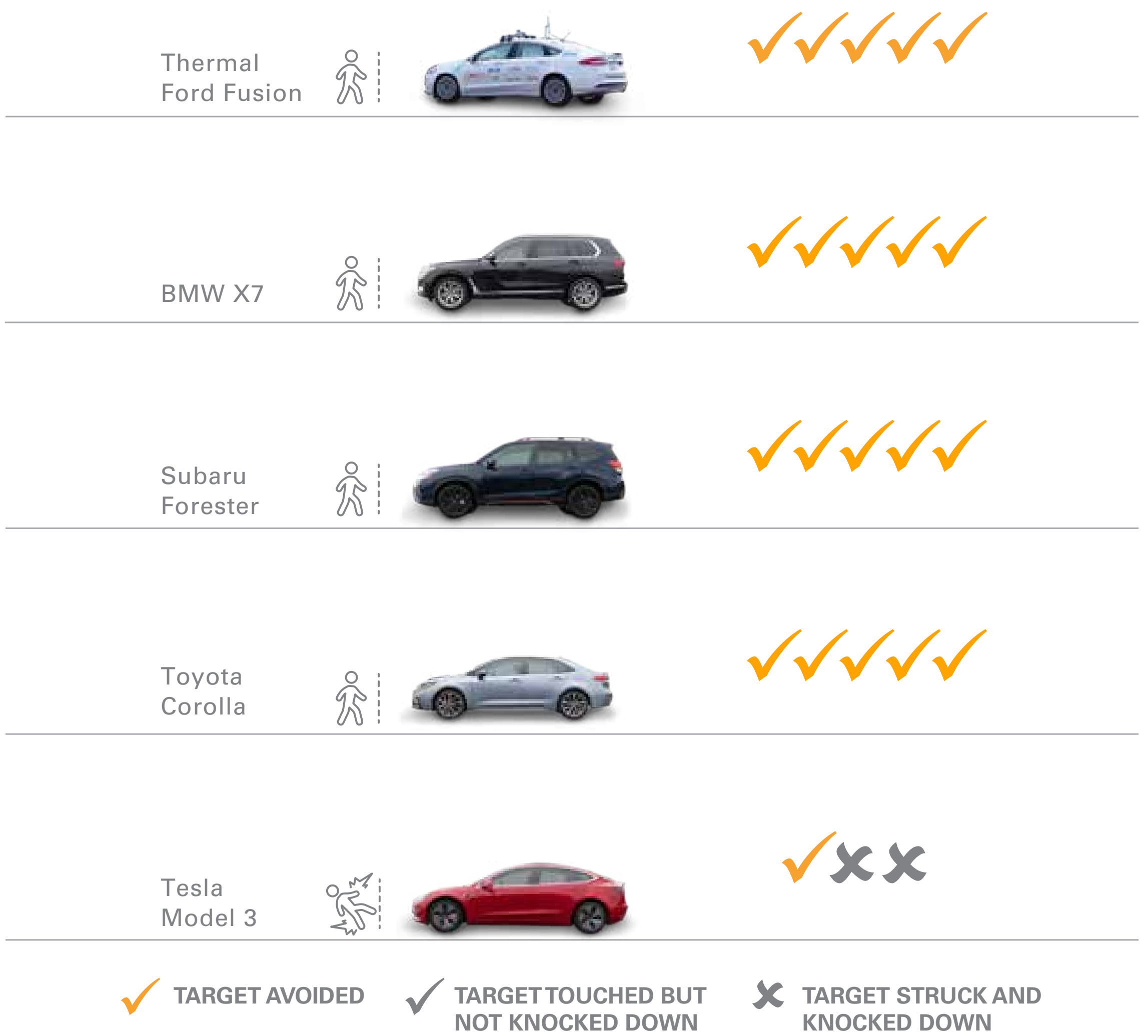
STOP RESULTS:
DAYTIME OVERSIZED CLOTHING OBSCURATION GAP TEST

Set-up for the Daytime Oversized Clothing Obscuration test

DAYTIME CLOTHING BLENDING GAP TEST

The daytime Clothing Blending gap test examines AEB system performance when the SPT was wearing white clothing in front of a white background, making pedestrian detection more difficult for visible cameras. This test was set-up like the NCAP CPNA-50 test, with one variation, the SPT was wearing white clothing, with a white barrier placed in the background behind the SPT. NCAP tests are typically conducted with a pedestrian with a black shirt and blue pants.

STOP RESULTS:
DAYTIME CLOTHING BLENDING GAP TEST

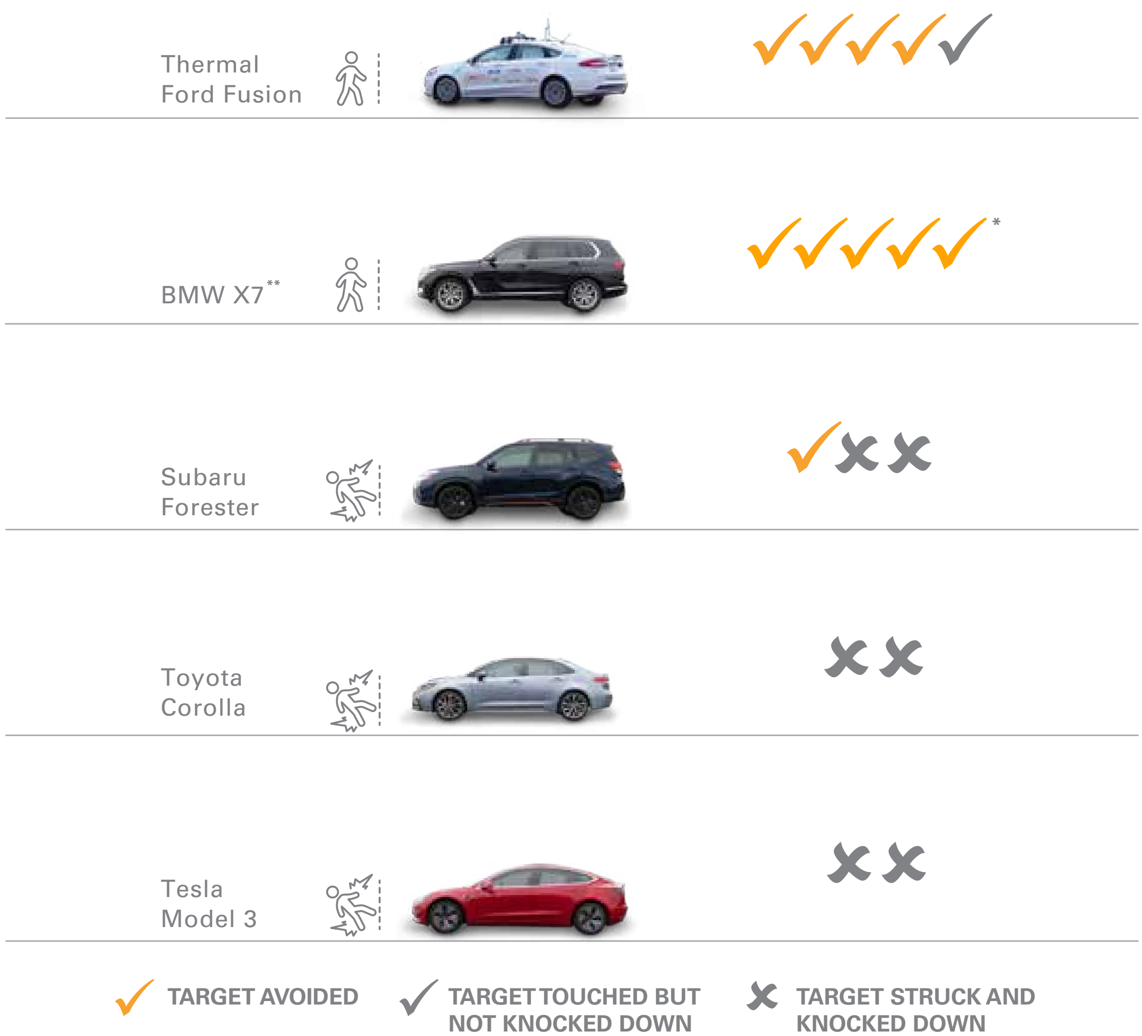


Set-up for the Clothing Blending test setup

DAYTIME TUNNEL SUNRISE DAZZLE GAP TEST

The Tunnel Sunrise Dazzle (blooming) gap test examines AEB system performance when a vehicle encounters a pedestrian target while exiting a dark tunnel against bright sunrise. VSI designed this test to challenge the AEB systems upon exiting the tunnel. This test can be viewed to represent a variety of driving conditions when drivers are blinded by sun glare at dawn and dusk.

STOP RESULTS:
DAYTIME TUNNEL SUNRISE DAZZLE GAP TEST



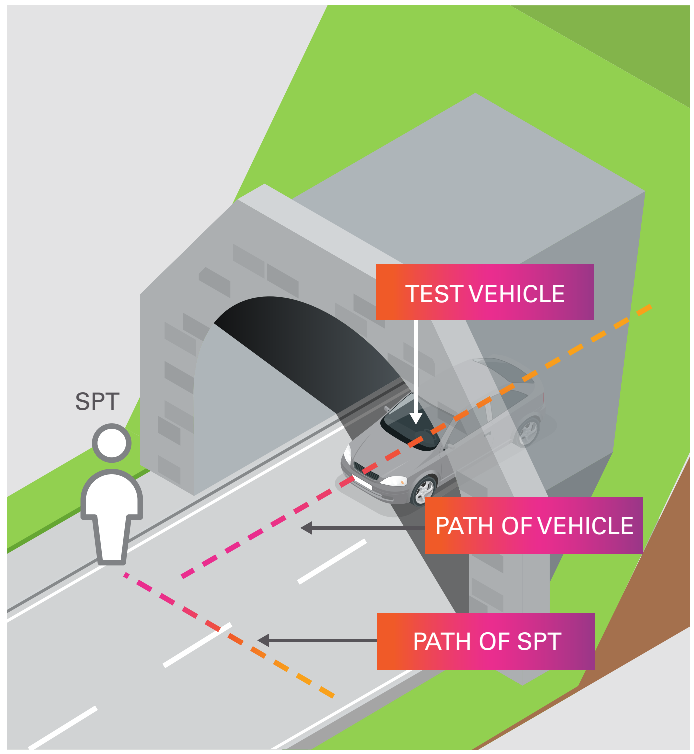
* *Sunrise glare tests started at 7:15 AM with VSI's test vehicle. Tests were run on the Tesla, Toyota, Subaru and BMW respectively. AEB performance improved as glare decreased. Glare had decreased significantly by 10:05 AM when the BMW tests started.*

** *The BMW X7 is available with an optional thermal camera Night Vision system for pedestrian and animal detection, this warning display is not connected to the AEB system.*

Camera views from inside the VSI Thermal Test Vehicle

NOTES ABOUT THE TUNNEL SUNRISE DAZZLE TEST

The tunnel dazzle effect can impact AEB sensors in several ways. For example, a drastic reduction in contrast can introduce halos or “ghosts” and even odd-shaped semi-transparent objects of various color intensities in visible cameras. When light rays coming from a bright source(s) of light reaches a camera lens front element, image quality can degrade, and unwanted artifacts can be present in the image. The sun shining into a tunnel creates a transition between two significantly different lighting conditions, which degrades the visible camera imagery. Object classifiers can struggle or lose the ability to perform accurately under these conditions. A visible camera will struggle driving into the sun while a thermal camera will be unaffected by the sun’s rays.



Tunnel Sunrise Dazzle gap test setup

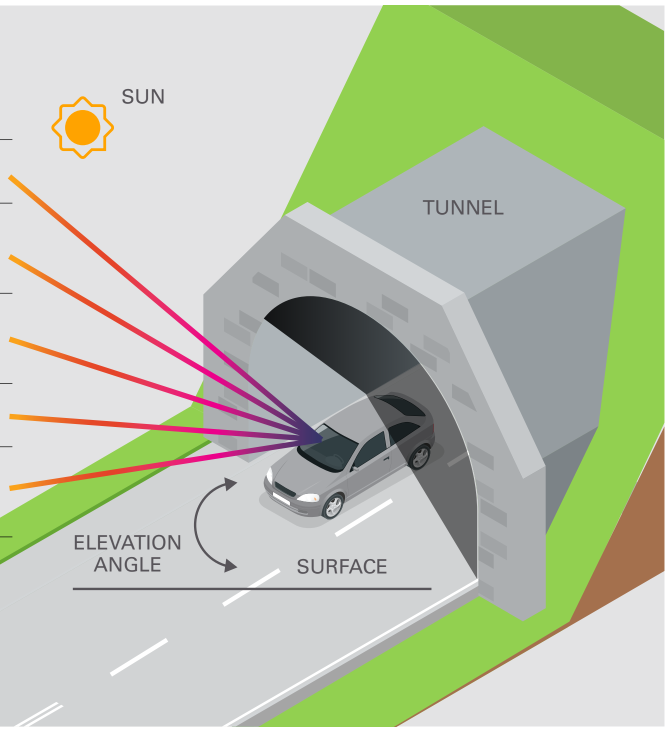
The test was set-up as per the NCAP CPNA-50 test, except that the SPT was placed approximately 10-meters (33-feet) longitudinally from the tunnel's exit. The tests were all performed on the same morning at sunrise. The key test parameter is the rising sun's angle above the horizon, called the "solar elevation angle", the angle between the horizon and the center of the sun's disc. Ideally, all vehicles would have been tested simultaneously, but this was not achievable during testing.

	SOLAR ELEVATION ANGLE (DEGREES)	SOLAR ELEVATION USING A	SOLAR AZIMUTH USING B	LIGHT READING IN LUX*	TIME OF THE DAY
2019 BMV X7	40.45	29.4	87.38	776	10:05am
2019 Subaru Forester	31.28	20.24	79.44	680	9:15am
2019 Toyota Corolla	26.67	15.74	75.56	599	8:50am
2019 Tesla Model 3	21.18	10.45	70.88	610	8:20am
Thermal Ford Fusion	11.98	0	60.34	339.6	7:15am

**As measured by VSI Labs*

A https://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html

B https://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html



ACM tunnel exit with solar elevation angle representation.

Tunnel sunrise dazzle tests were done in the following order: Ford (thermal), Tesla, Toyota, Subaru, and BMW. The tunnel sunrise dazzle tests on the thermal enhanced Ford Focus started at 7:15 AM with a solar angle of 12-degrees. The Tesla test started at 8:20 AM with a solar elevation of 21-degrees. The final test on the BMW began to at 10:00 AM, with a solar elevation of 40-degrees. AEB performance improved as the solar elevation angle increased, and the last commercially available VUT performed significantly better. The data illustrates that the vehicles that were tested earlier in the day with a smaller solar elevation angle were more negatively affected by the tunnel sunrise dazzle.

CHILD AT NIGHT GAP TEST

The Child at Night gap test challenged AEB system performance in nighttime lighting conditions with a child SPT. The test was set-up per the NCAP CPNC-50 test with two modifications: the SPT was heated to match a human child's thermal signature and performed at night. Per CPNC-50, the child SPT entered the vehicle's path from behind a parked vehicle obstruction reducing AEB reaction time.

The four commercially available cars struck the SPT twice and the testing stopped. The VSI thermal enhanced Ford Fusion completed all five tests, four at complete success and one touching the SPT but not knocking it over.

Child SPT Nighttime test

DARK CLOTHING AT NIGHT GAP TEST

The purpose of the Dark Clothing at Night gap test was to examine how all the AEB systems perform in nighttime lighting conditions with dark clothing that is difficult to visibly see in the dark. This test was set-up like the NCAP CPNA-50 test with the addition of the heated adult SPT dressed in dark clothing, and the tests conducted at night. The dark clothing at night intended to challenge the visible camera sensors in the AEB system.

STOP RESULTS:
DARK CLOTHING AT NIGHT GAP TEST

Adult SPT Nighttime test

CONSOLIDATED RESULTS

This section contains the aggregated average test results and some of the significant results for mitigation and stopping of the VUT's. In Appendix II you will find the complete results.

✓ TARGET AVOIDED ✔ TARGET TOUCHED BUT NOT KNOCKED DOWN ✗ TARGET STRUCK AND KNOCKED DOWN

	Day Dark Clothing	Day White Clothing	Sunrise Tunnel Exit into Sun Glare	Night Child SPT	Night Dark Clothing
Thermal Ford Fusion 	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✔	✓✓✓✓✔	✓✓✓✓✓
BMW X7** 	✓✓✓✓✓	✓✓✓✓✓	✓✓✓✓✓*	✗✗	✓✗✗
Subaru Forester 	✓✓✓✓✓	✓✓✓✓✓	✓✗✗	✗✗	✗✗
Toyota Corolla 	✓✓✓✓✓	✓✓✓✓✓	✗✗	✗✗	✗✗
Tesla Model 3 	✓✓✓✓✓	✓✗✗	✗✗	✗✗	✓✗✗

* *Sunrise glare tests started at 7:15 AM with VSI's test vehicle. Tests were run on the Tesla, Toyota, Subaru and BMW respectively. AEB performance improved as glare decreased. Glare had decreased significantly by 10:05 AM when the BMW tests started.*

** *The BMW X7 is available with an optional thermal camera Night Vision system for pedestrian and animal detection, this warning display is not connected to the AEB system.*

Overall test results table. Each check-mark or "x" represents a trial.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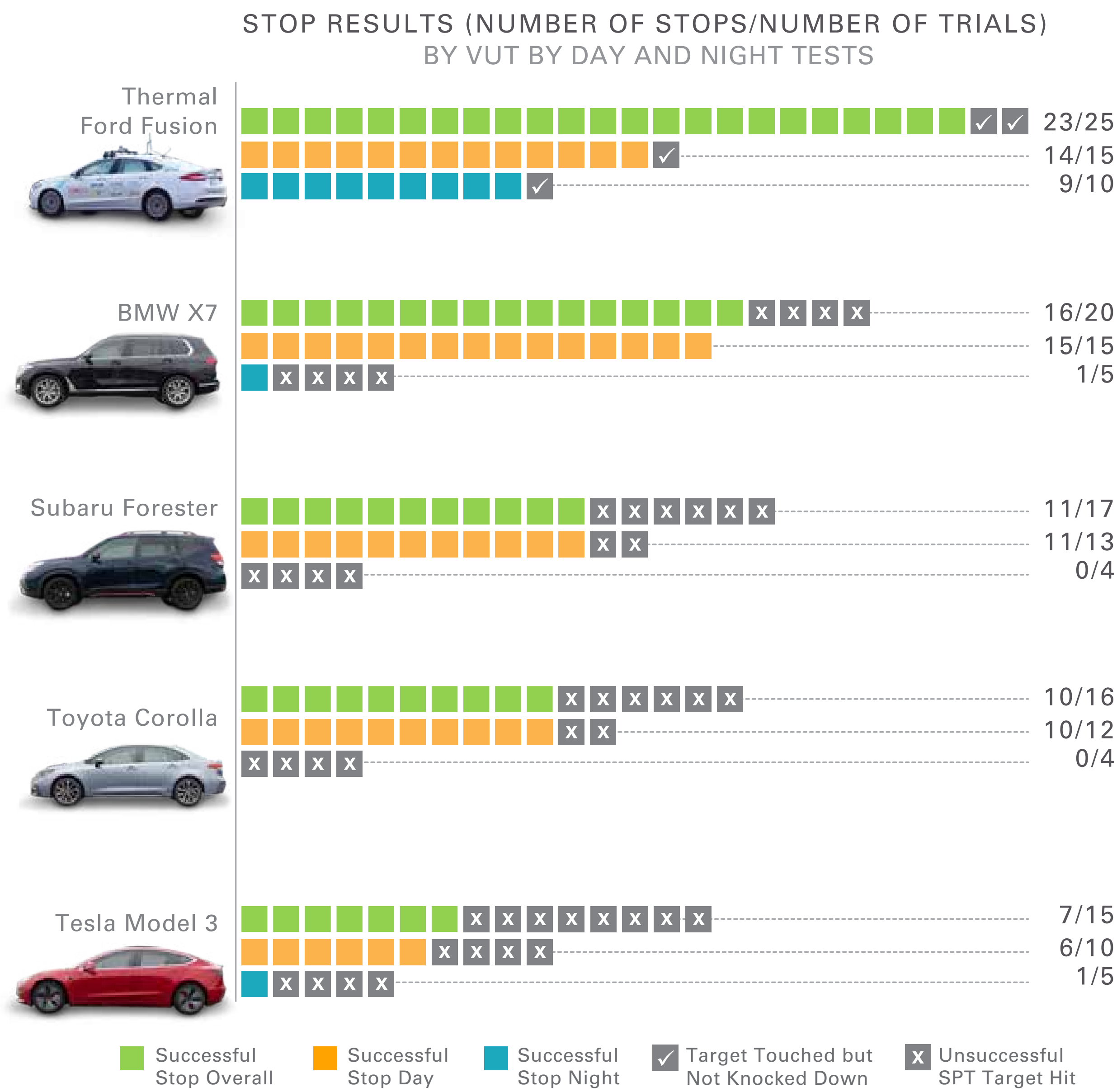
STOP RATE RESULTS

The final number of successful stops were tallied for each vehicle throughout the AEB tests. A successful stop counted only if the vehicle completely avoided a collision with the SPT. The tables below show the stop rate for each car in the format of number-of-stops/number-of-trials. Each test case was repeated five times or until the VUT collided with the SPT a maximum of two times to reduce the risk of damage to the SPT or vehicle with repeated collisions.

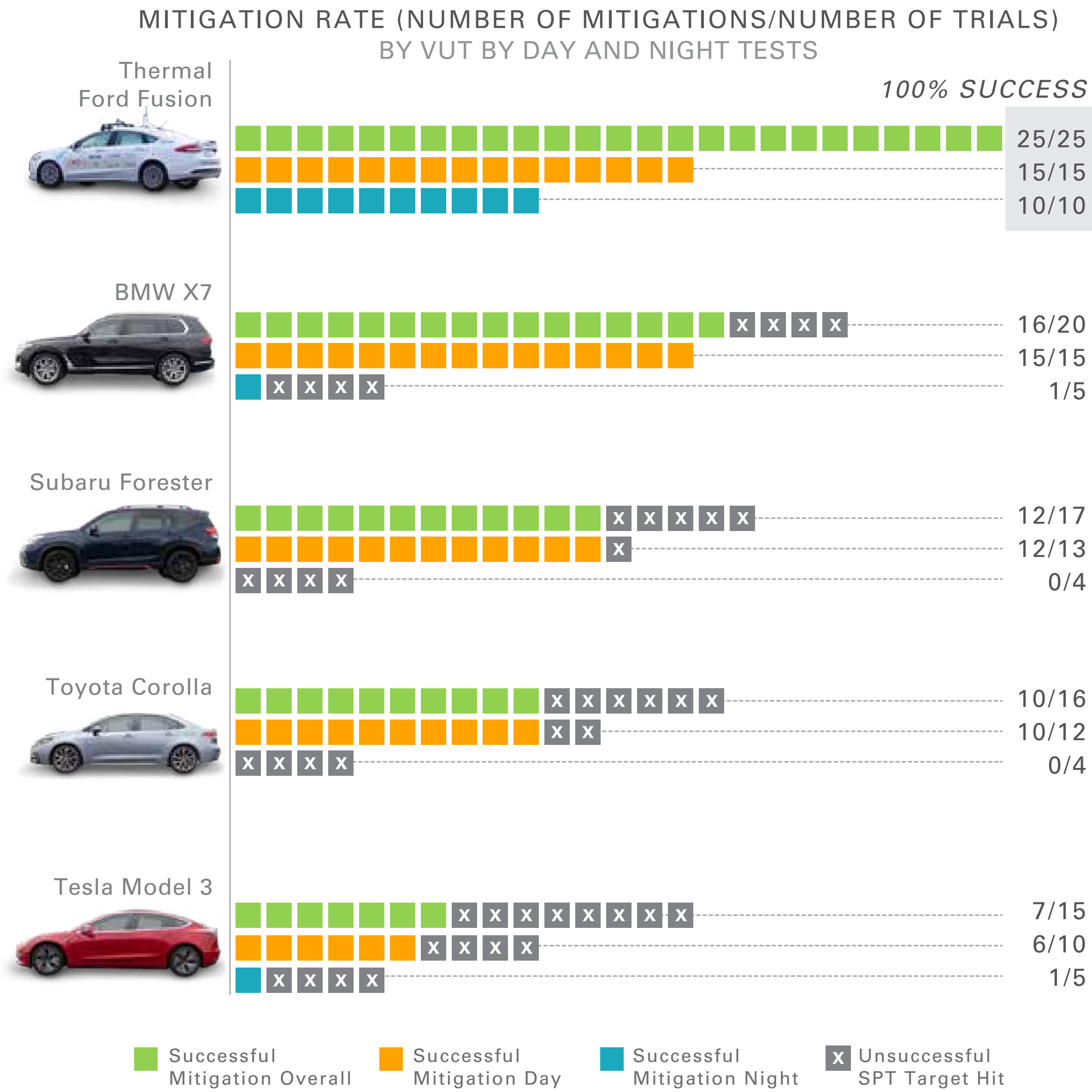


The stop rate (number of stops/number of trials) by VUT by test case

MITIGATION RATE RESULTS

Many AEB systems are designed to mitigate a collision by reducing speed before a collision, not necessarily completely avoid a collision. Therefore, when evaluating the results, speed reduction at impact is an important performance metric.

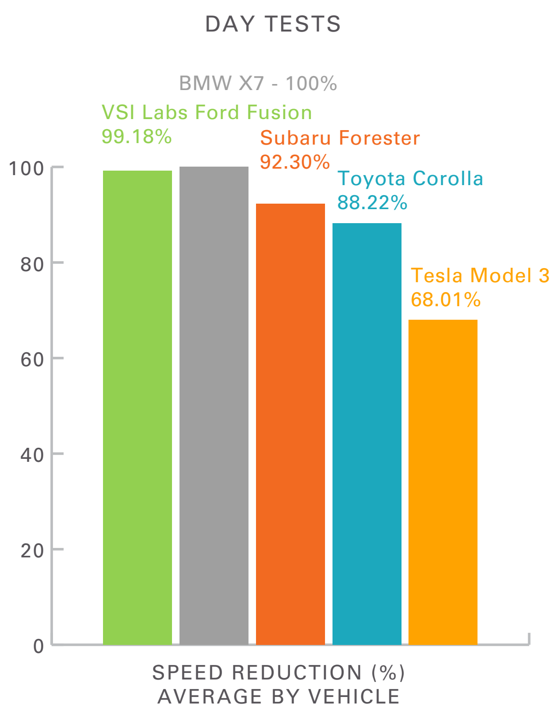
A trial was considered mitigated if the impact speed was less than 50% of the initial speed of 40 kph (25 mph), which is 5.58 m/s or 12.5 mph or altogether avoided a collision with the SPT. The table below includes the mitigation rate for each VUT by test case. The tables below show the mitigation rate for each car in the format of number-of-mitigations/number-of-trials where the vehicle either slowed to 5.58 m/s (12.5 mph) or avoided a collision for all gap tests and the night gap tests, respectively. Note, each test case was repeated five times or until the VUT collided with the SPT a maximum of two times to reduce the risk of damage to the SPT with repeated collisions.

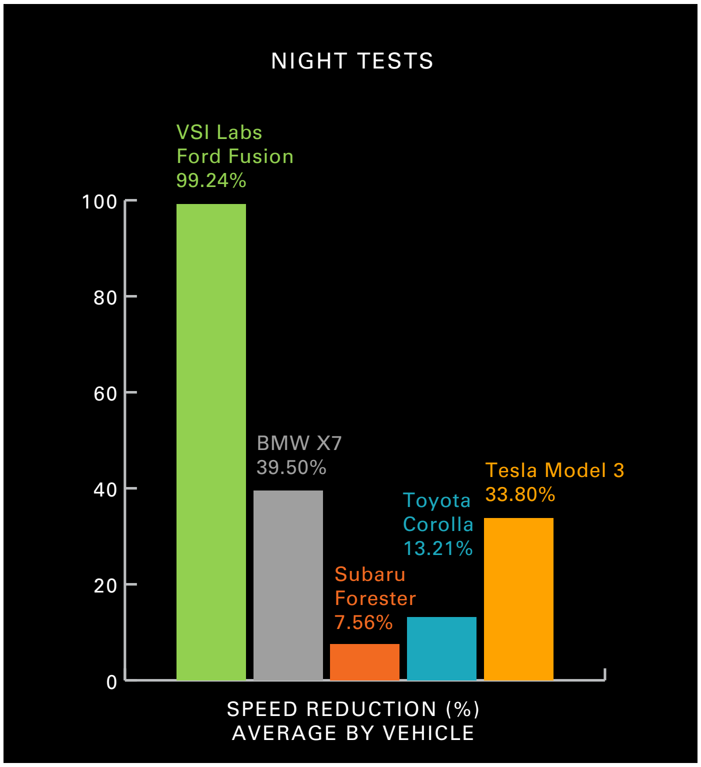


Mitigation rate of the vehicle collided with the SPT at less than 5.58 m/s (12.5 mph) or completely avoided a collision with the SPT.

SPEED REDUCTION RESULTS

Speed reduction percent is useful because it shows an AEB system's performance on a continuous spectrum rather than as a discrete success or failure. For instance, if the VUT comes to a complete stop before colliding with the SPT, the speed reduction would be 100%. However, if the vehicle slowed from the initial speed of 40 kph to 20 kph (25 mph to 12 mph), the speed reduction would be 50%. Rather than labeling the trial as a failure, this metric shows how successful the vehicle VUT was at mitigating the collision. The figures below show the average speed reduction percent for each vehicle in the gap tests and the night gaps tests.





Speed Reduction (%) by VUT for day and night tests

CONCLUSION

As the tests results show, the AEB system with the added thermal LWIR camera performed significantly better than existing commercial AEB systems in several gap tests of common real-world scenarios.

The thermal-enhanced AEB system improves the AEB functionality in potentially dangerous situations, including low-light conditions, darkness, and when exposed to blinding conditions such as emerging from a dark tunnel into bright light. Additional positive detection gap tests scenarios are under consideration including headlight glare which would further demonstrate the increased performance that the added thermal camera provides.

Developing AEB systems with thermal LWIR camera technology can reduce human injuries and deaths significantly. FLIR is currently working with several top AV developers, auto manufacturers and Tier 1 suppliers to continue the advancement of thermal cameras in ADAS and AV system design with the goal of improved safety. The VSI tests show that thermal sensing can help reduce pedestrian deaths on our streets. This report demonstrates that testing standards and regulations can be adjusted to replicate several real-life situations that cause pedestrian deaths.

APPENDIX I

ONGOING AEB FALSE POSITIVE TESTING

It is equally as important for an AEB system to have high true positive rate as it is to have a low false positive rate. An AEB false positive would be a situation in which the system triggers AEB when it is not desired. This can be a very dangerous consequence. The VSI software is programmed to trigger an AEB when there is a valid pedestrian track in the vehicle's line of travel and within a certain distance varying on the vehicle speed. A valid pedestrian track requires radar object detection from the Delphi radar and a pedestrian detection from one of the CNNs from one of the cameras that is calculated to be significant for the radar object to match.

VSI has and continues to test the same hardware and software configuration that was tested in highway and urban conditions for false positive testing. During these tests, the system was and is configured not to brake, but instead recording when an AEB-would have triggered a braking event. This allows VSI to safely examine the performance of the system in the real world. Even before the finalized hardware and software was finished for ACM, throughout the entire development process VSI iteratively performed false positive tests to make sure the system was developed appropriately. FLIR believes that the likelihood of false positive AEB events is reduced when using a thermal camera as compared to a visible camera since the thermal camera is capable of measuring actual temperatures of real living things as compared to a visible camera's ability to detect colors.

False Positive Results / Data

Fused thermal and radar (top left), visible (bottom left), green represents thermal in the radar field of data (right)

APPENDIX II

COMPLETE TEST DATA

VSI Ford Fusion Test Vehicle NCAP Test Results

The VSI Ford Fusion was tested against the NCAP standards to ensure the new thermal, visible and radar AEB system was comparative to the commercially available vehicles that had already passed the same NCAP standards before production.

Thermal Ford Fusion - NCAP CPNA-50 (Car-to-Pedestrian Nearside Adult 50%)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.57	9.74	9.65	9.85	9.70	9.70	0.10
Max. Deceleration (m/s²)	15.82	16.41	14.44	17.37	14.66	15.74	1.22
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	1.66	2.44	2.38	2.28	2.25	2.20	0.31

Thermal Ford Fusion - NCAP CPNA-25 (Car-to-Pedestrian Nearside Adult 25%)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.47	9.72	9.41	9.67	9.69	9.59	0.14
Max. Deceleration (m/s²)	19.91	15.36	13.27	15.71	14.78	15.80	2.48
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	1.95	2.43	2.06	2.27	2.22	2.19	0.19

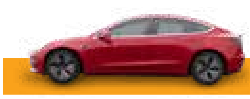
Thermal Ford Fusion - NCAP CPLA-50 (Car-to-Pedestrian Longitudinal Adult 50%)

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	8.99	9.04	9.15	8.98	7.75	8.78	0.58
Max. Deceleration (m/s²)	13.79	14.02	14.17	14.20	16.23	14.48	0.99
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	1.58	2.14	0.96	1.58	1.63	1.58	0.42

GAP TEST: WHITE CLOTHING DAYLIGHT

Thermal Ford Fusion

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.88	9.53	9.60	10.10	9.78	9.78	0.23
Max. Deceleration (m/s^2)	16.85	16.73	12.69	12.56	15.38	14.84	2.11
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	1.98	1.61	1.77	2.29	1.98	1.93	0.26



2019 Tesla Model 3

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.14	4.95	4.12	-	-	6.07	2.69
Max. Deceleration (m/s^2)	14.70	13.21	13.18	-	-	13.70	0.87
Impact Speed (m/s)	None	5.88	7.70	-	-	6.79	1.28
Speed Reduction (%)	100.00	47.40	31.14	-	-	59.51	35.99
Separation Distance (m)	1.26	-	-	-	-	1.26	N/A

2019 Subaru Forester

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	13.04	9.03	9.02	13.39	13.06	11.51	2.27
Max. Deceleration (m/s^2)	10.43	10.46	10.74	10.31	10.50	10.49	0.16
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	0.67	0.15	0.43	0.50	0.53	0.45	0.19

2019 Toyota Corolla

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	11.59	11.74	12.32	13.63	11.17	12.09	0.96
Max. Deceleration (m/s^2)	9.70	9.69	9.92	9.84	9.68	9.77	0.10
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	0.59	0.50	0.40	0.46	0.39	0.47	0.08

2019 BMW X7

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.68	9.46	9.16	9.31	9.51	9.43	0.20
Max. Deceleration (m/s^2)	12.93	13.35	12.71	11.66	11.80	12.49	0.73
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	1.16	1.05	0.48	0.73	1.05	0.89	0.28

GAP TEST: DAYTIME OVERSIZED CLOTHING OBSCURATION

Thermal Ford Fusion

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.91	10.21	10.34	10.02	9.73	10.04	0.24
Max. Deceleration (m/s²)	13.14	15.57	13.47	16.93	14.08	14.64	1.58
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	2.06	2.23	2.55	2.11	1.86	2.16	0.26

2019 Tesla Model 3

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.88	6.37	9.58	10.03	9.98	9.17	1.58
Max. Deceleration (m/s²)	14.38	13.93	13.62	14.92	13.33	14.03	0.63
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	1.83	0.19	2.87	2.61	2.22	1.94	1.06

2019 Subaru Forester

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.06	14.85	13.85	13.10	13.26	12.83	2.21
Max. Deceleration (m/s²)	10.75	10.52	9.99	10.64	9.94	10.37	0.38
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	0.51	0.88	0.42	1.71	0.32	0.77	0.57

2019 Toyota Corolla

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	11.45	11.48	13.26	11.74	13.43	12.27	0.99
Max. Deceleration (m/s²)	9.67	9.39	9.98	9.64	9.68	9.67	0.21
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	0.51	0.47	0.52	0.58	0.54	0.52	0.04

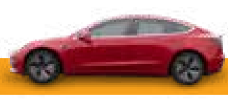
2019 BMW X7

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.25	9.55	9.06	9.62	9.25	9.34	0.23
Max. Deceleration (m/s²)	12.81	11.47	11.47	13.26	11.31	12.07	0.90
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	0.42	0.93	0.27	1.25	0.55	0.69	0.40

GAP TEST: DAYTIME TUNNEL DAZZLE SUNRISE

Thermal Ford Fusion

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	11.83	10.36	10.35	11.66	12.03	11.24	0.82
Max. Deceleration (m/s²)	12.11	12.25	12.54	12.81	11.92	12.33	0.35
Impact Speed (m/s)	None	None	1.38	None	None	1.38	N/A
Speed Reduction (%)	100.00	100.00	87.65	100.00	100.00	97.53	5.52
Separation Distance (m)	1.88	0.37	Mitigated	1.29	1.68	1.31	0.67



2019 Tesla Model 3

	Trial 1	Trial 2	Trial 3	Trial 4	Trail 5	Average	Std. Dev.
Initial Braking Distance (m)	-	-	-	-	-	N/A	N/A
Max. Deceleration (m/s²)	-	-	-	-	-	N/A	N/A
Impact Speed (m/s)	11.01	11.26	-	-	-	11.14	0.18
Speed Reduction (%)	1.52	-	-	-	-	-	-
Separation Distance (m)	-	-	-	-	-	N/A	N/A

2019 Subaru Forester

	Trial 1	Trial 2	Trial 3	Trial 4	Trail 5	Average	Std. Dev.
Initial Braking Distance (m)	-	-	-	-	-	-	1.42
Max. Deceleration (m/s²)	-	10.01	11.54	-	-	10.78	1.08
Impact Speed (m/s)	11.20	None	0.01	-	-	5.61	7.91
Speed Reduction (%)	-	100.00	99.87	-	-	66.62	57.70
Separation Distance (m)	-	0.89	Mitigated	-	-	0.89	N/A

2019 Toyota Corolla

	Trial 1	Trial 2	Trial 3	Trial 4	Trail 5	Average	Std. Dev.
Initial Braking Distance (m)	-	-	-	-	-	N/A	N/A
Max. Deceleration (m/s²)	-	-	-	-	-	N/A	N/A
Impact Speed (m/s)	10.53	11.68	-	-	-	11.10	0.82
Speed Reduction (%)	5.82	-	-	-	-	2.91	4.11
Separation Distance (m)	-	-	-	-	-	N/A	N/A

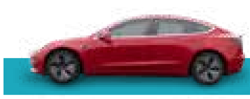
2019 BMW X7

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.88	9.39	9.62	9.49	9.01	9.48	0.32
Max. Deceleration (m/s²)	11.82	12.14	11.92	11.84	13.15	12.17	0.56
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	1.02	1.21	1.04	0.68	0.52	0.89	0.28

GAP TEST: CHILD AT NIGHT

Thermal Ford Fusion

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.12	10.36	7.68	9.62	9.19	9.19	0.98
Max. Deceleration (m/s²)	13.10	14.67	15.07	12.81	16.53	14.43	1.52
Impact Speed (m/s)	None	None	2.11	None	None	2.11	N/A
Speed Reduction (%)	100.00	100.00	81.08	100.00	100.00	96.22	8.46
Separation Distance (m)	1.22	2.42	Mitigated	1.95	1.49	1.77	0.53



2019 Tesla Model 3

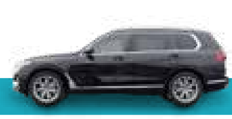
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	-	-	-	-	-	N/A	N/A
Max. Deceleration (m/s²)	-	-	-	-	-	N/A	N/A
Impact Speed (m/s)	10.25	10.97	-	-	-	10.61	0.51
Speed Reduction (%)	8.30	1.89	-	-	-	5.10	4.54
Separation Distance (m)	-	-	-	-	-	N/A	N/A

2019 Subaru Forester

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	-	-	-	-	-	N/A	N/A
Max. Deceleration (m/s²)	-	-	-	-	-	N/A	N/A
Impact Speed (m/s)	11.30	11.15	-	-	-	11.22	0.10
Speed Reduction (%)	-	0.21	-	-	-	0.11	0.15
Separation Distance (m)	-	-	-	-	-	N/A	N/A

2019 Toyota Corolla

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	-	-	-	-	-	N/A	N/A
Max. Deceleration (m/s²)	-	-	-	-	-	N/A	N/A
Impact Speed (m/s)	10.80	10.83				10.81	0.02
Speed Reduction (%)	3.38	3.11				3.25	0.19
Separation Distance (m)	-	-	-	-	-	N/A	N/A



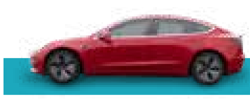
2019 BMW X7

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	-	-	-	-	-	N/A	N/A
Max. Deceleration (m/s²)	-	-	-	-	-	N/A	N/A
Impact Speed (m/s)	8.33	10.85				9.59	1.78
Speed Reduction (%)	25.45	2.93				14.19	15.93
Separation Distance (m)	-	-	-	-	-	N/A	N/A

GAP TEST: DARK CLOTHING NIGHT

Thermal Ford Fusion

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	9.64	9.60	9.31	9.41	9.59	9.51	0.14
Max. Deceleration (m/s^2)	14.38	13.90	15.91	15.57	13.60	14.67	1.02
Impact Speed (m/s)	None	None	None	None	None	N/A	N/A
Speed Reduction (%)	100.00	100.00	100.00	100.00	100.00	100.00	-
Separation Distance (m)	2.15	2.18	1.87	2.03	2.14	2.07	0.13



2019 Tesla Model 3

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	4.59	3.38	4.85	-	-	4.27	0.79
Max. Deceleration (m/s^2)	13.68	11.43	12.39	-	-	12.50	1.13
Impact Speed (m/s)	None	9.10	6.68	-	-	7.89	1.71
Speed Reduction (%)	100.00	18.57	40.23	-	-	52.93	42.18
Separation Distance (m)	0.251	-	-	-	-	0.25	N/A

2019 Subaru Forester

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	1.49	7.64	-	-	-	4.57	4.35
Max. Deceleration (m/s^2)	5.23	6.79	-	-	-	6.01	1.11
Impact Speed (m/s)	10.86	8.13	-	-	-	9.50	1.93
Speed Reduction (%)	2.79	27.24	-	-	-	15.01	17.29
Separation Distance (m)	-	-	-	-	-	N/A	N/A

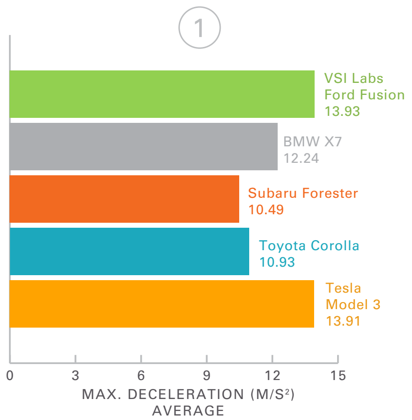
2019 Toyota Corolla

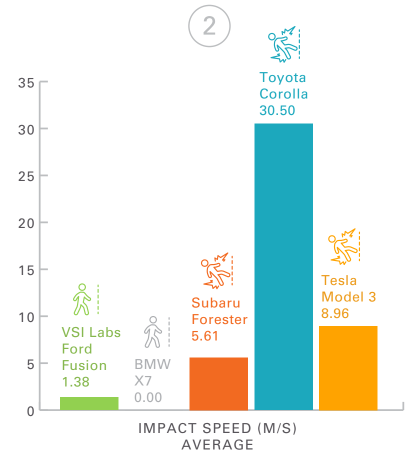
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	5.91	-	-	-	-	5.906	N/A
Max. Deceleration (m/s^2)	12.08	-	-	-	-	12.081	N/A
Impact Speed (m/s)	6.44	10.74	-	-	-	8.59	3.04
Speed Reduction (%)	42.42	3.93	-	-	-	23.17	27.22
Separation Distance (m)	-	-	-	-	-	N/A	N/A

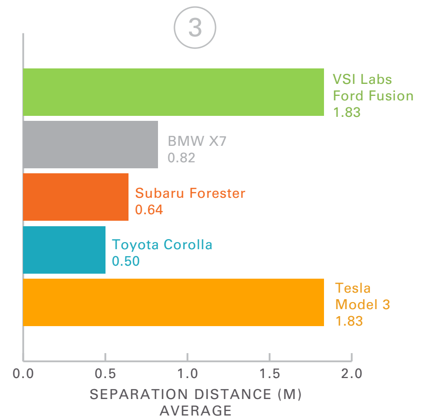
2019 BMW X7

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average	Std. Dev.
Initial Braking Distance (m)	7.83	3.91	4.59	-	-	5.44	2.10
Max. Deceleration (m/s^2)	12.78	13.96	13.35	-	-	13.36	0.59
Impact Speed (m/s)	None	7.84	6.78	-	-	7.31	0.75
Speed Reduction (%)	100.00	29.83	39.30	-	-	56.38	38.07
Separation Distance (m)	0.10	-	-	-	-	0.10	N/A

DAYTIME TEST DATA

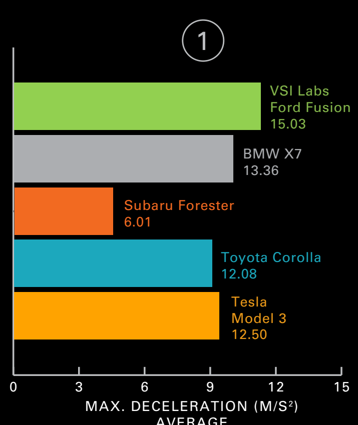


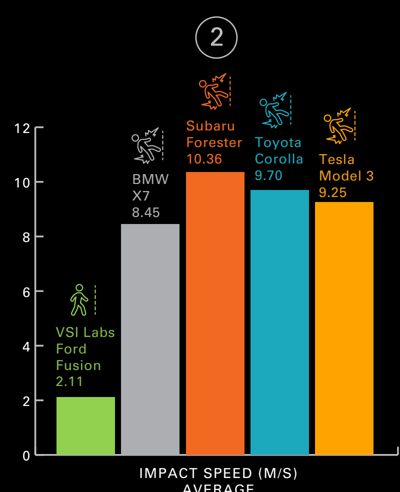


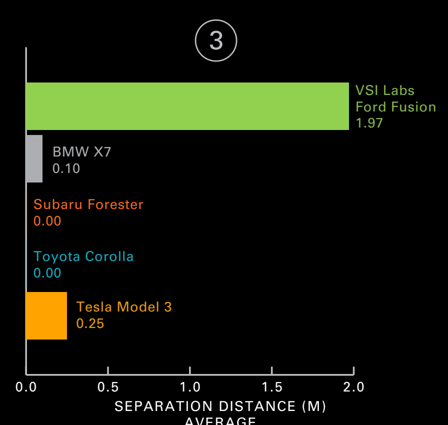


	VSI Labs Ford Fusion		BMW X7		Subaru Forester		Toyota Corolla		Tesla Model 3	
	Average	Std. Dev	Average	Std. Dev	Average	Std. Dev	Average	Std. Dev	Average	Std. Dev
Initial Braking Distance (m)	10.35	0.81	9.42	0.24	11.77	3.91	12.77	0.92	8.00	2.46
(1) Max. Deceleration (m/s^2)	13.93	1.85	12.24	0.72	10.49	2.94	10.93	0.16	13.91	0.69
(2) Impact Speed (m/s)	1.38	N/A	0.00	N/A	5.61	6.46	30.50	0.82	8.96	2.62
Speed Reduction (%)	99.18%	3.19%	100.00%	0.00	92.30%	36.31%	88.22%	37.81%	68.01%	43.42%
(3) Separation Distance (m)	1.83	0.52	0.82	0.32	0.64	0.44	0.50	0.07	1.83	0.98

NIGHTTIME TEST DATA







	VSI Labs Ford Fusion		BMW X7		Subaru Forester		Toyota Corolla		Tesla Model 3	
	Average	Std. Dev	Average	Std. Dev	Average	Std. Dev	Average	Std. Dev	Average	Std. Dev
Initial Braking Distance (m)	9.36	0.58	5.44	2.10	4.57	4.35	5.91	N/A	4.27	0.79
(1) Max. Deceleration (m/s^2)	15.03	1.55	13.36	0.59	6.01	1.11	12.08	N/A	12.50	1.13
(2) Impact Speed (m/s)	2.11	N/A	8.45	1.72	10.36	1.50	9.70	2.18	9.25	1.88
Speed Reduction (%)	99.24%	3.78%	39.50%	36.36%	7.56%	13.18%	13.21%	19.48%	33.80%	39.76%
(3) Separation Distance (m)	1.97	0.40	0.1	N/A	0	N/A	0	N/A	0.25	N/A

APPENDIX III

EURO NCAP TESTING DEFINITIONS[6]

Car-to-Pedestrian Nearside Adult 50% (CPNA-50): a collision in which a vehicle travels forwards towards an adult pedestrian crossing its path running from the nearside and the frontal structure of the vehicle strikes the pedestrian at 50% of the vehicle's width when no braking is applied.

Car-to-Pedestrian Nearside Child 50% (CPNC-50): a collision in which a vehicle travels forwards towards a child pedestrian crossing its path running from behind and obstruction from the nearside and the frontal structure of the vehicle strikes the pedestrian at 50% of the vehicle's width when no braking action is applied.

Car-to-Pedestrian Nearside Adult 25% (CPNA-25): a collision in which a vehicle travels forwards towards an adult pedestrian crossing its path walking from the nearside and the frontal structure of the vehicle strikes the pedestrian at 25% of the vehicle's width when no braking action is applied.

Car-to-Pedestrian Longitudinal Adult 50% (CPLA-50): a collision in which a vehicle travels forwards towards an adult pedestrian walking in the same direction in front of the vehicle where the vehicle strikes the pedestrian at 50% of the vehicle's width when no braking action is applied.

GLOSSARY

Separation distance: The distance between the pedestrian target and the vehicle when the vehicle comes to a complete stop after initiating automatic emergency braking.

Initial Braking Distance: Longitudinal distance to the SPT when the test vehicle initiates braking.
FOV: The field of view or the angular range of the observable field that is seen at any given point. Here we primarily consider the FOV's of cameras.

Stereoscopic: It is the process of getting two images of the same object taken at slightly different angles and viewing them together, creating an impression of depth and solidity.

IR: Infrared

EPA: Environmental Protection Agency whose mission is to protect human and environmental health.
False positives: A test result which incorrectly indicates that a particular condition or attribute is present. In this case, we consider the incorrect pedestrian detections appears apart from the right pedestrian detections as false positives.

SPT: Soft Pedestrian Target which is a human dummy which could be heated and movable. For these tests we used an adult SPT and a child SPT as well.

ACM: American Center for Mobility is a facility located in Detroit which provides a ground for connected and automated vehicle test their technologies.

Fish-eye lens: A fish-eye lens is an ultra-wide-angle lens that produces strong visual distortion intended to create a wide panoramic or hemispherical image.

[6] https://cdn.euroncap.com/media/58226/euro-ncap-aeb-vru-test-protocol-v303.pdf

Telephoto lens: A specific type of a long-focus lens in which the physical length of the lens is shorter than the focal length.

AEB: Automatic Emergency Braking is a system integrated into a vehicle in order to detect an impending forward crash and apply brakes automatically to prevent the collision or reduce impact force when the driver's response is not sufficient to avoid the collision.

Neural Network: A neural network is a series of algorithms which designs to recognize underlying relationships in a set of data through a process that mimics the way the human brain operates and also which can adapt to changing input to generate the best possible result without needing to redesign the output criteria.

CNN: Convolutional Neural Network is a series of algorithms which can take in an input image, assign importance based on learnable weights and biases to various objects and aspects in the image and differentiate one from another.

OEM: Original Equipment Manufacturers are companies that produces parts and equipment that may be marketed by another manufacturer.

OxTS: Oxford Technical Solutions is a company which manufactures GNSS-aided inertial navigation systems for use in automotive industry.

CAN bus: A Controller Area Network is a robust vehicle bus standard designed to allow sensors and other devices to communicate with each other's application without a host computer.

ECU: Engine Control Unit is a type of electronic control unit that controls a series of electrical systems or subsystems in a vehicle.

VUT: Vehicles under test

Commercially Available Vehicles: Vehicles utilized to test AEB performance except the Ford Fusion (VSI)

Mitigation: We consider a test trial mitigated if there is a collision, however the impact speed is less than half of the initial speed, or the speed reduction is greater than 50%

Stop: We consider a test trial a stop if the vehicle stops before the target without colliding with it even slightly, when there is no impact and above zero separation distance.

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About FLIR Systems

FLIR produces the only automotive-qualified thermal camera in cars today. Through Tier 1 automotive supplier Veoneer, more than 700,000 cars have reliable night vision with pedestrian and animal detection. FLIR thermal cameras are revolutionizing AEB, ADAS and AV sensing, they provide the ability to reliably classify objects in the dark and through obscurants including smoke, sun glare, and most fog – day or night. Including thermal cameras increases the situational awareness, reliability, and safety capabilities of a sensor suite.

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About VSI Labs

VSI Labs (established 2014) provides research and advisory to companies that design, develop, or sell into the market for active safety and automated driving. Through its research and advisory services, VSI provides companies with a deep technical perspective on the technology landscape that serves these markets. What makes VSI unique is its applied research on its own research vehicles. From active safety systems to fully automated driving applications VSI's engineers routinely test out various combinations of hardware and software to determine their functional performance.

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