PART 1

PUTTING THERMAL AEB TO THE TEST

HOW THERMAL TECHNOLOGY FILLS THE GAPS OF CURRENT AEB SYSTEMS

VSI Labs

Test conducted by VSI Labs for FLIR Systems

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GENERAL TEST NOTES

TESTING DATES: December 17th and 18th, 2019

TESTING LOCATION: American Center for Mobility (ACM) at Willow Run – Ypsilanti, MI

TESTING VELOCITY: 25 mph (40 kmph)

SPT SPEED: 5 kmph

SPT MEETING POINT: 50% of the vehicle's width

TERMINOLOGY:

AEB: Automatic Emergency Braking

EPTA: Euro NCAP Pedestrian Target, Adult

VUT: Vehicle Under Test

SPT: Soft Pedestrian Target

EURO NCAP: European New Car Assessment Programme

AAA Automatic Emergency Braking with Pedestrian Detection document:
https://www.aaa.com/AAA/common/aar/files/Research-Report-Pedestrian-Detection.pdf

National Highway Safety Traffic Administration, "nhtsa.gov," March 2019. [Online]: CLICK HERE

SUMMARY

Automatic Emergency Breaking Pedestrian (AEBP) Using Thermal & Radar Sensors

Current typical automatic emergency braking (AEB) or pedestrian detection systems rely on systems using radar and, in some cases, visible-light cameras. There are several common conditions in which these sensors can have difficulty detecting a pedestrian. An October 2019 study by AAA tested several production AEB systems and describes many such scenarios. In nighttime conditions, the vehicle under test (VUT) traveling at 25 mph hit the soft pedestrian target (SPT) 100% of the time. During daylight tests, the VUT driving 20 mph struck the stationary SPT 60% of the time.[1] The following report describes a proof-of-concept thermal-camera-and-radar fused AEB algorithm that stopped the VUT in 100% of daytime and nighttime testing.

Pedestrian detection and AEB systems are critical to improving road safety. According to the National Highway Traffic Safety Administration (NHTSA), on average, a pedestrian is killed every 88 minutes in traffic crashes in the United States. In 2017, nearly 6,000 pedestrians' lives were lost in the United States, an increase of 35% since 2008. All other traffic deaths decreased by 6% during that same time period. NHSTA also reported that 75% of all pedestrian deaths occurred after sunset.[2]

A thermal camera provides complementary data to RGB cameras and radar. Thermal cameras "see" heat, not reflected light, and perform well both in daylight and in darkness. They can see through sun and headlight glare, most fog, and up to 4x farther than typical headlights illuminate in darkness. Given thermal camera's unique capability, FLIR Systems Inc. contracted VSI Labs to develop a proof-of-concept automatic pedestrian detection system that fuses radar and FLIR thermal camera data to detect and estimate the distance of a pedestrian from the front of a test vehicle. The VUT is programmed to automatically stop if a pedestrian is in the path of the vehicle at a proximity that it determines to be an emergency-stop distance.

6,000
PEDESTRIAN DEATHS IN THE U.S. IN 2017

75%
OCCUR AT NIGHT

AEB
CURRENT SYSTEMS

VERSUS

AEB
THERMAL + RADAR

SAVES LIVES

FIGURE 1: VSI test car equipped with the FLIR ADK, radar and neural network for AEB pedestrian detection

Initial tests were completed in December 2019 at the American Center for Mobility (ACM) near Detroit, MI. The test design was based on the Euro NCAP, but not all testing requirements were met as the winter weather was colder than the specified testing temperature range, roadways had snowy, wet, or slick surfaces and wind interfered with the test fixtures. Three test cases were conducted in both daylight and darkness, giving six datasets and 35 total test runs using an adult Euro NCAP Pedestrian Target (EPTa).

Test results were promising. In all runs for all test cases, the AEB system successfully brought the VUT to a stop before reaching the EPTa. Additional testing is recommended and planned for summer of 2020 following AEB algorithm optimization, EPTa heating improvements and when weather is in test parameters.

NCAP TEST CATEGORIES

CPLA-50 TESTS

1

Car-to-Pedestrian Longitudinal Adult 50% (CPLA-50):

A collision situation in which a vehicle travels forwards towards an EPTa (Euro NCAP pedestrian target adult) standing facing the same direction as the vehicle in front of the vehicle where the vehicle strikes the pedestrian at 50% of the vehicle's width when no braking action is applied.

CPFA-50 TESTS

2

Car-to-Pedestrian Far Side Adult 50% (CPFA-50):

A collision situation in which a vehicle travels forwards towards an EPTa crossing its path running from the far side and the frontal structure of the vehicle strikes the pedestrian at 50% of the vehicle's width when no braking action is applied.

CPFAO-50 TESTS

3

Car-to-Pedestrian Far Side Adult Obstructed 50% (CPFAO-50):

A collision situation in which a vehicle travels forwards towards an EPTa crossing its path running from the far side from behind an obstruction and the frontal structure of the vehicle strikes the pedestrian at 50% of the vehicle's width when no braking action is applied. SPT comes at 5 kmph behind two parked cars as to nullify the chances of partial recognition of a part of the SPT's form from behind the obstruction.

Figure 2: Proof-of-concept testing based on three Euro-NCAP test cases

PROOF-OF-CONCEPT AEB SYSTEM OVERVIEW

AEB systems detect pedestrians in front of the vehicle and trigger the brakes to attempt to prevent or mitigate a collision. While most AEB systems pair a RGB camera with radar to detect pedestrians, VSI Labs fused perception data from the FLIR ADK® thermal camera and the Delphi® ESR 2.5 radar.

The YOLOv3 Deep Learning architecture was chosen to implement pedestrian detection because of its real-time capable speed and reasonable ability to detect small objects. Extrinsic calibration and depth estimation with a neural network were used to project each 2-dimensional detection in the thermal image to a position in 3D space. The detection was then matched to a radar point for more reliable distance and velocity measurements. The AEB algorithm checked if any of the sensor fusion objects were in the vehicle's path and calculated a time-to-collision for each in-path object. If the time-to-collision was nearing the time it would take the vehicle to decelerate to a stop, then the AEB algorithm would trigger the brake through a drive-by-wire interface. Figure 3 shows an overview of VSI Labs' AEB system used for testing on December 17 and 18, 2019.

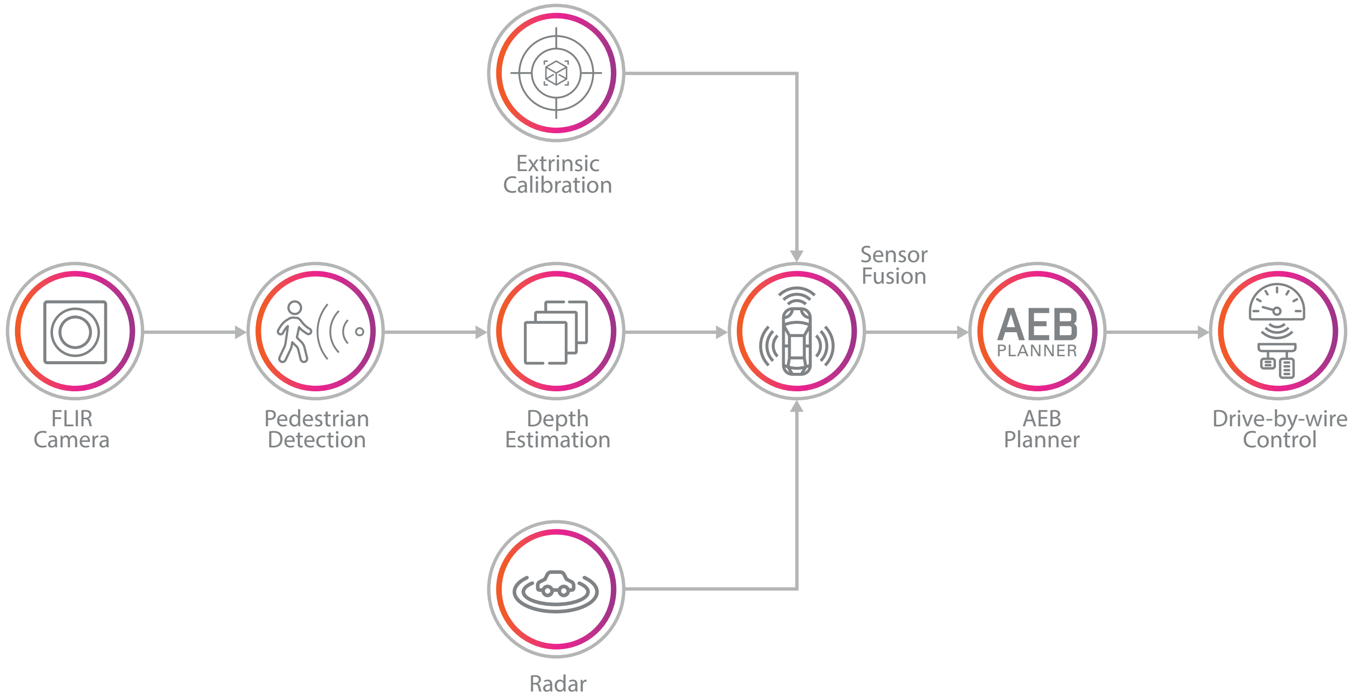


Figure 3: A systems overview of VSI Labs' AEB system using a thermal camera and radar

TEST CASES IMPLEMENTED

Three test cases were included in both daylight and darkness giving six datasets of five tests each and resulting in 30 total tests. These trials included the VUT implementing these scenarios and the AEB system responding accordingly.

1 CPLA-50 TESTS

2 CPFA-50 TESTS

3 CPFAO-50 TESTS

EURO NCAP TESTING COMPLIANCE/NON-COMPLIANCE

The AEB system tests were based on many of the Euro NCAP requirements. In addition, there were Euro NCAP requirements that were attempted to be met in the experimental design but were not realized onsite due to environmental factors. These elements are denoted with an asterisk and described further below in the section titled, "Challenges Encountered During Testing." NCAP non-compliance are not listed exhaustively. Points of compliance and non-compliance are denoted with their relevant sections in the NCAP TEST PROTOCOL – AEB VRU systems 3.0.2 document.

EXAMPLES OF NCAP COMPLIANCE:
6.1 Test Track
6.1.2 Three meters on either side of the VUT and 30 meters ahead when the test ends
6.2 Weather Conditions
6.1.4 Testing in nighttime conditions (ANNEX B) Illuminance less than 1.0 lx.
Actual Condition: Less than 0.25 lx
7.2.14 CPLA AEB Pedestrian target speed: 5 kmph
Actual EPTa target speed: 5 kmph
7.2.14 CPLA, CPFA VUT Speed: 20-60 kmph
Actual VUT Speed: 40 kmph

EXAMPLES OF NCAP NON-COMPLIANCE:
5 Euro NCAP Articulated Pedestrian Target *Weather Impacted
6.1 Test Track
6.1.1 Uniform and solid paved surface *Weather Impacted
6.1.3 Parallel lane markings not present within 3 meters on either side
Actual Condition: There were lane markings parallel to test path on the track. These were not used to identify driving lanes, nor were they identified by the system.
6.1.4 Junction and Lane Markings
Actual Condition: Tests were not performed at a junction.
6.2 Weather Conditions
6.2.1 Conduct tests with ambient temperature between 5°C and 40°C
Actual Condition: December 17, 2019 ambient temperature ranged from -4°C to 1.1°C. December 18, 2019 ambient temperature ranged from -12°C to -2°C.
6.2.2, 6.2.3 and 6.2.5 – Measurements relating to precipitation, windspeed, natural ambient light, and track surface temperature were not taken.
7.2.7 Car to Pedestrian Longitudinal Adult walking
Actual Condition: EPTa was stationary
7.2.14 CPFA AEB Pedestrian target speed: 8 kmph
Actual EPTa Speed: 5 kmph

TEST RESULTS

Initial test results are promising. We consider a test successful if the vehicle braked to a complete stop before ever reaching the EPTa. We consider a test a failure if the vehicle did not brake soon enough or hard enough to avoid an impact with the EPTa. For each of the 6 test cases performed, all runs of the test case succeeded. The separation distance for each test run varied. Average separation distance is included in Figure 5. A combination of weather, roadway conditions, algorithm maturity and EPTa function attributed to the variation in the separation distance.

Additional testing is recommended and planned for summer of 2020 following AEB algorithm optimization, EPTa heating improvements and when test-track weather permits.

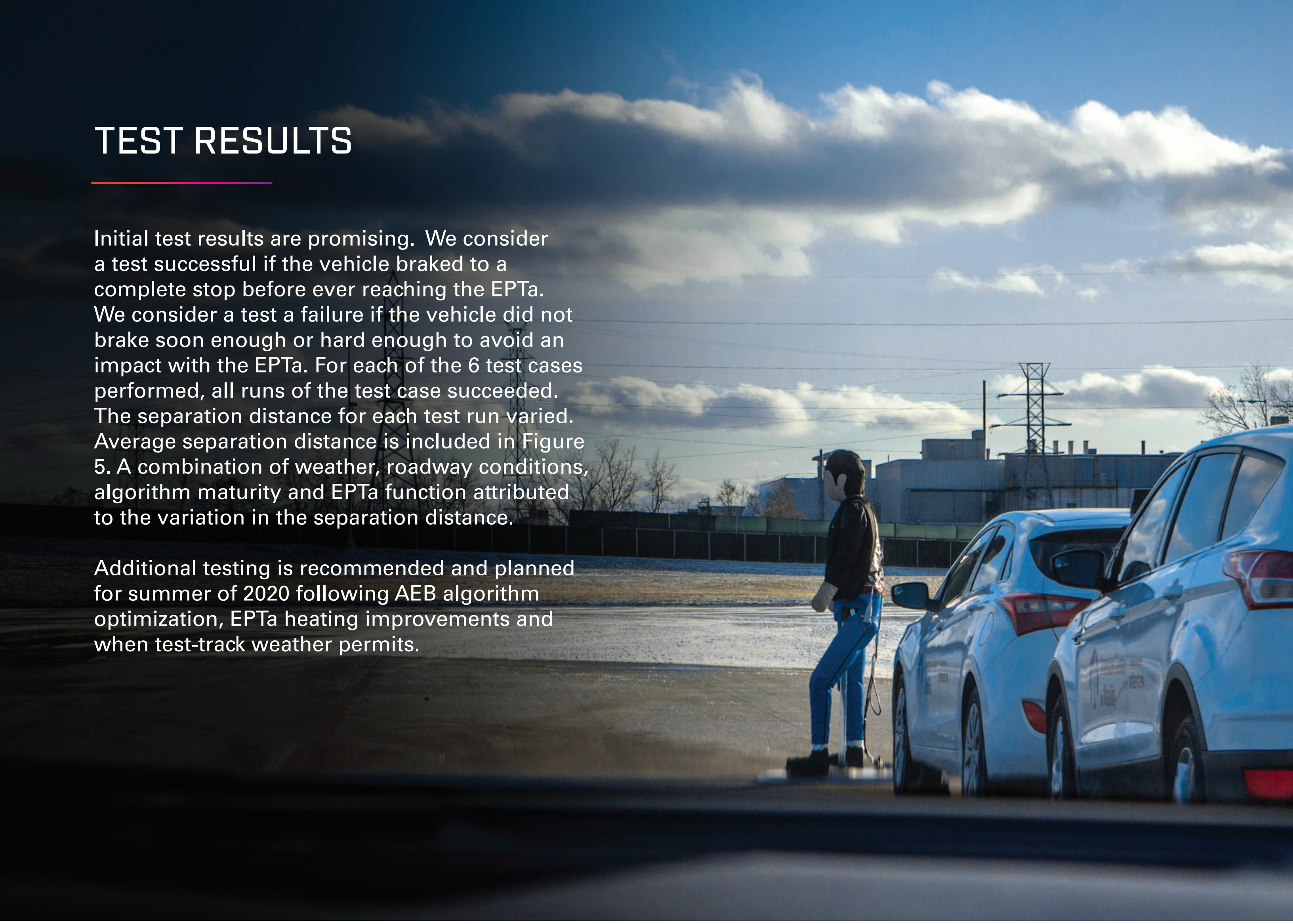
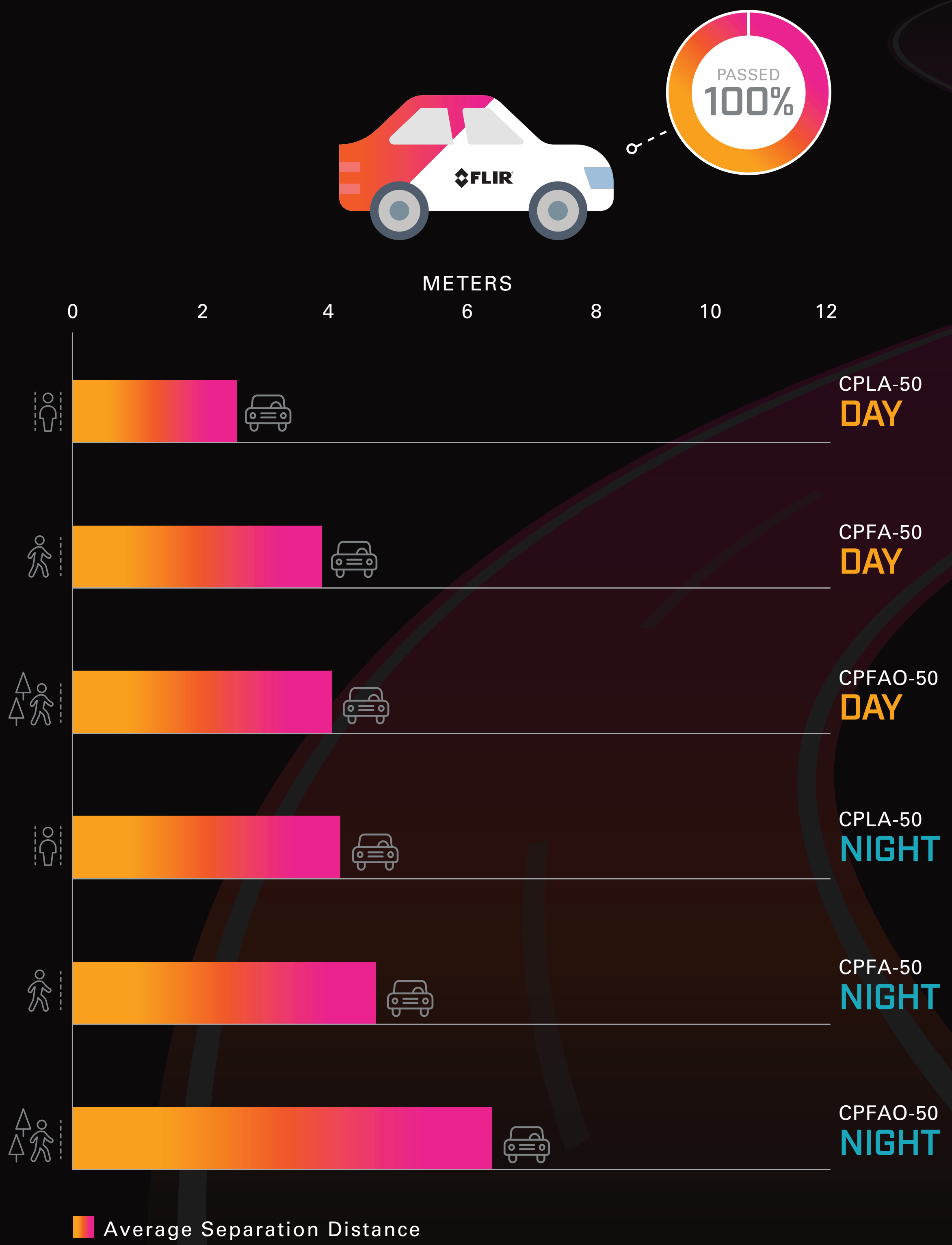


Figure 4: Thermal image of EPTa and human in test environment

AVERAGE STOPPING DISTANCE



*NOTE:

With the dark and wet roadway, it was difficult to correctly repeat the approach to the EPTa during the CPFAO-50 night tests. This created a situation where the thermal camera would detect the partially occluded EPTa, but the radar would measure from the rear corner of the parked vehicle. In these cases, the VUT stopped at distances greater than necessary to avoid the EPTa. Adjustments were made, but six tests were run and recorded that were impacted. To account for this, ten runs were completed for this test case and are included in the data analysis.

Figure 5: Average stopping distance VUT and EPTa

PROOF-OF-CONCEPT TEST RESULTS

Automatic Emergency Braking (AEB) System Fused Thermal Camera and Radar Pedestrian Detection

CPLA-50 - DAY	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	AVG
Notification Time (s)	2.67	2.85	3.62	4.53	3.55	3.44
Notification Distance (m)	29.79	31.89	40.49	50.59	39.69	38.49
Braking Distance (m)	16.078	15.984	15.767	15.888	15.591	15.86
Max Deceleration (m/s^2)	-8.15	-6.28	-6.91	-9.89	-7.45	-7.74
Max Deceleration Distance (m)	11.67	12.68	12.56	9.68	11.89	11.70
Impact Speed (kmph)	N/A	N/A	N/A	N/A	N/A	N/A
Separation Distance (m)	3.86	0.8128	2.5146	4.699	1.955	2.77
CPFA-50 - DAY	**TRIAL 1**	**TRIAL 2**	**TRIAL 3**	**TRIAL 4**	**TRIAL 5**	**AVG**
Notification Time (s)	2.63	3.15	3.44	3.30	3.23	3.15
Notification Distance (m)	29.4	35.17	38.39	36.89	36.08	35.19
Braking Distance (m)	15.832	16.462	16.542	16.533	15.874	16.25
Max Deceleration (m/s^2)	-10.08	-9.79	-9.89	-6.49	-7.27	-8.70
Max Deceleration Distance (m)	10.19	11.21	11.29	12.85	12.69	11.65
Impact Speed (kmph)	N/A	N/A	N/A	N/A	N/A	N/A
Separation Distance (m)	5.334	5.893	6.083	2.21	3.683	4.64
CPFAO-50 - DAY	**TRIAL 1**	**TRIAL 2**	**TRIAL 3**	**TRIAL 4**	**TRIAL 5**	**AVG**
Notification Time (s)	N/A	1.85	N/A	1.83	N/A	1.84
Notification Distance (m)	N/A	20.66	N/A	20.45	N/A	20.56
Braking Distance (m)	11.077	19.445	15.91	13.167	12.454	14.41
Max Deceleration (m/s^2)	-9.69	-9.07	-9.86	-11.12	-9.53	-9.85
Max Deceleration Distance (m)	5.941	14.88	10.93	5.26	7.384	8.88
Impact Speed (kmph)	N/A	N/A	N/A	N/A	N/A	N/A
Separation Distance (m)	0.406	7.899	5.817	4.394	2.311	4.17

*NOTE:

With the dark and wet roadway, it was difficult to correctly repeat the approach to the EPTa during the CPFAO-50 night tests. This created a situation where the thermal camera would detect the partially occluded EPTa, but the radar would measure from the rear corner of the parked vehicle. In these cases, the VUT stopped at distances greater than necessary to avoid the EPTa. Adjustments were made, but six tests were run and recorded that were impacted. To account for this, ten runs were completed for this test case and are included in the data analysis.

CPLA-50 - NIGHT	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	AVG
Notification Time (s)	5.52	5.32	5.37	5.54	5.36	5.42
Notification Distance (m)	61.69	59.49	59.99	61.89	59.89	60.59
Braking Distance (m)	16.894	15.699	16.23	16.56	15.7	16.22
Max Deceleration (m/s^2)	-7.14	-9.16	-10.51	-9.42	-10.09	-9.26
Max Deceleration Distance (m)	12.99	4.29	4.79	5.49	5.69	6.65
Impact Speed (kmph)	N/A	N/A	N/A	N/A	N/A	N/A
Separation Distance (m)	3.2	3.861	4.597	5.258	4.521	4.29
CPFA-50 - NIGHT	**TRIAL 1**	**TRIAL 2**	**TRIAL 3**	**TRIAL 4**	**TRIAL 5**	**AVG**
Notification Time (s)	1.56	N/A	1.53	1.65	1.48	1.56
Notification Distance (m)	17.45	N/A	17.14	18.43	16.51	17.38
Braking Distance (m)	16.958	16.521	16.545	16.267	15.421	16.34
Max Deceleration (m/s^2)	-10.72	-10.17	-9.89	-10.09	-10	-10.17
Max Deceleration Distance (m)	5.39	6.38	5.59	5.39	5.09	5.57
Impact Speed (kmph)	N/A	N/A	N/A	N/A	N/A	N/A
Separation Distance (m)	4.572	5.613	5.029	5.283	4.521	5.00

CPFAO-50 - NIGHT	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	TRIAL 6
Notification Time (s)	1.95	2.23	1.72	1.94	15.71	19.11
Notification Distance (m)	21.76	24.91	19.24	21.66	15.709	19.11
Braking Distance (m)	19.63	19.24	16.24	19.044	15.709	19.11
Max Deceleration (m/s^2)	-9.8	-9.78	-10.5	-10.34	-9.12	-9.86
Max Deceleration Distance (m)	12.88	8.19	6.37	10.47	9.78	11.32
Impact Speed (kmph)	N/A	N/A	N/A	N/A	N/A	N/A
Separation Distance (m)	8.331	8.128	4.724	9.779	3.683	9.449
Radar Measurement*	Parked Vehicle	Parked Vehicle	EPTa	Parked Vehicle	EPTa	Parked Vehicle

CPFAO-50 - NIGHT	TRIAL 7	TRIAL 8	TRIAL 9	TRIAL 10	AVG
Notification Time (s)	15.32	1.59	1.89	17.45	8.58
Notification Distance (m)	15.318	17.73	21.14	17.453	17.00
Braking Distance (m)	15.318	15.536	19.725	17.453	15.70
Max Deceleration (m/s^2)	-9.56	-10.77	-10.32	-10.07	-9.99
Max Deceleration Distance (m)	6.16	5.09	13.34	6.09	6.85
Impact Speed (kmph)	N/A	N/A	N/A	N/A	N/A
Separation Distance (m)	4.166	4.14	8.839	5.766	4.18
Radar Measurement*	EPTa	EPTa	Parked Vehicle	Parked Vehicle	N/A

RESULTS HIGHLIGHTS & RECAP

A key performance metric is the separation distance after the AEB system had brought the VUT to a complete stop ahead of the EPTa.

1 CPLA-50 TESTS

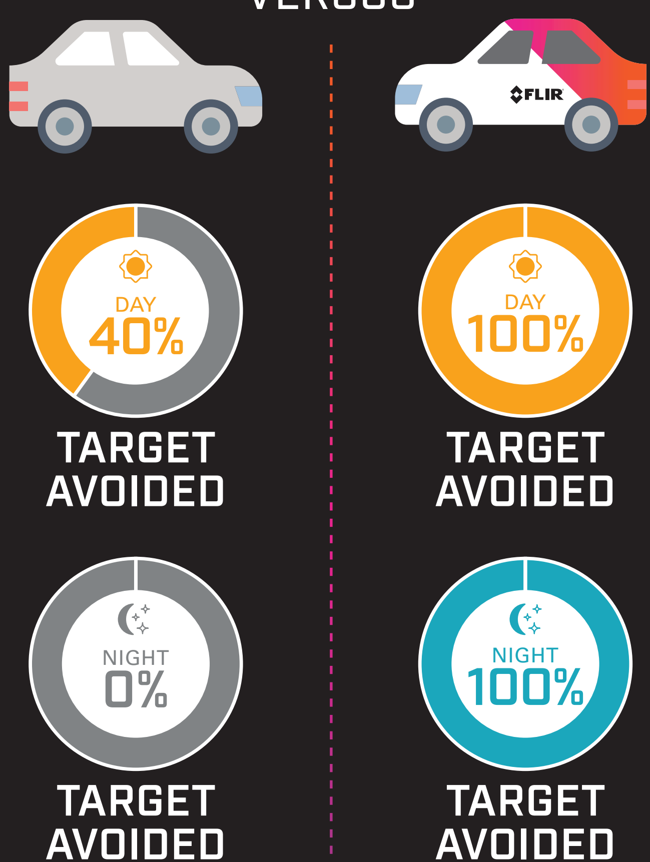
NOTIFICATION DISTANCE	BRAKING DISTANCE
38.49M	15.86M

The proof-of-concept fused algorithm stopped the VUT and did not collide with the EPTa in all tests. In all runs for all test cases, the AEB system successfully brought the VUT to a stop before reaching the EPTa.

AEB CURRENT SYSTEMS

VERSUS

AEB THERMAL + RADAR



Test Table Result Descriptions

NOTIFICATION TIME: This is the first instance where the SPT is deemed to be ‘in-path’ is detected by the thermal-radar fusion detection algorithm. In-path means that the pedestrian is within a certain distance laterally from the center of the vehicle. This table value is the time in seconds until the vehicle would collide with the detected SPT assuming the vehicle does not decelerate. If this value is N/A, it means that as soon as the SPT was detected in path, it is already calculated to be within braking range, so the AEB system brakes immediately rather than first issuing a warning notification.

NOTIFICATION DISTANCE: This is similar to notification time, except this value is the distance to the SPT in meters when the notification.

BRAKING DISTANCE: This is the distance in meters from the VUT to the SPT when the brakes are first applied.

MAX DECELERATION: This is maximum deceleration value recorded from the Inertial Measurement Unit.

MAX DECELERATION DISTANCE: This is the distance in meters from the VUT to the SPT at the instance where the maximum deceleration value was recorded.

IMPACT SPEED: This would be the speed of the VUT when it strikes the SPT. However, for all of our trials this value is Not Applicable.

SEPARATION DISTANCE: This is the distance in meters measured from the VUT once it has stopped, to the SPT or the path the SPT was traveling on in cases where the SPT was moving.

CHALLENGES ENCOUNTERED IN TESTING

There were challenges in conducting the tests where aspects of the Euro NCAP standard that were intended to be met in the experimental design were not met in practice. They were to do intermingling of the EPTa and environmental conditions, as well as the environmental conditions themselves.

Water and Snow Cover of Test Roadway:

The Euro NCAP requirement of testing on a dry (no visible moisture on the surface) uniform surface was not met. On December 19 there was light snow on the roadway before testing, which melted into patches of water and snow after brushing and treatment with salt. Due to intermittent strong wind, snow frequently blew into the path of the vehicle. The road conditions were inconsistent during testing and did not meet NCAP standards. The AEB algorithm required adjustment to the braking coefficient to account for the inconsistent road condition, which added variability to the minimum and maximum stopping separation between VUT and EPTa.

EPTa Leg Heating:

The EPTa was heated by electric resistance heaters to allow it to match the exterior surface temperature of a clothed pedestrian. This required constant wired connections that were often in the way of the EPTa as it was being reset to a neutral position. On December 17, a power cord to the heaters located in one of the legs was severed during testing. Testing-track staff alternated the remaining power cord between both legs to keep the legs at the target temperature. This was a failure of the EPTa to properly replicate the thermal (visual) attributes of a typical pedestrian and thus meet the NCAP standard.

EPTa Thermal Signature:

There was a general challenge of heating the EPTa to properly replicate the thermal appearance of a typical pedestrian. The thermal signature was different enough from a typical pedestrian's thermal signature that recognition performance at longer ranges was significantly reduced. At closer ranges, the recognition performance more closely matched with test performance on a pedestrian. This was a failure of the EPTa to closely replicate the thermal (visual) attributes of a typical pedestrian and thus meet the NCAP standard.

EPTa Leg Articulation:

The NCAP standard describes the need for the EPTa to articulate in terms of leg movement. Given some difficulties on-site with the combination of environmental conditions (strong gales) and leg articulation causing the EPTa legs to repeatedly fall off and the EPTa to fall over. This led to reinforcement of the leg connection the termination of the EPTa leg articulation. This was a failure of the EPTa to articulate and thus meet the NCAP standard.

Braking Distance During CPFAO-50 Night Tests:

With the dark and wet roadway, it was difficult to correctly repeat the approach to the EPTa during the CPFAO-50 night tests. This created a situation where the thermal camera would detect the partially occluded EPTa, but the radar would measure from the rear corner of the parked vehicle. In these cases, the VUT stopped at distances greater than necessary to avoid the EPTa. Adjustments were made, but six CPFAO-50 night tests were impacted as well as one CPFAO-50 day. To account for this, ten runs were completed for the CPFAO-50 night case and are included in the data analysis.

Figure 6: Track staff alternated heating the EPTa legs to maintain desired temperature

COMING IN FALL 2020:

Part 2 - Featuring NCAP rated vehicles VS. FLIR Thermal + visible fused system

CLICK HERE TO BE NOTIFIED WHEN PART 2 IS RELEASED.

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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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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.

For more information about ADAS systems please visit www.flir.com/adas

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