Vehicle-to-Vehicle Front Crash Prevention 2.0 Test Protocol

Version I

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Contents

SUMMARY

This document describes the Insurance Institute for Highway Safety (IIHS) Vehicle-to-Vehicle Front Crash Prevention 2.0 Test Protocol. The protocol is available from the *Test protocols and technical information* section of the IIHS website.

From 2013 to 2022, IIHS (2013) evaluated automatic emergency braking (AEB) systems when a vehicle approached a stationary surrogate passenger-car target at 20 and 40 km/h (12 and 25 mph). These scenarios represent less than 3% of police-reported front-to-rear crashes potentially relevant to this technology (Kidd, 2022).

Multiple studies using varying methods and data sources have reported that vehicles equipped with AEB reduce the incidence of police-reported front-to-rear crashes by 34% to 50% compared with similar vehicles without AEB (Cicchino, 2017; Leslie et al., 2021; Spicer, et al., 2021), so existing systems are preventing crashes that are beyond the currently tested scenarios. IIHS research indicated that increasing the maximum test speed to 56–72 km/h (35–45 mph) and including nonpassenger vehicle targets like motorcycles and medium/heavy trucks in testing would increase the relevance of physical tests to 36% of police-reported rear-end crashes and 43% of fatal rear-end crashes (Kidd, 2022). Earlier IIHS research indicated that AEB systems may not work optimally at higher speeds or with a nonpassenger vehicle crash partner (Cicchino & Zuby, 2019).

This protocol describes the test procedure for evaluating the performance of front crash prevention (FCP) systems on passenger vehicles that warn, brake, or steer to mitigate or prevent front-to-rear crashes with passenger cars, motorcycles, and tractor trailers at higher speeds. The test procedure is based on a potential front-to-rear collision in which the crash partner is stationary prior to impact. The stationary vehicle in the test is a surrogate target representing a car or motorcycle or an actual dry van trailer.

Performance requirements are based on the test vehicle's ability to

1. notify the driver of a potential crash and avoid or mitigate crashes with two stationary targets (a passenger-car surrogate and motorcycle surrogate) in the center of the lane and to the left or right of the lane center at 50, 60, and 70 km/h (31, 37, and 43 mph); and
2. warn of a potential collision with a stationary dry van trailer in the center of the lane at 50, 60, and 70 km/h.

TEST ENVIRONMENT

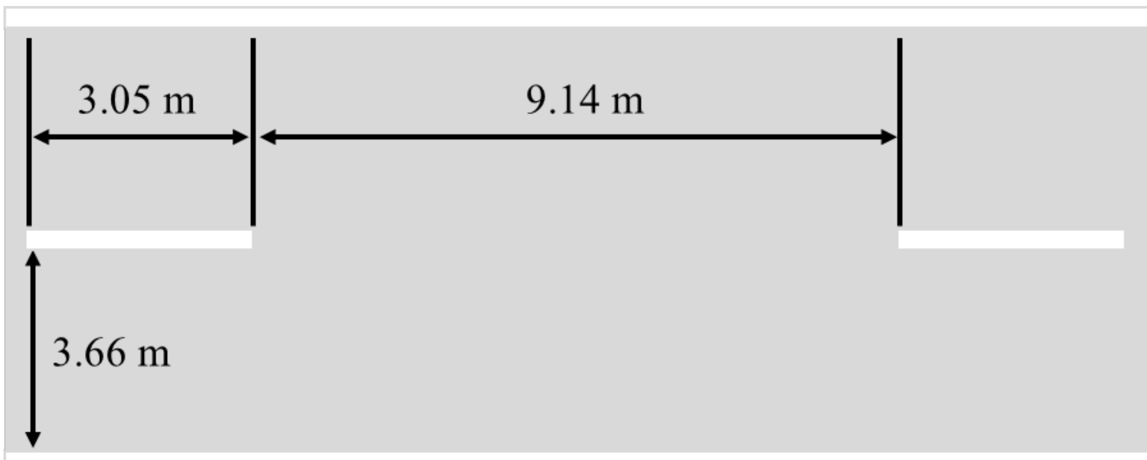
Surface and markings

Tests are conducted on a dry asphalt surface without visible moisture. The surface is straight and flat, with a 1% lateral slope for water management. The asphalt is in good condition, free of potholes, bumps, and/or cracks that could cause the test vehicle to pitch excessively.

Testing is conducted in the left or right lane of a two-lane roadway (Figure 1). The roadway is marked with continuous solid white lane markers on the outside and dashed white lane markers in the center. The lane widths are 3.66 m (12 ft), and the dashed lines are 3.05 m (10 ft) in length separated by 9.14 m (30 ft). The width of the lines is 0.1 m (4 in).

Figure 1

Lane markings



Surroundings

During testing, no other vehicles, obstructions, or other objects may be within 3 m (9.8 ft) on either side of the test path or any closer than 25 m (82 ft) from the stationary test target. Overhead signs, bridges, gantries, or other significant structures within the lane must be more than 5 m (16 ft) above the ground.

Ambient conditions

Testing is not conducted during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, and/or ash. The ambient air temperature must be between 32 and 100 °F (0 and 38° C) during testing. Peak wind speeds shall be below 10 m/s (22 mph) to minimize target and test vehicle disturbance.

Natural ambient illumination must be more than 2,000 lux as measured in a plane parallel to the asphalt surface. The solar azimuth angle measured in degrees from the horizon should not be less than 15 degrees during testing.

Ambient temperature, ambient illumination, wind speed, and wind direction are measured and recorded at 1-minute intervals during testing.

TARGET VEHICLES

Stationary passenger-car target

The Soft Car 360 Guided Soft Target (GST) system produced by AB Dynamics is used as the stationary passenger-car target (https://www.abdynamics.com/en/products/track-testing/adas-targets/soft-car-360). The Soft Car 360, henceforth referred to as the Global Vehicle Target (GVT), is Revision F or later.

The GVT is mounted on a stationary stand with a Teflon sheet underneath for maneuverability (Figure 2). The GVT is equipped with a U.S.-specific license plate. The GVT must be assembled per manufacturer requirements prior to each test.

Figure 2

Passenger car target (GVT Revision F or later)

Stationary motorcycle target

The 4activeMC produced by 4active systems (https://www.4activesystems.at/4activemc-gmt) or the Soft Motorcycle 360 (https://www.dri-ats.com/soft-motorcycle-360/) is used as the stationary motorcycle target.

The 4active MC motorcycle target mounted on the 4activeXS low-profile platform is shown in Figure 3. The front tire of the motorcycle target rests on the low-profile platform and the rear tire rests on the road. The motorcycle target must be assembled per manufacturer requirements prior to each test.

Figure 3

Motorcycle target

Stationary dry van trailer

A 2021 Vanguard dry van trailer is used as the stationary trailer target.

The dry van trailer is 16.13 m (52.92 ft) long, 2.59 m (8.50 ft) wide, and 4.10 m (13.45 ft) tall from the ground to the top of the dry van trailer. The distance from the ground to the bottom of the bumper guard is 0.51 m (1.67 ft). The distance from the rear of the trailer to the center of the rearmost axle is 1.42 m (4.66 ft).

Trailer payload should be 1,000 kg (2,205 lb) or less during testing.

Trailer tires must be inflated to the manufacturer's recommended cold inflation pressure prior to each test. The dry van trailer may be connected to a three-axle tractor or trailer dolly during testing. The rear tires may be chalked to prevent the trailer from rolling backwards.

Figure 4

2021 Vanguard dry van trailer

TEST VEHICLE PREPARATION

General

Tests shall be undertaken using a new vehicle in the "as received" condition with accumulated mileage between 200 and 5,000 miles (322 and 8,047 km) indicated on the odometer. Prior to commencing preparation and testing ensure that:

- the tires are new, original equipment tires inflated to the manufacturer's recommended cold inflation pressure. If more than one recommendation is provided, the tires are inflated to the lightly loaded condition;
- the fuel tank is filled to at least 90% of capacity with the appropriate fuel and maintained to at least 75% capacity throughout the testing; and
- all other fluid reservoirs are filled to at least their minimum indicated levels.

The vehicle includes the driver and all required equipment during testing. Where possible, the equipment is placed on the passenger side of the vehicle. The vehicle test weight should not exceed the vehicle curb weight by more than 200 kg (441 lb).

Instrumentation

The test vehicle is equipped with an Oxford RT2002 Inertial and GPS Navigation System to measure and record speed, longitudinal and lateral acceleration, longitudinal and lateral position, and angular velocity. These data are sampled and recorded at a frequency of 100 Hz. Steering wheel angle may be obtained from the vehicle onboard diagnostics port or video recording.

A Racelogic Video VBOX Pro is used to overlay data obtained from the Oxford RT2022 onto a video image recording using a 30-fps camera. One camera is positioned with a driver perspective out of the front windshield. A second camera is used to show the forward collision warning (FCW).

Table 1

Test vehicle instrumentation

Measurement	Equipment	Accuracy
Speed	Oxford RT2022 GPS	0.1 km/h
Longitudinal and lateral acceleration	Oxford RT2022 GPS	0.01 m/s^2
Longitudinal and lateral position	Oxford RT2022 GPS	0.02 m
Angular velocity	Oxford RT2022 GPS	0.02 °/s
Steering wheel angle	OBDII or video	1.0 °
Impact time	Oxford RT2022 GPS	n/a

Note. n/a = not applicable.

Timing and distance settings

Forward collision warning, automatic emergency braking, and automatic emergency steering features of an FCP system that have different settings for the timing of the warning or intervention activation are set to the middle setting.

If there are an even number of settings, then the setting one increment further or earlier from the midpoint is selected. For example, if the four available settings are “furthest,” “further,” “closer,” or “closest,” then the “further” setting is selected.

TEST VEHICLE PRETEST CONDITIONING

Brake warm-up and maintenance

Before testing, 10 stops are performed from a speed of 56 km/h with an average deceleration of approximately 0.5 to 0.6 g.

Immediately following the series of 56 km/h stops, three additional stops are performed from a speed of 72 km/h with sufficient brake pedal force to activate the vehicle’s antilock braking system (ABS) for most of each stop.

Following the series of 72 km/h stops, the vehicle is driven at a speed of 72 km/h for 5 minutes to cool the brakes.

At any point during testing, if the test vehicle remains stationary for longer than 15 minutes, a series of three brake stops shall be performed from a speed of 72 km/h to warm the brakes. The longitudinal deceleration of these stops should be approximately 0.7 g. A minimum of 3 minutes must elapse between the completion of the last warm-up stop and the onset of a valid test trial. A minimum of 3 minutes must elapse between each individual test run with the passenger-car and motorcycle surrogate targets.

FCP initialization

Some vehicles require a brief period of initialization before FCP system performance can be properly assessed. During this time, diagnostics to verify functionality and sensor calibrations are performed.

If system initialization is required, IIHS will obtain and perform the appropriate procedure from the vehicle manufacturer.

STATIONARY TARGET TEST

Test vehicle width and target vehicle position

The test vehicle's width is measured between the outermost body locations above the front wheel axle centerlines. The 25% overlap position is based on a percentage of the vehicle's width measured from the front-left or front-right side depending on the target vehicle position. A Romer arm is used to mark the midline and the 25% overlap positions on the vehicle.

Two target positions are used during testing with the passenger car and motorcycle targets: the center position and either the left or right position. The target positions are as follows:

- **Center**: The passenger car and motorcycle targets must be positioned with their longitudinal midline aligned with the center of a travel lane (Figures 5 and 6).
- **Left:** The passenger car and motorcycle targets must be positioned with their longitudinal midline offset to the left of the test vehicle's centerline by 25% ± 1% of the vehicle width.
- **Right:** The passenger car and motorcycle targets must be positioned with their longitudinal midline offset to the right of the test vehicle's centerline by 25% ± 1% of the vehicle width.

Only the center target position is used in testing with the dry van trailer (Figure 7).

The distance between the vehicle midline and the 25% overlap positions is measured from the center of the travel lane to identify the location of the target midline in the left and right target positions. For every position, the target vehicle must be positioned with its longitudinal axis oriented parallel to the roadway edge, facing the same direction as the front of the test vehicle, so that the test vehicle approaches the rear of the target vehicle.

Figure 5

Passenger-car target position

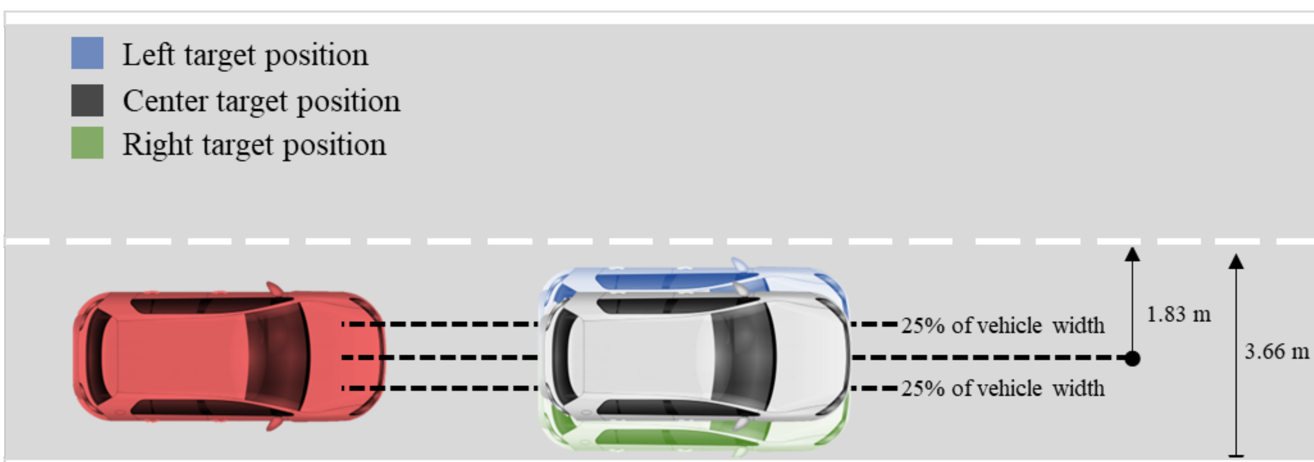


Figure 6
Motorcycle target positions

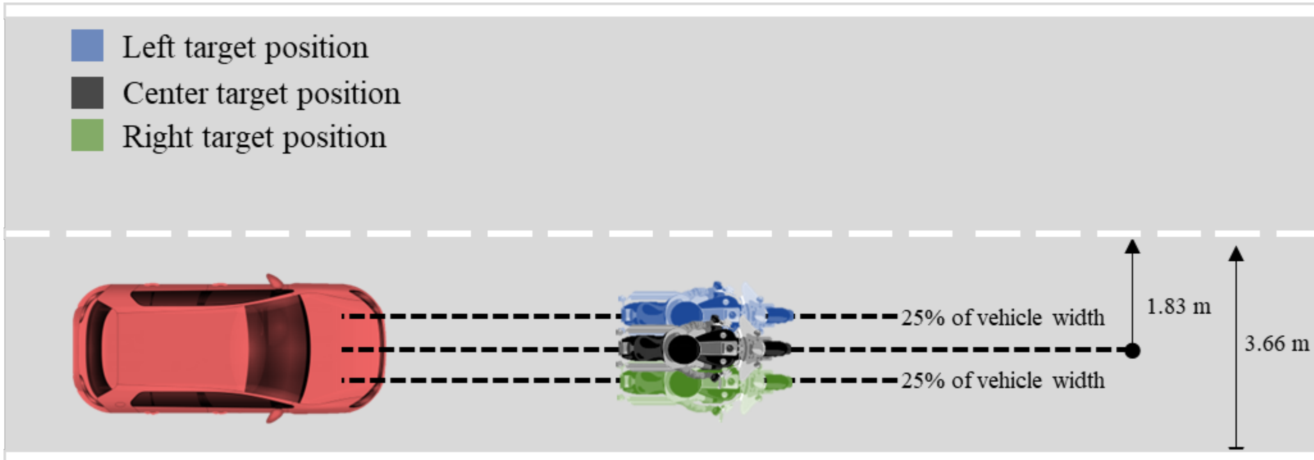


Figure 7
Dry van trailer target position

Test scenarios and requirements

Testing at a given test speed and target position proceeds until data from three valid trials is collected. Each trial with the passenger car or motorcycle target ends when the test vehicle impacts or avoids the target. Each trial with the dry van trailer ends when the test vehicle provides a forward collision warning, or the test vehicle is 1.75 or fewer seconds from colliding with the dry van trailer (24.3 m at 50 km/h; 29.2 m at 60 km/h; 34.0 m at 70 km/h).

An evasive steering maneuver to the left or right is used to abort tests with the trailer and FCW tests with the passenger car or motorcycle targets.

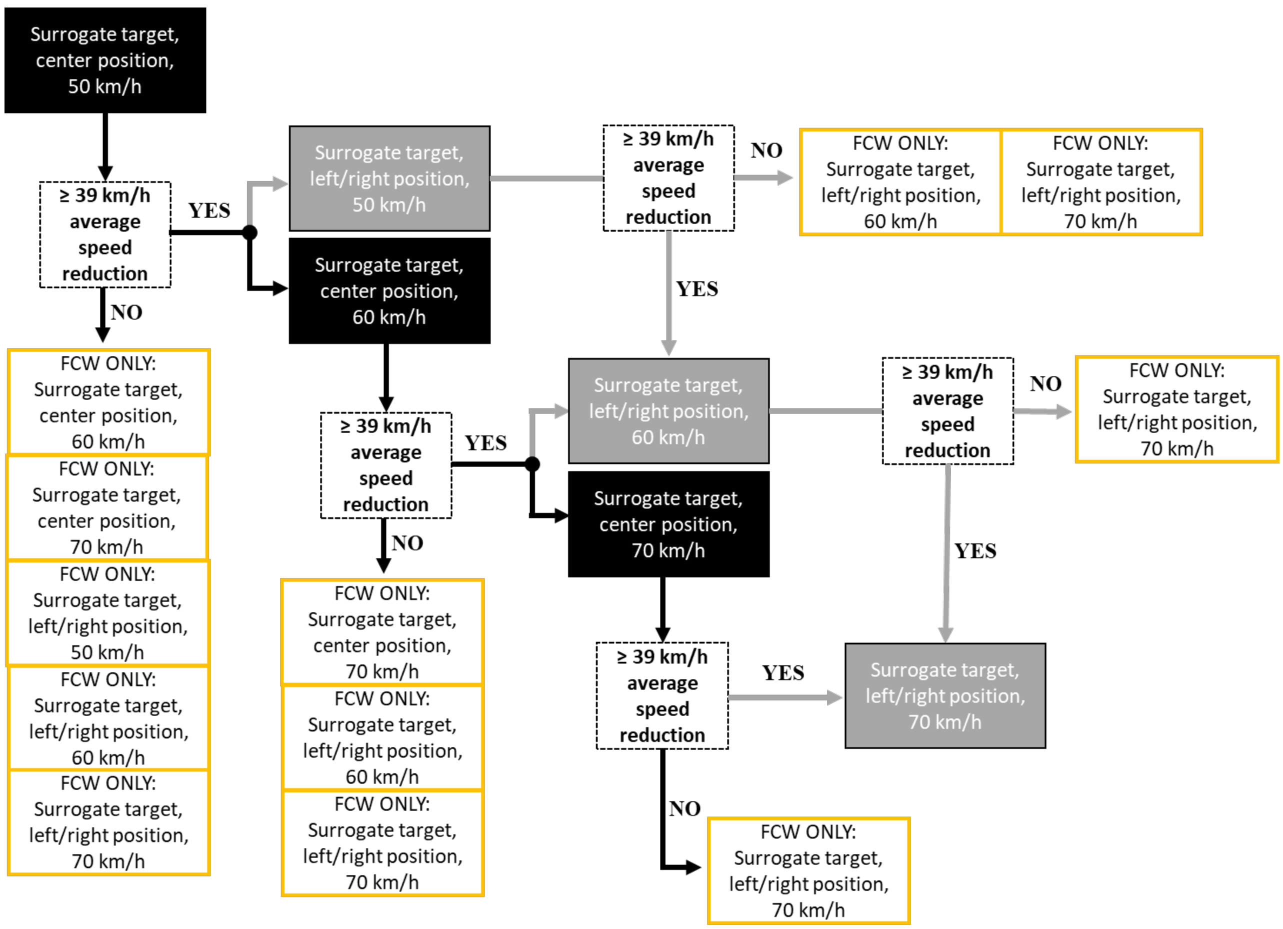
Passenger car and motorcycle targets

FCP system performance is evaluated with the passenger car and motorcycle targets in the center position and either the left or right position. The test scenarios and requirements for evaluating crash avoidance with the passenger-car and motorcycle surrogate targets is the same and illustrated in Figure 8. If the manufacturer indicates the FCP system does not detect a motorcycle, then only the activation of FCW is tested with the motorcycle target and crash avoidance is not evaluated.

Testing begins with the test vehicle approaching the passenger car or motorcycle target in the center position at 50 km/h. The average speed reduction across three valid trials is measured. If the average speed reduction is 39 km/h or greater across three trials, then the test speed is increased by 10-km/h increments up to 70 km/h. Crash avoidance testing ends if the average speed reduction is less than 39 km/h.

Figure 8

Test scenarios and requirements with the passenger-car and motorcycle surrogate targets



Crash avoidance testing with the passenger car or motorcycle target in the left or right position occurs after evaluating performance with the target in the center position. The left or right position is randomly selected and used for the entire test sequence. Testing with the target in the left or right position only proceeds if the average speed reduction is 39 km/h or more across three valid trials in the 50-km/h test with the target in the center position.

Testing with the target in the left or right position begins at the 50-km/h test speed. The average speed reduction across three valid trials is measured. If the average speed reduction is 39 km/h or more with the target in the left or right position **and** with the target in the center position at a test speed of 60 km/h (10 km/h more than the current test speed), then the test speed for the target in the left or right position is increased by 10-km/h increments up to 70 km/h.

For example, to be eligible for the 60-km/h test with a passenger car or motorcycle target in the right or left position, the average speed reduction must be 39 km/h or more in the 50-km/h test with the target in the right or left position **and** in the 60-km/h test with the target in the center position. Crash avoidance testing ends when one requirement is not met.

The activation of FCW is measured in three valid trials at **every** combination of test speed (50, 60, and 70 km/h) and target position (center, left or right) for both the passenger car and motorcycle targets **including** those combinations where crash avoidance is no longer being evaluated.

An evasive steering maneuver to the left or right is used to abort tests where crash avoidance is not evaluated. The test is aborted when the test vehicle provides an FCW, or the test vehicle is 1.75 or fewer seconds from colliding with the target (24.3 m at 50 km/h; 29.2 m at 60 km/h; 34.0 m at 70 km/h), whichever happens first.

Dry van trailer target

FCP system performance is evaluated with the dry van trailer target in the center position only. Testing begins with the test vehicle approaching the dry van trailer target in the center position at 50 km/h (Figure 9). Test speed is increased in 10-km/h increments up to 70 km/h once data from three valid trials is collected at a given test speed. There are no requirements for moving to the next test speed with the dry van trailer target. The activation of the FCW in three valid trials is measured at each test speed.

Figure 9

Test scenarios with the dry van trailer

Test vehicle approach

At the start of each test, the test vehicle begins moving between 200 and 250 m from the stationary target vehicle and accelerates towards the target. For the 50, 60, and 70-km/h tests, the approach phase begins 75, 90, and 105 m before the target, respectively. The approach phase ends when the test vehicle:

- impacts the passenger car or motorcycle target;
- avoids the passenger car or motorcycle target;
- provides a FCW for the dry van trailer, or
- is 1.75 seconds or less from impacting the dry van trailer.

During the approach phase, the driver is required to:

- modulate the throttle using smooth inputs to maintain the nominal test speed;
- use the least amount of steering input necessary to maintain the test vehicle in the center of the lane;
- avoid abrupt steering inputs or corrections; and
- not contact the brake pedal.

The following criteria must be met during the approach phase for the test to be valid:

- the vehicle speed shall remain within ± 1.0 km/h of the nominal test speed until impact with the target or activation of the FCW, automatic braking, or automatic steering;
- the angular velocity must remain within the range of ± 1 °/s; and
- the lateral distance between the centerline of the test vehicle relative to the centerline of the lane shall not exceed ± 0.2 m.

FCP activation

FCP systems may include several countermeasures for mitigating or avoiding a front-to-rear crash such as providing an audible, visual, or haptic FCW; automatically applying the brakes; or automatically performing an evasive steering maneuver. The activation time of each countermeasure is defined as follows:

- **Forward collision warning (FCW) activation:** the first frame with a visual or audible FCW identified during video review;
- **Automatic emergency braking (AEB) activation:** the final time point where acceleration is less than -0.5 m/s^2 when looking backwards from peak deceleration and the test vehicle is within 60 m of the target; and
- **Automatic emergency steering (AES) activation:** the first point at which the angular velocity exceeds ± 1 °/s prior to reaching maximum angular velocity.

Calculating FCP speed reduction

If the test vehicle does not contact a target and remains in an unoccupied travel lane, then the impact speed is zero (100% speed reduction) regardless of the countermeasure employed. In trials with contact, speed reduction is calculated by subtracting the test vehicle speed at the time of impact from the test vehicle speed prior to AEB or AES activation. The test vehicle speed before AEB or AES activation will be calculated based on the average speed for 0.1 second prior to AEB or AES activation. If the test vehicle automatically moves or attempts to move to an occupied travel lane or off the marked road, then the speed reduction is 0%.

Impact point

The impact point is measured when the forwardmost location of the test vehicle contacts the target vehicle. The position of the target vehicle should be easily reproducible for multiple tests. The impact point is only recorded in trials with the passenger car and motorcycle targets.

DATA ANALYSIS

Lateral and longitudinal position

The lateral and longitudinal position is measured in meters, and the raw data is used to evaluate the vehicle position.

Longitudinal acceleration

Longitudinal acceleration is measured with an accelerometer in m/s^2. The raw data is filtered with a 12-pole phaseless Butterworth filter with a cutoff frequency of 6 Hz.

Speed

The speed is measured in km/h, and the raw data is used to evaluate speed.

Angular velocity

The angular velocity is measured in degrees per second. The raw data is filtered with a 12-pole phaseless Butterworth filter with a cutoff frequency of 6 Hz.

Target impact point

The impact point is measured by the Oxford System. The “zero” location is the point where the front of the test vehicle meets the rear of the target vehicle. A tape switch may be used to verify impact at the “zero” location.

SCORING AND RATING SYSTEM

Points are awarded per Table 2 based on the average speed reduction in three valid test runs at each test speed (50 km/h, 60 km/h, 70 km/h) in each scenario with the passenger-car and motorcycle surrogate targets (center position, right or left position). Decimal values of average speed reduction are truncated before awarding points. For example, an average speed reduction of 49.1 km/h is truncated to 49 km/h and 2 points are awarded.

Table 2
Points awarded for average speed reduction

Speed reduction range (km/h)	Points
39 to 48	1.0
49 to 58	2.0
59 to 68	3.0
69 to 71	4.0

Points are awarded for vehicles with an average FCW time-to-collision (TTC) greater than or equal to 2.1 seconds across three valid test runs at each test speed in every test scenario. Two points are awarded for each test speed with the dry van trailer and 1 point is awarded for each test speed in every scenario with the passenger car or motorcycle. The average FCW TTC value is rounded to the nearest tenths of a second. Partial credit is not given for FCW.

The points for average speed reduction and FCW TTC are summed for each test scenario. The total score is the sum of all test scenario subtotals. The final rating scale is shown in Table 3.

Table 3
Final rating scale

Total score range	Rating	Rating icon
49–54	Good	G
37–48	Acceptable	A
25–36	Marginal	M
0–24	Poor	P

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