

Adaptive Cruise Control & Motorcycle Recognition

An Indicative Study



Figure 1 - Photo Preceding Entry onto RDW Test Centre Track for Tesla ACC Testing (20 December 2017)

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Preface

As an intern at RDW, my five-month role was to further the progress of advanced driver assistance systems (ADAS) testing conducted by Hogeschool Rotterdam alumnus Robert Rood. As such, this report acts to detail and highlight my progress in quantitatively evaluating the motorcycle recognition performance of adaptive cruise control (ACC) systems on ADAS equipped vehicles from a range of vehicle manufacturers. Due to the nature of this project, this report and that of Robert Rood's (titled ADAS Testing, Hoe reageren Advanced Driver Assistance Systemen op motorrijders?) are inherently reliant on each other. Consequently, it is recommended that both reports be referred to concurrently, as extraneous details were omitted in this report when fully elaborated in that of Robert's.

This report may be used as an indication of the current situation of ACC technology in recognizing and responding to motorcycles. However, it must be wholly remembered that limitations did exist during testing and because of these, this report and its contents describe nothing more than an *indicative* study.

I extend my appreciation and gratitude to all my RDW colleagues, and to those stationed at the RDW Test Centre. Whether you directly aided the progress of my assignment, welcomed me to participate in your own work, elucidated the progress of your tasks and roles, or even otherwise conversed with me over lunch, hartelijk bedankt voor alles!

Lelystad (NL), 19 January 2018, Eric Westerband

Summary

In October of 2016, motorcycle associations FEMA, KNMV, and MAG NL contacted RDW expressing concerns regarding the safety of motorcyclists with the admittance of (semi-)autonomous vehicles on European roadways. To address these concerns, RDW proposed to conduct its own test program evaluating the motorcycle recognition performance of adaptive cruise control (ACC) systems from a range of vehicle manufacturers. In this way, the question whether ACC systems detect motorcycles worse than cars, and if so, in what circumstances and in which manner may be answered. All in all, this report presents the development of this investigation.

While quantitative research was the primary method used for this investigation, desk research was also performed to better address the questions from several angles of analysis. Only thereafter was a test plan, comprised of three evaluations, devised and executed. Over the course of six separate test days, it was observed that the ACC systems of the Jeep Grand Cherokee, Hyundai Ioniq Electric, Skoda Octavia Combi, Volvo V40, VW Golf Variant, and Tesla Model S detect motorcycles worse than cars when the motorcyclist is riding more than 1,20 metres from the centreline of the vehicle/lane. However, due to the small number of repetitions conducted per evaluation, the results from these tests have little to no statistical significance. As a result, this report and its contents describe nothing more than an *indicative* study; and real-world results may vary.

Recommendations proposed include further processing of data, investigating if and how adjacent objects and vehicles affect the performance of advanced driver assistance systems (ADAS), presenting project findings to vehicle manufacturers, governing bodies and to motorcycle action groups and clubs, and testing the advanced driver assistance (ADA) system blind spot monitoring (BSM).

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List of Abbreviations

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADA	Advanced Driver Assistance
ADAS	Advanced Driver Assistance Systems
AEBS	Advanced Emergency Braking System
AI	Artificial Intelligence
BSM	Blind Spot Monitoring
EC	European Commission
EU	European Union
FEMA	Federation of European Motorcyclists' Associations
IMU	Internal Measurement Unit
KNMV	Koninklijke Nederlandse Motorrijders Vereniging
MAG NL	Motorrijders Actie Groep Nederland
PB	Product Assessment
PTI	Periodic [motor vehicle] Technical Inspection
TCL	Test Centre Lelystad
TTV	Admission & Supervision on Vehicles
UNECE	United Nations Economic Commission for Europe
VRT	Vehicle Regulations & Admission
ZBO	Independent Administrative Body

1 Introduction

In October of 2016, Federation of European Motorcyclists' Associations (FEMA), Koninklijke Nederlandse Motorrijders Vereniging (KNMV), and Motorrijders Actie Groep Nederland (MAG NL) contacted RDW expressing concerns regarding the safety of motorcyclists with the admittance of (semi-)autonomous vehicles on European roadways [1]. Prompted by a multi-vehicle collision in Norway where a motorcyclist was severely injured when rear-ended by a Tesla driving in 'autopilot' mode [2], FEMA, KNMV, and MAG NL advocate that cars with advanced driver assistance systems (ADAS) have been insufficiently tested in combination with motorcycles or other two-wheeled vehicles [3]. Moreover, citing German- and US-based articles and publications, they ask that RDW reassess the requirements of European whole vehicle type approval certification [4].

To address these concerns in the interest of public safety and others, RDW proposed to conduct its own test program to "objectively assess what the current state of affairs is in the technique that should ensure motorcycles and other powered two wheelers are detected by the sensors [of cars] and whether that technology also responds correctly to the presence of motorcycles" [1]. In February of 2017, RDW began this investigation and by considering motorcycle crash statistics and ADAS legislation in Europe, an effective test setup to quantitatively evaluate the advanced driver assistance (ADA) systems adaptive cruise control (ACC), advanced emergency braking system (AEBS), and blind spot monitoring (BSM) was developed.

To further the progress, RDW wishes to quantify the motorcycle recognition performance of ACC systems on ADAS equipped vehicles from a range of vehicle manufacturers. Hence, this report – which details the design, implementation, method, results, and conclusion of field tests – presents the enhancement of this investigation.

2 Project Description

To address the concerns of FEMA, KNMV, and MAG NL, RDW wishes to quantify the motorcycle recognition performance of ACC systems on ADAS equipped vehicles from a range of vehicle manufacturers. To accomplish this, RDW personnel were tasked with quantitatively evaluating whether the ACC systems of vehicles detect motorcycles worse than cars, and if so, in what circumstances and in which manner.

2.1 Problem

Motorcycle associations FEMA, KNMV, and MAG NL suspect that the driver assist systems of vehicles pose a significant safety risk to motorcyclists.

2.2 Importance

Proactively responding to these concerns is worthwhile and necessary for several reasons. For one, these concerns involve and regard all road users in the Netherlands and abroad. As driving continues towards its expected transition into full artificial intelligence (AI) autonomy, an extended period of hardware and software development will be necessary. Regardless, public safety should remain a top priority and will require effort from the whole of society. Secondly, RDW and other organizations have the authority to publish and therefore catalyse a follow-up response from legislators should the results from this indicative study suggest it. In the same way, vehicle and product manufacturers, and the human drivers responsible for the correct and appropriate use of ADAS features are also accountable to

minimize the risk for the driver, passengers, and other road users not limited to occupants in other vehicles, motorcyclists, bicyclists, and pedestrians.

3 Literature & Theory on Adaptive Cruise Control

ADAS is comprised of all automated vehicle systems that support a driver with his/her responsibility to drive safely and prudently. With the goal of improving traffic safety, these systems support the driver, “ranging from the simple provision of information (e.g. navigation, speed limit), through assisting (e.g. advanced cruise control, stop-and-go) or even taking over all of the driver’s tasks (e.g. the automated highway system)” [5]. ACC, a development of conventional cruise control, automates the non-directional driving task by controlling a vehicle’s headway and speed [5]. Fundamentally comprised of a bumper mounted radar, vehicles with ACC “automatically increase the following distance to a vehicle ahead by reducing fuel flow and/or actively braking the vehicle if it is set to a cruise speed that is faster than the speed of a vehicle ahead” [5]. In doing so, the vehicle can control or otherwise supervise the longitudinal driving task of the driver.

While ACC is considered by some as a safety system, many vehicle manufacturers solely market ACC as a convenience for drivers. While this decision could be primarily motivated due to a system’s limited oversight or braking ability, avoiding an untold number of liability issues is likely a factor as well [6]. As a result, “the driver remains fully responsible for vehicle manoeuvring” [5]. Furthermore, while the working principles and limitations of vehicle ACC systems are almost exclusively found in the vehicle owner’s manual, “a remarkable percentage of drivers do not read [it]” [7].

ACC system limitations commonly shared between manufacturers include the following:

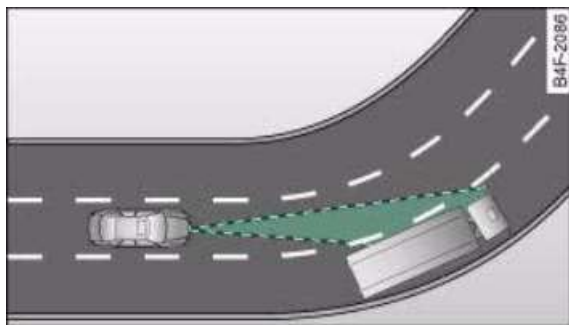


Figure 2 - ACC Limitations; driving into a bend [8]

When driving into a bend or curve in the road, the vehicle may react to vehicles traveling in an adjacent lane [8].

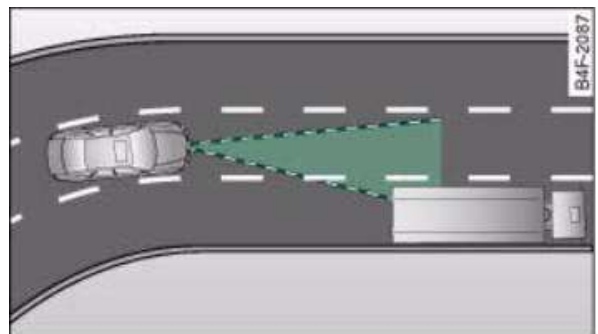


Figure 3 - ACC Limitations; driving out of a bend [8]

When driving out of a bend or curve in the road, the vehicle may react to vehicles traveling in an adjacent lane [8].

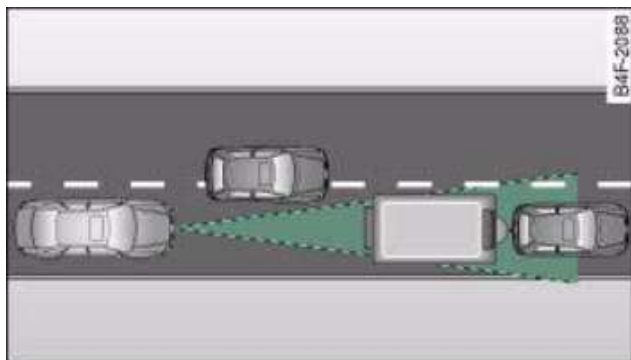


Figure 4 - ACC Limitations; vehicle out of line [8]

Vehicles not in line with the range of the radar sensor will not be detected until within range of the sensor [8].

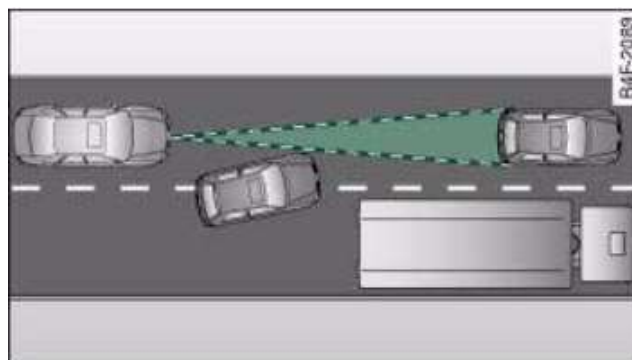


Figure 7 - ACC Limitations; vehicle changing lanes [8]

Other vehicles entering the driver's lane within close proximity "cannot be detected by the radar sensor until they move into its range" [8].

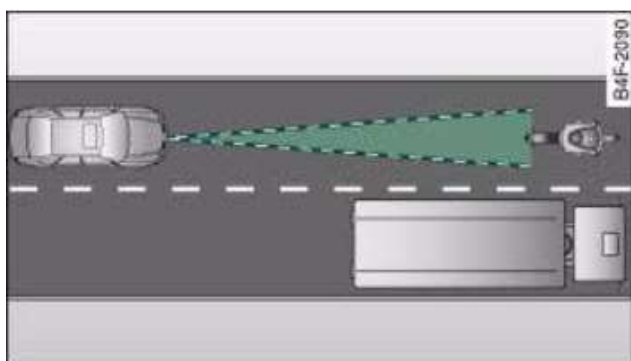


Figure 5 - ACC Limitations; non-clearly discernible vehicles [8]

"Vehicles that are not clearly discernible, e.g. a motorcycle ... are often identified late or may not be detected at all" [8].

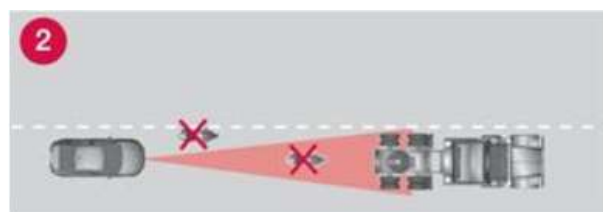


Figure 8 - ACC Limitations; small vehicles out of line [10]

"Small vehicles, such as motorcycles, or vehicles not driving in the centre of the lane may remain undetected" [11].

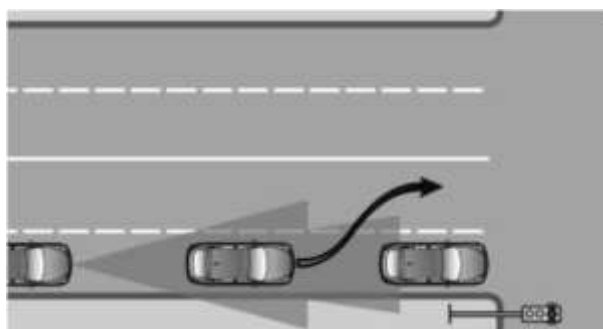


Figure 6 - ACC Limitations; unexpected lane change [9]

"The [ACC] system does not react to stopped vehicles" [9].

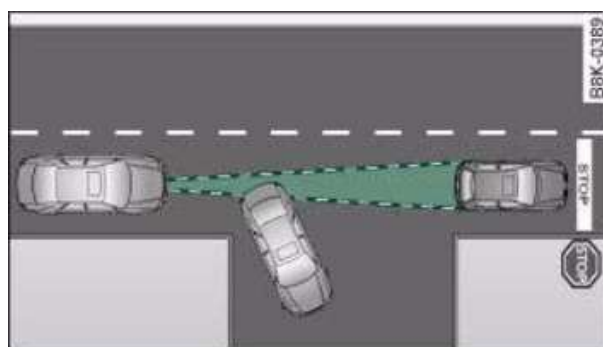


Figure 9 - ACC Limitations; stationary vehicles [8]

"The ACC system will not react to the stationary vehicle" [8].

Along with investigating ACC system limitations, desk research exploring the driving behaviour of humans when ACC systems are active was also conducted. While it was revealed that users of ACC exhibit a decrease in reaction time, “defining an overarching general conclusion as to what extent ACC affects driving characteristics and driver’s mindset [was] otherwise difficult” [12] due to demographic disparities and particularities (e.g. age, gender, driving experience) between referenced studies and their participants [12].

4 Test Plan Design and Implementation

The test plans used to evaluate the ACC system performance of vehicles is heavily based on that outlined in ADAS Testing, Hoe reageren Advanced Driver Assistance Systemen op motorrijders?. Where apposite, changes were implemented based on the suggestions and recommendations to improve suitability and participant safety.

4.1 Finalized Test Plan

To address the concerns of the motorcycle action groups, a test plan was developed to quantify the motorcycle recognition performance of ACC systems on ADAS equipped vehicles from a range of vehicle manufacturers. While all versions of the test plan consisted of the same three evaluations, modifications were made between test days to improve relevance and feasibility. In this section, the final form of the test plan is described.

4.1.1 Test Day Instructions

Evaluations 1, 2, and 3 were performed in numerical order. Furthermore, before testing the performance of an ACC system when interacting with a motorcycle, Evaluations 1 and 2 were performed with a control vehicle first. Reasons for this were to provide a baseline performance of the ACC system while test participants became more acquainted with the system and its behaviour. In this way, the risk of grave bodily harm resulting from a collision due to driver-system unfamiliarity or from complete system failure is minimized. If a speed combination (paired subject and vehicle speed) or evaluation was deemed unsafe by either the ACC vehicle driver and co-pilot, the motorcycle rider, or the safety tower supervisor, the test was stopped immediately, and any higher speed combinations of that exercise were not performed. Participant safety is the absolute top priority.

4.1.2 Understanding the Tables

Table 1 - Example Test Plan Table

		Subject Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Target Vehicle [km/h]	30	N	1	2						
	40	L8R		N						
	50			L8R		3				
	60				4	N	6			
	70					5				
	80							N		
	90							7	8	9

- The speeds indicated (in white) in each table are real world speeds indicated by the VBOX measuring equipment; they are not the indicated speeds given by the vehicle's speedometer. This was done to provide consistency when time to analyse the data from test days.
- The coloured cells of teach table correlate to the risk of each speed combination for each evaluation. Based on a colour spectrum scale, green equates to lower risk while red equates to higher risk. Cells in black represent invalid speed combinations since the target vehicle needs to be traveling slower than the subject vehicle.
- The characters within each coloured cell have their own meaning:
 - L8R – Speed combination will be performed in a later evaluation.
 - 1 – Perform speed combination once.
 - 2 – Perform speed combination twice (if time allows).
 - ...
 - 9 – Perform speed combination nine times (if time allows).
 - N – Perform speed combination as many times as would time allow while remaining considerate of the time needed to perform the other evaluations/speed combinations.

4.1.3 Evaluation 1: Target Vehicle Interruption

The purpose of this evaluation was to verify if (and less so how) the subject vehicle recognizes and responds to an overtaking target vehicle that performs a lane change within the subject vehicle's furthest following distance.

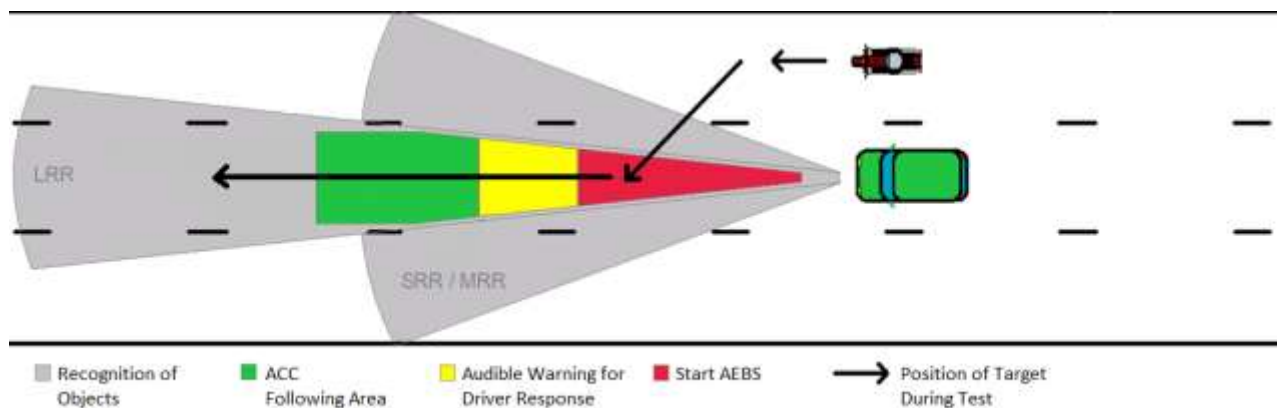


Figure 10 - Interruption of the ACC reaction area [not to scale] (modified photo of [13])

Table 2 - Target Control Vehicle Interruption Speed Combinations

Speed Combinations at RDW Test Centre				
Subject Vehicle		Target Control Vehicle		Safe to continue?
Lane	Speed [km/h]	Lane	Speed [km/h]	(circle)
2	30	3	40	Yes / No
2	50	3	60	Yes / No
2	70	3	80	Yes / No
2	90	3	100	Yes / No
2	110	3	120	Yes / No

Table 3 - Motorcycle Interruption Speed Combinations

Speed Combinations at RDW Test Centre				
Subject Vehicle		Motorcycle		Safe to continue?
Lane	Speed [km/h]	Lane	Speed [km/h]	(circle)
3	30	2	40	Yes / No
3	50	2	60	Yes / No
3	70	2	80	Yes / No
3	90	2	100	Yes / No
3	110	2	120	Yes / No

4.1.4 Evaluation 2: Subject Vehicle Approach

The purpose of this evaluation was to observe how the ACC system performed when approaching a slower moving vehicle in its lane of travel. Based on indication and response distances measured, one can observe whether the tested vehicles respond to motorcycles later than cars. Note that for Evaluation 2, the motorcycle rider is riding in the middle of the lane (i.e. position 3).

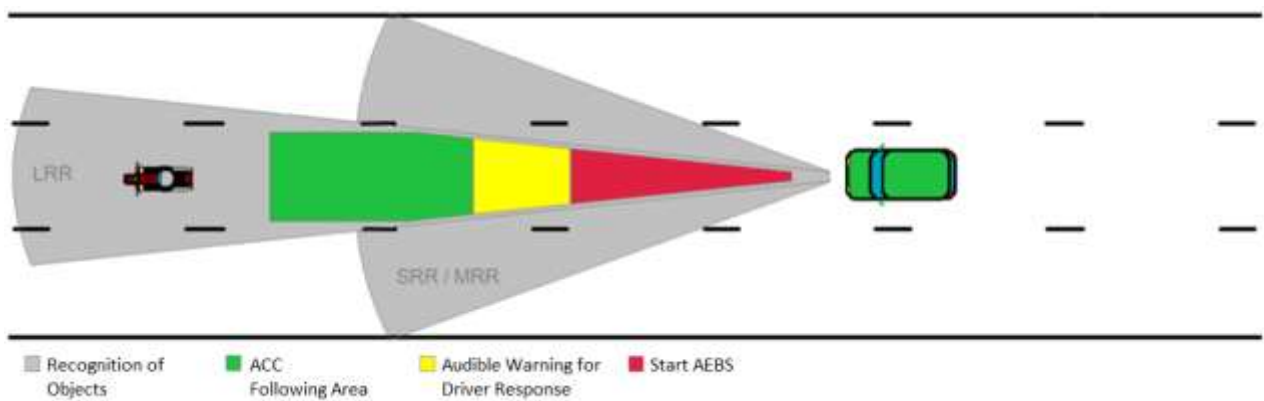


Figure 11 - ACC recognition, reaction, warning, and AEBS area [not to scale] [13]

Table 4 - Speed Combinations with Target Control Vehicle

		Subject Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Target Control Vehicle Speed [km/h]	30	N	2	2						
	40	N		N						
	50			N		2				
	60				2	N	2			
	70					2				
	80							N		
	90							2	2	2

Table 5 - Speed Combinations with Motorcycle

		Subject Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Motorcycle Speed [km/h]	30	L8R	1	1						
	40	L8R								
	50			L8R		1				
	60			L8R	1	1	1			
	70					1				
	80							1		
	90							1	1	1

4.1.5 Evaluation 3: Lane Position Detection

The purpose of this evaluation was to observe if a motorcycle's lane position effects the performance of the subject vehicle's ACC. This evaluation is identical to Evaluation 2 with the exceptions that:

- 1) It is not performed with the target control vehicle.
- 2) The motorcycle will ride in each of the five lane positions for each speed combination.

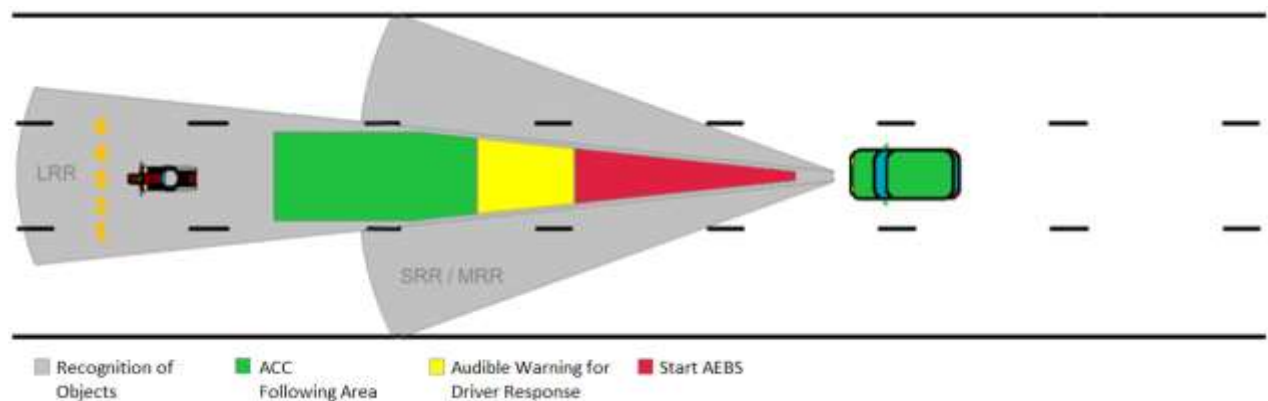


Figure 12 - Lane Position Detection [not to scale] (modified photo of [13])

Table 6 - Lane Position Speed Combinations with Motorcycle

		Subject Vehicle Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Motorcycle Speed [km/h]	30	N								
	40	N		N						
	50			N						
	60									
	70									
	80									
	90									

4.1.6 Recommended Abort Distances

Table 7 - Recommended Abort Distances for Evaluations 2 & 3

Abort Distance [m]		Subject Vehicle Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Target Vehicle Speed [km/h]	30	22	30	39	49	60	72	85	98	113
	40	18	26	35	45	56	68	81	95	110
	50		22	31	41	52	64	77	91	106
	60			26	36	47	59	72	85	100
	70				29	40	52	65	79	94
	80					33	45	58	72	87
	90						37	50	64	79

If the distance between the subject and target vehicles fell within the distance indicated per speed combination, it was recommended that the run be aborted. This was motivated because the numbers represent the maximum separation distance where contact would be made if both vehicles brake to their fullest potential. Elaboration of how these distances were calculated can be found in 11.2.1.

4.2 Vehicle Selection

The aim of this project is to evaluate the ACC system of vehicles from multiple vehicle manufacturers. As such, significant effort was made to select test vehicles that were unique for such a reason. Additionally, to maximize the relevance of this study, vehicles that have a considerable market share on Europe roads were prioritized over others. Since this project is a continuation of that conducted previously, consistency in the target control vehicles and motorcycles selected was maintained.

4.2.1 Subject Vehicles

All subject vehicles tested were either RDW lease vehicles or were vehicles otherwise acquired by the RDW for company business. The reason for this was due to the difficulties previously encountered when trying to outsource test vehicles from rental/lease companies. Referencing ADAS Testing, Hoe reageren Advanced Driver Assistance Systemen op motorrijders?, the VW Golf, VW Polo, Ford Focus, VW Passat, Skoda Octavia, Audi A3, Opel Astra, Mercedes-Benz C-Class, VW Tiguan, and Kia Sportage were the ten vehicle models most purchased in Europe in 2015 [13]. Hence, all this considered, the six subject vehicles selected for testing were:

- Jeep Grand Cherokee (2013) – Fiat Chrysler Automobiles (Italy)
- Hyundai Ioniq Electric (2017) – Hyundai Motor Group (South Korea)
- Skoda Octavia Combi (2017) – Volkswagen Group (Germany)
- Volvo V40 (2012) – Geely (China)
- VW Golf Variant (2013) – Volkswagen Group (Germany)
- Tesla Model S (2017) – Tesla (United States)

4.2.2 Target Control Vehicles

A Seat Toledo was previously used as the target control vehicle due to its ideal and standard classification (M1 AA saloon) used for ECE truck and bus AEBS testing requirements. Hence, for project unison, the target control vehicles used were:

- Seat Toledo (2014)
- VW Polo (2010)

Although the Seat was the target control vehicle for five of the six test days, it was absent during one of the test days, and as a result, an available VW Polo was used as its replacement.

4.2.3 Motorcycles

Several factors were considered when selecting a motorcycle for testing. Due to the associated risks, it was decided that a large displacement motorcycle would be used for the safety and comfort of the test riders. In this way, the motorcycle will have sufficient power to quickly drive away from a dangerous situation. Additionally, the motorcycles selected were without panniers to minimize the vehicle's width. Lastly, all motorcycles carried a standard Dutch license plate to mimic real-world driving conditions. The motorcycles used for testing were:

- Suzuki GSX-S1000F (2017)
- Ducati 900SS [modified] (1998)
- Triumph Tiger 1050 (2007)
- Yamaha MT-09 Tracer (2017)
- Suzuki V-Strom 650A (2017)

While attempts were made to acquire a single motorcycle for all test days, it was not possible to do so. This, however, does not nullify the results because the aim of the project is to evaluate the ACC performance of each vehicle rather than to make a comparison between them.

5 Test Method

The following chapter further elaborates the test method used during testing and data processing.

5.1 Test Equipment

To measure and record subject and target vehicle parameters during testing, Racelogic VBOX data loggers were used. Modular in design, VBOX equipment exhibits high accuracy in dynamic single-vehicle and multi-vehicle testing and allows for convenient testing of ACC and other ADA systems. When active, the VBOX units can measure and log up to 80 unique vehicle parameters. However, for ACC testing, solely six parameters are required to support a comparative evaluation of the distance a vehicle indicates, reacts to, and follows a target. For a single vehicle test, the required parameters are as follows:

Table 8 - Required VBOX Parameters for ACC Evaluation

Channel Name	Channel Description	Units
<i>UTC Time</i>	Coordinated Universal Time	[s]
<i>Speed</i>	Subject vehicle speed	[km/h]
<i>LngRsv-tg1</i>	Longitudinal distance between the Subject and Target Vehicles measured in the direction of the Subject Vehicle heading	[m]
<i>LatRsv-tg1</i>	Lateral distance between the Subject and Target Vehicles measured at right angles to the Subject Vehicle heading	[m]
<i>Angle-tg1</i>	Angle to the Target Vehicle with respect to the heading of the Subject Vehicle	[°]
<i>Spd-tg1</i>	Target vehicle speed	[km/h]
<i>Brake Trigger</i>	I/O measurement of a manual trigger	n/a

Near identical to the setup outlined in ADAS Testing, Hoe reageren Advanced Driver Assistance Systemen op motorrijders?, the key VBOX equipment used for ACC testing included:

- (2x) VBOX 3i RTK [100 Hz]
- (2x) VBOX Manager
- (2x) Dashboard Monitor
- DGPS
 - (1x) DGPS base station
 - (2x) DGPS transponder
- (2x) Telemetry Transponder
- (1x) Video VBOX Pro [20 Hz]
 - (3x) video cameras
 - (2x) microphone

Using this equipment, GPS measurements were accurate to within two centimetres. Additionally, note that an internal measurement unit (IMU) – used to obtain highly accurate measurements in pitch, roll, and yaw rate – was not used as these parameters are not necessary for ACC testing. A full technical specification sheet for equipment setup can be found in 11.5.

5.2 Video Recording

Unique to all Racelogic Video VBOX data loggers is the ability to customize the video display. Using the paired software, a scene was created to overlay several vehicle parameters onto the primary video feed in real time. While the primary camera faces forward displaying what is visible through the front windscreen, cameras 2 and 3 display the views out the rear of the vehicle and of the instrument cluster, respectively. The latest version of the video scene used for all vehicles apart from the Jeep can be seen in 11.4.

5.3 Data Processing

To process the data acquired, the data analysis software program VBOX Tools was used due to its powerful and highly flexible analysis ability. Unfortunately, the functionality of the built-in report generator was insufficient given the number of parameters needed to be processed and compared, and hence, all data points were instead identified and exported manually.

For Evaluations 1, 2, and 3, the parameters *UTC Time*, *Speed*, *LngRsv-tg1*, *LatRsv-tg1*, *Spd-tg1*, and *Brake Trigger* were exported to Excel by hand using a standard keyboard number pad. While this form of exportation risks typing errors, the ability to copy and paste the data was unavailable. To compensate for this risk, all data entries were double-checked for accuracy. Since all tests were conducted on the straight portions of the track, the parameter *Angle-tg1* was assumed to be zero.

The data presented in chapter 6 showcase the distance observed between the subject and target vehicles when the subject vehicle first indicates that it detects a vehicle ahead and when the subject vehicle first begins to react to it by autonomously braking. These distances are defined by the parameter *LngRsv-tg1*. The vehicle parameters at the indication distance are all taken from the moment the ACC system indicates to the driver (via the instrument cluster display) that a vehicle is seen ahead. To achieve this, the Video VBOX scene is played frame by frame until this occurs. The vehicle parameters at the reaction distance are all taken the moment the ACC system begins to decelerate from its cruising speed. Thus, when the vehicle decreases its speed from 80,31 [km/h] to 79,99 [km/h] or from 50,60 [km/h] to 49,99 [km/h] for example, the vehicle parameters are recorded. If for example, the vehicle speed decreases from a cruising speed of 50,31 [km/h] and jumps from 50,00 [km/h] to 49,97 [km/h], skipping 49,99 [km/h], the highest decimal value is recorded (in this case: 49,97 [km/h]).

For Evaluations 2 and 3, the speeds of the vehicles were numerically rounded to the nearest tens place during data analysis. As an example, if the subject and target vehicles were traveling at 52 [km/h] and 28 [km/h] respectively, the speeds were rounded to 50 [km/h] and 30 [km/h]. Similarly, if the subject and target vehicles were traveling at 56 [km/h] and 35 [km/h] respectively, the speeds were rounded to 60 [km/h] and 40 [km/h] respectively.

Further elaboration of data processing for the three evaluations can be seen below:

Evaluation 1

While the vehicle parameters at the indication distance are all taken from the moment the ACC system indicates to the driver that a vehicle is seen ahead, in the case of the Jeep, all parameters were recorded the moment all tyres of the target vehicle enter the subject vehicle's lane. Reasoning for this is explained in 7.1

Evaluation 2

While the vehicle parameters at the reaction distance are all taken the moment the ACC system begins to decelerate from its cruising speed, certain driving conditions make this more of a challenge. They are as follows:

- When the subject vehicle speed is increasing to its not yet reached cruising speed and abruptly begins to decelerate.
- When the subject vehicle speed is slowly decreasing to its not yet reached cruising speed and continues to decelerate past its set cruising speed.

When the subject vehicle speed is increasing to its not yet reached cruising speed and abruptly begins to decelerate, vehicle parameters are recorded at 0,01 less than the maximum speed reached (e.g. from 80,31 [km/h] to 79,99 [km/h] as explained above). When the subject vehicle speed slowly decreases to its not yet reached cruising speed and continues to decelerate past this set cruising speed, one of two things happen. If it is too difficult to discern at which moment the subject vehicle begins to autonomously brake, data from that particular speed combination trail is scrapped. If it is possible to discern at which moment the subject vehicle begins to autonomously brake (e.g. rate of deceleration increases suddenly and noticeably), the vehicle parameters are recorded at 0,01 less than the speed at which this was observed (e.g. from 50,60 [km/h] to 49,99 [km/h] as explained above).

Evaluation 3

Differentiating Evaluation 3 from Evaluation 2 is the fact that the motorcycle is no longer constrained to riding in the middle of the lane. The lane width of the banked circuit is 4,00 [m]. By dividing the lane into 5 equal segments, data from the parameter *LatRsv-tg1* was compared to the lane position. As such, with the subject vehicle driving in the middle of the lane:

- Position 1 concerns the *LatRsv-tg1* range: -2,00 [m] to -1,20 [m] (inclusive)
- Position 2 concerns the *LatRsv-tg1* range: -1,20 [m] to -0,40 [m] (exclusive)
- Position 3 concerns the *LatRsv-tg1* range: -0,40 [m] to +0,40 [m] (inclusive)
- Position 4 concerns the *LatRsv-tg1* range: +0,40 [m] to +1,20 [m] (exclusive)
- Position 5 concerns the *LatRsv-tg1* range: +1,20 [m] to +2,00 [m] (inclusive)

Complicating the matter is that the lateral position of the motorcycle with respect to the subject vehicle's heading is not constant. As a result, subjective reasoning was utilized where needed to account for the lane position of the motorcycle over the duration of the test run. Overlaying the video file onto the results from VBOX tools aided the ability for one to see in which lane position the motorcycle rider was in.

6 Vehicle Performance Results

In the following section, results obtained during the six test days are presented in either tabular or graphical format. Elaboration and interpretation of these results can be found in chapter 7.

6.1 Evaluation 1: Target Vehicle Interruption

Results from Evaluation 1: Target Vehicle Interruption are presented in table form. Elaboration of the non-numerical entrees is as follows:

Subject Vehicle, Target Control Vehicle, LngRsv tg1 columns:

Dash (-) = The data is unavailable or is otherwise invalid and is consequently excluded.

Indication column:

Yes = The instrument cluster displays an image of a vehicle indicating that the system detects a vehicle ahead.

No = The instrument cluster does not display an image of a vehicle indicating it does not see a vehicle ahead.

Dash (-) = The data is unavailable or is otherwise invalid to draw a Yes or No result.

Reaction column:

Yes = The subject vehicle decreases its cruising speed to account for the vehicle ahead.

Yes = The subject vehicle maintains its cruising speed.

Yes/No = The data is invalid prohibiting the ability to draw a Yes or No result.

Dash (-) = The data is unavailable and thus, a Yes or No entry cannot be made.

6.1.1 Jeep Grand Cherokee

Table 9 - Jeep_Target Control Vehicle Interruption

Subject Vehicle	Target Control Vehicle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
28	42	-	No	9.4
47	60	-	No	13.4
66	82	-	No	11.2
86	97	-	Yes	11.8
105	126	-	Yes	14
125	132	-	Yes	19.3

Table 10 - Jeep_Motorcycle Interruption

Subject Vehicle	Motorcycle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
28	40	-	No	4.6
47	66	-	No	5
66	80	-	Yes	3.7
86	99	-	Yes	2.9
105	120	-	Yes	4.6

6.1.2 Hyundai Ioniq Electric

Table 11 - Hyundai_Target Control Vehicle Interruption

Subject Vehicle	Target Control Vehicle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
30	41	Yes	No	9.8
51	60	Yes	No	9.3
70	78	Yes	Yes	7.3
90	100	Yes	No	8.2
109	118	Yes	No	8.1

Table 12 - Hyundai_Motorcycle Interruption

Subject Vehicle	Motorcycle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
30	41	Yes	No	9.3
50	62	Yes	No	10.6
70	79	Yes	Yes	8.5
90	99	Yes	Yes	7.8
109	120	Yes	No	10.2

6.1.3 Skoda Octavia Combi

Table 13 - Skoda_Target Control Vehicle Interruption

Subject Vehicle	Target Control Vehicle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
30	40	Yes	Yes/No	7.7
49	59	Yes	No	9
70	79	Yes	Yes/No	8.5
89	98	Yes	Yes/No	9.9
110	119	Yes	Yes	9.8

Table 14 - Skoda_Motorcycle Interruption

Subject Vehicle	Motorcycle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
30	-	Yes	Yes/No	-
50	-	Yes	Yes/No	-
69	-	Yes	Yes/No	-
89	-	Yes	Yes/No	-
109	-	Yes	Yes/No	-

6.1.4 Volvo V40

Table 15 - Volvo_Target Control Vehicle Interruption

Subject Vehicle	Target Control Vehicle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-

Table 16 - Volvo_Motorcycle Interruption

Subject Vehicle	Motorcycle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
30	44	Yes	Yes	7.3
50	62	Yes	No	9.3
70	77	Yes	Yes	10
89	102	Yes	No	8.9
109	119	Yes	No	11

6.1.5 VW Golf Variant

Table 17 - VW_Target Control Vehicle Interruption

Subject Vehicle	Target Control Vehicle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
28	41	Yes	No	11.6
47	61	Yes	No	11
66	80	Yes	No	12.1
88	99	Yes	No	11.2
108	116	Yes	No	10.9
131	139	Yes	No	10.4

Table 18 - VW_Motorcycle Interruption

Subject Vehicle	Motorcycle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
30	42	Yes	No	13.1
50	60	Yes	Yes/No	13.7
70	84	Yes	No	17.7
88	101	Yes	No	12.8
108	123	Yes	No	24.5

6.1.6 Tesla Model S

Table 19 - Tesla_Target Control Vehicle Interruption

Subject Vehicle	Target Control Vehicle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
31	40	Yes	No	8.7
50	59	Yes	No	9.3
70	80	Yes	No	10.4
90	98	Yes	No	11.1
109	110	Yes	Yes	11.6
131	138	Yes	-	12.1

Table 20 - Tesla_Motorcycle Interruption

Subject Vehicle	Motorcycle	Yes or No		LngRsv_tg1
Speed [km/h]	Speed [km/h]	Indication	Reaction	[m]
31	43	Yes	No	13.1
50	64	Yes	No	14.2
70	83	Yes	No	11.4
90	100	Yes	No	10.5
110	116	Yes	No	6.3

6.2 Evaluation 2: Subject Vehicle Approach

Results from Evaluation 2: Subject Vehicle Approach are presented in graphical form. The graphs should be read from bottom to top as if one is observing the approach from overhead (i.e. from a bird's eye view). Elaboration of the axis titles, labels, and legends of the graphs are as follows:

Bumper to Bumper Distance [m]: Distance between the subject vehicle front bumper and target vehicle rear bumper.

Car: Result from when the subject vehicle approaches the target control vehicle from behind.

Motorcycle: Result from when the subject vehicle approaches the motorcycle from behind.

(Number 1) | (Number 2): Number 1 is the speed of the subject vehicle in [km/h] and Number 2 is the speed of the target vehicle in [km/h]. These two speeds are otherwise known as the speed combination.

Variable: Response of the subject vehicle following its initial reaction.

Avg. Reaction: The average distance (in metres) from the target vehicle where the subject vehicle begins to brake.

Interlude: The distance (in metres) between the start of indication and the start of reaction.

Avg. Indication: The average distance (in metres) the subject vehicle indicated on the instrument cluster that it detects the target vehicle ahead

6.2.1 Jeep Grand Cherokee

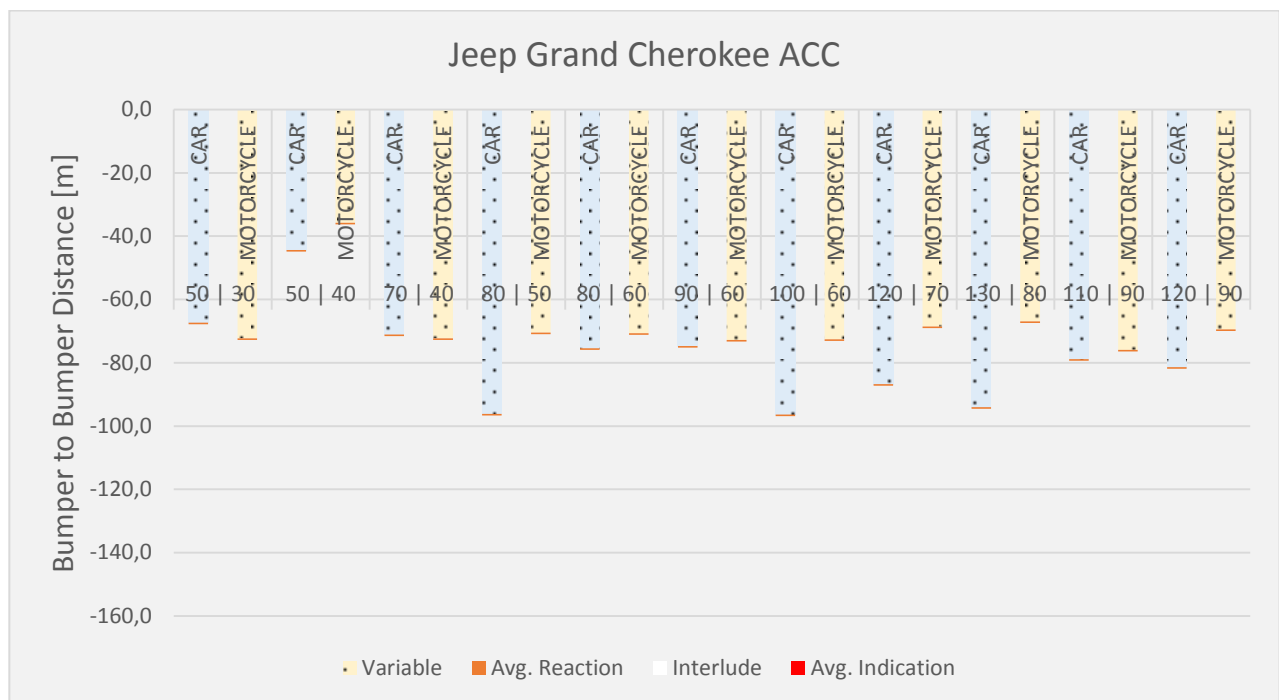


Figure 13 - Jeep_Subject Vehicle Approach Comparison

6.2.2 Hyundai Ioniq Electric

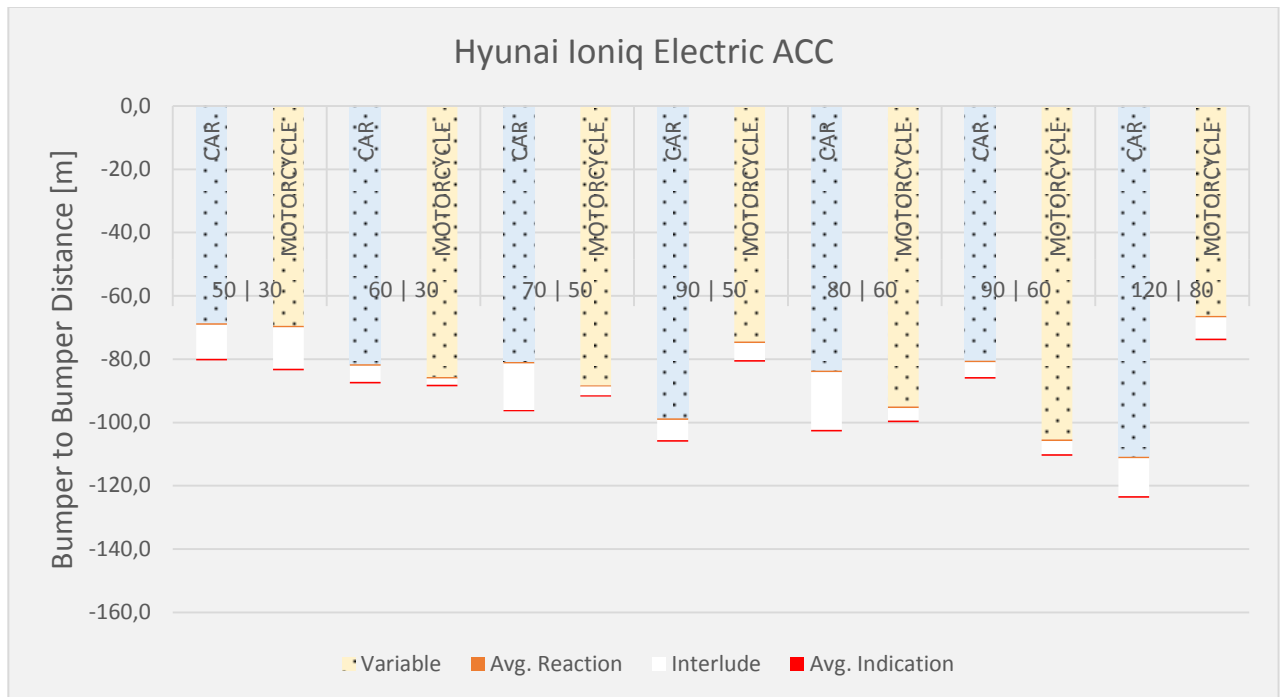


Figure 14 - Hyundai_Subject Vehicle Approach Comparison

6.2.3 Skoda Octavia Combi

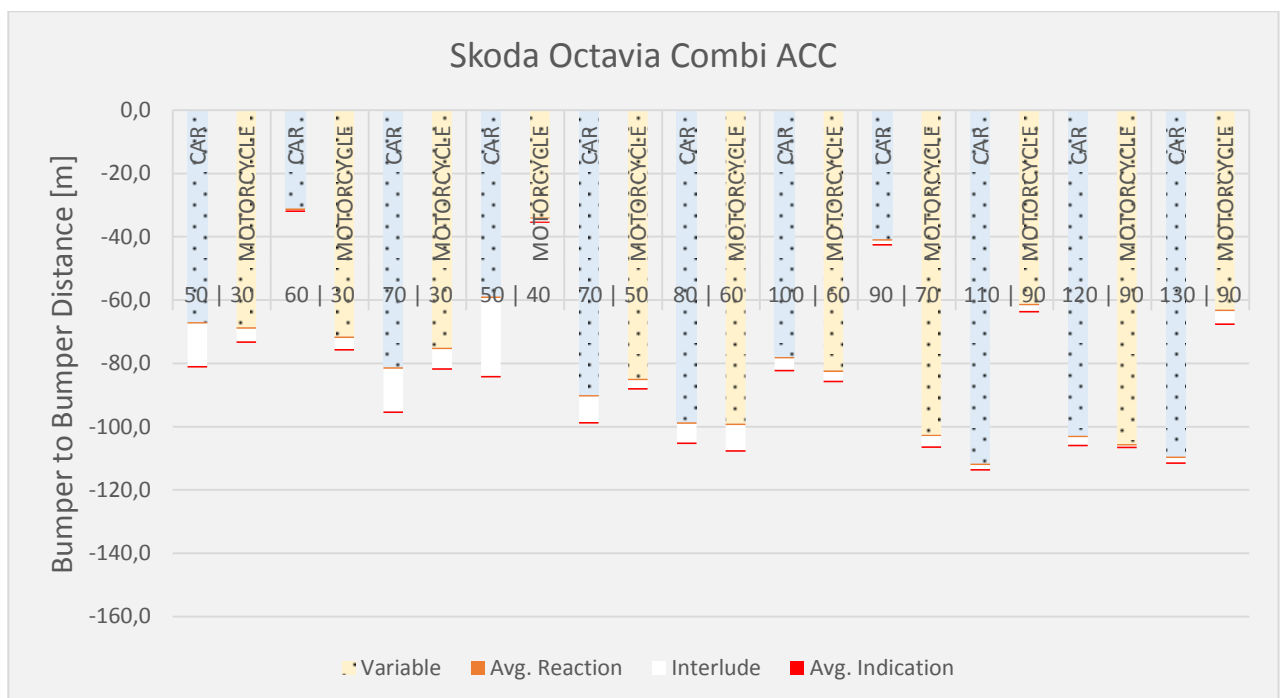


Figure 15 - Skoda_Subject Vehicle Approach Comparison

6.2.4 Volvo V40

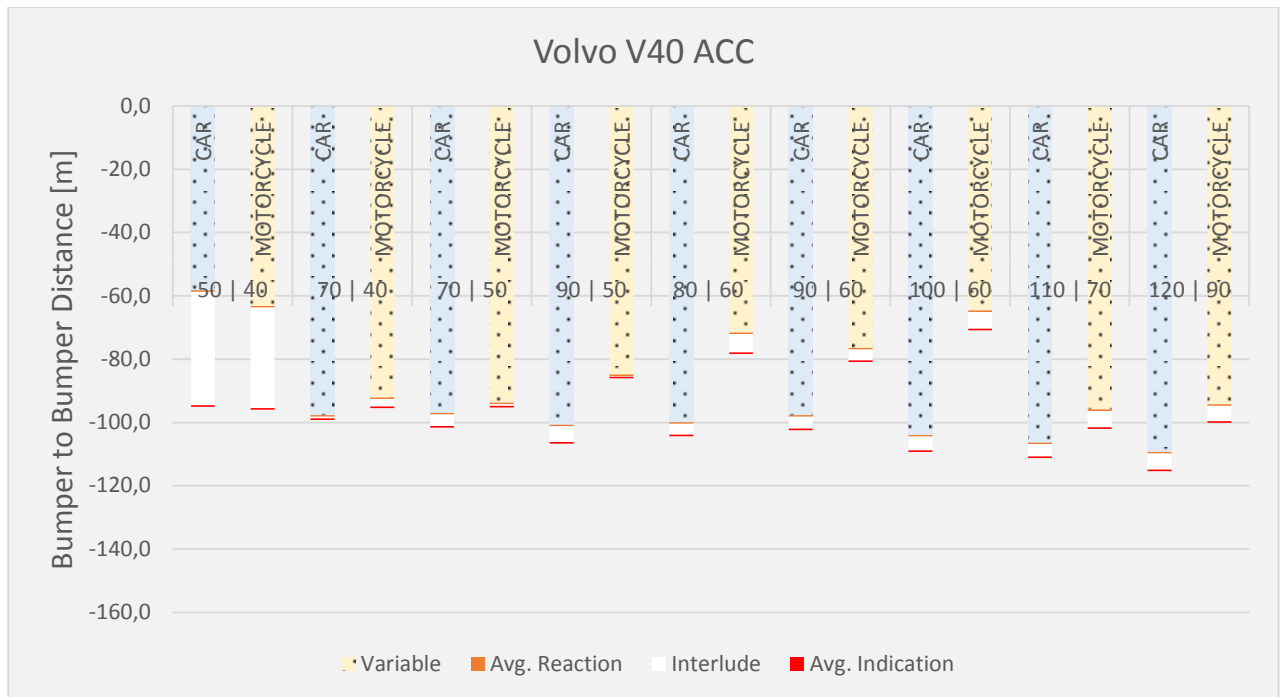


Figure 16 - Volvo_Subject Vehicle Approach Comparison

6.2.5 VW Golf Variant

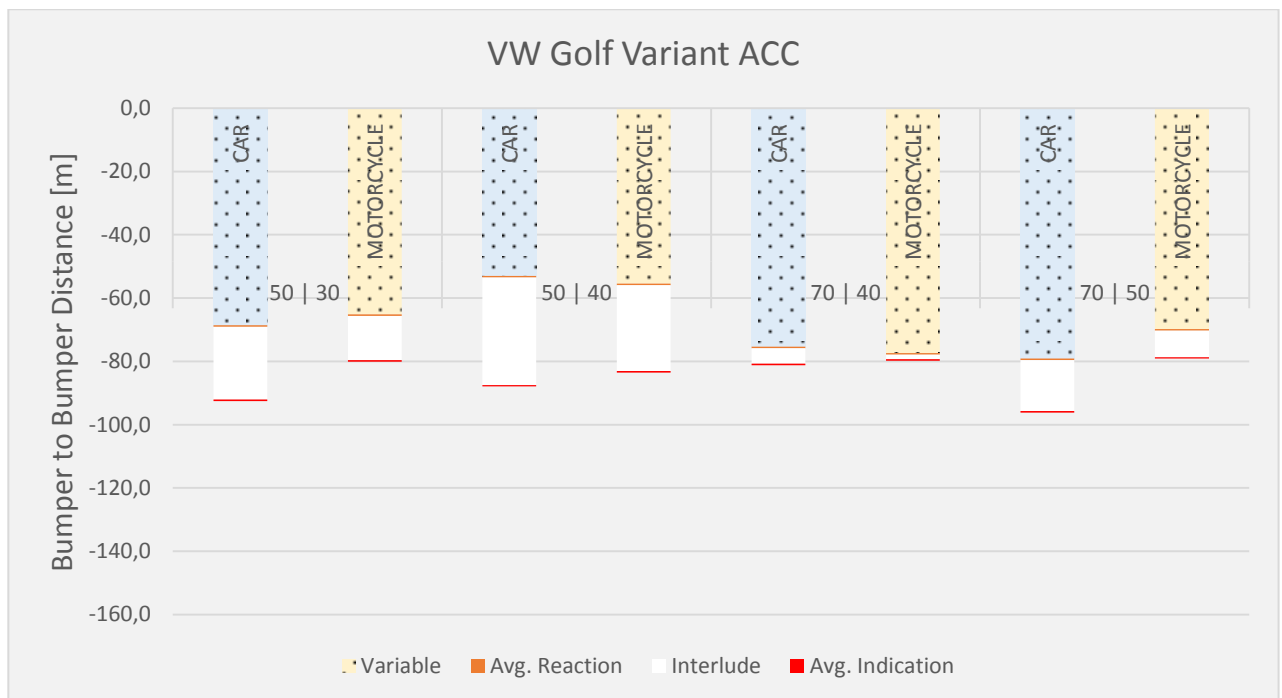


Figure 17 - VW_Subject Vehicle Approach Comparison

6.2.6 Tesla Model S

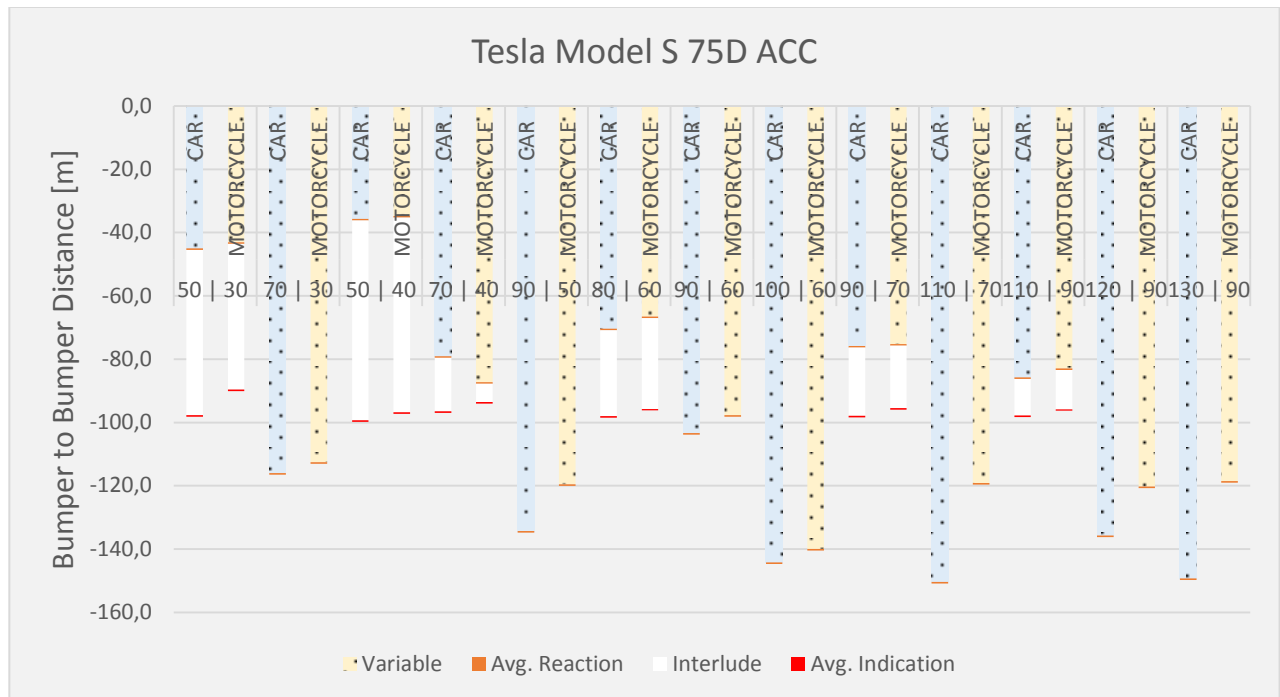


Figure 18 - Tesla_Subject Vehicle Approach Comparison

6.3 Evaluation 3: Lane Position Detection

Results from Evaluation 3: Lane Position Detection are presented in both tabular and graphical form. The graphs should be read from bottom to top as if one is observing the approach from overhead (i.e. a bird's eye view). Elaboration of the axis titles, labels, and legends of the graphs are as follows:

Bumper to Bumper Distance [m]: Distance between the subject vehicle and target vehicle bumper in metres.

LP1: Results from when the motorcycle was riding in position 1.

LP2: Results from when the motorcycle was riding in position 2.

LP3: Results from when the motorcycle was riding in position 3.

LP4: Results from when the motorcycle was riding in position 4.

LP5: Results from when the motorcycle was riding in position 5.

Variable: Response of the subject vehicle after beginning its reaction.

Min. Reaction: The minimum distance (in metres) between vehicles when the subject vehicle began to react.

Avg. Reaction: The average distance (in metres) between vehicles when the subject vehicle begins to react.

Max. Reaction: The maximum distance (in metres) between vehicles when the subject vehicle began to react.

Interlude: The distance covered (in metres) between the minimum indication and maximum reaction distances.

Min. Indication: The minimum distance (in metres) between vehicles when the subject vehicle indicated on the instrument cluster that it detects a target vehicle ahead.

Avg. Indication: The average distance (in metres) between vehicles when the subject vehicle indicates on the instrument cluster that it detects a target vehicle ahead.

Max. Indication: The maximum distance (in metres) between vehicles when the subject vehicle indicated on the instrument cluster that it detects a target vehicle ahead.

As a supplementary aid, colour coded tables describing the end response of each speed combination during the variable phase of the graphs are included. A table legend and corresponding description of each response are provided below.

Pass: The ACC system successfully follows the motorcycle during the straight section of the track with the indication light always illuminated.

Loss then Follow: The ACC system loses notice of the motorcycle at some point and begins to accelerate again up until the motorcycle is re-detected. The vehicle then follows the

motorcycle for the remaining length of the track.

Table 21 - ACC Actions During the Test Trials

Legend	
Pass	
Loss then Follow	
Loss of Notice x2+	
Loss of Notice x1	
No Reaction	!

Loss of Notice x2+: The ACC system loses notice of the motorcycle at some point and begins to accelerate again up until the motorcycle is re-detected and the vehicle slows down once more. This loss of notice occurs at least twice until, during the final loss of notice, the vehicle fails to redetect the motorcycle and manual application of the brakes is needed to avoid rear-ending the motorcyclist.

Loss of Notice x1: The ACC system loses notice of the motorcycle at some point and begins to accelerate. The vehicle fails to redetect the motorcycle and manual application of the brakes is needed to avoid rear-ending the motorcyclist.

No Reaction: The ACC system never indicates or reacts to the motorcycle ahead and manual application of the brakes is needed to avoid rear-ending the motorcyclist.

6.3.1 Jeep Grand Cherokee

Table 22 - Jeep_Lane Position Detection (LP1)

LP1		Pass, Loss then Follow, Loss of Notice x2+, Loss of Notice x1, No Reaction
Subject Vehicle	Motorcycle	
Speed [km/h]	Speed [km/h]	
50	30	
70	30	
90	50	
110	70	

Table 23 - Jeep_Lane Position Detection (LP5)

LP5		Pass, Loss then Follow, Loss of Notice x2+, Loss of Notice x1, No Reaction
Subject Vehicle	Motorcycle	
Speed [km/h]	Speed [km/h]	
50	30	!
50	30	!
50	30	!
70	60	!
70	60	
70	60	!
70	60	!
70	60	!

6.3.2 Hyundai Ioniq Electric

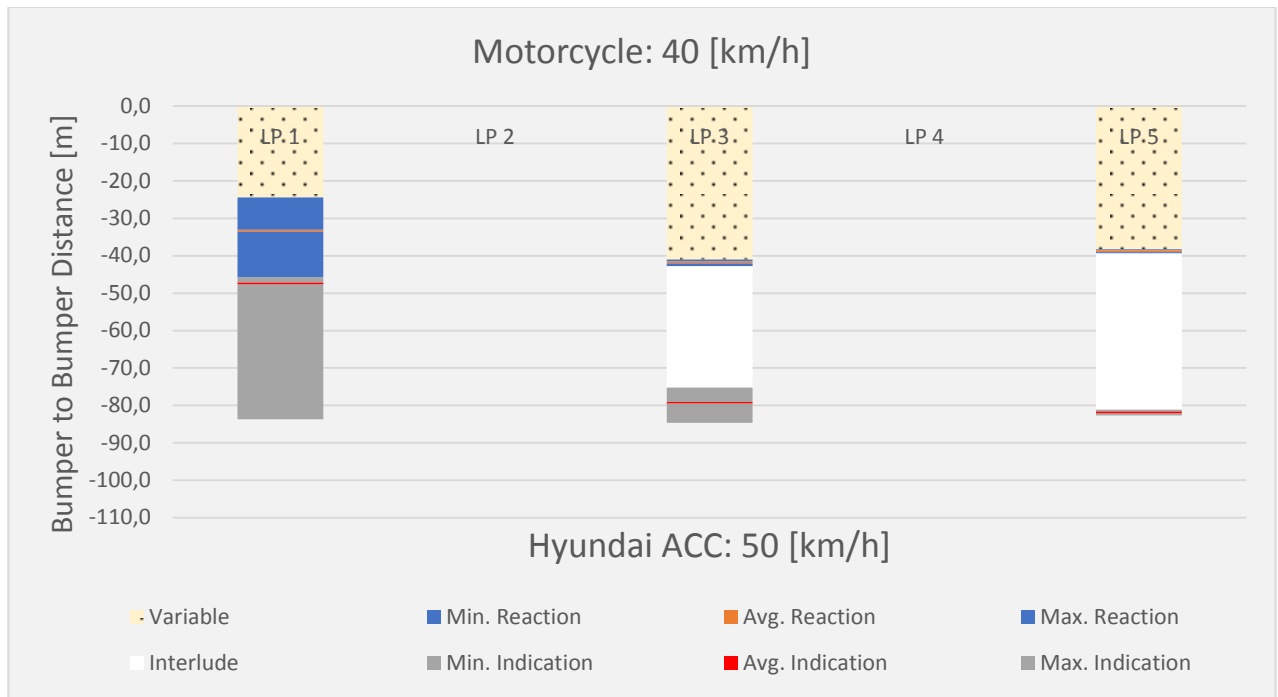


Figure 19 - Hyundai_Lane Position Detection (50 [km/h] | 40 [km/h])

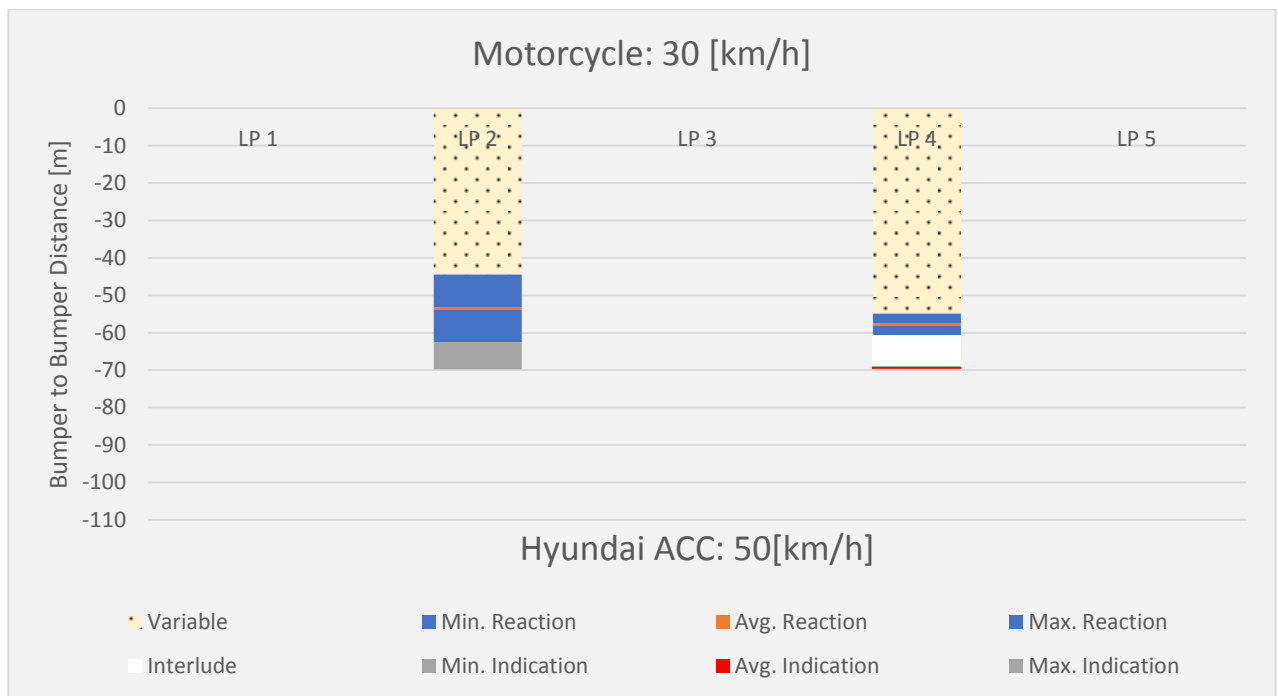


Figure 20 - Hyundai_Lane Position Detection (50 [km/h] | 30 [km/h])

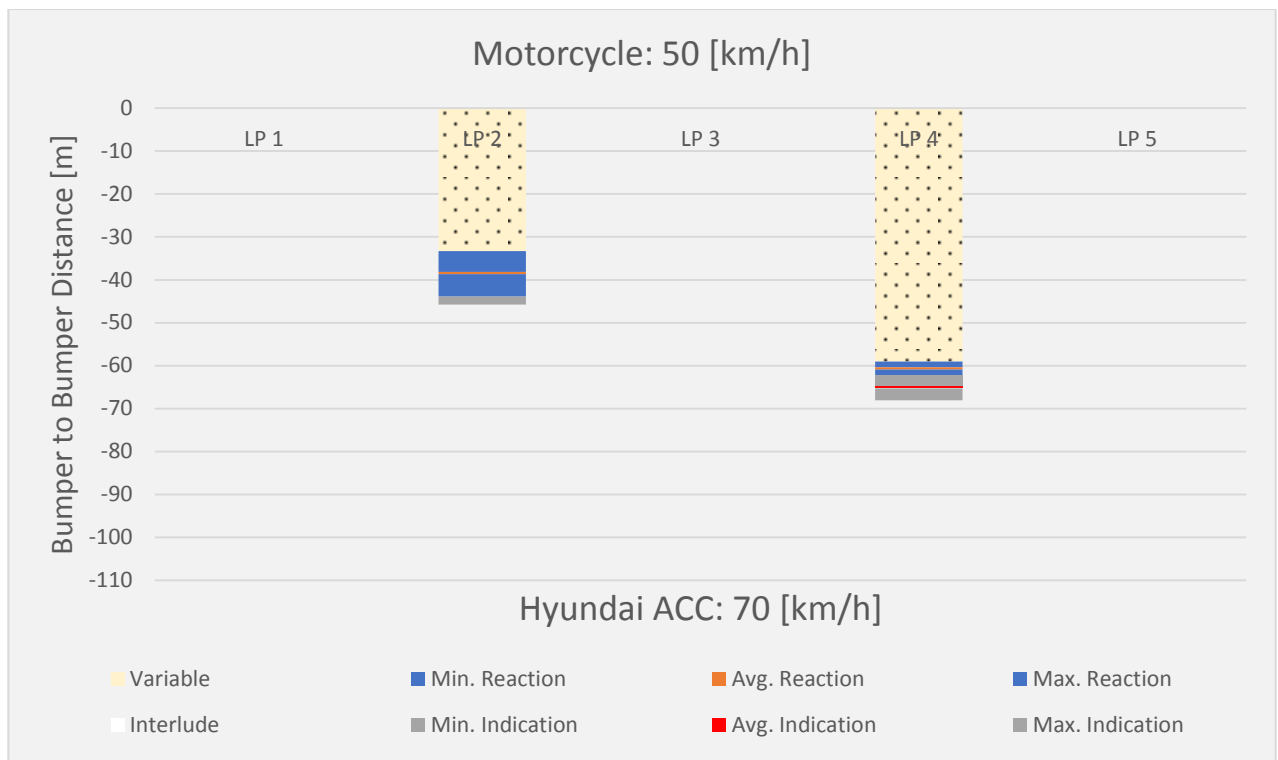


Figure 21 - Hyundai_ Lane Position Detection (70 [km/h] | 50 [km/h])

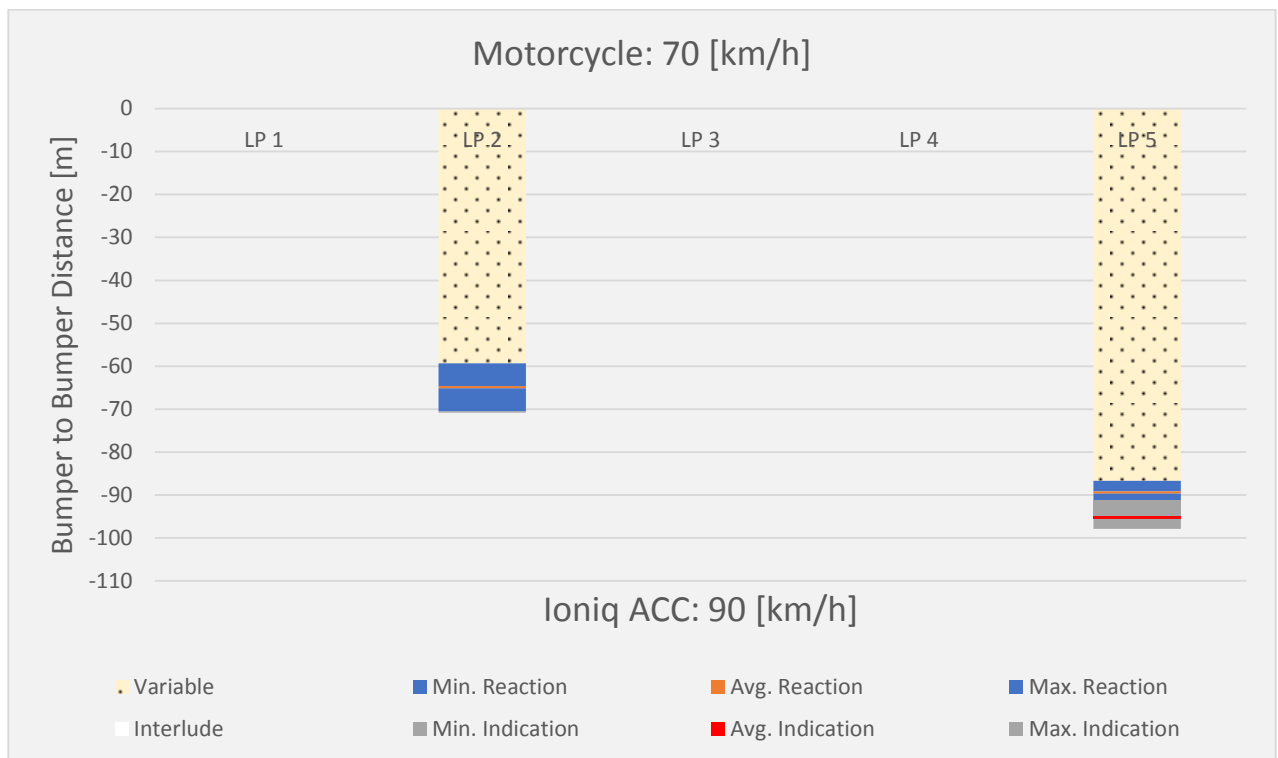


Figure 22 - Hyundai_ Lane Position Detection (70 [km/h] | 40 [km/h])

Table 24 - Hyundai ACC Response During the Test Trials (50 [km/h] | 40 [km/h])

Hyundai ACC: 50 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 25 - Hyundai ACC Response During the Test Trials (50 [km/h] | 30 [km/h])

Hyundai ACC: 50 [km/h] Motorcycle: 30 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 26 - Hyundai ACC Response During the Test Trials (70 [km/h] | 50 [km/h])

Hyundai ACC: 70 [km/h] Motorcycle: 50 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 27 - Hyundai ACC Response During the Test Trials (90 [km/h] | 70 [km/h])

Hyundai ACC: 90 [km/h] Motorcycle: 70 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1	!				
Trial 2	!				
Trial 3	!				
Trial 4					
Trial 5					
Trial 6					

6.3.3 Skoda Octavia Combi

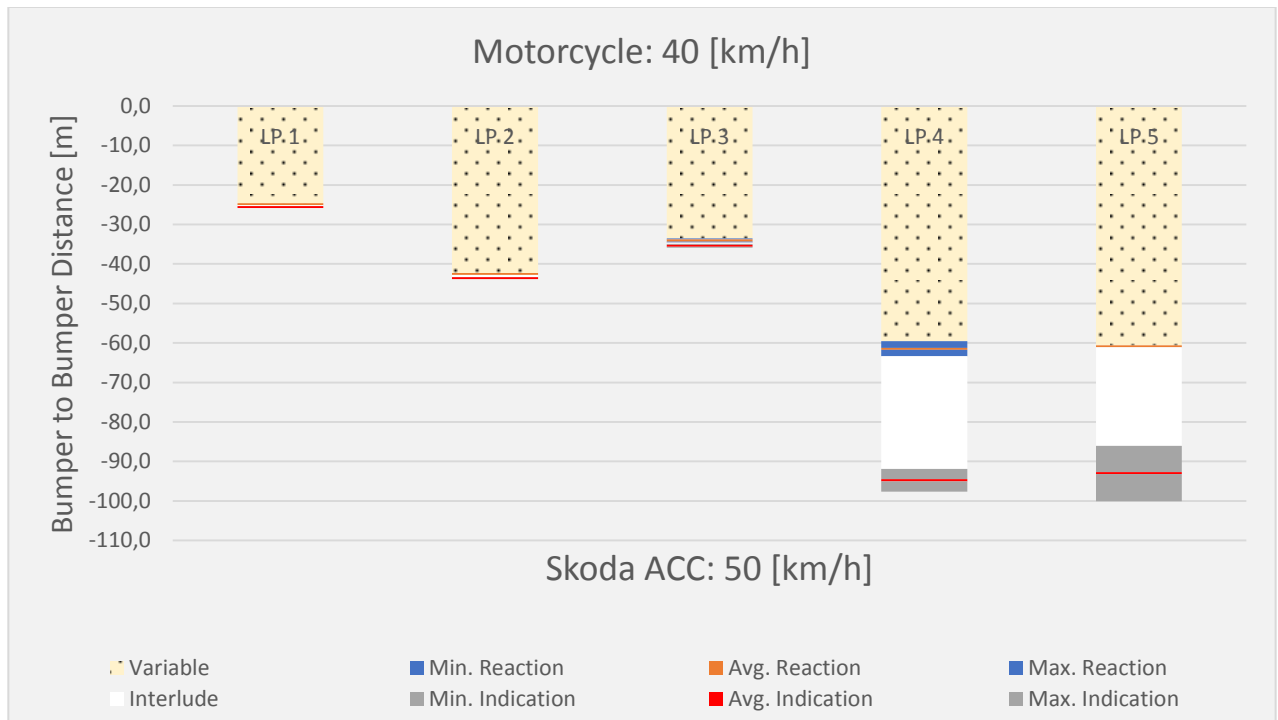


Figure 23 - Skoda_Lane Position Detection (50 [km/h] | 40 [km/h])

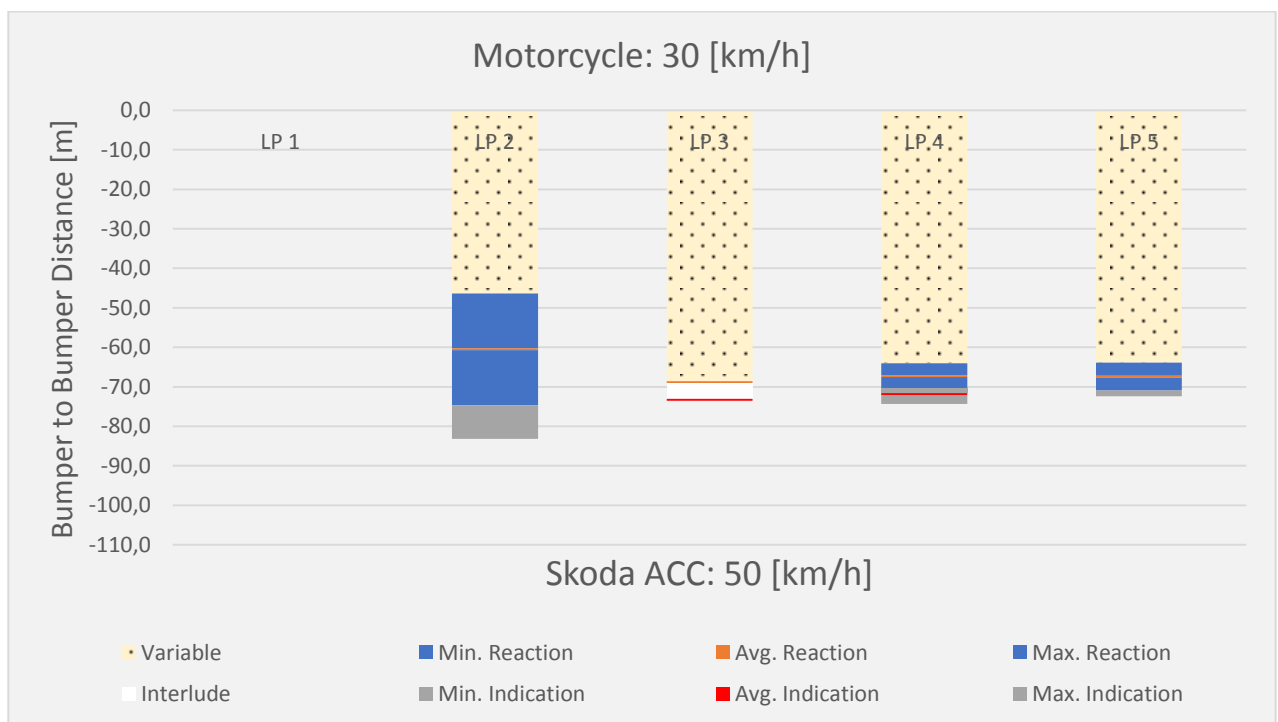


Figure 24 - Skoda_Lane Position Detection (50 [km/h] | 30 [km/h])

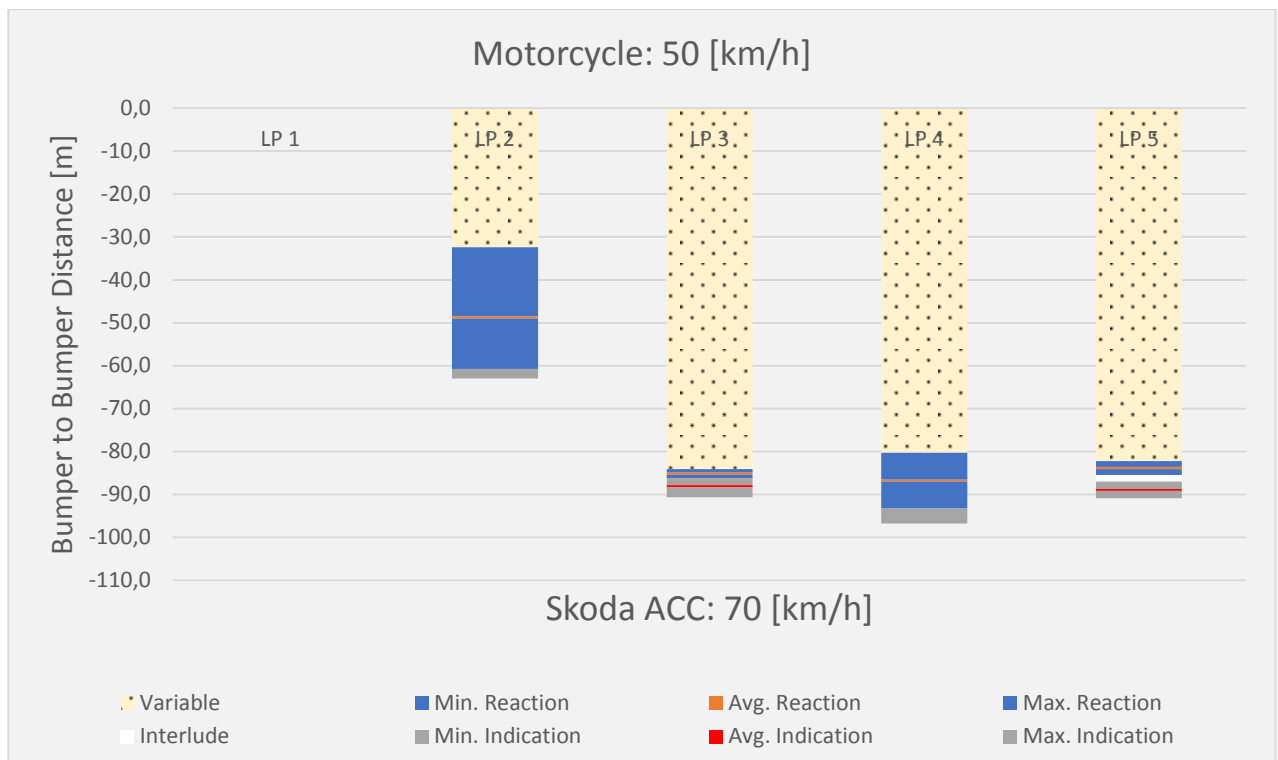


Figure 25 - Skoda_Lane Position Detection (70 [km/h] | 50 [km/h])

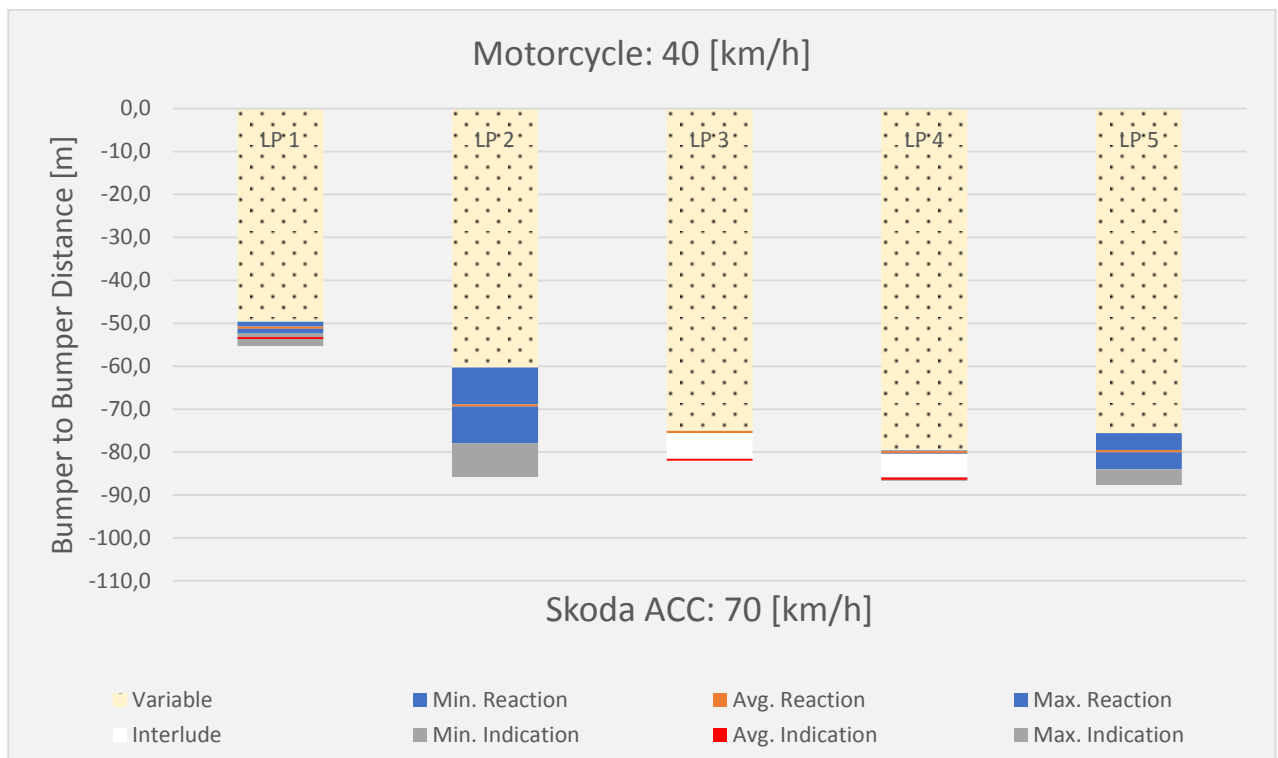


Figure 26 - Skoda_Lane Position Detection (70 [km/h] | 40 [km/h])

Table 28 - Skoda ACC Response During the Test Trials (50 [km/h] | 40 [km/h])

Skoda ACC: 50 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2	!				
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 29 - Skoda ACC Response During the Test Trials (50 [km/h] | 30 [km/h])

Skoda ACC: 50 [km/h] Motorcycle: 30 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1	!				
Trial 2	!				
Trial 3	!				
Trial 4					
Trial 5					
Trial 6					

Table 30 - Skoda ACC Response During the Test Trials (70 [km/h] | 50 [km/h])

Skoda ACC: 70 [km/h] Motorcycle: 50 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1	!				
Trial 2	!				
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 31 - Skoda ACC Response During the Test Trials (70 [km/h] | 40 [km/h])

Skoda ACC: 70 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

6.3.4 Volvo V40

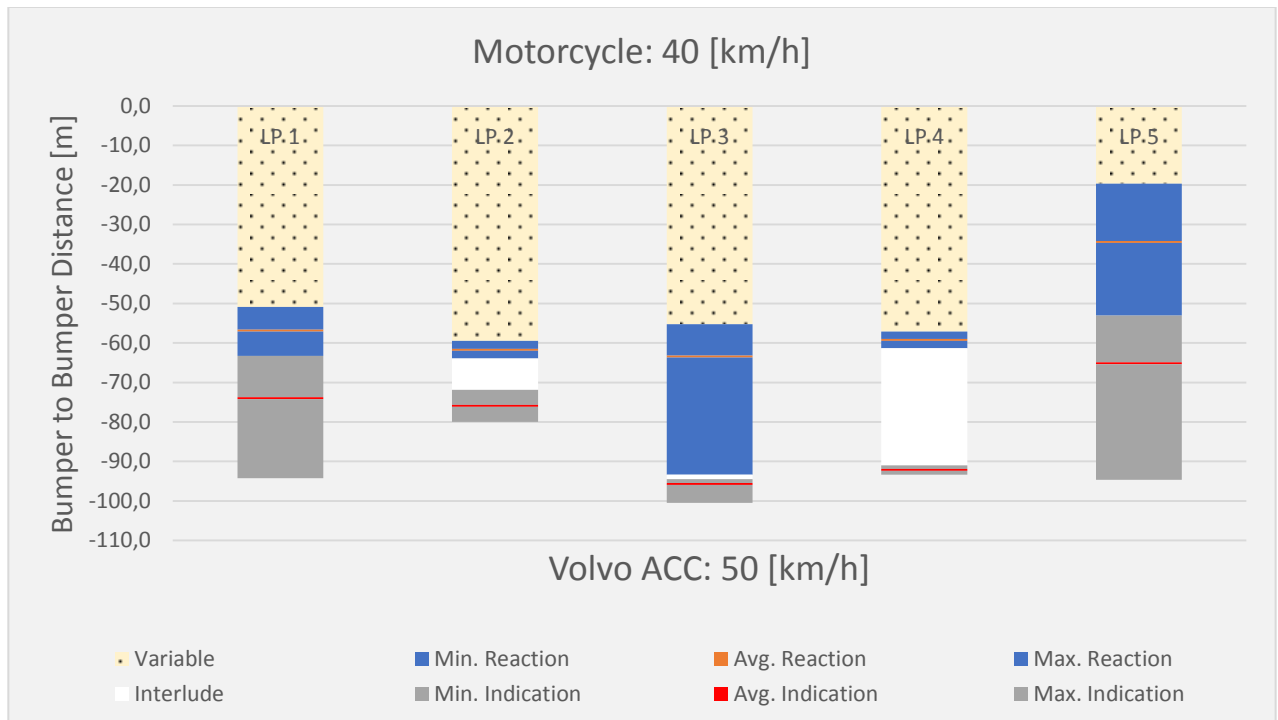


Figure 27 - Volvo_Lane Position Detection (50 [km/h] | 40 [km/h])

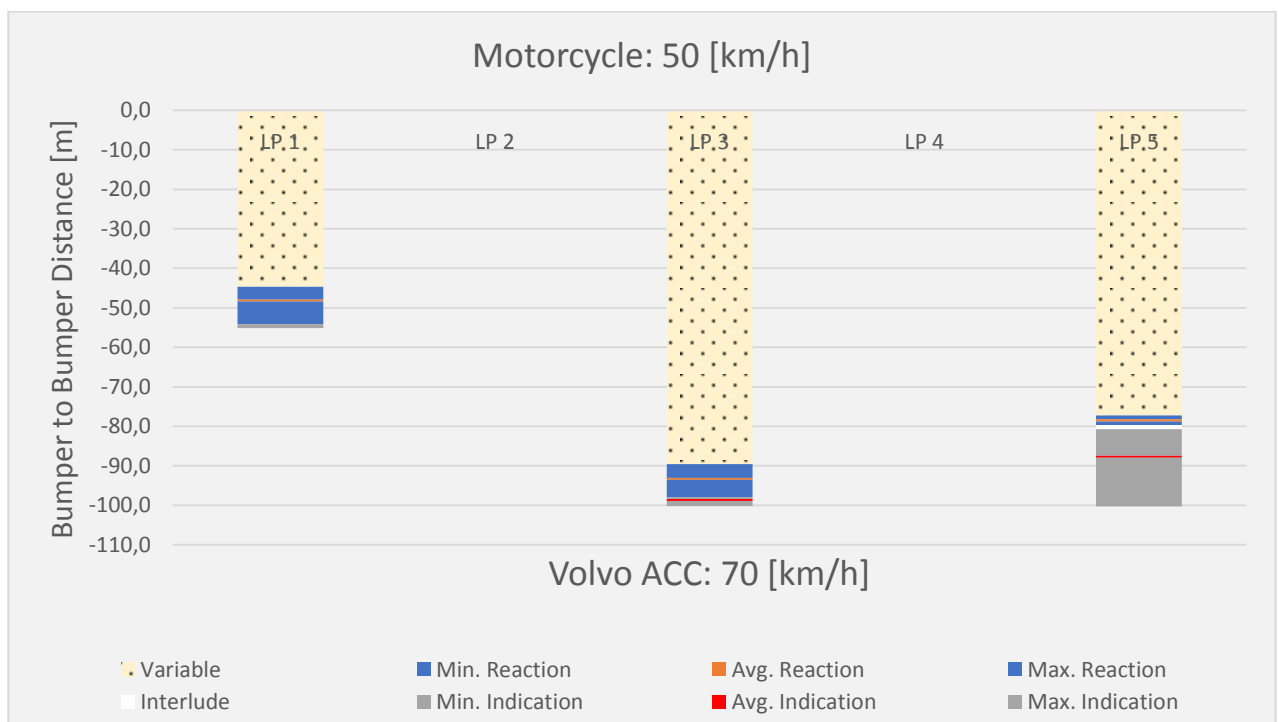


Figure 28 - Volvo_Lane Position Detection (70 [km/h] | 50 [km/h])

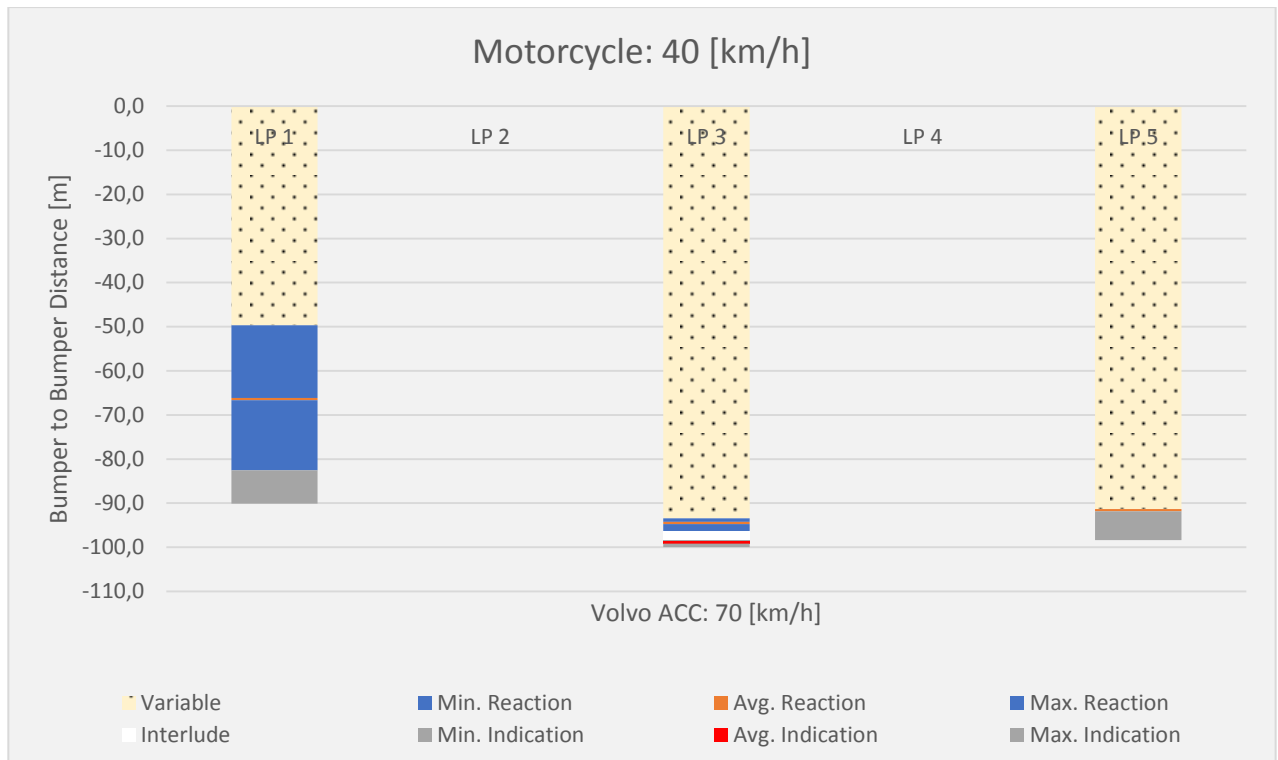


Figure 29 - Volvo_Lane Position Detection (70 [km/h] | 40 [km/h])

Table 32 - Volvo ACC Response During the Test Trials (50 [km/h] | 40 [km/h])

Volvo ACC: 50 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					!
Trial 2					!
Trial 3					!
Trial 4					
Trial 5					
Trial 6					!
Trial 7					

Table 33 - Volvo ACC Response During the Test Trials (70 [km/h] | 50 [km/h])

Volvo ACC: 70 [km/h] Motorcycle: 50 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					!
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 34 - Volvo ACC Response During the Test Trials (70 [km/h] | 40 [km/h])

Volvo ACC: 70 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					!
Trial 3	!				!
Trial 4					
Trial 5					
Trial 6					

6.3.5 VW Golf Variant

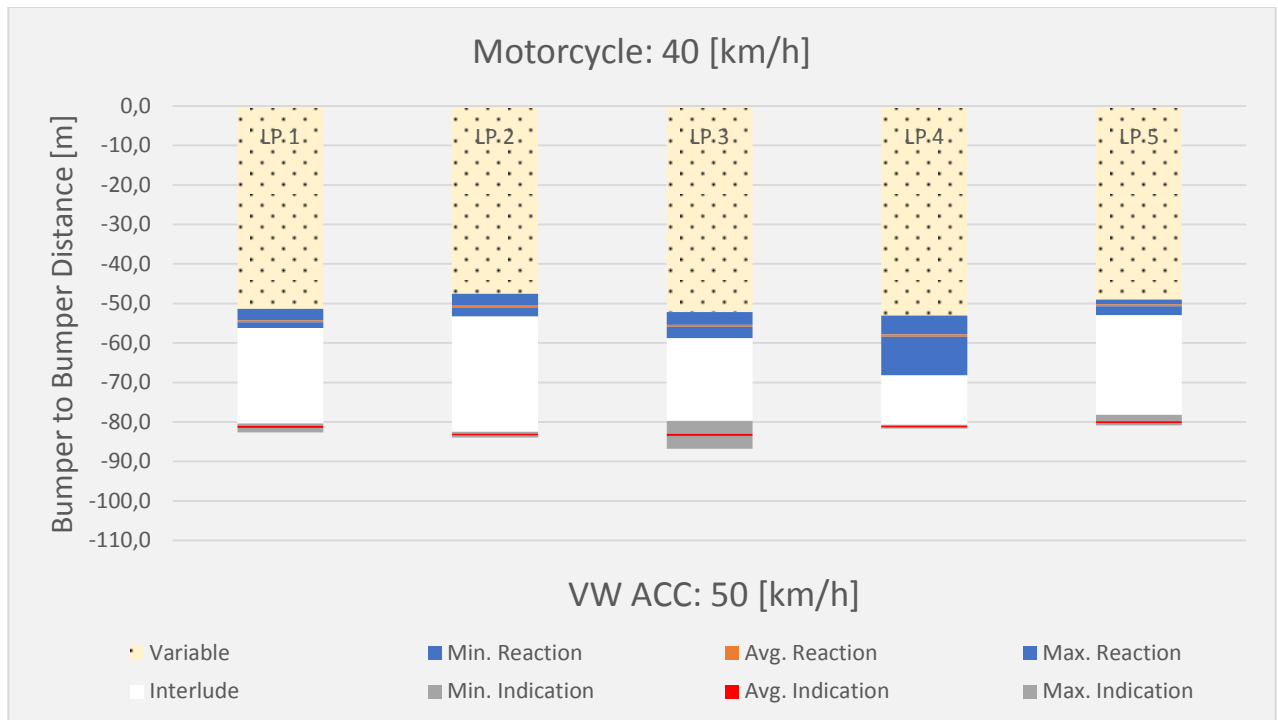


Figure 30 - VW_Lane Position Detection (50 [km/h] | 40 [km/h])

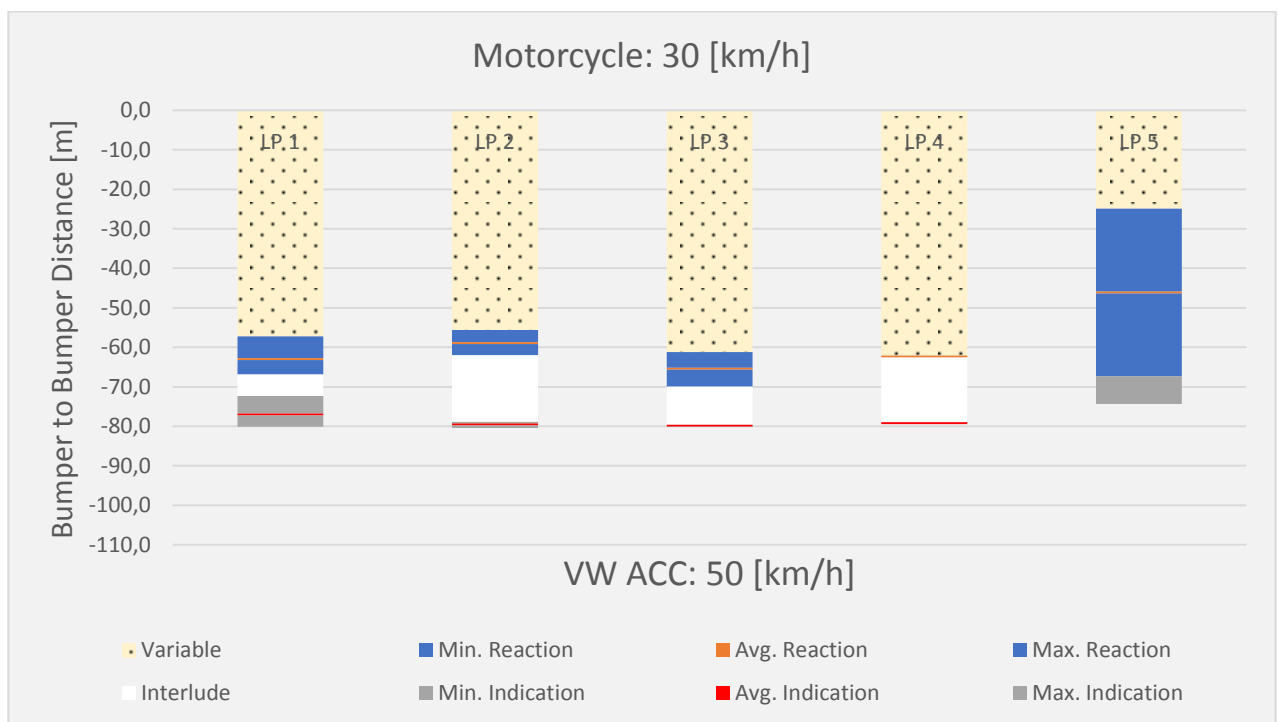


Figure 31 - VW_Lane Position Detection (50 [km/h] | 30 [km/h])

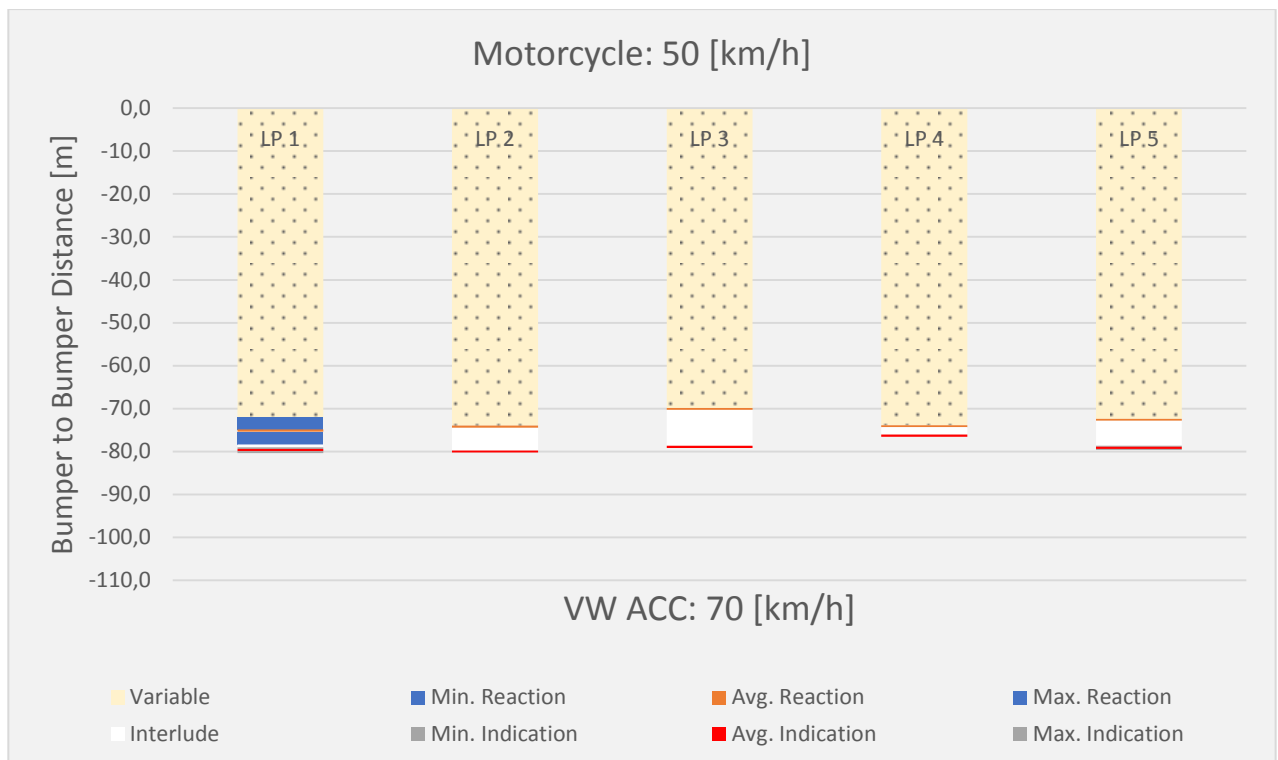


Figure 32 - VW_Lane Position Detection (70 [km/h] | 50 [km/h])

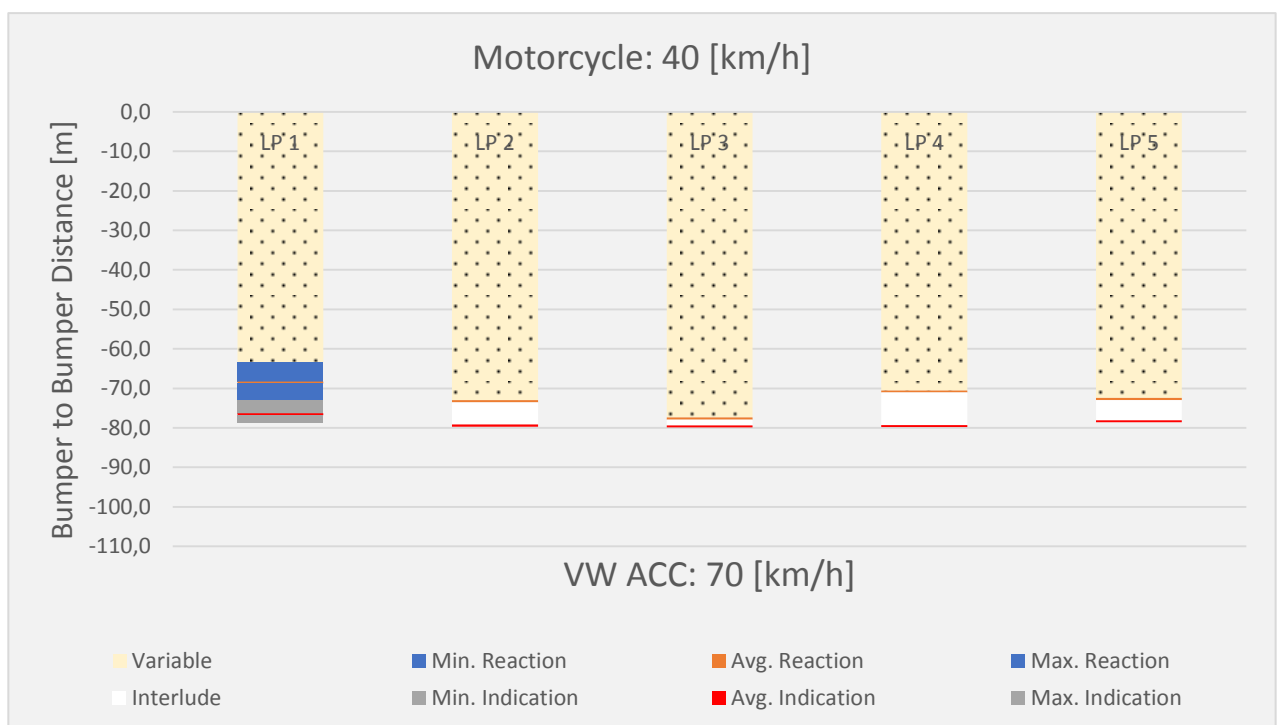


Figure 33 - VW_Lane Position Detection (70 [km/h] | 40 [km/h])

Table 35 - VW ACC Response During the Test Trials (50 [km/h] | 40 [km/h])

VW ACC: 50 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 36 - VW ACC Response During the Test Trials (50 [km/h] | 30 [km/h])

VW ACC: 50 [km/h] Motorcycle: 30 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					!
Trial 2				!	
Trial 3				!	
Trial 4					
Trial 5					
Trial 6					

Table 37 - VW ACC Response During the Test Trials (70 [km/h] | 50 [km/h])

VW ACC: 70 [km/h] Motorcycle: 50 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 38 - VW ACC Response During the Test Trials (70 [km/h] | 40 [km/h])

VW ACC: 70 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

6.3.6 Tesla Model S

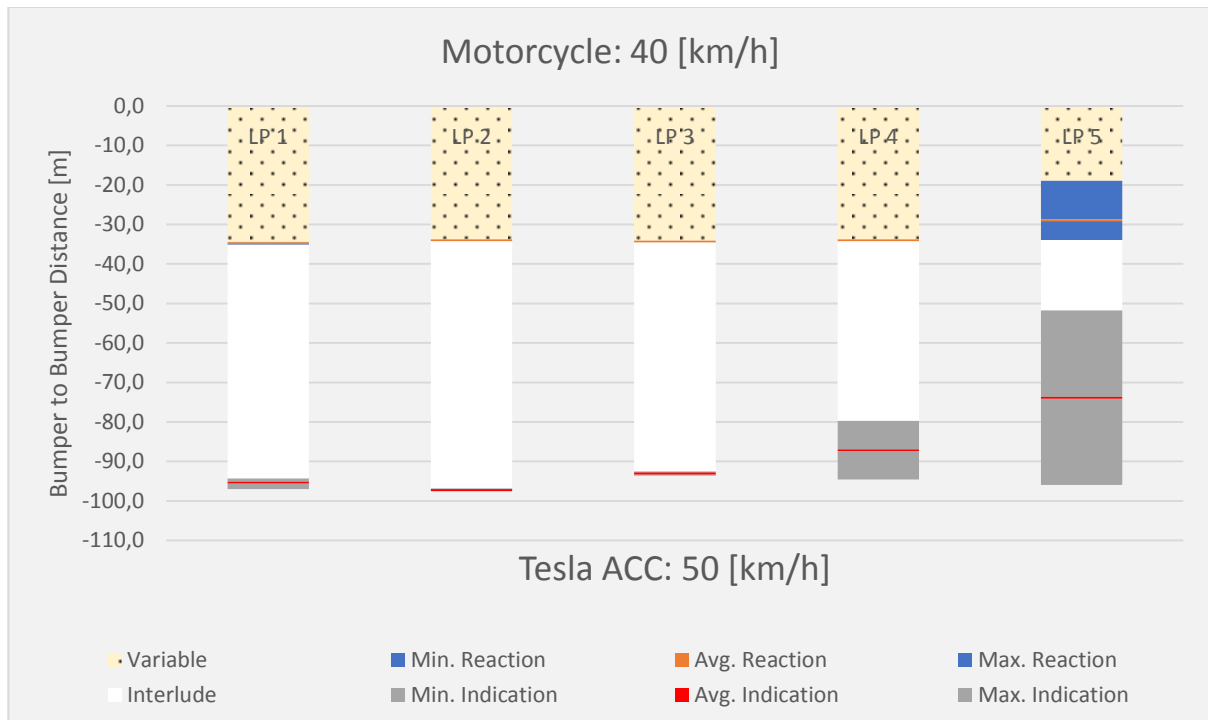


Figure 34 - Tesla_Lane Position Detection (50 [km/h] | 40 [km/h])

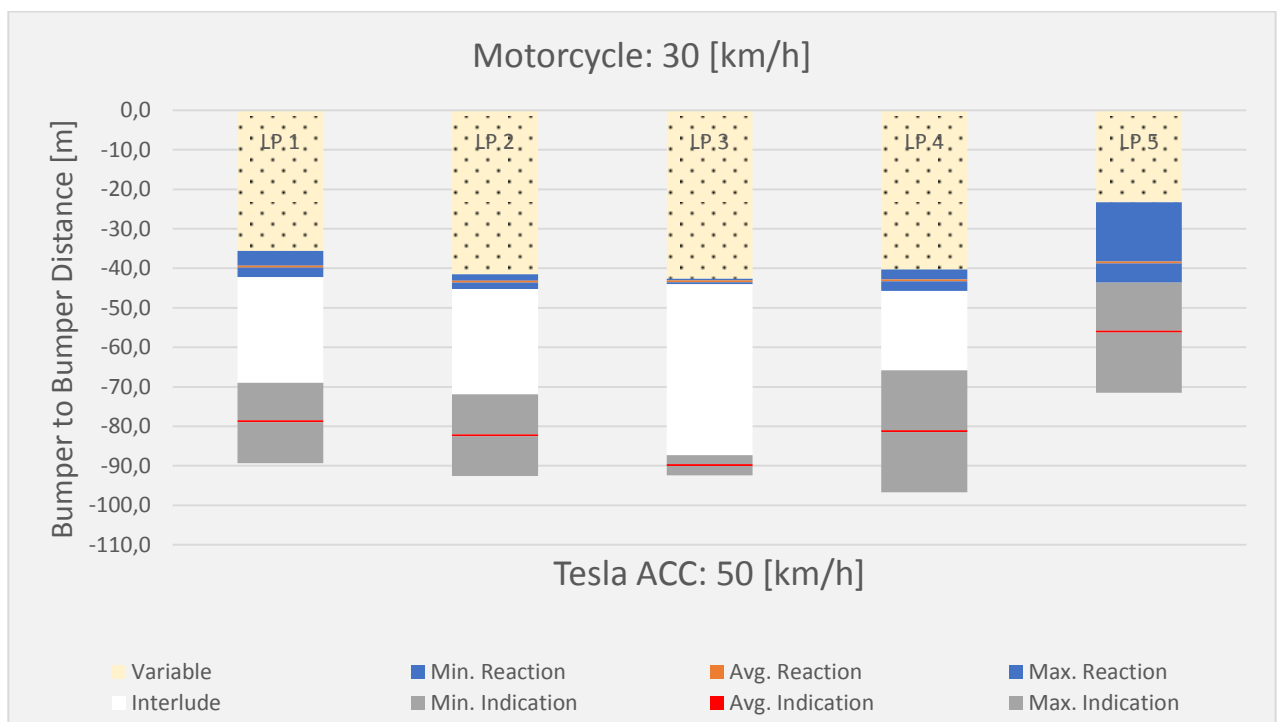


Figure 35 - Tesla_Lane Position Detection (50 [km/h] | 30 [km/h])

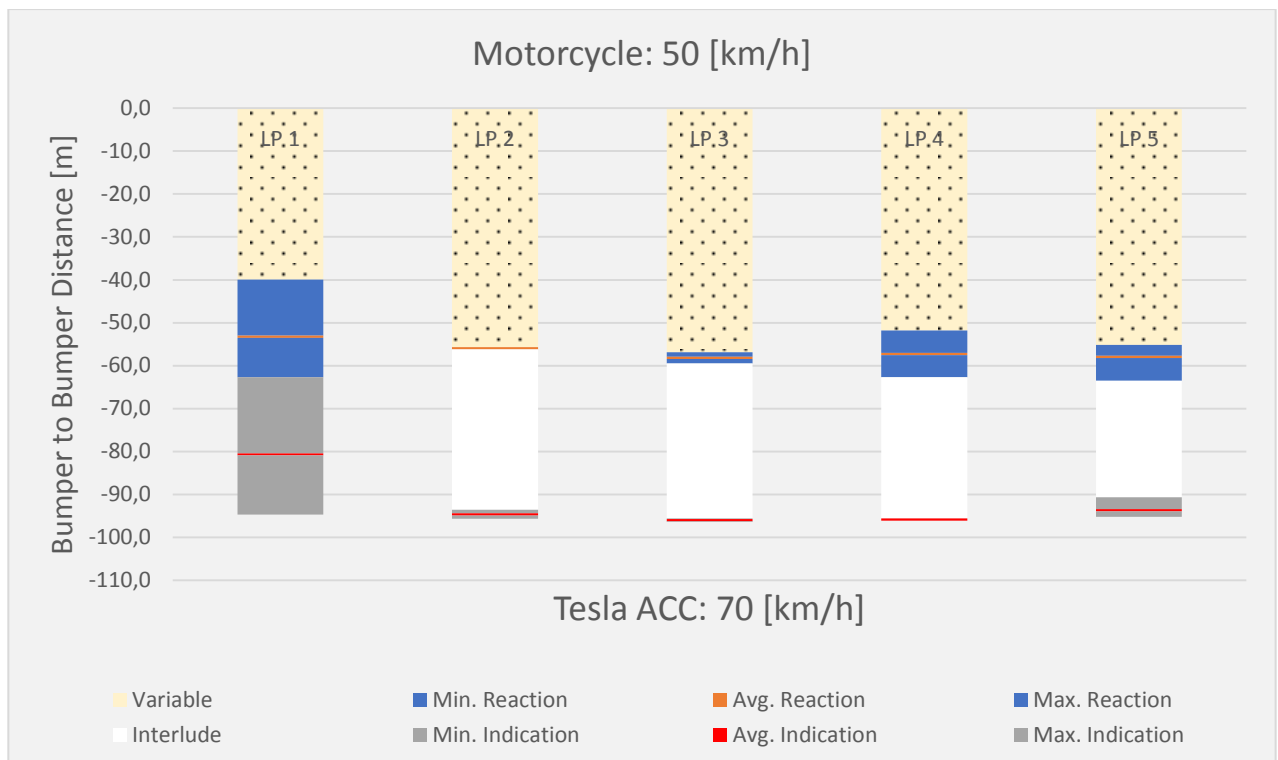


Figure 36 - Tesla_Lane Position Detection (70 [km/h] | 50 [km/h])

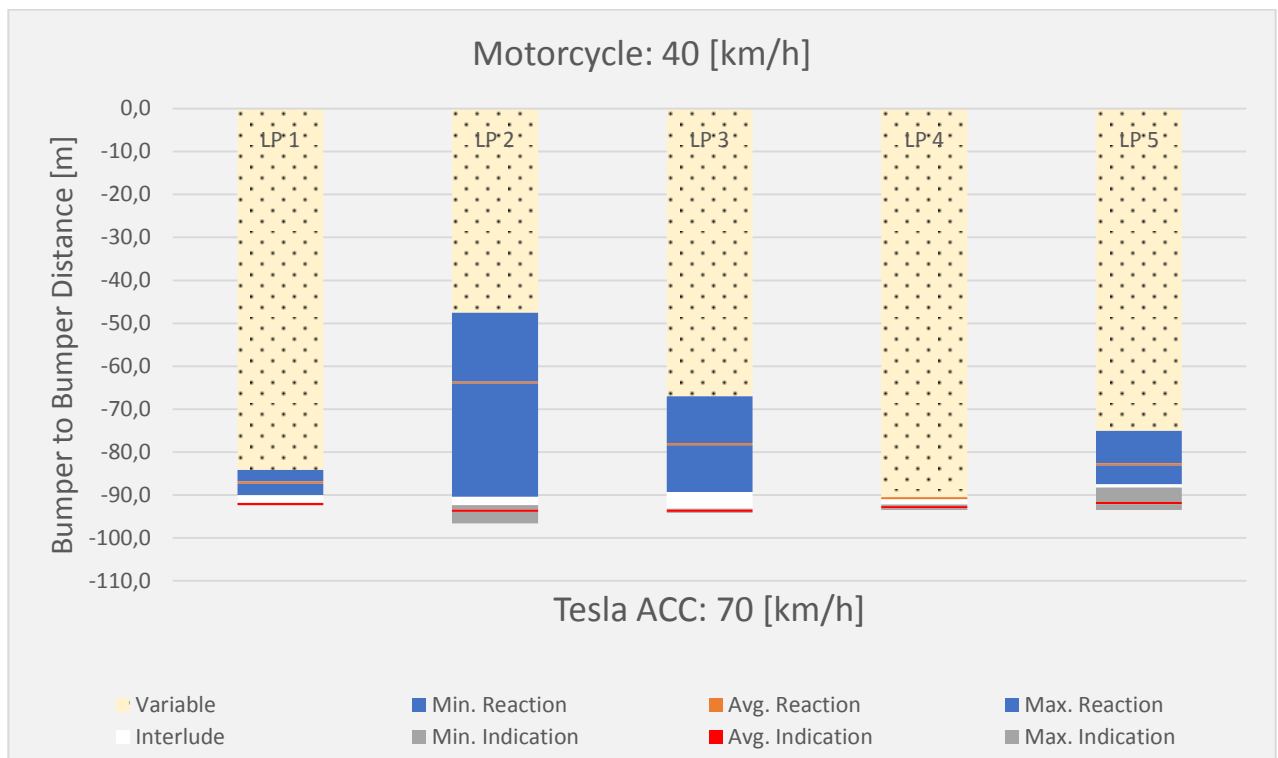


Figure 37 - Tesla_Lane Position Detection (70 [km/h] | 40 [km/h])

Table 39 - Tesla ACC Response During the Test Trials (50 [km/h] | 40 [km/h])

Tesla ACC: 50 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 40 - Tesla ACC Response During the Test Trials (50 [km/h] | 30 [km/h])

Tesla ACC: 50 [km/h] Motorcycle: 30 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					!
Trial 5					
Trial 6					

Table 41 - Tesla ACC Response During the Test Trials (70 [km/h] | 50 [km/h])

Tesla ACC: 70 [km/h] Motorcycle: 50 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

Table 42 - Tesla ACC Response During the Test Trials (70 [km/h] | 40 [km/h])

Tesla ACC: 70 [km/h] Motorcycle: 40 [km/h]					
	LP1	LP2	LP3	LP4	LP5
Trial 1					
Trial 2					
Trial 3					
Trial 4					
Trial 5					
Trial 6					

7 General Discussion

In this section, the results and performance of the vehicles will be discussed and further explained where needed. Please recall that given the nature of this study, results and the subsequent discussion are only indicative as the number of test trials are not large enough to give any statistical relevance. Additionally, comparison between vehicles is not warranted due to differences in test conditions (motorcycle used, weather, lane of track etc.)

7.1 Evaluation 1: Target Vehicle Interruption

As mentioned in 4.1.3, the purpose of this evaluation was to verify if (and less so how) the subject vehicle recognized and responded to an overtaking target vehicle that performed a lane change within the subject vehicle's furthest following distance. As the first evaluation, it not only allowed the driver to become familiar with the ACC system but also minimized the risk associated since the target vehicle would continue to pull away from the subject vehicle as it maintains its +10 [km/h] speed. Each speed combination of this evaluation was performed only once because this evaluation has less weight/significance than Evaluations 2 and 3.

At every speed combination, the subject vehicles all successfully indicated via the instrument cluster display that they detected the target vehicle ahead. In many instances however, the subject vehicles would not react to the target vehicle ahead as the drivers assumed they would. A plausible reason for this is because the subject vehicles concurrently measure the speed of the target vehicle and deem it unnecessary to brake when the target vehicle has a higher relative speed. If, however, the longitudinal distance between the subject and target vehicles is too small for a tested speed combination, the subject vehicle may have slowed down as programmed by the vehicle/system engineers.

When testing the **Jeep Grand Cherokee**, the test participants were unable to keep the ACC indication display active on the instrument cluster. To avoid losing too much time, it was decided that testing would go without it. Please note however that a couple months after testing, it was discovered through the system interface how to keep the display active.

When testing the interaction between the **Skoda Octavia Combi** and the target control vehicle, three of the five speed combinations tested resulted in a Yes/No reaction. The reason for this entry is because the Skoda waited several seconds before marginally slowing down (while still maintaining engine load). Due to this, it was uncertain whether other factors could have come into play accounting for this delayed reaction. At the same time, this delay in reaction could have been intentionally programmed by the vehicle/system engineers.

When testing the interaction between the **Skoda Octavia Combi** and the motorcycle, entries for the columns Subject Vehicle Speed [km/h], Motorcycle Speed [km/h], and LngRsv-tg1 [m] are absent because of a problem with the telemetry and radio receivers. Since the Video VBOX camera feed still works, it was decided to continue with the evaluation as is to avoid losing the two lanes reserved on track. Furthermore, all reaction entries received a Yes/No status since it was only noticed when processing the data that the motorcycle rider eased off throttle thereby decreasing his speed, which may have caused the reaction rather than the car deciding that for itself.

Conducting Evaluation 1 between the **Volvo V40** and the target control vehicle was not possible because of other traffic using the adjacent lanes of the banked circuit. Only after transferring all the test equipment to the motorcycle, did two lanes become available for use.

When testing the **VW Golf Variant** and the motorcycle, it was observed during data processing for the speed combination 50 | 60 that while a reaction of -1 [km/h] occurred, the motorcycle speed was also decreasing.

When testing the **Tesla Model S** and the target control vehicle at the speed combination of 131 | 138, a reaction was not possible due to the fast approaching bank that the driver had to brake for.

7.2 Evaluation 2: Subject Vehicle Approach

As mentioned in 4.1.4, the purpose of this evaluation was to observe how the ACC system reacted when approaching a slower moving vehicle in its lane of travel. First performed with the target control vehicle and later with the motorcycle, the goal of this evaluation was to answer if ACC detects motorcycles later than cars.

While the VBOX 3i RTK data loggers recorded 80 different vehicle parameters at 100 [Hz], it was decided that solely the parameters *UTC Time*, *Speed*, *LngRsv-tg1*, *LatRsv-tg1*, *Spd-tg1*, and *Brake Trigger* would be considered during the data analysis while the parameter *Angle-tg1* was assumed to be 0 [°] as explained in 5.3. Not critical for analysis, the *UTC Time* of each data entry was recorded so that one could quickly refer to the moment in time where the parameters were taken from. Also, the *Brake Trigger* parameter was monitored to confirm that the vehicle was braking itself rather than the driver.

The distance (parameter: *LngRsv-tg1*) at which the subject vehicle indicates and reacts to the slower moving target vehicle ahead allows the best means of comparison between the subject vehicle's interactions with the target control vehicle and with that of the motorcycle. Even so, the parameters *Speed*, *LatRsv-tg1*, and *Spd-tg1* were closely considered as explained in section 5.3.

Before discussing the performance of each vehicle further, realize that in many instances, each speed combination was performed once. As a result, their performance should be only suggestive of how they would perform during a similar test in the future. Furthermore, note that any invalid data resulting from telemetry noise/interference or improper execution of the testing procedure were omitted from the results presented. Also understand that due to track time availability restrictions, certain speed combinations could not be conducted.

A summary of the subject vehicles performances are as follows:

- At the speed combinations tested (as seen in 6.2.1), the **Jeep Grand Cherokee** reacted to the motorcycle later than the target control vehicle in 9/11 cases. The average indication distance is absent for the reason as explained in 7.1.
- At the speed combinations tested (as seen in 6.1.2), the **Hyundai Ioniq Electric** indicated the motorcycle later than the target control vehicle in 4/7 cases and reacted to the motorcycle later than the target control vehicle in 2/7 cases. Additionally, notice that the interlude period is shorter for the motorcycle in 6/7 cases, and thus suggests that the Hyundai responds to non-clearly discernible vehicles sooner as a precaution.
- At the speed combinations tested (as seen in 6.2.3), the **Skoda Octavia Combi** indicated the motorcycle later than the target control vehicle in 6/11 cases and reacted to the motorcycle later than the target control vehicle in 5/11 cases. It was also observed during testing that the behaviour of the Skoda in terms of indication and reaction distances was very difficult to predict. Definitive reasons for this are unknown.

- At the speed combinations tested (as seen in 6.2.4), the **Volvo V40** indicated the motorcycle later than the target control vehicle in 8/9 cases and reacted to the motorcycle later than the target control vehicle in 8/9 cases. These results suggest that the Volvo V40 indicates and reacts to motorcycles later than cars.
- At the speed combinations tested (as seen in 6.2.5), the **VW Golf Variant** indicated the motorcycle later than the target control vehicle in 4/4 cases and reacted to the motorcycle later than the target control vehicle in 2/4 cases. Insufficient time available for testing was the reason for the small number of speed combinations tested.
- At the speed combinations tested (as seen in 6.2.6), the **Tesla Model S** indicated the motorcycle later than the target control vehicle in 6/6 cases and reacted to the motorcycle later than the target control vehicle in 12/13 cases. This suggests that the Tesla indicates and responds to motorcycles later than cars. Also note that the Tesla often reacts to a vehicle ahead before indicating this on the instrument cluster if the speed difference between vehicles is large.

7.3 Evaluation 3: Lane Position Detection

As mentioned in 4.1.5, the purpose of this evaluation was to observe if a target vehicle's lane position effects the performance of the subject vehicle's ACC system. Only tested with the motorcycle, the goal of this evaluation was to answer in what circumstances and in which manner ACC struggles to detect motorcycles. Similar to Evaluation 2, the differentiating condition is that the motorcycle now rides in up five different 0,80 [m] wide lane positions. Hence, apart from this condition, all data were analysed in an identical fashion as in Evaluation 2.

As can be seen in 6.3, the results presented for the Jeep Grand Cherokee are in a different format than for that of the Hyundai Ioniq Electric and others. This is because the original test plan (used when testing the Jeep) advised testing with the motorcycle riding in the left part of the lane (equivalent to LP1) and in the right part of the lane (equivalent to LP5). Starting with the slowest speed combination, the Jeep was tested if it successfully followed the motorcycle during the length of the track, and if so, the test would continue to the next speed combination. As a result, the speed combinations in LP1 were only tested once. Furthermore, upon realizing that the Jeep struggled to follow the motorcycle when in position 5, the speed combinations were repeated for confirmation. Only after the end of the test day was it decided to investigate more lane positions and to repeat the speed combinations more than once if possible. Additionally, investigation into the indication and reaction distances were also included. This change was implemented while testing the Hyundai Ioniq Electric.

Before discussing the performance of each vehicle further, it should again be reminded that the ACC performance of each vehicle is only suggestive of how they may perform during a comparable situation in the future. Furthermore, note that any invalid data resulting from telemetry noise/interference or improper execution of the testing procedure were omitted from the results presented. Also understand that due to track time availability restrictions, certain speed combinations could not be conducted.

A summary of the subject vehicles performances are as follows:

- At the speed combinations and lane positions tested (as seen in 6.3.1), the **Jeep Grand Cherokee** successfully reacted to the motorcycle riding in position 1. Additionally, the Jeep successfully followed the motorcycle for the remaining distance before the start of the next bank. When the motorcycle was riding in position 5, the

Jeep completely failed to detect the motorcycle except for one instance. Reasons for the Jeep's performance may be due to the limitations stated in 7.4. The minimum, average, and maximum indication distances are absent for the reasons explained in 7.1.

- At the speed combinations and lane positions tested (as seen in 6.3.2), the **Hyundai Ioniq Electric** successfully indicated, responded to, and followed the motorcycle when riding in lane positions 2, 3 and 4. At least once did the Hyundai fail to detect the motorcycle when in position 1. Additionally, at least once did the Hyundai fail to follow the motorcycle when in position 5. Furthermore, results suggest that the Hyundai indicates and responds more poorly when the motorcycle is riding in the left part of the lane than in the right. Reasons for the Hyundai's performance may be due to the limitations stated in 7.4 or to software-based decisions made by the vehicle/system designers.
- At the speed combinations and lane positions tested (as seen in 6.3.3), the **Skoda Octavia Combi** successfully indicated, responded to, and followed the motorcycle when riding in lane positions 2, 3 and 4. At least once did the Skoda fail to detect the motorcycle when in position 1. Additionally, at least once did the Skoda fail to follow the motorcycle when in position 5. Furthermore, results suggest that the Skoda indicates and responds more poorly when the motorcycle is riding in the left part of the lane than in the right. Reasons for the Skoda's performance may be due to the limitations stated in 7.4 or to software-based decisions made by the vehicle/system engineers.
- At the speed combinations and lane positions tested (as seen in 6.3.4), the **Volvo V40** successfully indicated, responded to, and followed the motorcycle when riding in lane positions 2, 3 and 4. At least once did the Volvo fail to detect the motorcycle when in position 1. Additionally, at least once did the Volvo fail to detect the motorcycle when in position 5. Furthermore, results suggest that the Volvo fails to detect the motorcycle more frequently when in position 5 than when in position 1. However, if the Volvo does detect the motorcycle in position 1, this occurs sooner than when the motorcycle is riding in the left part of the lane. Reasons for the Volvo's performance may be due to the limitations stated in 7.4 or to software-based decisions made by the vehicle/system designers.
- At the speed combinations and lane positions tested (as seen in 6.3.5), the **VW Golf Variant** successfully indicated, responded to, and followed the motorcycle when riding in lane positions 2 and 3. At least once did the VW fail to follow the motorcycle when in position 1. Additionally, at least once did the VW fail to detect the motorcycle when in positions 4 and 5. Furthermore, results suggest that the Volvo performs more poorly when the motorcycle is riding in the right part of the lane than in the left. Reasons for the VW's performance may be due to the limitations stated in 7.4 or to software-based decisions made by the vehicle/system engineers.
- At the speed combinations and lane positions tested (as seen in 6.3.6), the **Tesla Model S** successfully indicated, responded to, and followed the motorcycle when riding in lane positions 2, 3 and 4. At least once did the Tesla fail to detect the motorcycle when in position 1. Additionally, at least once did the Tesla fail to detect the motorcycle when in position 5. Further remarks are difficult to draw based on performance inconsistencies between speed combinations. Regardless, reasons for the Tesla's performance may be due to the limitations stated in 7.4 or to software-based decisions made by the vehicle/system designers.

A common observation from the results presented is that the test vehicles struggle to detect or otherwise follow the motorcycle when riding in the far left and right sides of the lane. This similarity in performance suggests that the ACC system of the tested vehicles projects a strong filter which limits the view of the system. This may be done to limit the

interference adjacent traffic may have on the performance of the system. With that said, it should be noted that the motorcycle never crossed into an adjacent lane during testing. As such, this also suggests that the lane markings of the test track are not considered or used by the vehicle to define the width of the filter. Lastly, in all failed trials, manual application of the brakes was required; without doing so, the motorcyclist certainly would have been rear-ended or at the least, severely side-swiped.

7.4 Project Limitations

To minimize the risks of ACC testing, all evaluations and measurements were performed on a closed course. As such, real world results may vary. Project limitations include but are not limited to:

- TCL lane width is 4,00 [m].
- NL lane width is 2,75 [m], 3,10 [m], 3,25 [m] and 3,5 [m] dependant on type of road.
- The number of test repetitions are too low to have any statistical significance
- Variable weather conditions existed on test days.
- ACC performance on road curves or crests/dips is unknown.
- The choice of lane used may have influenced ACC performance (e.g. safety cones and guard rails).
- Other vehicles on track may have influence ACC performance (e.g. buses and lorries in adjacent lanes).
- Wind possibly pushed the motorcyclist into another lane position allowing for detection before the correction could be made.
- The method used to export and compile the data contains many possible opportunities for inaccuracies or errors.

8 Project Conclusion

To address the concerns of FEMA, KNMV, and MAG NL regarding the safety of motorcyclists with the admittance of (semi-)autonomous vehicles on European roadways, RDW conducted its own test program to quantitatively evaluate the performance of ACC from a range of vehicle manufacturers. With the intention of answering whether ACC detects motorcycles worse than cars, and if so, in what circumstances and in which manner, a test plan comprised of three evaluations was devised and progressively refined. Over the course of six separate test days, it was observed that the ACC systems of the Jeep Grand Cherokee, Hyundai Ioniq Electric, Skoda Octavia Combi, Volvo V40, VW Golf Variant, and Tesla Model S detect motorcycles worse than cars when the motorcyclist is riding more than 1,20 metres from the centreline of the vehicle/lane. While the data obtained presents results far more specific than what was just stated, the number of repetitions conducted per evaluation was too low and thus, have no statistical significance. Additionally, discrepancies between test days and test runs mean that this report and its contents describe nothing more than an *indicative* study. All tests were performed on a closed-course at RDW Test Centre (Lelystad, NL) and real-world results may vary.

9 Subsequent Steps

In light of this project outcome, recommendations on where to go next include:

- Further processing of data.
 - If desired, more accurate results can be obtained if the parameter *Angle-tg1* is analysed and processed. However, doing so may not be worth the effort as hyper-accurate distances between the subject and target vehicles are offset by the small number of test repetitions. All in all, the data from this project will only ever be indicative.
- Testing if lane position and barriers have an influence on ACC performance.
 - Based on the results obtained while testing at TCL, it would be interesting to further investigate if and how adjacent objects and vehicles affect the performance of ADAS vehicles. If possible, it is also encouraged that the RDW reaches out to manufacturers to obtain further information about the intricacies of how their ACC software works and the conditions considered when it makes its decisions.
- Present findings of this report to vehicle manufacturers, governing bodies, and to motorcycle groups.
 - Although the results presented in this report are solely indicative, involvement and collaboration with affected and responsible parties are encouraged. In this way, proactive measures can be taken as ADAS technology continues to evolve and improve towards a fully autonomous driving future.
- Testing BSM.
 - While an effective test setup was developed previously to quantitatively evaluate a vehicle's BSM system, it was left untouched during this project term due to the ambitions of investigating ACC. Regardless, since many motorcycles in Europe have the legal right or expectation to filter between stopped or slow-moving traffic, obtaining further insight into whether BSM responds appropriately to the presence of motorcycles is well worth the effort. It could also be a great project for an internship or graduation thesis work placement.

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11 Appendices

Supplemental information relevant to the project, and less so to the report, is presented here.

11.1 Test Day Specifications

Specifications regarding the vehicles used and participants present for each test day are presented here.

11.1.1 Test Day #1

Date: 08 November 2017

Test Location: RDW Test Centre [Talingweg 76, 8218 NX Lelystad]

Weather: 8 °C/1°C, 0 [mm], Overcast [14]

ACC Subject Vehicle ^[1]: Jeep Grand Cherokee [4x4 S Limited CRD], 10-ZPR-9, 1C4RJFBM3CC339555

Target Control Vehicle ^[2]: Seat Toledo, 4-XFF-08, VSSZZZNHZF1009382

Target Motorcycle ^[3]: Suzuki GSX-S1000F, 92-MH-TG, JS1DG1144G01023196

11.1.2 Test Day #2

Date: 17 November 2017

Test Location: RDW Test Centre [Talingweg 76, 8218 NX Lelystad]

Weather: 10°C/1°C, 0 [mm], Partly Cloudy [14]

ACC Subject Vehicle ^[1]: Hyundai Ioniq Electric, PN-363-J, (unknown)

Target Control Vehicle ^[2]: Seat Toledo, 4-XFF-08, VSSZZZNHZF1009382

Target Motorcycle ^[3]: Ducati 900SS, MG-LD-64

11.1.3 Test Day #3

Date: 20 November 2017

Test Location: RDW Test Centre [Talingweg 76, 8218 NX Lelystad]

10°C/1°C, 0 [mm], Overcast & Rain [14]

ACC Subject Vehicle ^[1]: Skoda Octavia Combi [1.6 TDI Greentech Ambition Business DSG 5d], PK-025-L, TMBJG9NE8J0114340

Target Control Vehicle ^[2]: Seat Toledo, 4-XFF-08, VSSZZZNHZF1009382

Target Motorcycle ^[3]: Triumph Tiger 1050, 36-MF-LD,

11.1.4 Test Day #4

Date: 29 November 2017

Test Location: RDW Test Centre [Talingweg 76, 8218 NX Lelystad]

4°C/1°C, 0 [mm], Overcast & Drizzle [14]

ACC Subject Vehicle ^[1]: Volvo V40, 57-XRG-5, (not verified)

Target Control Vehicle ^[2]: VW Polo, 83-NFP-7, (unknown)

Target Motorcycle ^[3]: Yamaha MT-09 Tracer, 70-MH-KH

11.1.5 Test Day #5

Date: 7 December 2017

Test Location: RDW Test Centre [Talingweg 76, 8218 NX Lelystad]

7°C/4°C, 7 [mm], Overcast & Drizzle [14]

ACC Subject Vehicle ^[1]: VW Golf Variant [1.4 TSI 103kW 7-DSG Highline 5d], 3-SPD-96, (unknown)

Target Control Vehicle ^[2]: Seat Toledo, 4-XFF-08, VSSZZZNHZF1009382

Target Motorcycle ^[3]: Suzuki V-Strom 650A, 17-MH-LP

11.1.6 Test Day #6

Date: 20 December 2017

Test Location: RDW Test Centre [Talingweg 76, 8218 NX Lelystad]

9°C/8°C, 0 [mm], Foggy/Misty [14]

ACC Subject Vehicle ^[1]: Tesla Model S [75 kWh AWD 5d], NZ-214-K, (not verified)

Target Control Vehicle ^[2]: Seat Toledo, 4-XFF-08, VSSZZZNHZF1009382

Target Motorcycle ^[3]: Suzuki V-Strom 650A, 17-MH-LP, 5YJSA7E20HF188590

11.2 Calculations

Any mathematical calculations relevant to the test plan or final report are presented here.

11.2.1 Recommended Abort Distances

The equations for calculating the theoretical braking distances can be derived with either the energy equations or with Newton's Second Law and the equations of motion. The derivations have been omitted from this report but can be easily found from other sources (e.g. dynamics books, Internet). Here, we begin with a short elaboration of how the recommended abort distances were calculated.

$$\textit{Abort Distance} = \textit{Stopping Distance (Subject Vehicle)} - \textit{Stopping Distance (Target Vehicle)}$$

$$\textit{Stopping Distance} = \textit{Response Distance} + \textit{Braking Distance}$$

$$\text{Response Distance} = \text{driver reaction time [s]} \times \text{vehicle speed [m/s]}$$

$$\text{Braking Distance [m]} = \frac{(v \text{ [m/s]})^2}{2 \times a \text{ [m/s}^2\text{]}}$$

where:

v = initial velocity of vehicle

a = deceleration rate of vehicle

Example

Assume a maximum deceleration of 8 [m/s²] for all vehicles and a reaction time of 1 [s] for the driver of the subject vehicle and 0 [s] for that of the target vehicles.

Subject Vehicle:

$$\text{Response Distance} = 1 \text{ [s]} \times \left(50 \left[\frac{\text{km}}{\text{h}} \right] \times \frac{1000 \text{ [m]}}{1 \text{ [km]}} \times \frac{1 \text{ [h]}}{3600 \text{ [s]}} \right) = 13,889 \text{ [m]}$$

$$\text{Braking Distance} = \frac{(13,889 \text{ [m/s]})^2}{2 \times 8 \text{ [m/s}^2\text{]}} = 12,056 \text{ [m]}$$

$$\text{Stopping Distance} = 13,889 \text{ [m]} + 12,056 \text{ [m]} = 25,945 \text{ [m]}$$

Target Vehicle:

Response Distance = 0 [m] because the target vehicle is the first to brake

$$\text{Braking Distance} = \frac{\left(30 \left[\frac{\text{km}}{\text{h}} \right] \times \frac{1000 \text{ [m]}}{1 \text{ [km]}} \times \frac{1 \text{ [h]}}{3600 \text{ [s]}} \right)^2}{2 \times 8 \text{ [m/s}^2\text{]}} = 4,340 \text{ [m]}$$

$$\text{Stopping Distance} = 0 \text{ [m]} + 4,340 \text{ [m]} = 4,340 \text{ [m]}$$

Abort Distance:

$$\text{Abort Distance} = 25,945 \text{ [m]} - 4,340 \text{ [m]} = 21,605 \text{ [m]}$$

By following these steps, the recommended abort distance for any speed combination can be calculated.

11.3 Latest Version of Test Plan

ACC & Motorcycle Safety Test Day

19 January 2017

Test Location: RDW Testcentrum [Talingweg 76, 8218 NX Lelystad]

ACC Subject Vehicle [1]:

Target Control Vehicle [2]:

Target Motorcycle [3]:

Driver 1: _____

Driver 2: _____

Driver 3: _____

Visitor 1: _____

Visitor 2: _____

Visitor 3: _____

Visitor 4: _____

Visitor 5: _____

Visitor 6: _____

Project Background

Towards the end of 2016, motorcycle associations FEMA, KNMV, and MAG NL contacted RDW expressing concerns regarding the safety of motorcyclists with the admittance of (semi-)autonomous vehicles on European roadways. Due to the intrinsic risks towards all road users, if such is the case, RDW decided to address these concerns. In February of 2017, RDW commenced this investigation and in the following eight months, developed an effective program to quantitatively evaluate the motorcycle detection performance of the ADAS systems adaptive cruise control (ACC), advanced emergency braking system (AEBS), blind-spot detection (BSD). Following a preliminary evaluation of a Tesla Model S' ACC system, RDW wishes to further quantify the safety of ACC systems from a range of vehicle manufacturers by performing an indicative study.

Test Day Objective

The purpose of this project assignment is to evaluate if vehicles' ACC systems detect motorcycles worse than cars, and if so, in what circumstances and in which manner.

Method

The aim of this test day is to quantify the performance of ACC systems' in identifying and reacting to a target control vehicle and a motorcycle. Using data logging and video recording equipment, many vehicle parameters will be collected and recorded to support a comparative evaluation of the distance a vehicle indicates, reacts to, and follows a target.

Other

This test plan is heavily based on that developed in ADAS Testing, Hoe reageren Advanced Driver Assistance Systemen op motorrijders?. Where appropriate, changes were implemented based on the suggestions and recommendations to improve suitability and participant safety. Also, speeds given in graph are real world speeds given by the VBOX, not indicated speeds given by the vehicle's speedometer.

Preceding Setup and Shakedown

- ☐ Equip target control vehicle with VBOX test equipment.
- ☐ Equip subject car with VBOX and Video VBOX test equipment.
- ☐ Ensure communication between vehicles.
- ☐ Set smoothing distance to 1 [m] and speed threshold to 5 [km/h].
- ☐ Set contact point between control and subject vehicles.
- ☐ Ensure sample data is sound.
 - Pay close attention to contact points and brake trigger response.
- ☐ Take pictures of owner manual pages describing ACC use.
- ☐ Park vehicles inside overnight to avoid frosted roofs and windows when it comes time to tape down the GPS and telemetry antennas.

Test Day Procedure

- ☐ Welcome any visitors and provide a brief tour of the facility if they would like.
- ☐ Gather remaining setup equipment necessary for subject and target vehicles.
 - 12V DC battery (x2)
 - SD cards (for subject vehicle VBOX and Video VBOX).
- ☐ Check tyre pressure and note the weather forecast for today.
- ☐ Verify VBOX setup options.
- ☐ Run through Test Day Procedure with test participants and visitors.
- ☐ Run through safety precautions with visitors and participants and determine who will be where (e.g. in which vehicle) during testing.
- ☐ Perform evaluations with the target control vehicle first.
 - Every so often, return to the parking lot for brief pause and to verify data collection.
- ☐ Transfer target vehicle equipment to motorcycle.
- ☐ Reset contact points, but now with the motorcycle.
- ☐ Perform evaluations till 15:30.
 - Every so often, return to the parking lot for brief pause and to verify data collection.
- ☐ After the afternoon pause, decide if we need to remove the test equipment from the subject vehicle due to an early return the following day.
 - If not, continue testing until 16:30.

Evaluation 1: Target Vehicle Interruption

The purpose of this evaluation is to verify if (and less so how) the subject vehicle responds to an overtaking target vehicle that performs a lane change within the subject vehicle's furthest following distance.

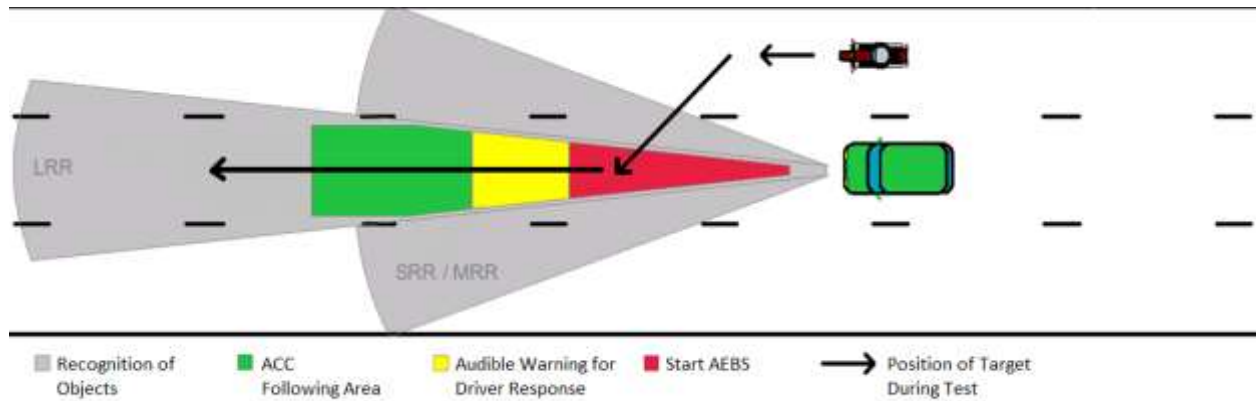


Figure 38 - Interruption of the ACC reaction area method (modified drawing of [18])

Subject Vehicle

- 1) Drive on the banked circuit with ACC enabled and active at the slowest speed combination and in the lane as indicated in Table 43/Table 44.
 - a. Note however that if the ACC refuses to maintain speed during banking, manually apply the gas pedal and re-engage ACC on the straights.
- 2) Select the farthest following distance possible.
- 3) When ACC is at the desired speed, communicate this with the target vehicle's driver.
- 4) Allow the target vehicle to overtake you at the start of either straight section with the anticipation that it will soon enter your lane.
- 5) With your foot hovering over the brake pedal in case of an emergency, observe whether the vehicle's ACC responds to the cut-in (by indicating and decreasing its travel speed).
- 6) Brake before the start of the bank if needed.
- 7) Repeat the steps for each speed combination in the order of slowest speed to highest speed.
- 8) If a speed combination is deemed unsafe, all greater speed combinations will not be tested.

Target Vehicle Steps

- 1) Drive on the banked circuit (behind [and NOT adjacent to] the subject vehicle) at the subject vehicle's speed as indicated in Table 43/Table 44.
 - a. If preferable, use of lane two may be used during banking as well.
- 2) At the exit of the bank, return to the lane as indicated in Table 43/Table 44.
- 3) Once the subject vehicle communicates that ACC is enabled and at the correct speed, overtake the subject vehicle with the indicated (target vehicle) speed as in Table 43/Table 44.
- 4) Once approximately one car length ahead of the subject vehicle, perform a lane change into the subject vehicle's lane.
- 5) Maintain your speed as you drive away from the subject vehicle.
- 6) Brake before the start of the bank if needed.
- 7) Repeat the steps for each speed combination in the order of slowest speed to highest speed.

- 8) If a speed combination is deemed unsafe, all greater speed combinations will not be tested.

----- Perform this evaluation with the target control vehicle followed by the motorcycle. -----

Table 43 - Target Control Vehicle Interruption Speed Combinations

Speed Combinations at RDW Test Centre				
Subject Vehicle		Control Vehicle		Safe to continue?
Lane	Speed [km/h]	Lane	Speed [km/h]	(circle)
2	30	3	40	Yes / No
2	50	3	60	Yes / No
2	70	3	80	Yes / No
2	90	3	100	Yes / No
2	110	3	120	Yes / No

Comments: _____

Table 44 - Motorcycle Interruption Speed Combinations

Speed Combinations at RDW Test Centre				
Subject Vehicle		Motorcycle		Safe to continue?
Lane	Speed [km/h]	Lane	Speed [km/h]	(circle)
3	30	2	40	Yes / No
3	50	2	60	Yes / No
3	70	2	80	Yes / No
3	90	2	100	Yes / No
3	110	2	120	Yes / No

Comments: _____

Evaluation 2: Subject Vehicle Approach

The purpose of this evaluation is to observe how the ACC system reacts when approaching a slower moving vehicle in its lane of travel. Based on response distance, one can observe whether the response distance depends on own speed, on target speed, or a combination of both.

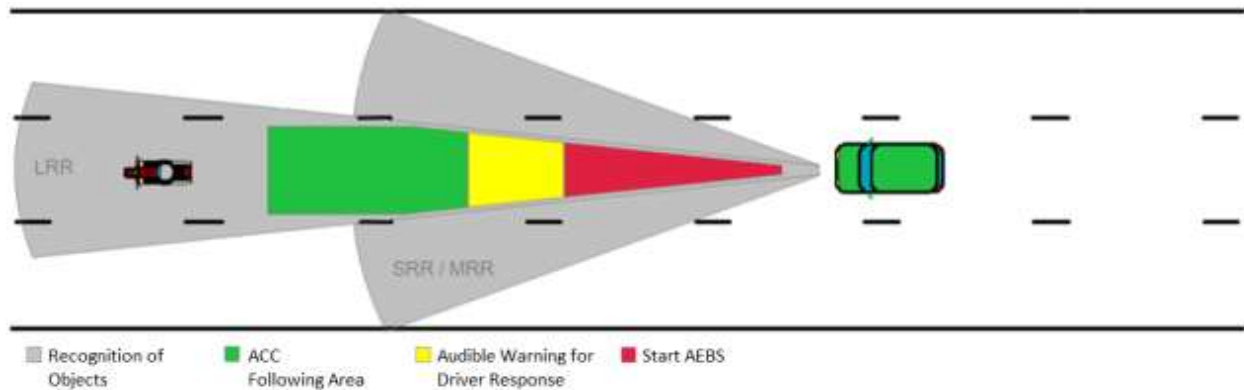


Figure 39 - ACC recognition, reaction, warning, and AEBS area (not to scale) [18]

Subject Vehicle

- 1) Drive on the banked circuit with ACC parameters pre-set if possible.
 - a. Select the farthest following distance possible.
- 2) With the on-board display, watch and wait that the target vehicle maintains their indicated speed.
- 3) Rapidly accelerate to your indicated speed combination and enable ACC at the furthest following setting.
 - a. Communicate to the target vehicle that you are on the approach.
- 4) With your foot hovering over the brake pedal in case of an emergency, allow to ACC system to 'drive' with the expectation that it may not detect the target vehicle. **Take note of the recommended abort distance indicated for each speed combination in Table 47.**
 - a. If the ACC responds accordingly, move to the next speed combination.
 - b. If the ACC does not respond appropriately, repeat the speed combination and avoid progressing to different speed combinations unless both test drivers feel comfortable to do so.
- 5) Follow the target vehicle for the entirety of the straight section to collect following distance data.
- 6) Brake before the start of the bank if needed.
- 7) Repeat the steps for each speed combination in the order of slowest speed to highest speed.
- 8) If a speed combination is deemed unsafe, all greater speed combinations will not be tested.

Target Vehicle Steps

- 1) Drive on the banked circuit at the speed indicated in Table 45/Table 46.
- 2) During the bank, try your best to hover around the target vehicle speed necessary if possible.
- 3) At the exit of the bank, maintain your target vehicle speed.
- 4) The subject vehicle will thereafter communicate to you that it is on the approach.
- 5) Continue to maintain your speed as best as possible.
 - a. The subject vehicle is responsible for reacting to impending danger, the target vehicle should maintain its course.

- b. The default driver reaction is to brake if the ACC is unresponsive. If such it the case, it will be clearly discussed if the driver will instead overtake on the left with ACC enabled.
- 6) Brake before the start of the bank if needed.
 - 7) Repeat the steps for each speed combination in the order of slowest speed to highest speed.
 - 8) If a speed combination is deemed unsafe, all greater speed combinations will not be tested.

----- Repeat this evaluation twice, first with the target control vehicle, and second with the motorcycle. -----

Table 45 - Speed Combinations with Target Control Vehicle

		Subject Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Target Control Vehicle Speed [km/h]	30	N	2	2						
	40	N		N						
	50			N		2				
	60				2	N	2			
	70					2				
	80							N		
	90							2	2	2

Comments: _____

Table 46 - Speed Combinations with Motorcycle

		Subject Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Motorcycle Speed [km/h]	30	L8R	1	1						
	40	L8R								
	50			L8R		1				
	60			L8R	1	1	1			
	70					1				
	80							1		
	90							1	1	1

Comments: _____

Table 47 - Recommended Abort Distances for Evaluation 2

Abort Distance [m]		Subject Vehicle Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Target Vehicle Speed [km/h]	30	22	30	39	49	60	72	85	98	113
	40	18	26	35	45	56	68	81	95	110
	50		22	31	41	52	64	77	91	106
	60			26	36	47	59	72	85	100
	70				29	40	52	65	79	94
	80					33	45	58	72	87
	90						37	50	64	79

Comments: _____

Evaluation 3: Lane Position Detection

The purpose of this evaluation is to observe if a target vehicle's lane position effects the reaction of the subject vehicle's ACC.

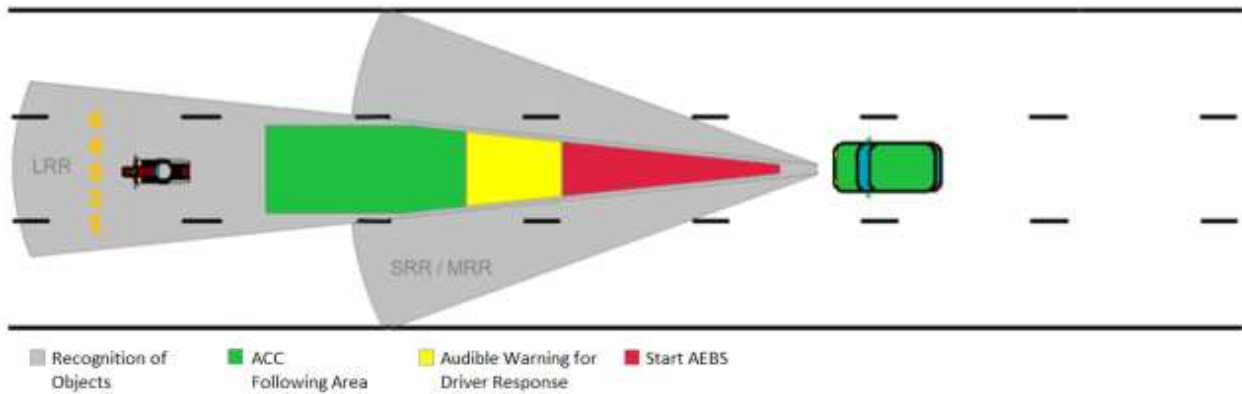


Figure 40 - Lane Position Detection (modified photo of [18])

Subject Vehicle

- 1) Drive on the banked circuit at the same speed as the target vehicle (slowest speed combination) with an appropriate following distance.
 - a. Decide with target vehicle driver which lane to use if two are given.
- 2) Upon the exit of the bank, rapidly accelerate to your indicated speed from Table 48 and enable ACC at the furthest following setting.
- 3) With your foot hovering over the brake pedal, allow to ACC system to 'drive' with the expectation that it may not detect the target vehicle.
 - a. Take note of the recommended abort distance indicated for each speed combination in Table 8.
- 4) Brake before the start of the bank if needed.
- 5) Repeat the steps for each speed combination in the order of slowest speed to highest speed.
- 6) If a speed combination is deemed unsafe, all greater speed combinations will not be tested.

Target Vehicle Steps

- 1) Drive on the banked circuit at the indicated speed given in Table 48.
- 2) As you leave the banked section of the track and approach either straight section, attain and/or maintain the indicated target speed seen in Table 48.
 - a. At the same time, maintain the appropriate lane position as indicated by the run number.
- 3) Brake (where comfortable) before the start of the bank if needed.
- 4) Repeat the steps for each speed combination in the order of slowest speed to highest speed.
- 5) If a speed combination is deemed unsafe, all greater speed combinations will not be tested.

Table 48 - Lane Position Speed Combinations with Motorcycle

		Subject Vehicle Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Motorcycle Speed [km/h]	30	N								
	40	N		N						
	50			N						
	60									
	70									
	80									
	90									

Comments: _____

Table 49 - Recommended Abort Distances for Evaluation 3

Abort Distance [m]		Subject Vehicle Speed [km/h]								
		50	60	70	80	90	100	110	120	130
Target Vehicle Speed [km/h]	30	22	30	39	49	60	72	85	98	113
	40	18	26	35	45	56	68	81	95	110
	50		22	31	41	52	64	77	91	106
	60			26	36	47	59	72	85	100
	70				29	40	52	65	79	94
	80					33	45	58	72	87
	90						37	50	64	79

Comments: _____

11.4 Video VBOX Scene

Unique to all Racelogic Video VBOX data loggers is the ability to customize the graphics of the video display. Figure 41 is the scene created for current and future ACC testing.

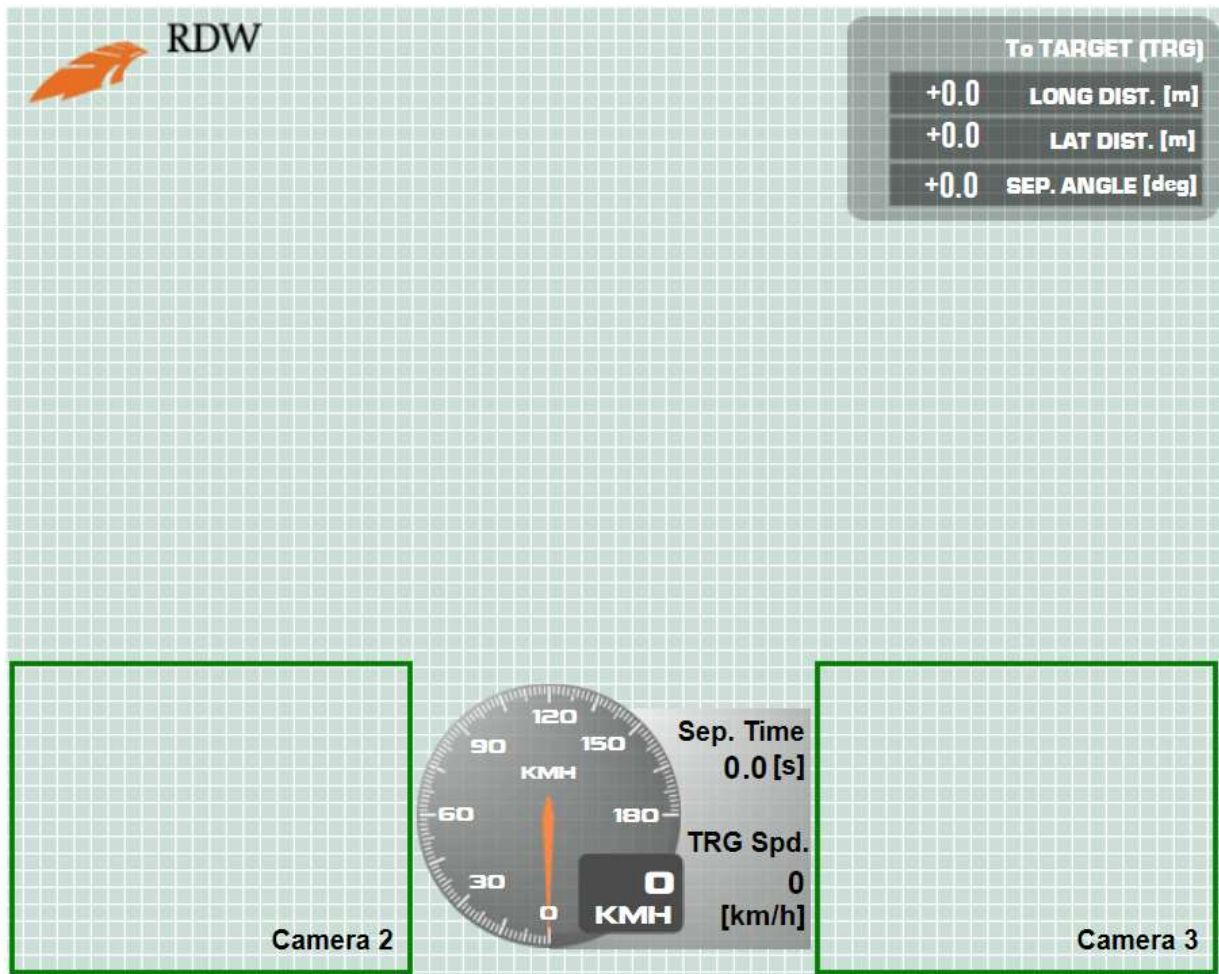


Figure 41 - Video VBOX Test Scene (RDW ACC)

Unique to this scene is the following (relevant) properties:

- Smooth level settings
 - Speed – 1
 - Lateral accel. – 5
 - Long. acc. – 2
 - Radius of turn – 5
- GPS Settings
 - VVB Type – 20Hz VVB
 - DGPS Mode – 20 cm
- Serial Application - None
- Video Settings
 - Format – PAL 720x576
 - Quality – High
- Audio Settings
 - Channels – Stereo
 - ACL Sensitivity – High
- CAN and module configuration
 - Baud Rate – 500 Kbit
 - Mode – VCI; send acknowledge

Note that Sep. Time stands for that parameter *SepTim-tg1* which represents the time it would take the Subject Vehicle to travel across the Vehicle separation distance at its current speed. All other parameters were explained in 5.1.

11.5 VBOX Equipment Setup

The follows subjects present a schematic of the equipment needed for ACC testing in the subject and target vehicles. Figure 42 and Figure 43 are modified photos from the RACELOGIC ACC - Single Target (Static Base) User Manual [15].

11.5.1 Subject Vehicle

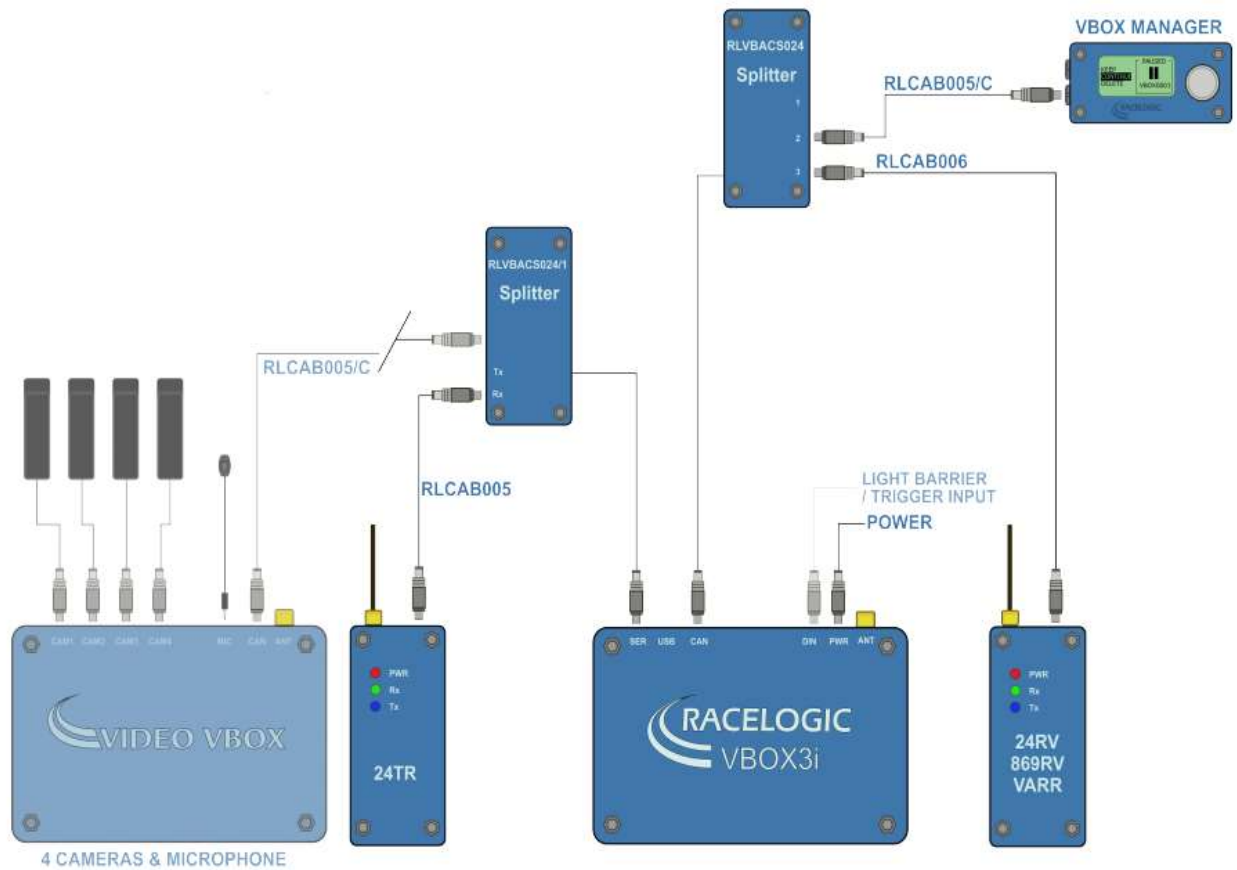


Figure 42 - VBOX Equipment Setup (Subject Vehicle)

11.5.2 Target Vehicle

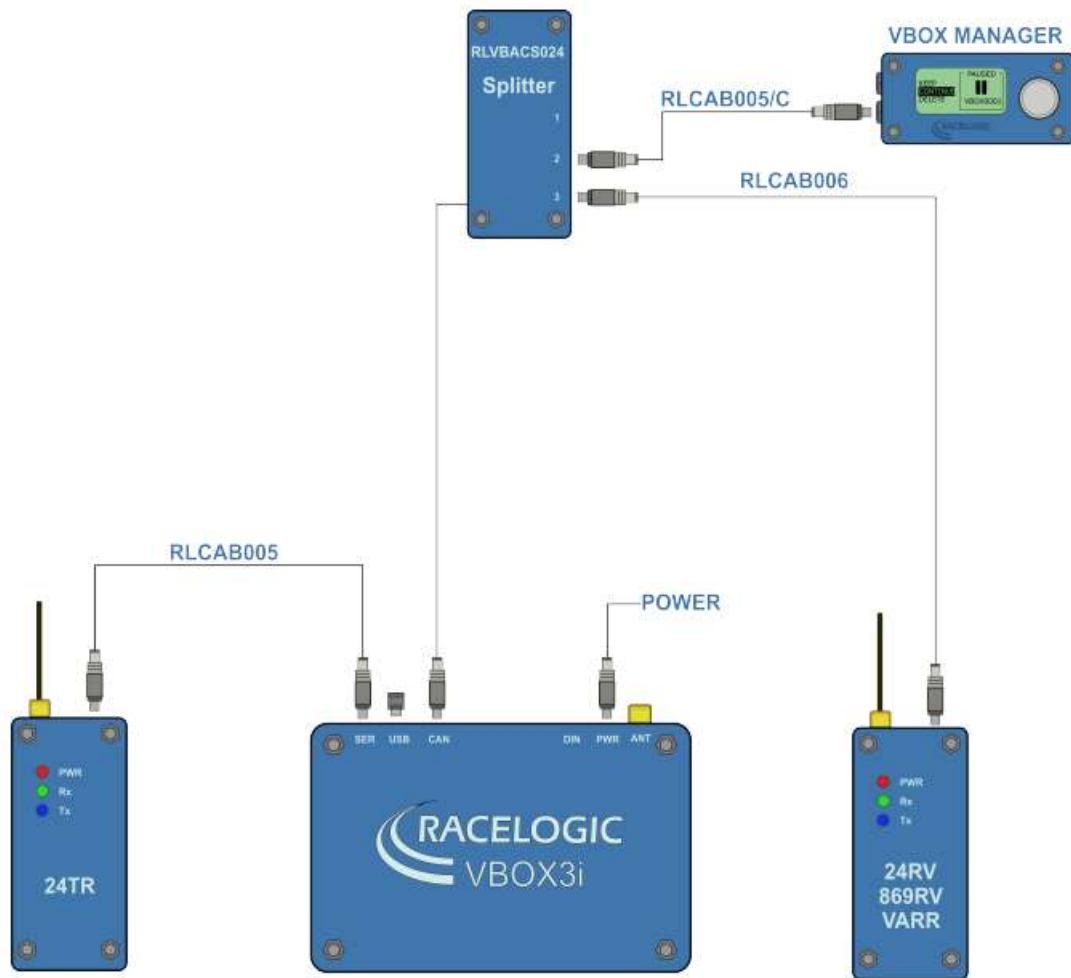


Figure 43 - VBOX Equipment Setup (Target Vehicle)

11.6 News Articles of Referenced Accident

The following news articles [16], [17] from newspaper Drammens Tidende refer to the Norwegian accident referenced.

Drammens Tidende

TUESDAY, JANUARY 16, 2018 [Become a subscriber!](#)

MENY

ACCIDENT TRAFFIC NEWS

Female to hospital after chain collision




Photo: Ida Elisabeth Mjøs Angeltveit

By [Mathias Høibakk Bergquist](#) , [Lars Helgerud](#) and [Ida Angeltveit](#)
July 27, 2016, at: 2:44 p.m. [v](#)

The article is over 1 year old

A female motorcycle driver has been sent to hospital after four vehicles were involved in an accident on the E18 in Drammen.

SHARE

f

...

DRAMMEN: Three cars and a motorcycle were involved in a chain collision on the E18 around 14.40 Wednesday afternoon.

The motorcycle must have been thrown over the midst of the motorway bridge and ended up in the opposite lane. The motorcycle driver, a young woman, has been sent to hospital. According to [NRK](#), the woman is seriously injured.

"She has gotten an air trip after being hit from behind by a car, but she was aware when she was driven to Drammen Hospital. The damage is not declared serious as far as we know, says operations manager in Søndre Buskerud police district Olav Myrvold.

Four people were involved in the accident, but it was only the female MC driver who was sent to hospital.

The road was completely closed in the southbound direction, and there was reduced accessibility in the northbound direction. In half past four, the road was opened again in both directions.

For a while there were long queues on the spot, but after the road opened again, it had loosened something up. On the bridge itself, however, it was close for a while. The Norwegian Public Roads Administration recommends a detour through the city center, Bangeløkka and Kobbervikdalen (county road 282).

Other issues on dt.no:

- [Armed action in Lier](#)
- [Claiming clubs thanks no to Ødegaard because of the salary](#)
- [Five things you should not wear at your office](#)





Photo: Ida Elisabeth Mjøs Angeltveit



Photo: Ida Elisabeth Mjøs Angeltveit



[NEWS](#) [TRAFFIC](#) [DRAMMEN](#)

Slo Tesla alarm after this accident



According to the police, Teslaen should have used autopilot when it crashed on Motorveibrua this summer, Photo: Ida Angeltveit

By [Rolf-Martin Hansen](#)

October 25, 2016, at, 10:14 ▾

The article is over 1 year old

Norwegian Motorcycle Union went straight to Tesla entrepreneur Elon Musk when a female MC driver was mowed by a Tesla on the autopilot in Drammen this summer.

SHARE



...

ANNONSE

DRAMMEN: It was July 27 this year that three cars and a motorcycle were involved in a serious traffic accident on Motorveibrua.

The motorcycle was thrown over the mid-race and ended up in the opposite lane. The young female driver also got an air ride, but luckily escaped without serious damage.

According to the police, the accident occurred when a Tesla on the autopilot failed to stop in time.

"We know that the driver was wearing it, but it was not the case that the car drove alone. The warning devices warned a little too late, unfortunately, says Jarl Hågensen, investigator in the South East police district to [E24](#). It was the ones who first mentioned the matter.

BACKGROUND: [Female to hospital after chain collision](#)

worryingly

The accident led the Norwegian Motorcycle Union to look red. They addressed, among other things, to the Minister for Transport, Ketil Solvik-Olsen and Tesla-entrepreneur Elon Musk.

"It's worrying if the Tesla autopilot is unable to detect a motorcycle but it's even more worrying if the driver has been tricked into thinking that something really is a driver support system is an autopilot that makes it possible to cross the arms and no longer carry the car," the [letter](#) says to Solvik-Olsen.

[The motorcycle federation also asked Musk](#) to stop marketing the car with autopilot. They think there should be no self-propelled cars but that it should be a competent and aware driver behind the wheel.

Tesla driver judged

The driver of Tesla had to meet in Drammen District Court earlier this October. He was charged with violations of the Road Traffic Act, which states that everyone should be considerate and be active and warm in traffic.

"The victim caused a relatively serious accident that could end up being worse," the judgment says.

The driver was sentenced to jail for 18 days. He also loses the patch for five months.

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