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ASSESS
ASSESSMENT OF VEHICLE SAFETY SYSTEMS

ASSESS
Assessment of Integrated Vehicle Safety Systems for improved vehicle safety

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Executive summary

Based on the test scenarios and target specifications as described in the ASSESS deliverable D4.2 "Draft test and assessment protocol" a second series of pre-crash evaluation tests have been carried out by BAST, IDIADA, TNO and DAIMLER.
Like in the first series of test conducted by BASt and IDIADA within the second series only rear-end manoeuvres were conducted. This was in line with the specifications of the test vehicles and the available laboratory equipment. The main objective of the second series was to check the reproducibility and repeatability of the specified test program and the capability of the various laboratories with the newly implemented laboratory updates as realized within the ASSESS project.
IDIADA, as state of the art laboratory, has carried out tests with the OEM and IDIADA car lab vehicle, using a rabbit vehicle and the prototype target developed during the ASSESS project. A part of the scenarios were carried out successfully; problems were recorded with test scenarios which results in inconsistent warning and target resistance after extensive use (100+ estimated impacts).
The main activities of BASt were the development of a remote control kart (MARVIN) as propulsion system for the ASSESS target. The phase 2 tests with the OEM vehicles were focused on the feasibility and repeatability of the kart tests. During the test program many improvements on the kart system were carried out. Additionally, tests were carried out with ADAC target and a VW Passat to check tests feasibility with different types of targets.
Phase 2 testing activities at TNO were carried out using a relative movement based rig where the tested vehicle drives stationary on roller benches. The OEM vehicles as well as the TNO car lab equipped with a solely for this project developed simplified pre-crash algorithm were tested to check feasibility and repeatability of the selected scenarios.
Additional tests were done at Daimler using the AB Dynamics's robot vehicle in combination with ASSESSOR target. Tests were done with the both vehicles and were used to check test feasibility and repeatability of ASSESS test scenarios with an extended range of propulsion systems.
One of the major ASSESS activities is the development of a universal test targets according to the specifications as described in D4.2. The target, named ASSESSOR, was engineered by FTSS and two prototypes were produced by Deutsche Schlaugboot GmbH. A mounting interface was specified as connection to the various propulsions systems from IDIADA, BASt, TNO and other users.
As one of the main sensors for pre-cars systems is a radar sensor, the radar cross section (RCS) of the ASSESSOR and six reference vehicles has been measured. Based on the measurement results the RCS of the ASSESSOR has been tuned to be representative for an average European vehicle. For camera and lidar sensor systems a realistic geometry and colour scheme were achieved, also a license plate and LED lights are available.
The two prototype ASSESSOR targets have been used by the test labs for ASSESS testing as well as testing outside the project, mainly to compare the ASESSOR with alternative solutions such as balloon cars, the ADAC target and simple cone reflectors.
The pre-crash testing on outdoor tracks and indoor facilities has to be safe for test drivers and operators as well for the vehicles under test, test equipment and environment. As the tests are carried out with high relative speeds and automatic robot systems, a set of safety routines has been development (see ASSESS deliverable D4.2).
Finally the test results of the pre-crash tests, expressed in key safety indicators, such as TTC, impact speed, time exposure to TTC, timing of activation of passive safety features, timing of warning and time of braking, were analysed to check reproducibility and repeatability between vehicles and test labs. The conclusions of phase 2 tests is further used for ASSESS project recommendations to ongoing evaluation protocols actually under development such as Euro NCAP.

A draft test procedure (Appendix A) was set up which was also provided to Euro NCAP for further consideration for the definition of the upcoming Euro NCAP AEB protocols. Additionally, the efforts concerning the definition of the test scenarios, the update of the test houses as well as the target (ASSESSOR) development were compiled with the respective information from other initiatives (AEB, ADAC, vFSS) via Harmonization Platform 2 (HP2) and provided to Euro NCAP in report format (see Appendix F) for further consideration.

Contents

1 Introduction

Based on the test scenario's and target specifications as described in ASSES deliverable D4.2 "Draft test and assessment protocol" a second series of pre-crash evaluation tests have been carried out by BAST, IDIADA, TNO and DAIMLER based on the drafted test procedure for pre-crash testing which is presented in Appendix A.

Test facilities as well as the updates implemented after the phase 1 tests and additional tests performed by DAIMLER are presented in chapter 2.

One of the major ASSESS activities is the development of a universal test targets according to the specifications as described in D4.1. and D4.2. The target named ASSESSOR was engineered by FTSS and two prototypes were produced. The development activities are presented in chapter 3. Based on the phase 1 and events testing experiences updates were carried out with the ASSESSOR and propulsions system to achieve the maximum results for phase 2 of the testing programs.

Prior to the tests the selected tests for phase 2 are presented, they are based on rear-end scenarios and multiple repetitions of the same test by all the labs in order to analyse tests reproducibility and repeatability.

The second series of tests by IDIADA, BASt, TNO and DAIMLER only considered manoeuvers form the rear-end scenario. This approach was chosen, as current pre-crash systems are able to handle most rear end crashes whereas they are not yet ready to also handle frontal or crossing as well as most cut-in manoeuvers. The results of all the test labs are presented in paragraph 5.1, the results are discussed in paragraph 5.2.

The pre-crash testing on outdoor tracks and indoor facilities has to be safe for the test drivers and operators as well for the vehicles under test, test equipment and environment. As the tests are carried out with high relative speeds and automatic robot systems, a set of safety routines has been developed; the routines were presented in Deliverable D4.2. The main difference with phase 1 tests is the implementation of driver reaction tests using braking robots by all the test facilities.

Finally, in chapter 6 a quantification of the robustness of the procedures developed by the ASSESS project with respect to repeatability and reproducibility is presented. This will be used further to guide proposals for the number of tests proposed in the final test protocol so that the results are accurate, fair, repeatable and representative. In addition to this analysis, the relationships between the KPIs (Key Performance Indicators) and the test parameters were investigated to understand which of the test parameters had most effect on the test outcome (KPIs). This information was also useful to understand which initial test parameters require close control and which don't.

To assure an appropriate dissemination of the project results, WP4 communicated with other related initiatives as AEB, vFSS or ADAC amongst others via the Harmonisation Platforms that were set up. A draft test procedure (Appendix A) as well as information on the target and test houses gathered via HP2 (Appendix F) was provided to Euro NCAP for further consideration for the definition of the upcoming Euro NCAP AEB protocols.

2 Test facilities

2.1 BASt

At BASt, a remote-controlled kart system able to carry the rear end part of the ASSESSOR is used for testing. Status as of December 2010 (Deliverable D4.2) was as follows:

- Remote control only operated manually
- No actual distance information was available to the kart operator
- No driver reaction was implemented in the vehicle under test
- Crashability of the test setup was available up to 30 km/h impact velocity

Major improvements have moved the kart and ASSESSOR system crashability to 40 km/h with minor damage on the vehicle-under-test. A speed controller on the kart is able to control the speed with an accuracy of 1 km/h. A display in the vehicle-under-test (VUT) displays the actual velocity, relative velocity and distance in x-direction to the kart operator. All these quantities are calculated from GPS position and speed readings. Braking control is done via an open-loop control, and lateral motion is still controlled completely by the kart operator (for safety reasons).

The VUT is equipped with braking and (in some cases) accelerator robots that are able to accurately reproduce a synthetic driver reaction after a defined reaction time (1.2 s for the fast driver reaction, 1.9 s for the slow driver reaction, which was dropped after the experiments with test vehicle A).

At this point it is important to emphasize that there was no connection at any point of testing to the vehicle CAN bus: during regulatory or customer testing, there would also be no connection to the vehicle CAN bus. This also means that the measured signals are not based on manufacturer know-how in any case.

The acoustic warning signal of the cars consists of a few pulses with different frequencies. This signal is picked up with a microphone and fed into a fast frequency analyzer IC. This IC is capable of detecting the frequency after roughly 3 ms which is neglectable in this context. The generated TTL signal (low for warning) is recorded and also directly fed into the brake and accelerator robots.

After a waiting time of $t_{AcceletorRobot} = t_{wait} - 0.1$ seconds, the accelerator robot releases the accelerator pedal (for test vehicle A – for test vehicle B, the conventional no-radar cruise control was used and therefore no accelerator pedal actuation was needed), and after the total waiting time t_{wait}, the brake robot acts on the brake pedal and outputs a TTL signal which is also recorded. Total waiting times were defined in WP3 to 1.2s and 1.9s.

Belt pre-tensioner activity is detected via measurement of the current in the pre-safe fuse (which equals the current in the electric engine of the belt tensioner).

Two touch sensors monitor the driver's brake pedal activity and the time of impact into the target.

All trigger output for one test run is shown in Figure 2-1.

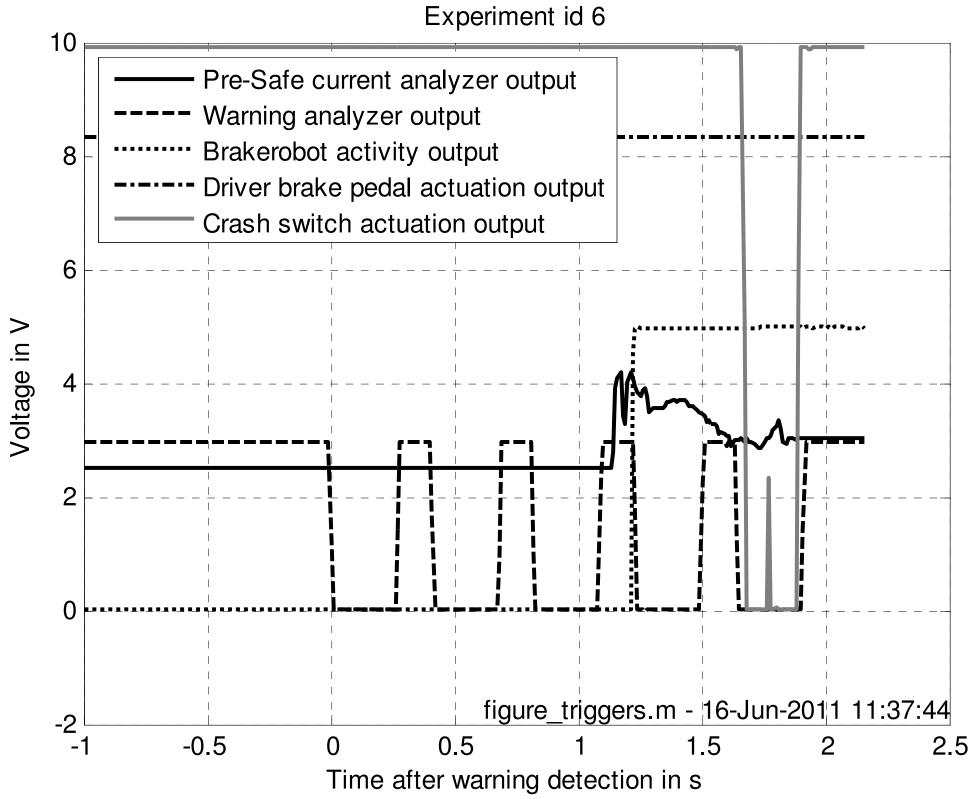


Figure 2-1: Trigger output during a test run

The most significant "weak point" of the setup with test vehicle A is the Wi-Fi bridge which is subject to random crashes after some minutes – which made it necessary to restart the communication before every test run. This connection has been replaced with a different system for the test vehicle B tests. Quality of the data is not affected.
One weak point of the test procedure for A2 scenarios has been the adjustment of initial distance. Distance calculated online from position measurements was unreliable. A new calculation method was introduced for the test vehicle B tests which shows good correlation with the actual distance.

Necessary improvements for the future will be:

- Closed-loop control of brake deceleration
- Closed-loop control of distance rather than kart velocity for A2 scenarios
- Yaw stabilizing assistance to compensate e.g. lateral wind on the test track

These improvements are not relevant for ASSESS and will be introduced only for the case that the kart setup is used for the upcoming Euro NCAP test procedures.

2.2 IDIADA

IDIADA used a rabbit vehicle during previous tests, as specified in D4.2 the rabbit mechanism was updated in order to reach higher impact speeds.

IDIADA rabbit system

The previous system was a mechanical trigger released by the impact force. The new mechanism uses electromagnets to quickly release the target. The magnets are controlled by a microprocessor monitoring 2 parameters:
1. Acceleration of both rabbit and target vehicle, if a difference higher than a limit is found the controller releases the target.
2. Touch sensor signal for the target: If the rear end of the target is touched then the target is released.
In addition the target can also be manually released by the operator.

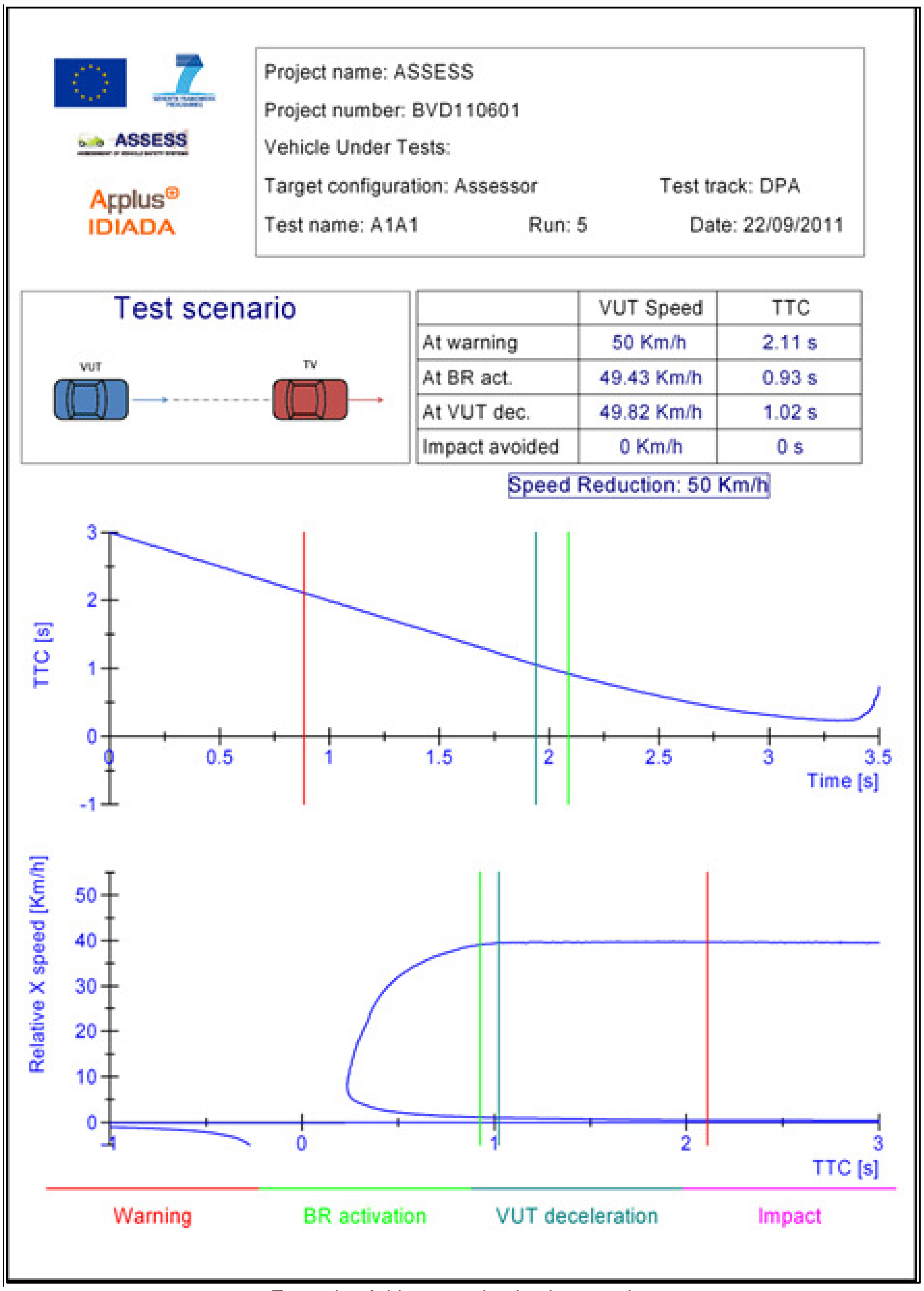
Magnets controller

The magnets solution has also the advantage of the redundancy of ways to release the system. In case of failure of the controller, the target will be released by the impact as the target is not mechanically locked.

The target trolley has been updated to be lighter and allow higher top speed and impact speed. The maximum speed of the target is 80Km/h in low wind conditions. The maximum impact speed is 50Km/h; this speed is usually limited depending on the tested vehicle to avoid any damage.
Maximum deceleration of the target is $6 m/s^2$.

New aluminum trolley

Regarding Subject Vehicle instrumentation a warning detector was created to detect audio warnings and send information to the braking robot controller to simulate driver reaction.



Example of driver reaction implementation


Braking robot installation

Some weaknesses were detected during tests:

1. The braking robot had some delay in the rising force command. This can be explained by the robot fixation mounted as standard on the driver's seat.
2. The audio warning detector is sensitive to audio noise, especially at human voice. That made the test synchronization between the target and tested vehicle more challenging than during others ADAS tests.

Typical accuracy:

Parameter	Trained driver	Driving robots
Speed	±0.5Km/h	±0.1Km/h
Distance (longitudinal)	±0.5m	±0.1m at constant speed
Distance (lateral)	±0.5m(dynamic target) ±0.2m(static target)	±0.1m(dynamic target) ±0.05m(static target)
Acceleration/Deceleration	±0.5m/s²	±0.2m/s² (depending on equipped vehicle)

2.3 TNO

The TNO test site called VeHIL (**Ve**hicle **H**ardware **i**n the **L**oop) is an indoor test track located in a large hall of 200x40m that allows for reproducible, effective, safe and efficient testing of active safety systems for intelligent vehicles on different levels. Initially, within VeHIL only the non crashable so called “moving base” was used as test object. Therefore, initially only tests with a TTC > 0.5 s could be conducted using 2 moving bases on collision course.

The vehicle under test is mounted on a 4WD roller bench that is able to simulate inertia and road load. This ensures, that the tested vehicle “feels no difference” compared to the real world while driving.

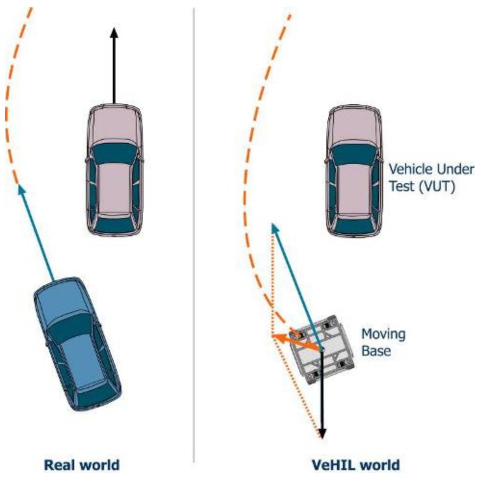


Figure 2-2 VeHIL motion principle

The VeHIL principle is based on relative motion of other road users with respect to the test vehicle (see Figure 2-2). Therefore, within VeHIL also tests with high absolute speeds can be conducted safe for both, environment and test driver.

VeHIL does allow for both, open loop as well as closed loop testing (see Figure 2-3). For closed loop testing, the speed of the test vehicle is processed real time by the so called EnSIM unit (**Enabling SIMulations**) and translated to the real world situation. From there, EnSIM feeds back all necessary information to the moving base resulting in an adaption of the moving bases’ speed according to the actions taken by the car on the roller bench.

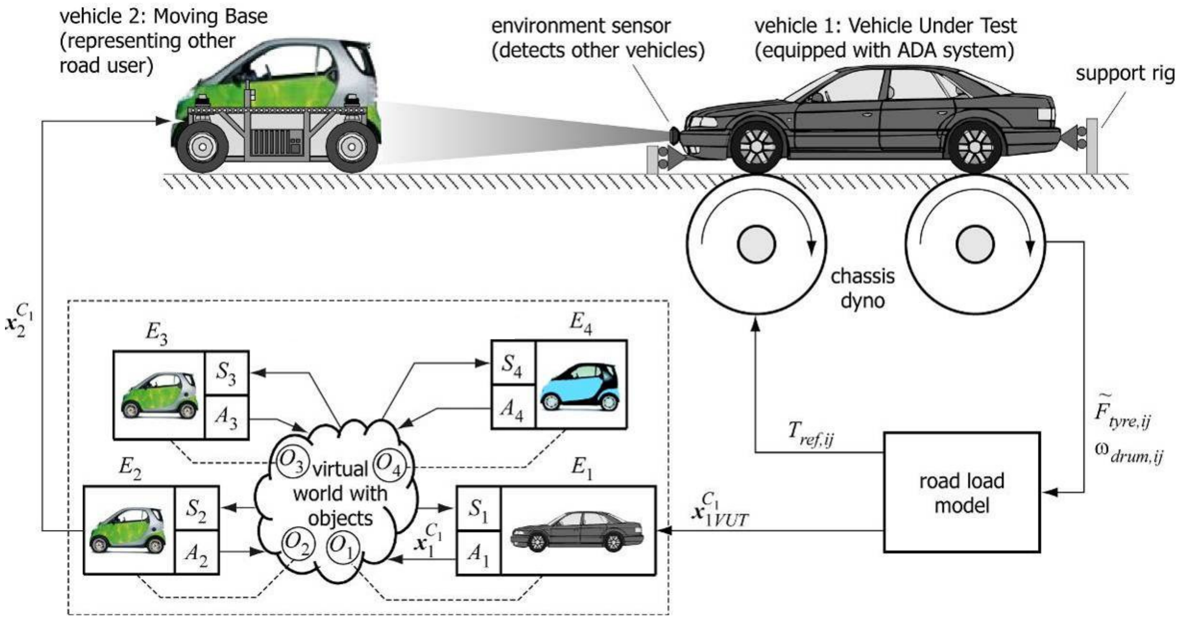


Figure 2-3 VeHIL: closed loop test set-up including all acting components

For ASSESS, VeHIL is extended with a sled set up (PCTS) that allows closed as well as open loop pre-crash testing up to TTC=0. The ASSESSOR is therefore mounted onto the central box as specified in the ASSESSOR interface document. This central box is fixed on a small trolley that itself is guided and driven back and forth by a guided rope like it can be found in crash labs. The rope itself is driven by a motor which is hardware in the loop coupled to the chassis dyno at which the VuT is placed. The VuT is placed on the chassis dyno in a controlled test environment. Reactions of the chassis dyno are coupled back to the main controller which uses this input to alter the setpoints of the PCTS. As such relative positions and speeds of VuT and Target can be controlled in real-time. The following metrics can be met:

- Max speed : 80 km/h relative speed between VUT and test target
- Max decel: 10 m/s2
- Lat. Pos. controllability: +/- 0.1 m
- Long. Pos. controllability: +/- 0.3 m
- Speed controllability: +/-0.5 m/s

The set-up as currently implemented is suitable for rear-end and frontal (high speed) scenarios with and without offset. Later versions will include lateral control of the target allowing for cut-in and crossing scenarios as well as even higher relative velocities.

Figure 2-4 PCTS set up in VeHIL for a 50% offset test configuration

On the VuT itself, no extra measurement systems have to be added to measure the position and the velocity, because this is done by using the chassis dyno. The chassis dyno has to be set upped for each car by tuning the road load parameters. These can be determined by performing a coast down analysis outdoor and on the chassis dyno. By comparing the results it is assured that the dynamic performance of the car on the chassis dyno is comparable to the dynamic performance on the road. The general set up with the rear end of the ASSESSOR mounted to the system is shown in Figure 2-4 for a 50% offset test configuration.

2.4 Additional tests at Mercedes

At Mercedes, additional to the tests initially planned at TNO, BASt and IDIADA tests were carried out using an AB Dynamics drive box with mounted ASSESSOR. This system is commercially available and can be regarded as a high end version of the set up used at BASt. For this set up, the target is built around a Central Drive Box which uses an electric motor with on-board batteries to propel the vehicle. It also houses the control system, which can accurately guide the vehicle along a pre-programmed course at a defined speed. The controller uses position feedback from a GPS-corrected inertial navigation system to ensure that high-precision guidance is achieved. A picture of the test set up is provided in Figure 2-5.

VuT control can be achieved with some full autonomous driving capabilities:

- steering robot (position in the lane)
- brake robot (brake reaction after the warning is issued)
  Relative positions and speeds of VuT and Target controlled in real-time
- Maximum Speed: 70 km/h
- Path Following Accuracy: Dependent upon motion pack type [2 cm (1 SD RMS) typical maximum]

Figure 2-5 Mercedes test set up with AB Dynamics drive box

3 Test target – ASSESSOR

3.1 Status of development

3.1.1 Development work

The ASSESSOR test target was developed during the first year of the ASSESS project [ref to D4.2]. Target Object requirements were discussed with the test labs IDIADA, BASt and TNO to make clear how the systems interrelate with the available carrier / propulsion systems. Daimler shared their prototyped SoftCrashTarget design based on the Mercedes C-class with FTSS. Partners agreed that the concept can be used for the Target Object development in the ASSESS-project. FTSS improved the design to make it compliant with the requirement specification. This included changes in outer contours (size and shape), increase of aerodynamic stability and improved crash backup for frontal and rear impacts. Two prototype Target Objects called ASSESSOR were produced by Deutsche Schlauchboot GmbH. The first prototype ASSESSORS became available July 05, 2010. In July, August and September a radar cross-section image was designed by Humanetics with support of TNO Defense and Security in The Hague. For this purpose 360 degrees radar reflection measurement were done on three cars at TNO in The Hague. Next the radar reflectivity of the ASSESSOR was fine tuned to meet corridors constructed from the 360 degrees measurements on cars.
The rear end parts of the ASSESSOR equipped with preliminary radar cross-section image participated in the Round Robin test series organized by vFSS (July 27-29, 2010 in Papenburg).

A more detailed description of the development work is given in ASSESS project Deliverable 4.2 chapter 3.

3.1.2 ASSESSOR Versions used in ASSESS

Over the past years the ASSESSOR target was tested extensively by ASSESS partners as well as third party projects like vFSS and AEB. During the testing refinements were introduced in the target. This concerned in particular the radar cross section characteristics. Figure 3-1below gives an overview.

1. The initial version of the ASSESSOR (Version 1.0) had a flat vertical layer of reflective material included (red lines in Figure 3-1). Tests with this version in ASSESS and vFSS showed that warning and autonomous braking was activated in most tests however, for angled approaches under 45 degrees from the rear reflections were too low.
2. For that reason the layout of the reflective material was updated to in Version 1.1 introducing a dihedral shape in the rear (this was done during the testing at TNO in The Hague described above). The performance of this version was found to be good and carlike. Therefore this version was used in most of the subsequent tests done in the ASSESS project.
3. In the evaluation of Version 1.1 it was found that the position and the stability of the radar cross-section needed further improvement. A curved application of the radar reflective material was proposed. To simulate this configuration, a mockup of Version 2.0 with curved vertical reflective material was made.

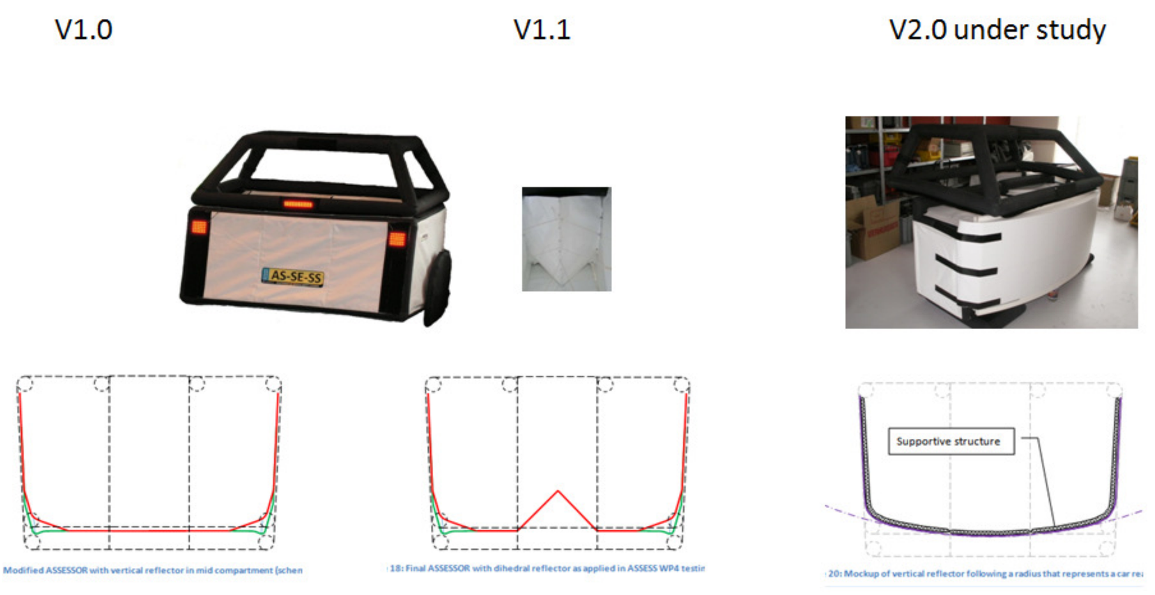


Figure 3-1: ASSESSOR Versions used in ASSESS WP4 testing

3.2 Configuration Control Table

In the table below a summary is given of the status of both ASSESSOR prototypes during the testing inside and outside that ASSESS project during the second half of 2010 and 2011. The configuration of the Rear Vented Box is taken as leading, other parts are provided as desired.

Table 3-1 Status summary of ASSESSOR Prototypes

***** restricted*****

4 Test set-up

4.1 Test matrix

An overview on the entire general pre-crash evaluation test matrix is provided in Appendix . This matrix does not only include the rear – end tests that were evaluated within the Phase II testing of the ASSESS project. It also includes the previously defined tests for the other scenarios (Oncoming traffic, Cut-in and Intersection) that are currently not testable with the systems evaluated within ASSESS as these systems are not designed to react under such circumstances. They have been included in the matrix however, so that the protocol is as robust as possible to future evolutions of the systems.

An overview on the tests conducted with the ASSESS test vehicles during the ASSESS Phase II testing is provided in Table 4-1. Tests that are marked in orange were requested to be conducted 10 times to provide input for the repeatability and reproducibility analysis to be conducted in task 1.4. Tests marked in red were likely to result in impact speeds that might not be testable anymore in most of the laboratories / test tracks. These tests did not need to be conducted if testing of less severe tests already indicated that the impact speeds that could be expected were too high for the respective propulsion – target combination.

Table 4-1 Test matrix for internal ASSESS Phase II testing

Scenario					SV	TV					Driver reaction
					Initial speed [km/h]	Initial speed [km/h]	initial lateral overlap [%]	Braking [m/s^2]	time to perform lane-change [s]	final intended lateral overlap [%]	
A	Rear end										
		A1		Slower lead vehicle							
		A1	A1	Urban scenario 1	50	10	100	no braking	n/a	n/a	no
		A1	A3	Urban scenario 1	50	10	100	no braking	n/a	n/a	fast
		A1	B1	Urban scenario 2	50	10	50	no braking	n/a	n/a	no
		A1	B3	Urban scenario 2	50	10	50	no braking	n/a	n/a	fast
		A1	C1	Motorway (Traffic jam)	100	20	100	no braking	n/a	n/a	no
		A1	C3	Motorway (Traffic jam)	100	20	100	no braking	n/a	n/a	fast
		A2		Decelerating lead vehicle (until stopped)							
		A2	A1	Urban normal driving	50	50	100	4	n/a	n/a	no
		A2	A3	Urban normal driving	50	50	100	4	n/a	n/a	fast
		A2	B1	Urban emergency braking	50	50	100	7	n/a	n/a	no
		A2	B3	Urban emergency braking	50	50	100	7	n/a	n/a	fast
		A2	C1	Motorway normal driving	80	80	100	4	n/a	n/a	no
		A2	C3	Motorway normal driving	80	80	100	4	n/a	n/a	fast
		A2	D1	Motorway emergency braking	80	80	100	7	n/a	n/a	no
		A2	D3	Motorway emergency braking	80	80	100	7	n/a	n/a	fast
		A3		Stopped lead vehicle							
		A3	A1	Urban scenario 1	50	0	100	no braking	n/a	n/a	no
		A3	A3	Urban scenario 1	50	0	100	no braking	n/a	n/a	fast
		A3	B1	Urban scenario 2	50	0	50	no braking	n/a	n/a	no
		A3	B3	Urban scenario 2	50	0	50	no braking	n/a	n/a	fast
		A3	C1	Motorway (Traffic jam)	80	0	100	no braking	n/a	n/a	no
		A3	C3	Motorway (Traffic jam)	80	0	100	no braking	n/a	n/a	fast

Initial Phase 2 tests at BASt showed that a driver reaction time of 1.9 seconds (and also in combination with the brake swell time of approximately 250 ms) does not differ from no-reaction tests. With a decision from the ASSESS General Assembly in June 2011, slow driver reaction tests were dropped to make room for e.g. more repetitions of the other tests. A comparison of slow, fast and no driver reaction is shown in Figure 4-1.

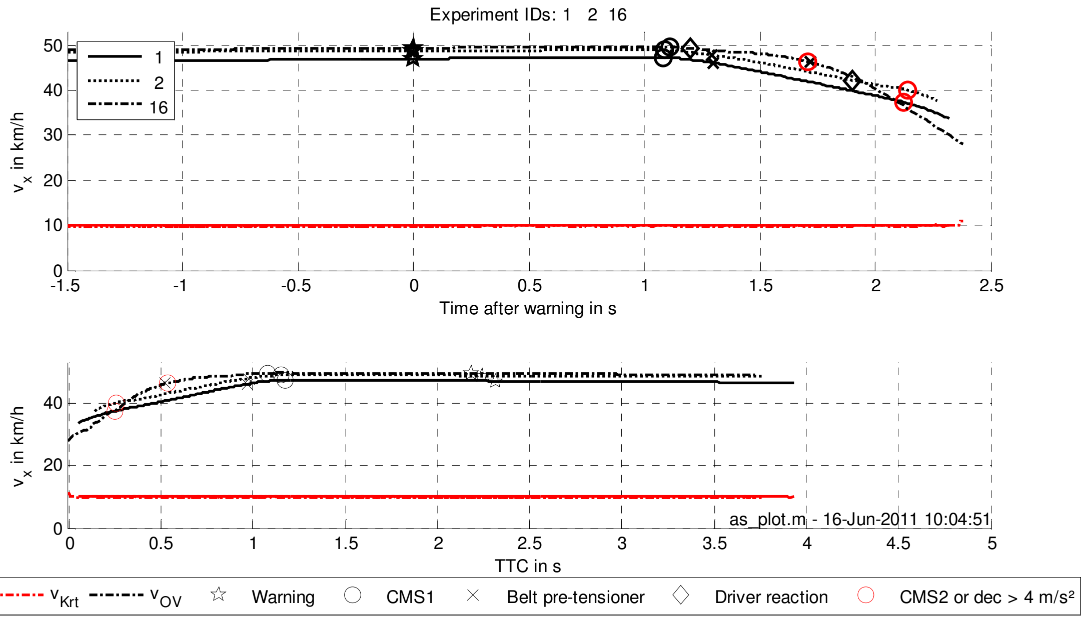


Figure 4-1: Velocity against time and against TTC for scenario A1 and three different driver reactions.

Note that – due to late warning – there is no significant difference between late driver reaction (1.9 s after warning, solid line) and no warning at all (dotted line), while the early driver reaction (1.2 s after warning, dash-dotted line) leads to a relatively more important speed reduction. Note that the speed for the “bullet” or “other” vehicle is too low for scenario A1A1. In that case, the speed limiter device was set to 50 km/h while a setting of 53 km/h would have delivered the correct 50 km/h.

4.2 Driver reaction

The original intention of the project was to quantify fast and slow driver brake reaction times. The purpose of identifying these data was to use the values in the pre-crash (WP4) testing so that the braking response to the system warning was representative.
Driving Simulator experiments were conducted in Toyota’s and Daimler’s driving simulators to quantify the driver reaction time. Although the experimental designs were based on the same concept, different results were observed, illustrating the difficulty in obtaining robust reaction times to a warning. The study concluded that it is very difficult to robustly define a generic driver reaction that is applicable to a range of different scenarios. Some driver reactions could be quantified from the Toyota’s experiments, taking into consideration only those subjects who were effectively distracted at the start of the event. The following observations were made:

- In all cases, all drivers reacted by a single braking action or by a combination of braking and steering. No cases of “no reaction” were found.
- Driver reaction times to the warning were:

Percentile	Estimate	Lower CI	Upper CI
25th	1.32 sec	1.24 sec	1.83 sec
50th	1.67 sec	1.32 sec	2.02 sec
75th	2.02 sec	1.62 sec	2.06 sec

- Average Brake force application observed was:
  - Gradient: 300 N/sec
  - Maximum force: 360 N.

After reviewing the simulator study results and other published information, WP3 partners highlighted the following conclusions:

- From literature, a wide range of driver reactions can be observed from different studies.
- Results from the Toyota driving simulator is just one of these various results:
  - The reaction times from Toyota Driving Simulator could be considered as a "worst case" example, only valid for the given scenario ("leading vehicle braking" at 0.7 g) and with the given (highly distracting) secondary task
  - The brake force applied will be significantly dependent on the particular brake pedal characteristics of the vehicle.

Based on the interpretation of reaction times from various studies, WP3 partners suggested using the following reaction times as a first step, but highlighted that further research would be needed to establish a robust driver reaction model:

- 25th percentile: 1.2 s.
- 50th percentile: 1.4 s
- 75th percentile: 1.6 s

Regarding the brake application, because the pedal displacement required to achieve a certain level of deceleration is known to be vehicle dependent, it is recommended to apply the brake pedal in a manner which corresponds to an average deceleration in a typical rear-end critical situation. Several studies on Event Data Recorders (EDRs) have reported typical deceleration levels in these situations to be around 4-5 m/s².

4.3 TNO simulation study

As described in the ASSESS deliverable D4.2, TNO conducted a simulation study to investigate the sensitivity of certain parameters as initial velocity or time delays on the potential outcome of the WP4 tests. The study was conducted using Matlab and not PreScan as initially intended. This was done, as no in-depth system or hardware information was available that could be implemented. Additionally, a more general approach that was independent of a specific system was considered more valuable for this study. It should be noted, that if detailed system information were available, this could have been used to investigate scenarios numerically instead of by means of testing. The outcome of this study was also presented on the Active Test workshop held in September 2011. The respective presentation is available in the proceedings of this event.

The focus of this simulation study was put on the rear end scenario, as those were also the focus of the actual physical WP 4 testing. Overlap manoeuvres were not considered separately as no information was available, how overlaps other than 100% would in general affect a system performance. It should be noted, that from the actual WP4 testing at a later stage in the project it could be seen that such an effect can be present depending on the strategy followed by the OEM.

The system that was modelled for the investigations is based on the system available in the Mercedes E class version as described in the ATZ (see picture below). Data obtained from this article are:

- mid-range radar: opening angle 60°, range 60m
- long-range radar: openings angle 18°, range 200m
- first autonomous braking action: TTC 1.6s with partial braking (level assumed -4 m/s²)
- second autonomous braking action: TTC 0.6s with full braking (level assumed -8 m/s²)

The driver reaction time used for fast and slow reaction was set to 0.78 sec and 1.81 sec, respectively. Please note, that these are not the final driver reaction times as found within WP3. However, these are the values that were available as intermediate results by the time this simulation study was conducted.

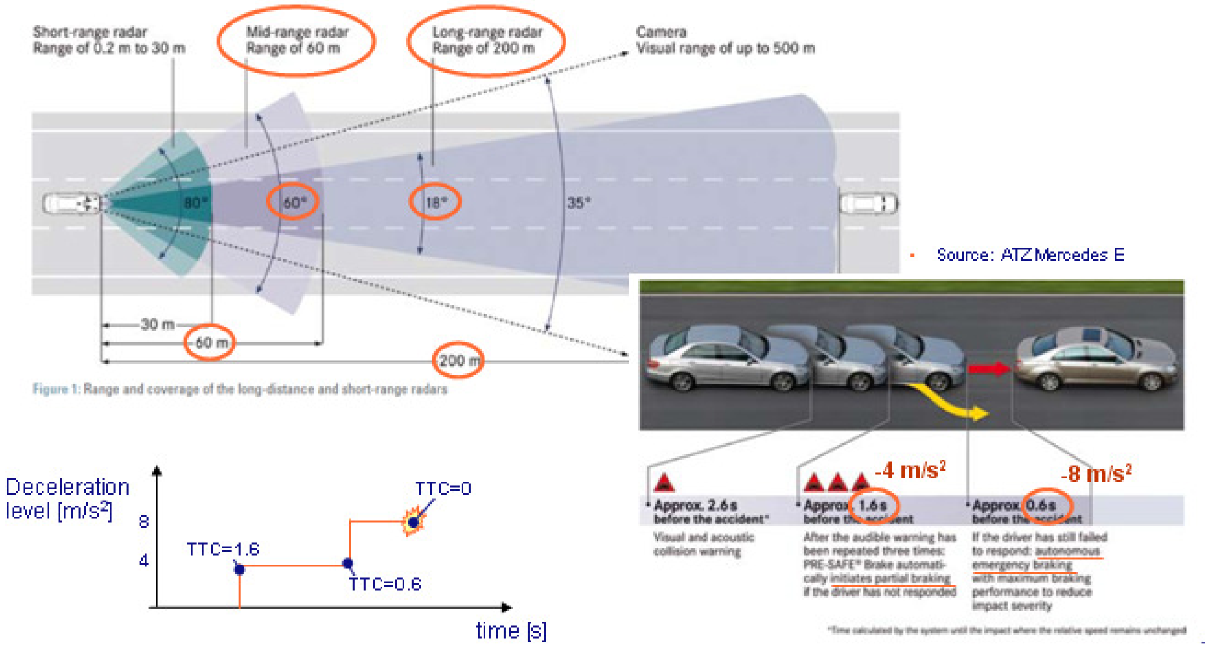


Figure 4-2 Mercedes E Class information retrieved from ATZ

In Figure 4-3 an example for manoeuvre A1A (SV 50 km/h, TV 10 km/h, 100% overlap) is presented that shows the different speed reductions and remaining distance between TV and SV at the end of the test for the different assumed driver and system reactions. It can be seen that depending on the action taken and its respective timing both, crash avoidance and mitigation are possible. The initial input values were varied separately in order to investigate the sensitivity of the expected speed reduction to these variations. It was found, that especially for emergency braking situations without prior driver reaction small variations in timing for initiation of the brake action can lead to significant variations for the respective impact speed (see Figure 4-4). Small variations of initial speed (± 1 km/h) were found to have the least impact on the results, whereas differences in deceleration performance (± 0.5 m/s2) and timing (± 0.1 sec) could have significant influence. To get a better feeling on which TTC and deceleration combinations the test could result in either collision avoidance or potential mitigation, further plots as shown exemplary in Figure 4-5 were generated for each rear end manoeuvre. Plots for the other rear end manoeuvres are provided in Appendix D.

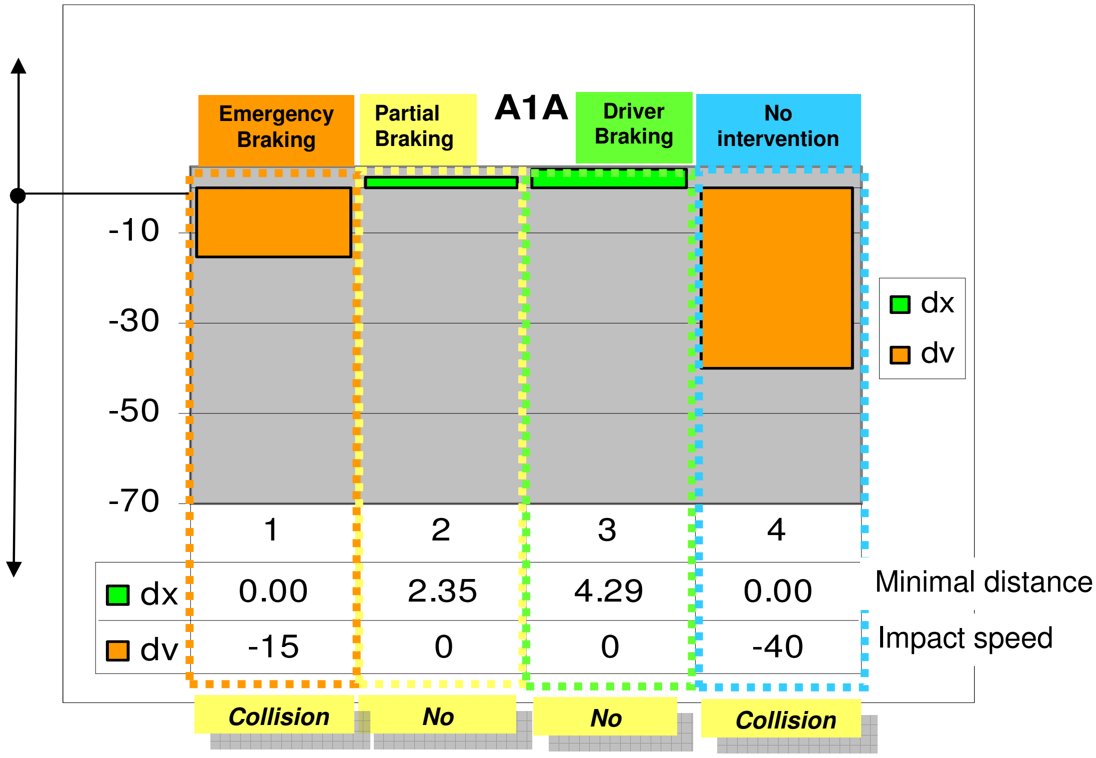


Figure 4-3 A1A default performance

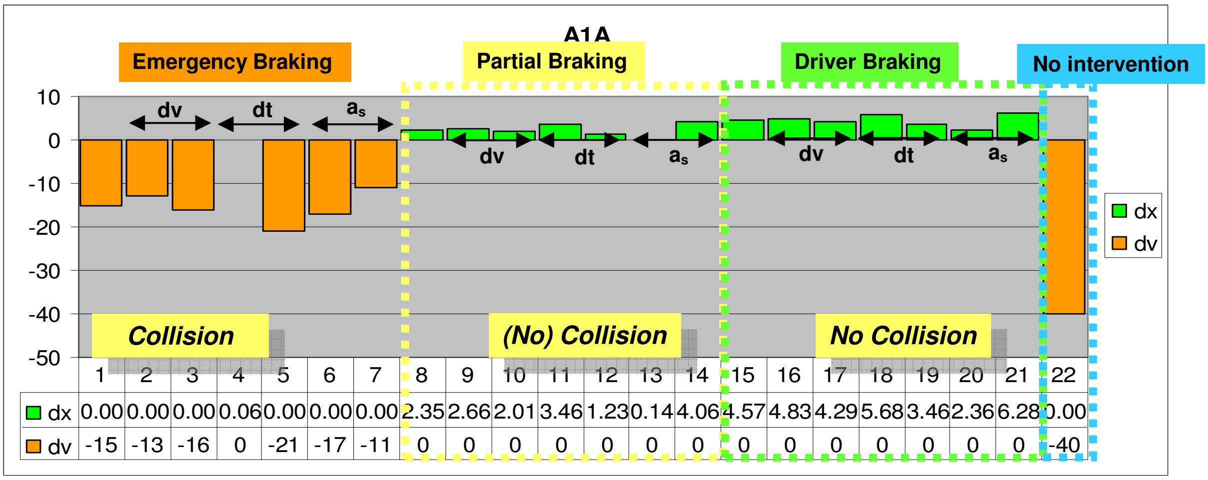


Figure 4-4 A1A results for parameter variation

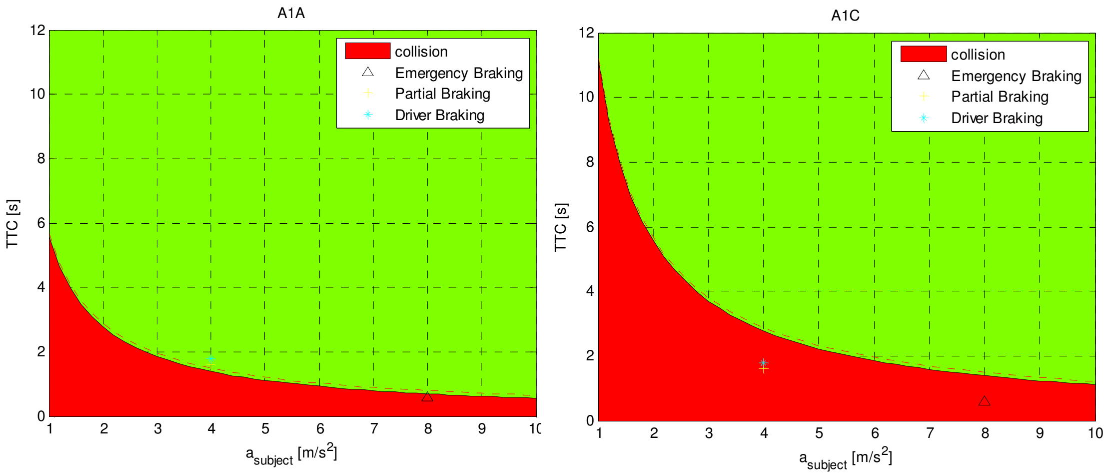


Figure 4-5 collision avoidance or mitigation potential for different TTC /a_{SV} combinations for maneuvers A1A (SV 50 km/h, TV 10 km/h, 100% overlap) and A1C (SV 100 km/h, TV 20 km/h, 100% overlap)

Based on these results, an order for conduction of the tests on a proving ground with increasing expected impact speed could be established (see Table 4-2).

Table 4-2 proposed test order for testing in proving ground

Scenario					SV	TV			Driver r	possible speed reduction				
					Initial speed [km/h]	Initial speed [km/h]	initial lateral overlap [%]	Braking [m/s^2]		max velocity delta possible (no system) [km/h]	velocity delta emergency braking with 8m/s^2 at TTC 0.6 s [km/h]	velocity delta partial braking with 4m/s^2 at TTC 1.6 s [km/h]	velocity delta partial braking with 4m/s^2 at TTC 1.8 s [km/h]	Ranking (severity increases)
A	**Rear end**													
	A1		**Slower lead vehicle**											
	A1	A1	Urban scenario 1		50	10	100	no braking	no	40	15	N/A	N/A	2
	A1	A3	Urban scenario 1		50	10	100	no braking	fast	40	N/A	0	0	1
	A1	B1	Urban scenario 2		50	10	50	no braking	no	40	15	N/A	N/A	4
	A1	B3	Urban scenario 2		50	10	50	no braking	fast	40	N/A	0	0	3
	A1	C1	Motorway (Traffic jam)		100	20	100	no braking	no	80	60	N/A	N/A	16
	A1	C3	Motorway (Traffic jam)		100	20	100	no braking	fast	80	N/A	52	47	15
	A2		**Decelerating lead vehicle (until stopped)**											
	A2	A1	Urban normal driving		50	50	100	4	no	38	20	N/A	N/A	10
	A2	A3	Urban normal driving		50	50	100	4	fast	38	N/A	21	21	9
	A2	B1	Urban emergency braking		50	50	100	7	no	50	32	N/A	N/A	12
	A2	B3	Urban emergency braking		50	50	100	7	fast	50	N/A	32	30	11
	A2	C1	Motorway normal driving		80	80	100	4	no	68	50	N/A	N/A	14
	A2	C3	Motorway normal driving		80	80	100	4	fast	68	N/A	49	47	13
	A2	D1	Motorway emergency braking		80	80	100	7	no	80	62	N/A	N/A	20
	A2	D3	Motorway emergency braking		80	80	100	7	fast	80	N/A	60	58	19
	A3		**Stopped lead vehicle**											
	A3	A1	Urban scenario 1		50	0	100	no braking	no	50	28	N/A	N/A	6
	A3	A3	Urban scenario 1		50	0	100	no braking	fast	50	N/A	14	0	5
	A3	B1	Urban scenario 2		50	0	50	no braking	no	50	28	N/A	N/A	8
	A3	B3	Urban scenario 2		50	0	50	no braking	fast	80	N/A	14	0	7
	A3	C1	Motorway (Traffic jam)		80	0	100	no braking	no	80	60	N/A	N/A	18
	A3	C3	Motorway (Traffic jam)		80	0	100	no braking	fast	80	N/A	52	47	17

4.4 Test vehicles

4.4.1 Test vehicle A

***** restricted*****

4.4.2 Test vehicle B

***** restricted*****

4.4.3 IDIADA car lab

***** restricted*****

4.4.4 TNO car lab

***** restricted*****

5 Results of Phase II testing

5.1 Overview

All test data collected during the WP4 Phase II testing is available and can be found in a separate Appendix. In the following sections, only a subsection of the graphs generated will be presented.

5.1.1 BAST test results

An overview on the key performance indicators of all single experiments conducted at BAST is shown in Table 5-1. Note that this overview contains tests that have been carried out only a single time as well as all repeated tests. A table containing all results as numeric values as well as plots for all relevant quantities and the conditions for all conducted test runs can be found in the annex C.

Not all test runs could have been conducted as planned, mainly due to the following problems:

- DGPS base station failure for all vehicle B testing (affecting the lateral position measurement only),, thus no lateral deviation available (TTC and longitudinal deviations however are available in a sufficient accuracy. This accuracy has been confirmed by a second method for TTC calculation.).
- Bad weather conditions led to only few testing days (true for both vehicles), however all tests that were used took place in good conditions (dry road surface, temperatures above 15 °C).
- DGPS configuration issues, detected after several test runs, led to reduced GPS accuracy for all vehicle A tests.
- GPS Satellites were not always visible for tests at BAST itself and led to insufficient position accuracy (all test vehicle A repeatability tests, all test vehicle B stationary tests).
- Last but not least, tests were not conducted when there was the danger of damaging either the target system or the vehicle under test.

Table 5-1 Overview of conducted test runs and resulting key performance indicators for all tests at BAST (red: not tested)

Scenario	Number of test runs			Speed reduction [km/h]		Warning TTC [s]		Pretension-er TTC [s]	Brake TTC [s]		Reaction TTC [s]	
	Total	A	B	A	B	A	B	A	A	B	A	B
A1A1	15	8	7	12,83	13,43	2,18	1,99	0,83	0,71	0,43	0,00	0,00
A1A2	1	1	0	10,75	0,00	2,14	0,00	0,86	0,15	0,00	0,35	0,00
A1A3	6	1	5	19,76	25,34	2,19	1,59	0,51	0,58	0,48	0,98	0,55
A1B3	1	1	0	48,78	0,00	2,29	0,00	0,45	0,72	0,00	1,08	0,00
A2A1	2	1	1	16,87	24,97	3,81	0,94	1,17	0,73	0,06	0,00	-0,53
A2A2	1	1	0	8,59	0,00	3,62	0,00	0,78	0,34	0,00	0,00	0,00
A2A3	1	1	0	20,95	0,00	3,41	0,00	0,82	0,53	0,00	0,75	0,00
A2B3	1	1	0	10,64	0,00	2,86	0,00	0,55	0,31	0,00	0,49	0,00
A3A1	6	1	5	6,57	8,14	2,15	1,22	0,50	0,42	0,32	0,00	0,00
A3A2	1	1	0	0,07	0,00	2,13	0,00	0,00	0,00	0,00	0,22	0,00
A3A3	6	1	5	3,92	8,40	1,73	1,25	0,16	0,22	0,30	0,53	0,44
A3B1	2	1	1	1,68	7,20	1,67	0,82	0,17	0,10	0,30	0,00	0,00
A3B2	1	1	0	6,10	0,00	2,17	0,00	0,23	0,22	0,00	0,27	0,00
A3B3	2	1	1	17,03	7,00	1,80	0,73	0,65	0,60	0,30	0,61	0,00
A3C1	1	1	0	-0,18	0,00	1,05	0,00	0,00	0,00	0,00	0,00	0,00
A3C3	1	1	0	27,47	0,00	1,92	0,00	0,72	0,73	0,00	0,73	0,00

A cumulative plot for all test runs is shown in Figure 5-1. This should be noted, that this plot serves only as an overview, since it includes different scenarios. The following conclusions can be drawn from that test:

- The test speed of 50 km/h has been reached quite reproducible,
- Warnings were found in all experiments, however with a varying TTC
- The achieved speed reductions range from “avoided” to very small numbers (hardly any mitigation).

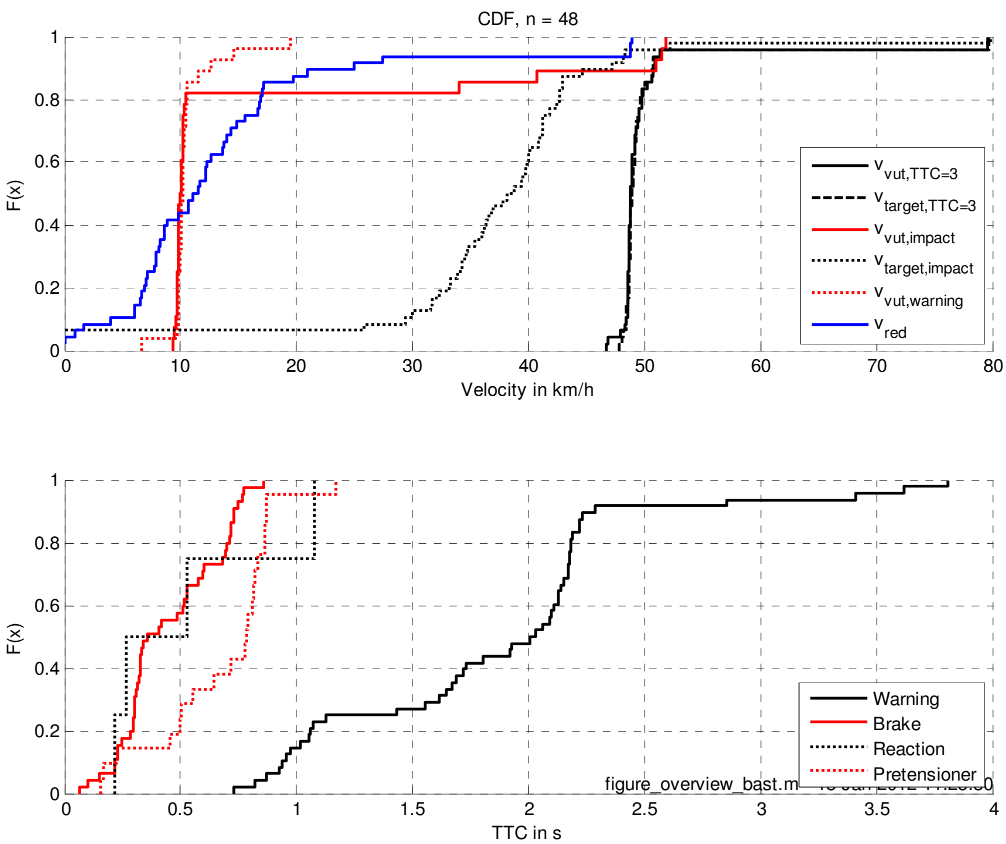


Figure 5-1: Overview of all BAST experiments

Several scenarios have been tested repeatedly to find out about the repeatability (in one lab) and the reproducibility (between all labs). Final conclusions from these repeatability and reproducibility tests will be drawn in chapter 6. Boxplots showing the achieved speed reductions and TTC values for warning, reaction, brake activation and belt pretensioning as well as plots of deceleration over TTC for the A1A manoeuvre (50 km/h to 10 km/h, with / without driver reaction) can be found in Figure 5-2
Some first conclusions from these results are:

- Test speeds are relatively repeatable.
- System performance seems to be repeatable only in cases without the warning – reaction – chain (see upper left diagram, black plots vs. red plots, see second row, variations of system performance without reaction vs. reaction).
- The spread of results is lower (repeatability is better) for test vehicle A, however mean speed reductions is better for test vehicle B.
- Test vehicle A warns and brakes earlier and more consistent than test vehicle B.

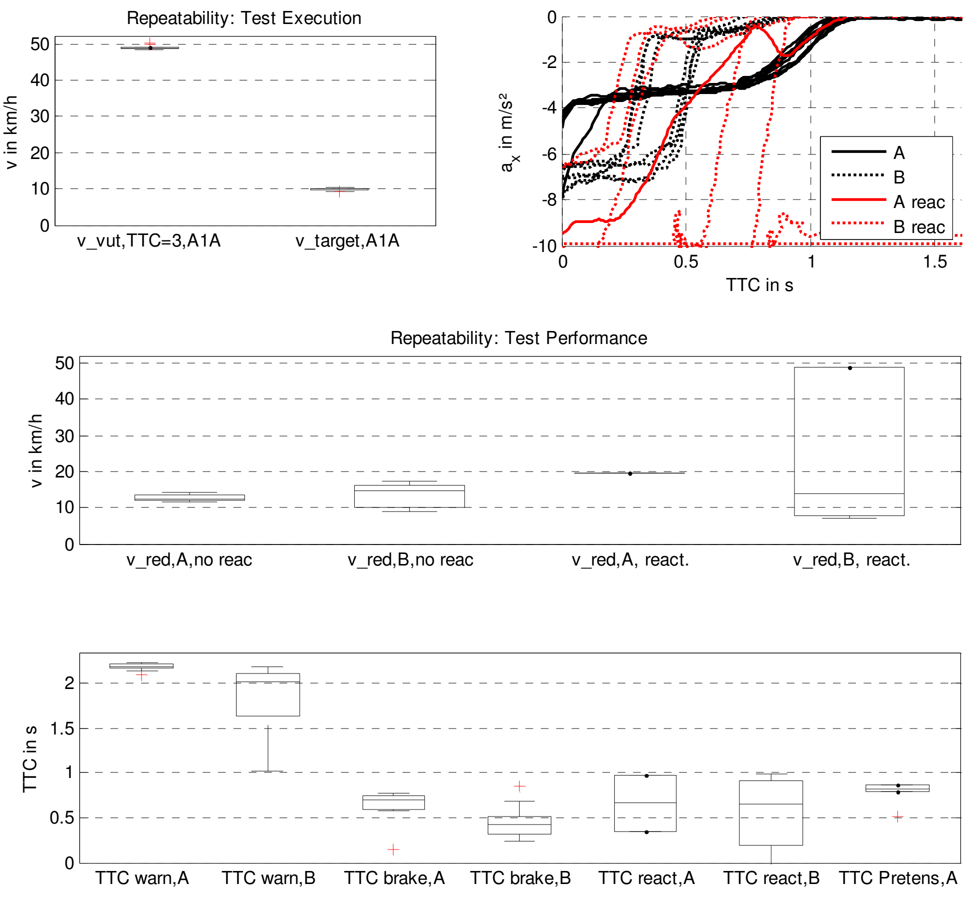


Figure 5-2: Repeatability of scenarios at BAST

Some examples for A1A scenarios (only test vehicle A) are shown in the following figure.

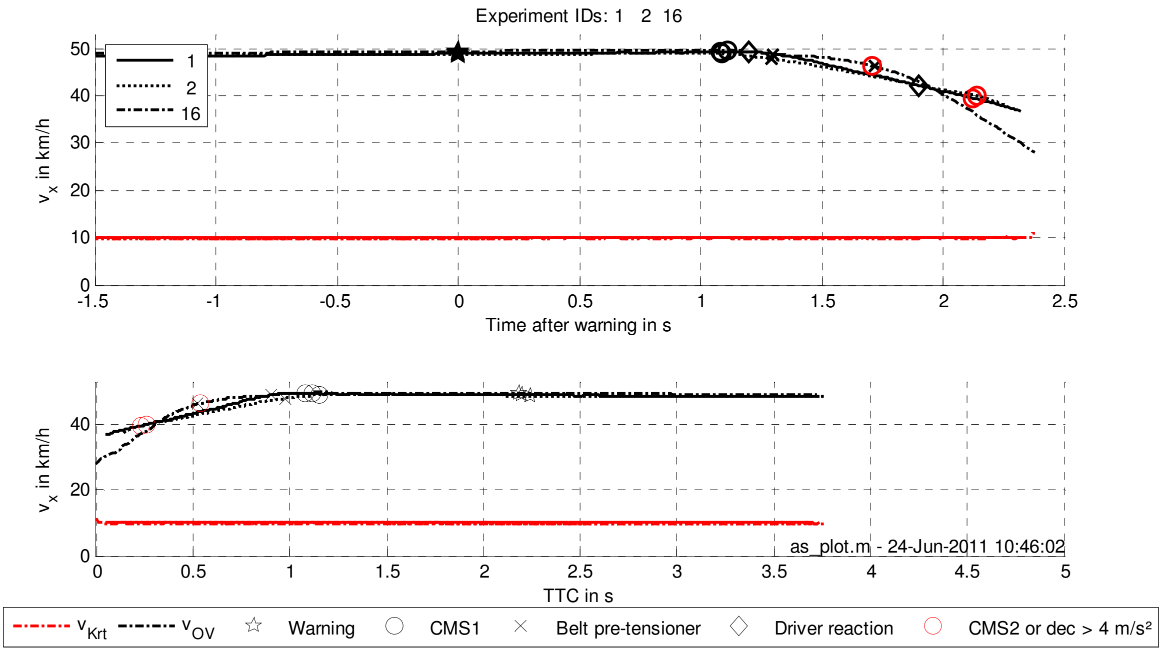


Figure 5-3: Examples of test results for Test Vehicle A, A1A scenarios, no reaction, fast reaction and slow reaction (not part of the final test program)

In addition to the tests conducted with the ASSESSOR, BASt was also able to conduct some tests with test vehicle A and the ADAC test target (see Figure 5-4). Manoeuver A1A1 and A3A1 were each conducted 10 times. The results are included in section 5.2.

Figure 5-4: ADAC test set-up (source: ADAC)

5.1.2 IDIADA test results

All test data collected from IDIADA tests are available in a separate appendix, here will be presented an overview of tests results.

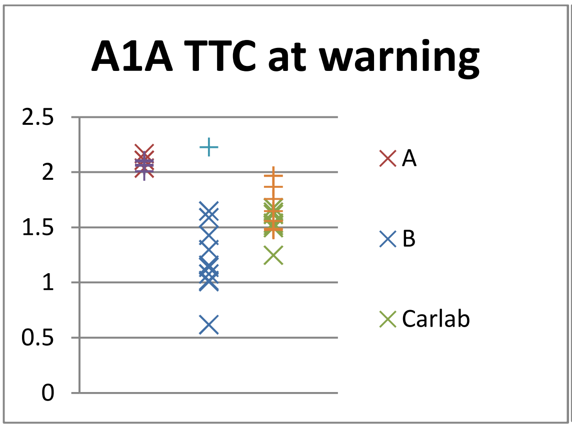
In some cases tests including driver reaction were not done because the warning time detected during non-reaction tests was with a TTC at warning inferior than 1.2s.

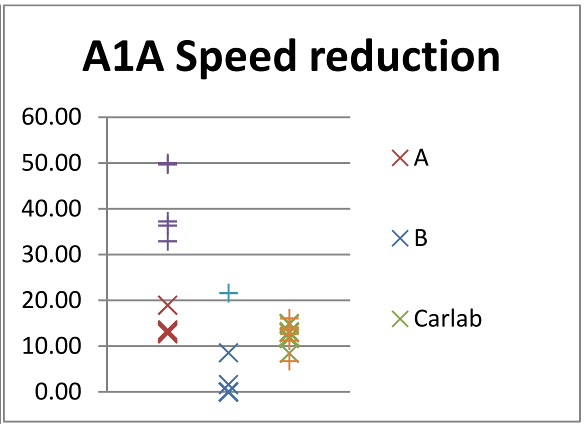
All tests could not be repeated the desired number of times because of vehicle damage detected after repeated impacts with the target.

Table 5-2 Overview of conducted test runs and resulting key performance indicators for all tests at IDIADA (red: not tested)

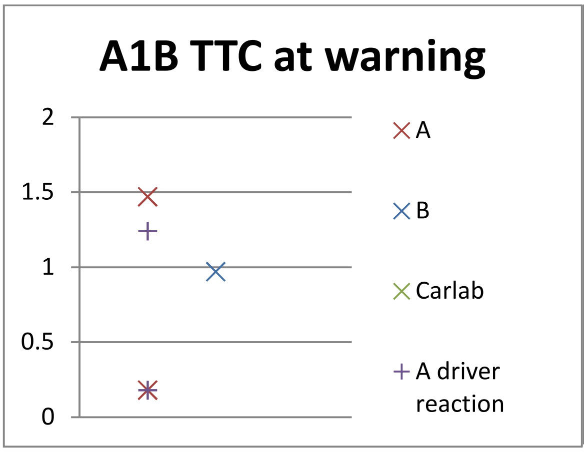
Scenario	Number of test runs				Speed reduction [km/h]			Warning TTC [s]			Brake TTC [s]			Reaction TTC [s]		
	Total	A	B	Carlab	A	B	Carlab	A	B	Carlab	A	B	Carlab	A	B	Carlab
A1A1	20	5	7	8	14.46	9.67	12.72	2.11	0.54	1.56	1.13	1.05	0.76	0.24	0.00	0.27
A1A3	12	5	1	6	41.22	50.00	13.61	2.07	0.00	1.70	1.11	1.32	0.61	0.87	0.00	0.48
A1B1	3	2	1	0	3.04	0.76	0.00	0.81	0.00	0.00	0.85	0.00	0.00	0.00	0.00	0.00
A1B3	2	2	0	0	4.37	0.00	0.00	0.71	0.00	0.00	0.87	0.00	0.00	0.25	0.00	0.00
A2A1	6	3	1	2	8.05	13.32	8.53	0.00	0.00	0.00	1.22	2.94	0.52	0.00	0.00	0.18
A2A3	11	5	0	6	11.98	0.00	1.73	0.00	0.00	0.00	1.62	0.00	0.35	0.57	0.00	0.25
A3A1	23	3	10	10	0.80	6.72	17.18	1.84	1.30	1.40	0.67	0.66	0.63	0.00	0.00	0.28
A3A3	4	1	0	3	8.53	0.00	12.02	1.99	0.00	1.45	0.58	0.00	0.63	0.74	0.00	0.27
A3B1	21	5	8	8	0.68	0.31	2.17	2.16	1.99	0.69	0.02	0.57	0.36	0.00	0.00	0.02
A3B3	5	3	0	2	3.65	0.00	3.11	1.51	0.00	0.35	0.62	0.00	0.43	0.45	0.00	0.05

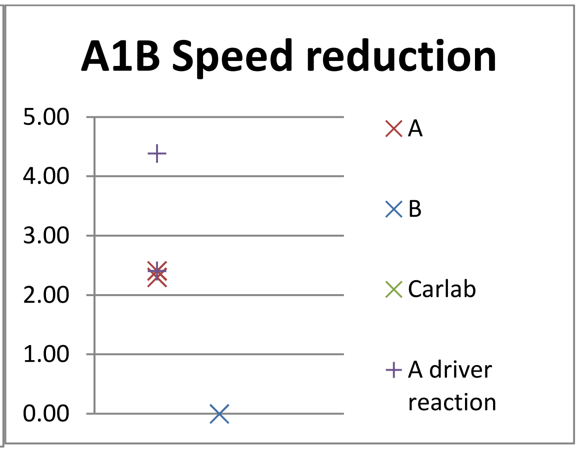
The following graphs are showing an overview of the tests done at IDIADA:



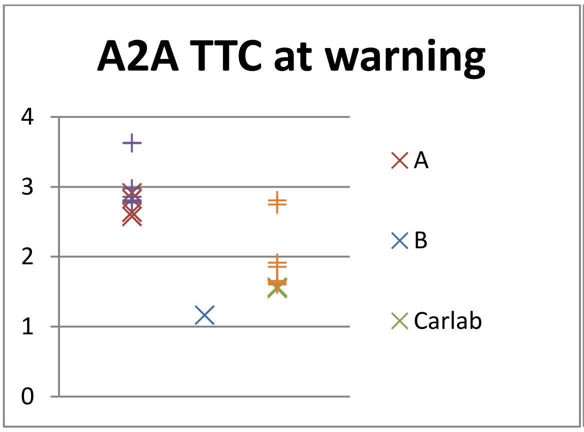


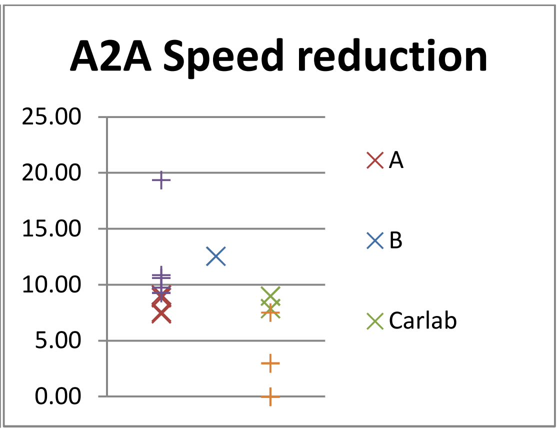
For vehicles A and B a speed reduction gain appears clearly for driver reaction tests. All cars warned the driver, no particular problems were detected during this test scenario.



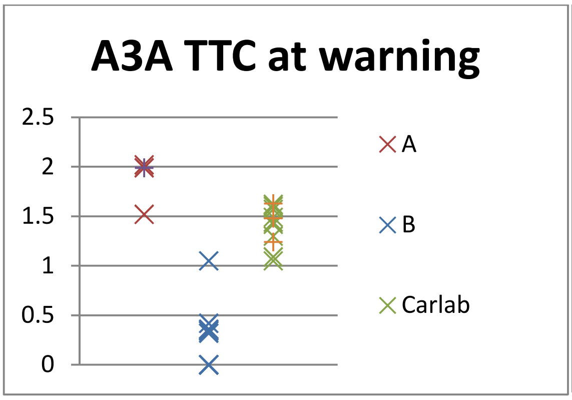


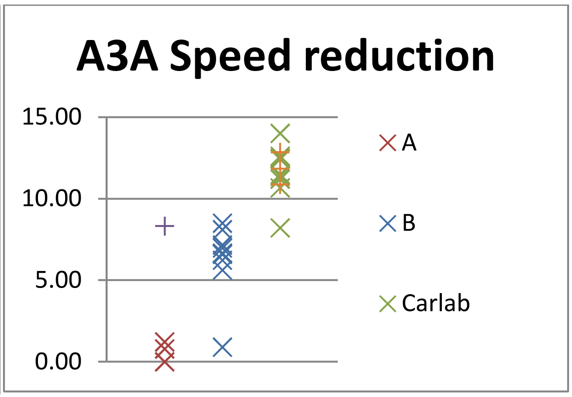
The cars B and Carlab had a lower performance for offset tests. In case of no detection of the vehicle during preparation tests the test scenario has been skipped to avoid any unnecessary damage to the vehicle or target.



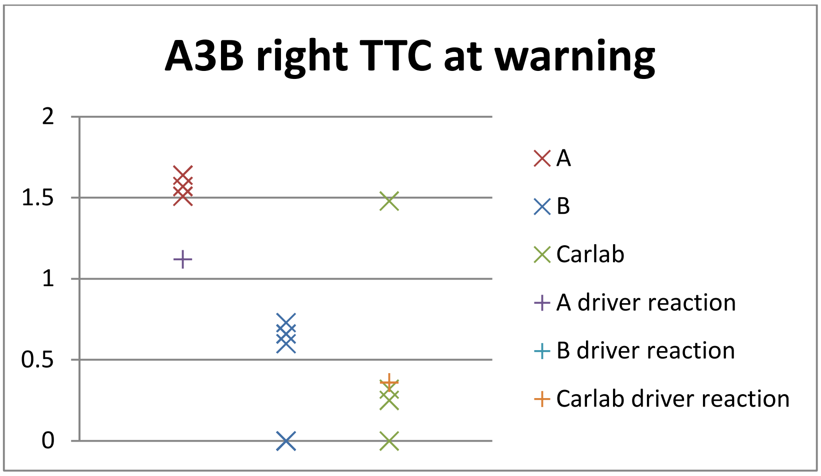


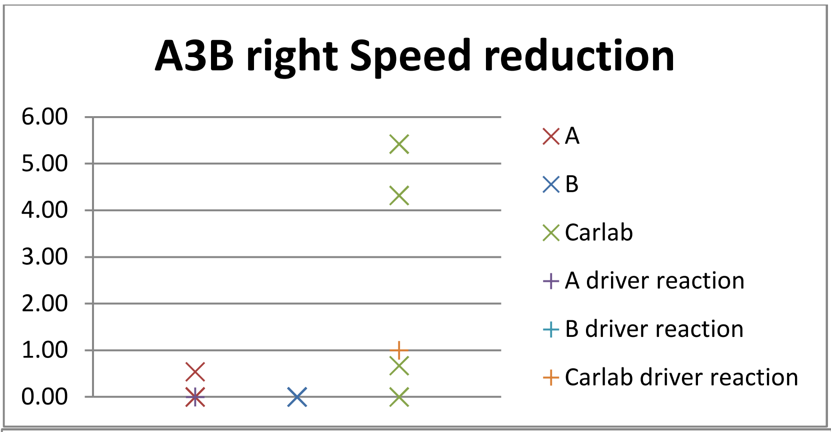
No problems were found in this test setup.
Regarding test feasibility, the initial distance stabilization requires constantly adjusting test vehicle throttle that may influence test speed controllability.
One suggestion from IDIADA would be to approach the target with a low relative speed (between 1 and 2m/s) and then trigger the braking when the relative distance is reached. This would improve the test repeatability and make its implementation easier.

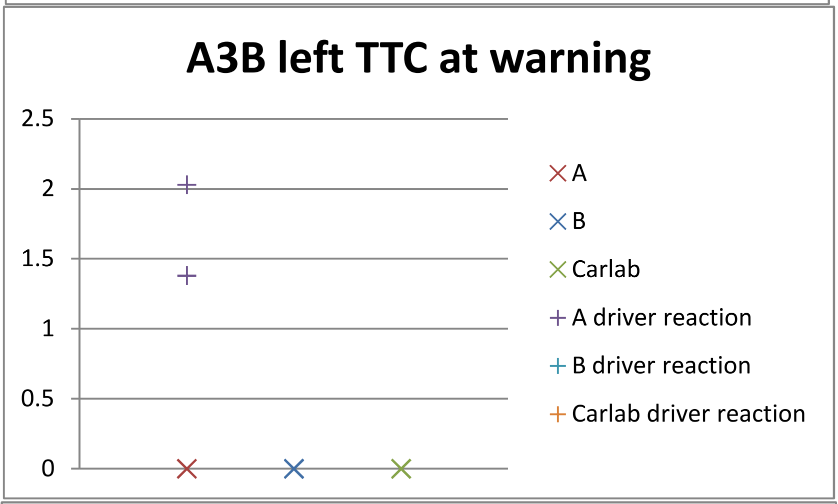


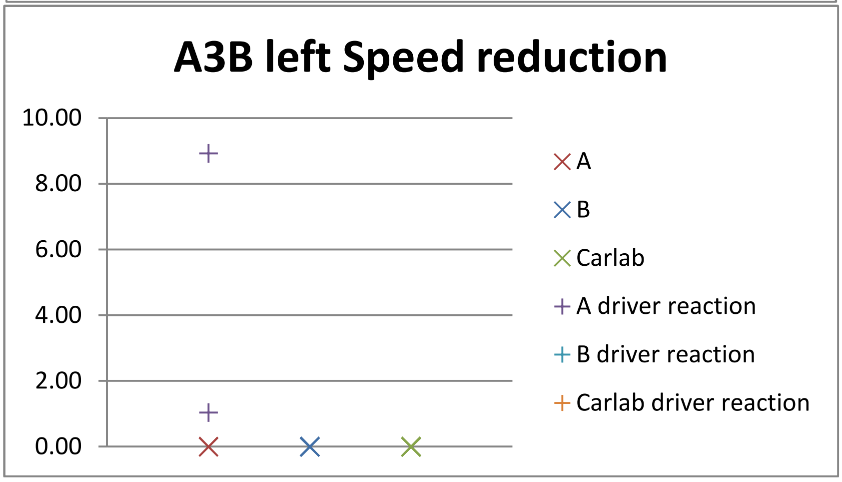


During test preparation we found target detection deterioration when it was close to our test track guardrails, to avoid any interference with radar detection the target was placed minimum 8m away from the guardrails.









IDIADA performed left and right offset tests to compare test setup influence on test results. It appeared that the target is significantly better detected in right offset than in left. As the test labs did not have the same target the offset influence would need more investigation. The first conclusions after labs test results comparison would be that the target used by IDIADA suffered a default.

Additionally, it is important to remark that vehicle B presented an unexpected low performance. It is believed, that this was due to incompatibilities with the ASSESSOR reflective properties. After the tests at IDIADA, vehicle B algorithms were upgraded. By this, it presented a better performance in the other labs. Thus, test results from vehicle B at IDIADA cannot be compared directly with results at other labs.

During tests the maximum impact speed of the ASSESSOR was set to 50km/h to avoid damages to the tested vehicles.

5.1.3 Daimler test results

Daimler operated some tests using AB Dynamics soft crash target and autonomous driving capabilities.
Test method used was the following:

- Both vehicles were controlled by driving robots.
- The test scenario was first repeated several times to measure the position of the subject vehicle when the warning was issued.
- On the following tests including a driver reaction, when the vehicle reached the warning position the braking robot applied the defined brake reaction.

In some cases the vehicle B did not warn the driver soon enough to apply the 1.2s delay brake reaction, so the reaction time was lowered or the warning position of vehicle A used.

As the warning time was not directly measured during tests but expected to occur in a defined position this test data will not be used

As DAIMLER's tests are not always recording the warning, assuming the warning will occur in an average measured position, test results will not be used to assess warning time but only test precision and reproducibility.

5.1.4 TNO test results

An overview on the key performance indicators of all single experiments conducted at TNO is shown in Table 5-3. Note that this overview contains tests that have been carried out only a single time as well as all repeated tests.

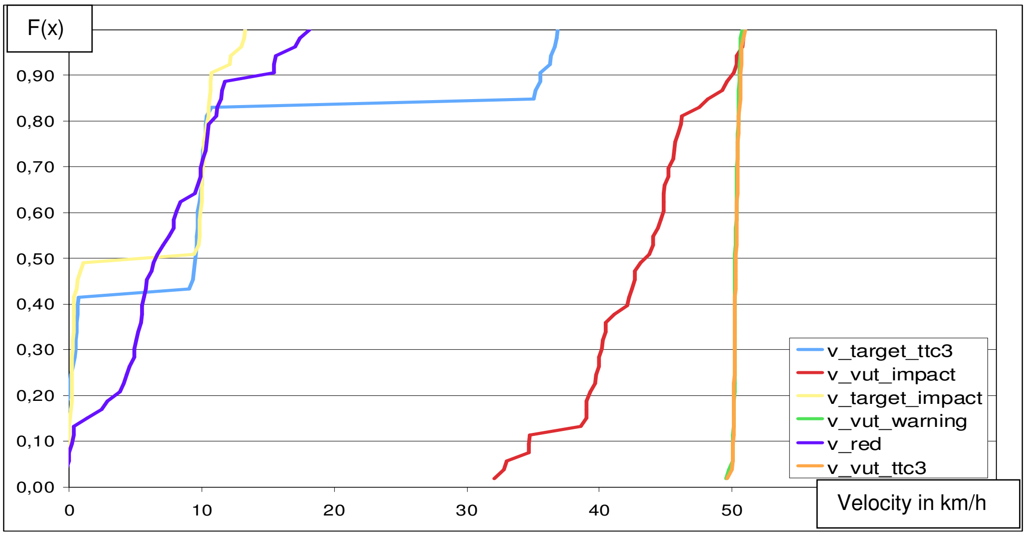
Table 5-3 Overview of conducted test runs and resulting key performance indicators for all tests at TNO (red: not tested)

Scenario	Number of test runs				Speed reduction [km/h]			Warning TTC [s]			Brake TTC [s]		
	Total	A	B	Carlab	A	B	Carlab	A	B	Carlab	A	B	Carlab
A1A1	23	10	10	3	18.43	8.98	43.47	2.23	1.97	3.22	1.08	0.71	2.32
A1A3	17	5	10	2	40.12	12.94	43.45	2.14	2.01	3.29	0.98	0.54	2.80
A1B1	3	0	1	2	0.00	8.42	42.32	0.00	0.68	3.55	0.00	0.58	2.57
A1B3	2	0	1	1	0.00	11.53	44.11	0.00	1.49	3.13	0.00	0.59	2.83
A1C3	1	1	0	0	81.24	0.00	0.00	3.24	0.00	0.00	1.84	0.00	0.00
A2A1	6	2	4	0	9.28	8.42	0.00	3.20	1.40	0.00	1.05	0.55	0.00
A2A3	6	5	1	0	10.57	8.12	0.00	2.87	1.42	0.00	0.91	0.46	0.00
A2B1	5	1	4	0	2.68	3.93	0.00	2.04	1.74	0.00	0.48	0.58	0.00
A3A1	14	2	10	2	16.19	5.14	48.30	2.09	1.25	2.96	1.08	0.49	2.05
A3A3	6	5	1	0	37.64	5.49	0.00	2.10	1.58	0.00	1.03	0.46	0.00
A3B1	18	0	10	8	0.00	3.71	44.25	0.00	0.71	3.53	0.00	0.55	3.00
A3B3	2	0	1	1	0.00	-0.65	47.62	0.00	3.00	3.04	0.00	0.00	3.07

As explained in section 2.3, the TNO proving ground "VeHIL" is an indoor facility working with the principle of relative motion. Therefore – contrary to an outside proving ground – in VeHIL the weather conditions are always similar: dry, normal lighting conditions (no direct sunlight, no vision impairment), no frost. Also, during all tests there were no objects directly located to the sides of the VuT that could have disturbed the test or influenced the respective results (as found for stationary vehicle tests during tests at IDIADA).

Due to the nature of this test set up, the initial conditions of tests that are more difficult to establish in outdoor proving grounds are fairly simple and very reproducible to achieve. For tests with a decelerating lead vehicle for example both, VuT and target initially stand still in the absolute world (though of course the VuT is driving at the set speed on the rollerbench). Tests with a standstill target on the other hand that are fairly simple to conduct in an outdoor proving ground are more difficult. For those tests the target in VeHIL needs to be started up with a constant velocity of up to 80 km/h and to be decelerated according to the VuT reaction. Partial overlap tests can be conducted as safe as tests without offset, as the impact is always a guided impact with the possibility to use additional dampers or crash-tubes that can absorb part of the energy during the crash. Changing the test set up from one 100% to 50% overlap takes approximately 4h at the moment. In an additional update planed for after this project where an automatic lateral sled will be installed this will take no extra time.

Similar as for BASt, in Figure 5-5 cumulative plots of the results for 1 test vehicle (test vehicle B) are provided. It should be noted, that these are results form 53 test runs in all conditions (maximum speed tested with this car: 50 km/h). TTC reaction was set to 3 seconds for the manoeuvres without driver reaction.



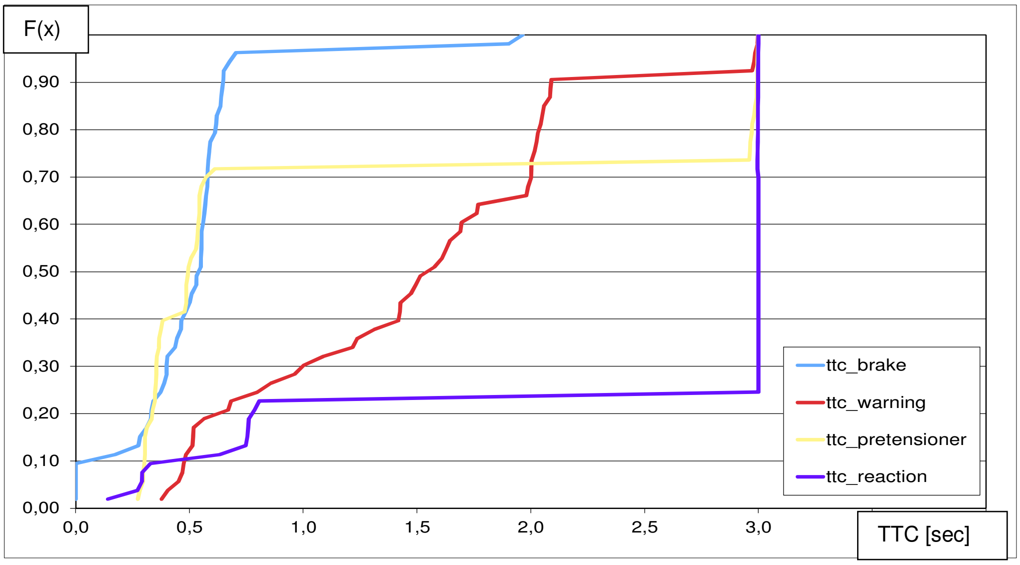


Figure 5-5: Overview of TNO vehicle B experiments

The following general conclusions can be drawn for the TNO tests based on the Figures above and the results provided in Annex C:

1. Target vehicle B:

The initial speed of both, target as well as VUT is very well controlled, there is hardly any deviation from the target values. For the VUT, the speed at TTC = 3 seconds varies between 49.66 and 51.04 km/h with an average of 50.35 km/h. This shows, that with the TNO set up in VeHIL, the initial conditions for the VUT can be met very precisely no matter the chosen test maneuver. For the maneuvers with stopped target vehicle (22 tests in total) the velocity of the target at TTC = 3 seconds varied from -1.07 to 0.72 km/h with a mean value of 0.02 km/h. This also shows a very robust handling of target vehicle speeds even in lower speed ranges. The test results (measured TTCs of various actions) vary for this test vehicle. However, in comparison to BASt and IDIADA the standard deviations obtained at TNO are in general lower. (see Figure 5-9 to Figure 5-12)

2. TNO Car lab:

The system installed on the TNO car lab was a very simple one that would not be able to pass a usability test as it would result in too many false reactions on the road. However, in the tests at TNO it was observed, that this car lab reacted in all test set up according to the initial boundary conditions set. Any variations in results can be explained by changes in these parameters. This shows, that the new TNO VeHIL set up is in general able to handle a system that is secure in detection of a target and according decision making in a robust manner.

5.2 Test result discussion

ASSESS testing has produced data of in total 337 experiments form all labs. This data has been used for evaluation in a condensed form, however the complete set of valid test results can be found in Annex C

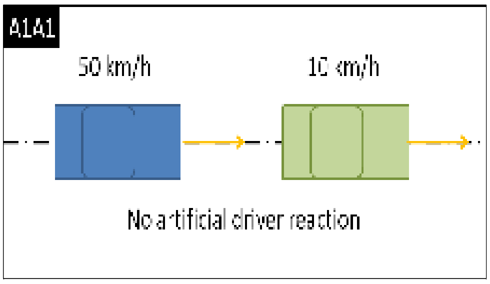
Each test run is described in three pages, for an example, see Figure 5-6 to Figure 5-8, with the following information:

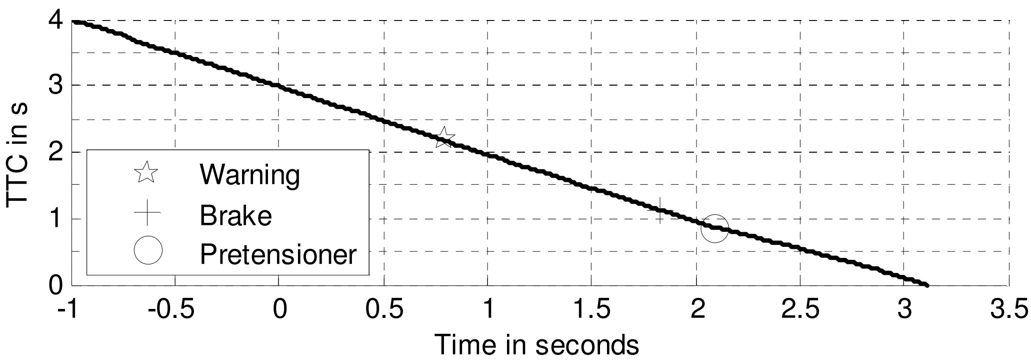
- Experiment data starts with a list of the key performance indicators, some relevant experiment parameters (test scenario, test lab, vehicle, comments) as well as a small icon depicting the general test setup.

- The plot of Time-To-Collision (TTC) over time shows the timing and TTC values for all events (warning, brake actuation, etc – note that not all incidents had been measured with all test vehicles. Belt pre-tensioning has been measured for Test Vehicle A only).
- Relative velocity over TTC gives the speed reduction and residual speed between both vehicles at one glance.
- Absolute speeds over time confirms that the experiment has been carried out according to the maneuver definitions. In addition, the initial distance between both vehicles is given for maneuvers with braking lead vehicle (A2).
- Deceleration over TTC is independent from the speed level and shows the implemented brake strategy of the AEB system. These plots show whether or not the system reacted similar at the different test houses.
- Deceleration over time shows the brake swell times (if any) in the time domain.
- Relative heading as well as lateral distance are believed to be contributing factors to a spread in test results. They are shown over time.
- Excessive steering input may be considered as overruling and could lead to a deactivation of some AEB systems. Yaw rate as well as yaw acceleration are connected to steering input. They are plotted over time.

Experiment Parameters and Key Performance Indicators, Exp. No. 1

ID...1
Vehicle:Test Vehicle A
Name.....A1A1
Lab.....BAST
Comment.....Vehicle speed set wrong
v_vut_ttc3.....13.47m/s
v_vut_warning.....13.57m/s
ttc_warning.....2.18s
v_vut_impact.....10.25m/s
v_red.....3.22m/s
v_target_impact.....2.79m/s
v_target_ttc3.....2.77m/s
v_residuum.....7.46m/s
ttc_pretensioner.....0.87s
ttc_reaction.....
ttc_brake.....1.13s
mfdd_kart.....
dist_x_initial.....
dist_y.....0.32m
relative_heading.....2.33°





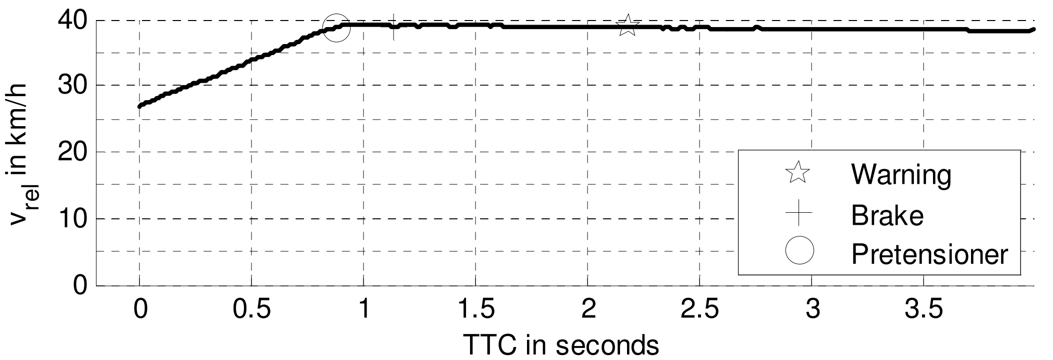


Figure 5-6: Example of results dataset for experiment no. 1 (page 1)

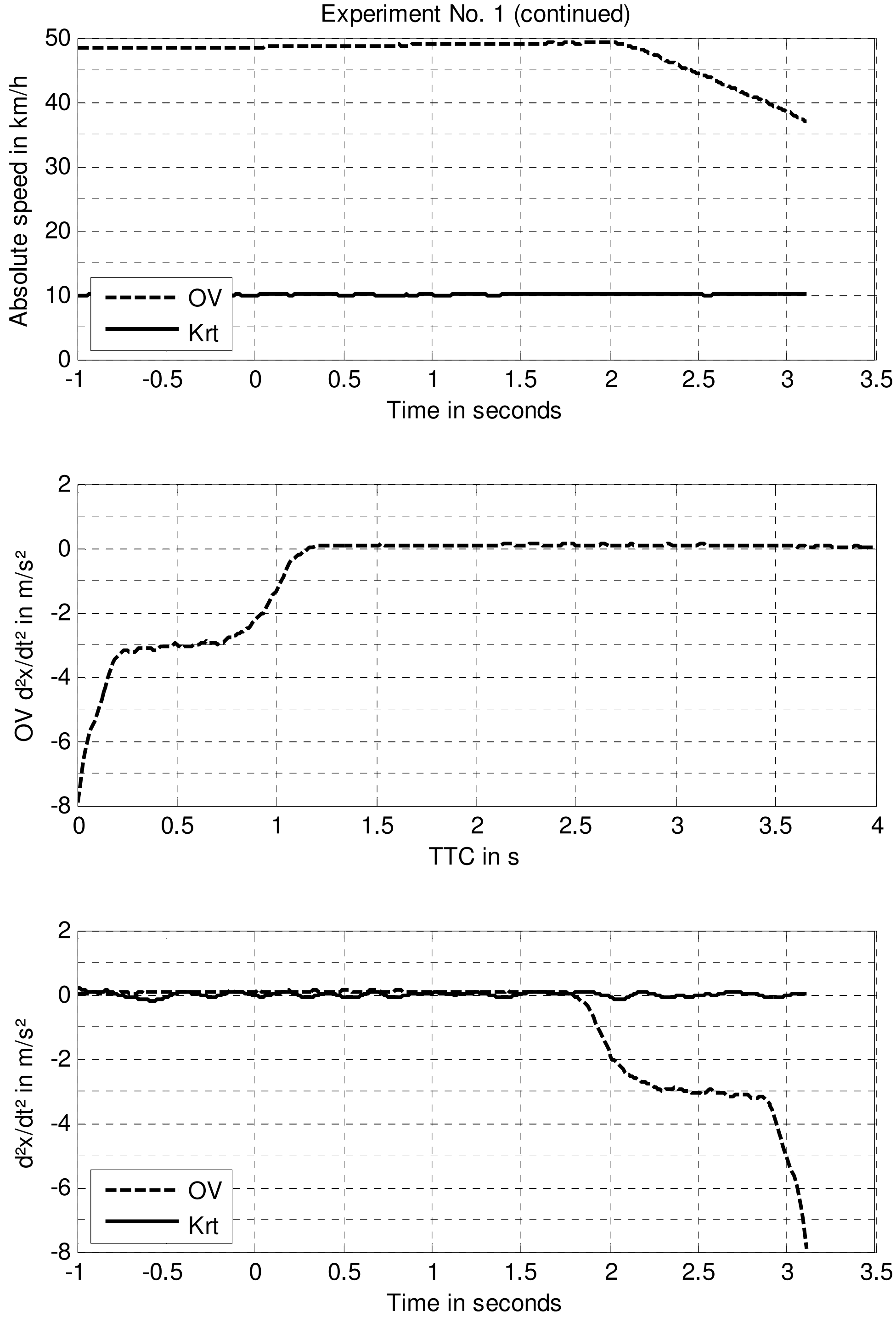


Figure 5-7: Example of results dataset for experiment no. 1 (page 2)

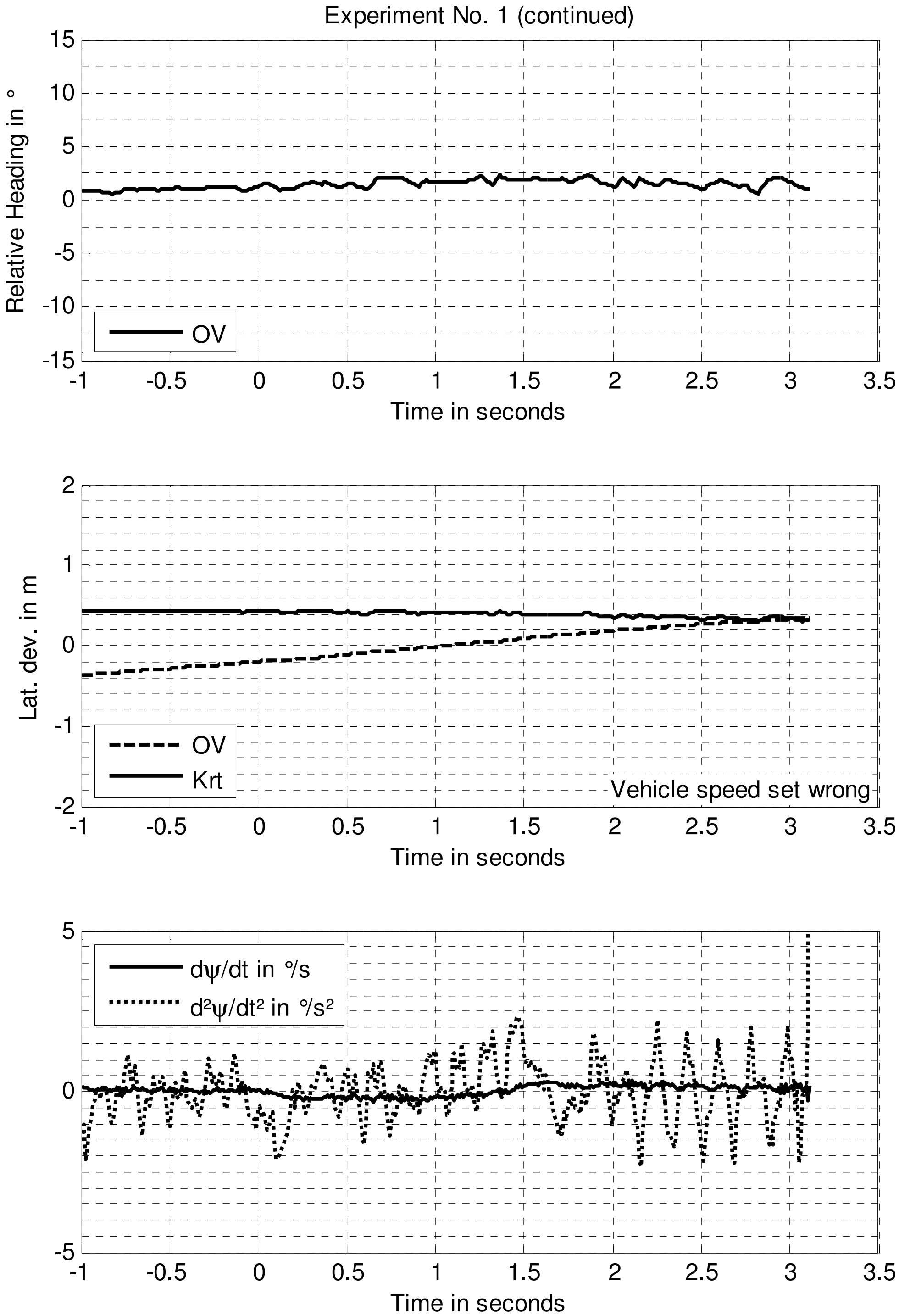


Figure 5-8 Results dataset for experiment no. 1 (page 3)

In addition to the three Euro NCAP test labs BAST, IDIADA and TNO, tests have also been carried out by Daimler with the state-of-the-art ABD robot vehicle. The test setup in this case was different to all other test labs: driver reactions were triggered by location, not by warning signal, so only autonomous braking scenarios are comparable to the data generated in WP4. In addition, parameters (e.g. initial speed) had been changed for the remaining manoeuvres, and in some cases tests were aborted in order not to damage the target vehicle.

As a consequence of these differences in test setup, only valid datasets (autonomous braking, parameters matching the parameters defined within ASSESS, all relevant variables available) were chosen for the following analyses. Aborted test runs were used for brake start timing only, while a few test runs could be used without limitations.

An overview of the mean values for the most relevant variables and the number of valid tests for all labs is shown in Table 5-4. Please note, that this table serves as an overview. The complete set of test results has been made available to Task 1.4 as a digital file and will be used to analyse statistical dependencies between all variables.

Table 5-4: Results (main KIPs) for all labs, test vehicles A and B only (no carlabs)

Scenario	Number of test runs			Speed reduction [km/h]		Warning TTC [s]		Pretensioner TTC [s]	Brake TTC [s]		Reaction TTC [s]	
Only TV A+B!	Total	A	B	A	B	A	B	A	A	B	A	B
A1A1	66	42	24	16,36	10,48	2,17	2,79	0,93	1,14	0,80	3,65	3,00
A1A2	1	1	0	10,75	0,00	2,14	2,83	0,86	1,13	0,00	0,35	0,00
A1A3	40	21	19	38,77	19,13	2,11	2,82	0,65	1,05	0,66	0,93	0,58
A1B1	5	2	3	3,04	0,00	0,81	2,44	0,00	0,85	0,58	0,00	3,00
A1B3	10	6	4	19,18	11,53	1,24	2,78	0,45	0,87	0,59	0,66	0,29
A2A1	1	1	0	81,24	0,00	3,24	0,66	1,41	1,84	0,00	1,89	0,00
A2A2	15	7	8	9,43	11,99	3,40	3,96	0,79	1,18	0,88	3,83	2,27
A2A3	1	1	0	8,59	0,00	3,62	4,05	0,78	1,19	0,00	0,00	0,00
A2B1	21	20	1	12,15	8,12	2,96	4,02	0,56	1,27	0,46	0,55	2,97
A2B3	5	1	4	2,68	3,93	2,04	0,06	0,06	0,48	0,58	3,75	2,96
A3A1	1	1	0	10,64	0,00	2,86	1,84	0,55	0,93	0,00	0,49	0,00
A3A2	42	17	25	12,81	6,37	2,08	-0,12	0,79	1,08	0,60	4,00	2,32
A3A3	1	1	0	0,07	0,00	2,13	0,00	0,00	0,13	0,00	0,22	0,00
A3B1	21	13	8	28,66	7,92	2,03	0,13	0,59	0,87	0,60	0,83	0,40
A3B2	28	9	19	0,77	2,46	2,06	-0,03	0,17	0,61	0,56	0,00	3,00
A3B3	1	1	0	6,10	0,00	2,17	0,00	0,23	0,29	0,00	0,27	0,00
A3C1	11	7	4	6,99	3,18	1,58	-0,19	0,65	0,76	0,66	0,50	3,00
A3C3	1	1	0	-0,18	0,00	1,05	0,00	0,00	0,00	0,00	0,00	0,00

5.2.1 Comparison of brake performance between different test labs

In the following section, CDF plots are presented for different KPI's as warning TTC or impact speed reduction. These plots are analysed to come to conclusions with respect to the methodology proposed by ASSESS WP4 for pre-crash testing. This type of plot shows the cumulative distribution of a collection of values. The y axis gives a percentile, while the x axis shows the corresponding value. For instance, the median value of the collection can be read from the 0.5 marker on the y-axis. This type of plot allows for display of cumulative results derived from different tests and different test houses

An overview of warning TTCs for all vehicles, all labs, all experiments (except target vehicle braking) is shown in Figure 5-9. Note that this plot is done for all experiments, regardless of the desired driver reaction, since warning comes earlier than all driver reactions. This gives a huge database of 76 experiments of type A1A (TV 10km/h, SV 50km/h, 100% overlap, no target braking).

Selected performance indicators for this plotting are: TTC at first warning: this shows how good the AEB system was able to detect the situation, TTC at first braking: this shows how fast the AEB system judged the situation as relevant and took action, and overall speed reduction, which combines the first two and also measures the strength of braking and shows how efficient the system is to mitigate the collision.

It should be noted, that for test vehicle A additional tests were conducted at ADAC using the ADAC test target instead of the ASSESSOR.

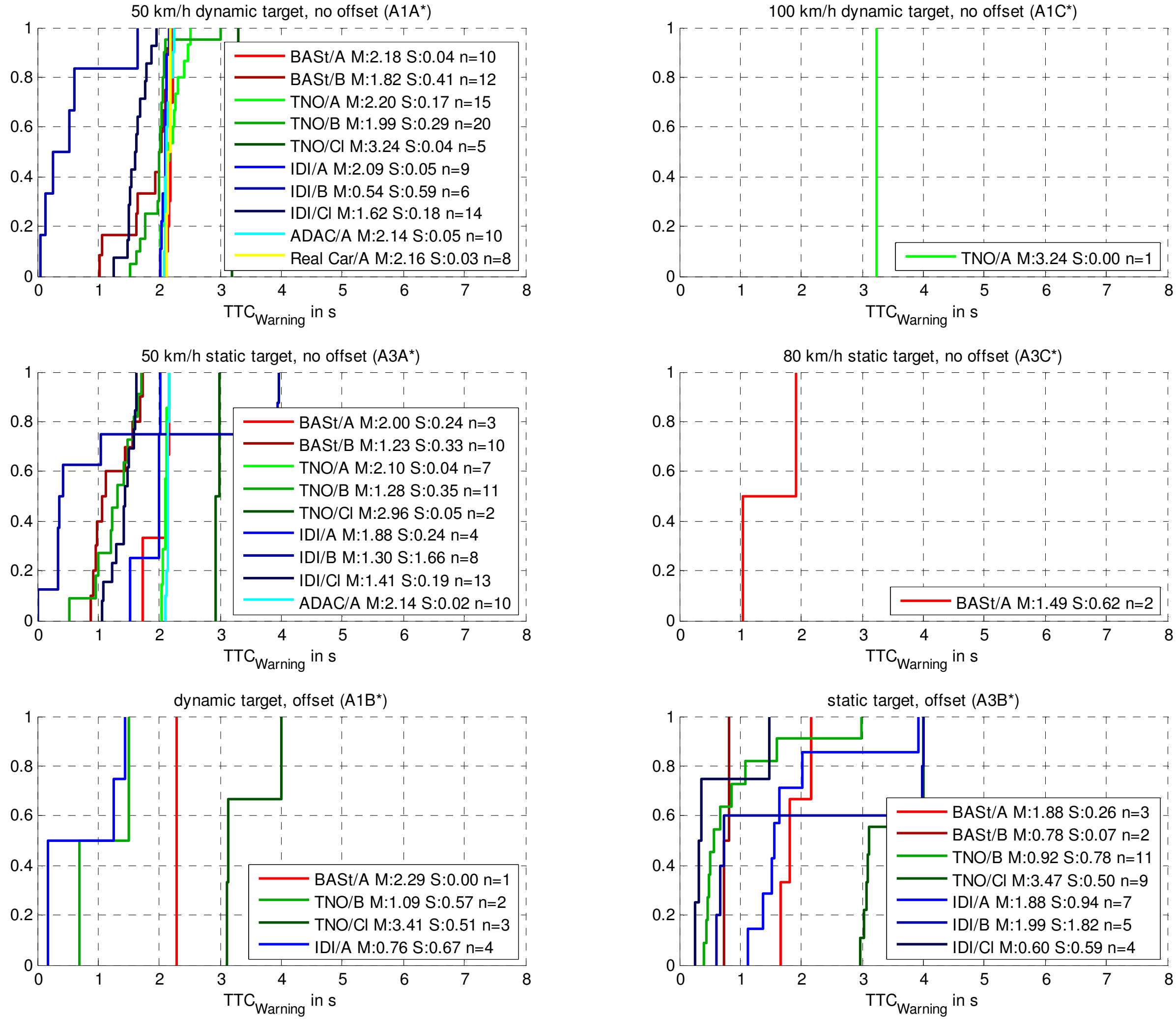


Figure 5-9: TTC of warning for all vehicles and all experiments except braking manoeuvres, also given mean value, standard deviation and number of tests

The conclusions on warning TTC that can be drawn from this figure are:

1. Test vehicle A has a lower spread in results than Test Vehicle B (standard deviation of warning TTC is 0.04s at BAST, 0.05s at IDIADA and ADAC as well as 0.17s at TNO for manoeuvre A1A, and 0.24s for BAST and IDIADA as well as 0.04s at TNO and 0.02s at ADAC with the static target for manoeuvre A3A).
2. Test Vehicle A and Test Vehicle B perform quite similar in the different test labs for manoeuvre A1A (TV A: TTC = 2.18s ± 0.04s at BAST vs. TTC =2.10±0.05s at IDIADA and TTC = 2.20±0.17 at TNO – TV B: TTC = 2.02±0.41s at BAST vs. 2.01±0.29s at TNO.) This is also found for manoeuvre A3A and test vehicle B.
3. For manoeuvre A3A tested with test vehicle A 2 clusters of results are found. At TNO and ADAC the TTC of the warning is found at 2.10 ± 0.04s and 2.14 ± 0.02s whereas at BASt and IDIADA this TTC is located at 2.0 ± 0.24s and 1.88 ± 0.24s, respectively. Tests at TNO and ADAC were conducted at a later stage in the project were more detailed information on how to calibrate the test vehicle prior to each test was available. Additionally, the ASSESSOR tends to quiver slightly when subjected to crosswind which is not the case for the ADAC target and cannot occur in a closed room like VeHIL. This might also have influenced the tests at BASt and IDIADA.

4. The IDIADA tests with TV B do not reflect the performance measured in the other two labs due to technical problems that were encountered during testing (TV B did not detect the target in most cases – only cases with warning were selected for the analysis).
5. Static target offset results do not show significant differences for test vehicle A between IDIADA and BAST and for test vehicle B between TNO and BAST. However the warning of TV B is observed later for offset tests than for full overlap tests This behaviour could be intended by the respective manufacturer. Accidents that start out of an overlap situation can still be avoided by the driver relatively late by introducing a steering action. Additionally, a later warning reduces the number of possible false warnings that could irritate the driver.
6. IDIADA performed offset testing with the target on the right and on the left hand side and found significant differences for all test vehicles. However please note that for the CDF plots provided all cases were selected no matter on which side the target was. For test vehicle B, no warning was triggered with the target set up on the left side of the vehicle at IDIADA , while the TNO setup provoked warnings in that case. It should be noted, that the target used at TNO and IDIADA was not the same prototype, though it had the same status version. For details on vehicle performance depending on the side of offset, see section 5.1.2 on page 27.
7. A limited number of reference A1A1 tests for the warning were conducted by BASt with test vehicle A using a real car as test target. From these tests it can be seen, that the warnings obtained with this test vehicle against a real car are in line with the warnings obtained in the same scenario using the ASSESSOR and the ADAC target as target vehicle.

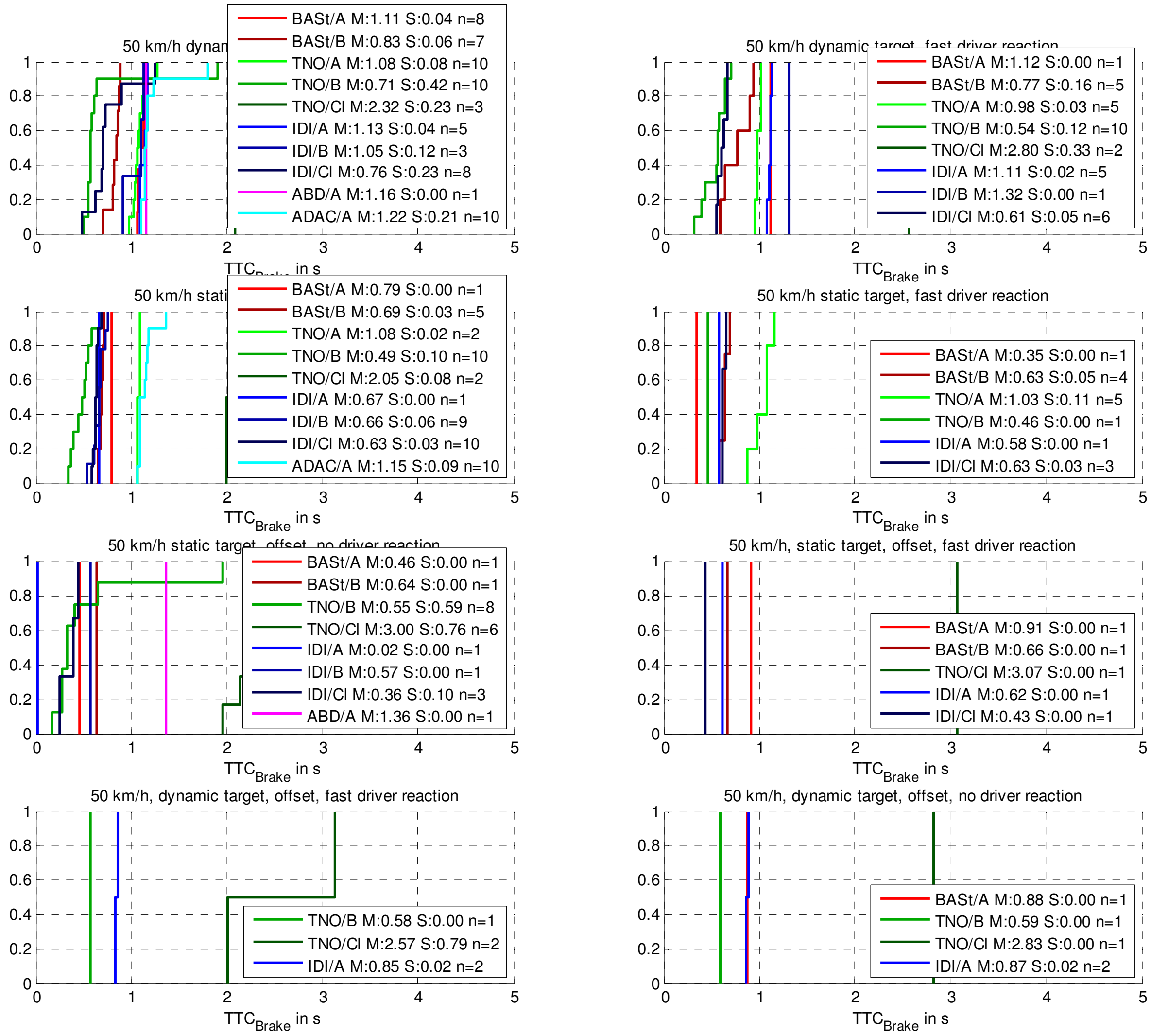


Figure 5-10: TTC at braking (threshold: 0.2 m/s²) for all vehicles and all experiments except braking scenarios, also given mean value, standard deviation and number of tests. Note that the left column reflects autonomous braking only (no driver reaction), the right column reflects braking after warning only (fast driver reaction). These plots here do not consider experiments without sufficient brake actuation.

The conclusions on braking TTC[1] are:

8. Test vehicle A performances is comparable at IDIADA, TNO and BAST,. *Autonomous braking:* Test vehicle A has a lower spread in results than Test Vehicle B for scenario A1A1 which is the only scenario with sufficient data. *Fast driver reaction*: for dynamic target tests, the one test result of TV A from BAST lies exactly in the middle of the five test runs from IDIADA. The TTC obtained at TNO is a bit lower (0.98s compared to 1.11s at IDIADA). However, the obtained standard deviation of 0.03s from 5 tests is reassuring.
9. *Autonomous braking with dynamic target, no offset*: Performance of TV B for dynamic target is definitely different in all three labs, and this effect cannot be

[1] The time of brake actuation is selected as the first time when deceleration is lower than -0.2 m/s² before the first time deceleration reaches -1 m/s². This definition is necessary to avoid considering signal noise as brake deceleration.

explained by the measured standard deviations. TV B brakes earliest at IDIADA, then BAST, then TNO.

10. Autonomous braking with static target, no offset: Performance of TV B at BAST and IDIADA is the same, with slightly later braking at TNO.
11. Some other scenarios (e.g. offset static and dynamic with and without reaction) show no consistent results throughout the test labs. It should however be noted, that these manoeuvres were also difficult to conduct in a safe manner at the outdoor test tracks, hence they were mostly aborted at a certain stage. The low standard deviation for the TNO tests (test vehicle B) shows, that it is possible to obtain a repeatable test result even for such a challenging test. It should be noted, that the standard deviation for the TNO test vehicle C is quite high, as here the headway distances for the system reaction were altered during the tests which has a significant influence on the braking TTC.

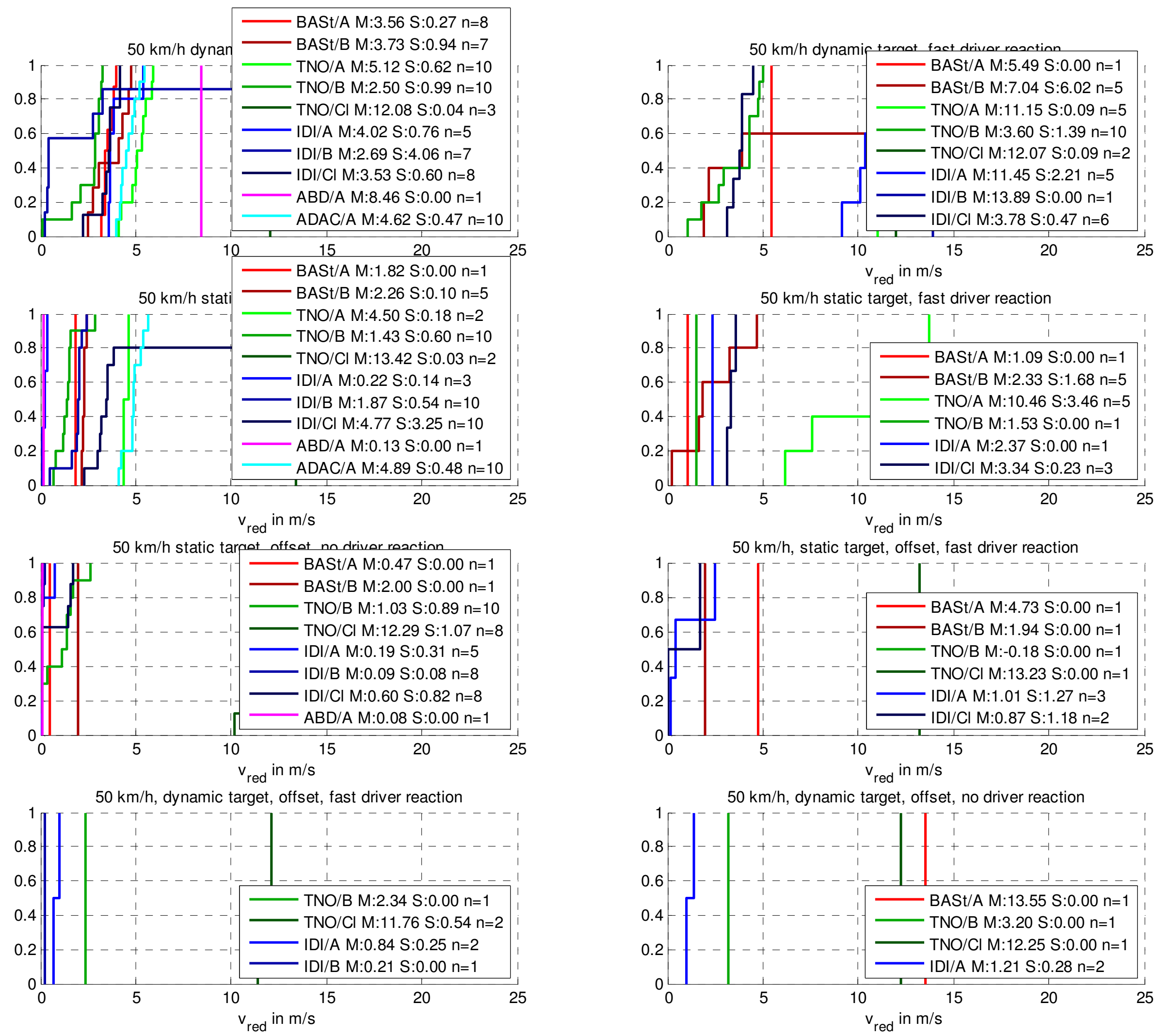


Figure 5-11: Speed reduction for all vehicles and all experiments except braking scenarios, also given mean value, standard deviation and number of tests. Note that the left column reflects autonomous braking only (no driver reaction), the right column reflects braking after warning only (fast driver reaction). Unlike the TTC-Brake-Plots shown before, these plots here do contain all experiments, even if no brake activation occurred (the speed reduction in this case would then be zero).

Together with success in avoiding the collision, speed reduction is the major key performance indicator identified for WP4, since it measures the overall AEB performance. The following conclusions can be drawn from the provided CDF plots:

12. TV A is consistent for dynamic target, no reaction, no offset between BAST and IDIADA. Speed reduction at TNO for this scenario is slightly higher (5.12m/s ± 0.62 at TNO vs. 4.02m/s ± 0.76 at IDIADA). For dynamic target without offset and with driver reaction, speed reduction is consistent for TNO (11.15m/s ± 0.09) and IDIADA (11.45m/s ± 2.21). The BAST data contains only one test run – in this test run there is a relatively high yaw acceleration which overruled the autonomous braking before finally the brake robot triggered full braking. Thus, the achieved speed reduction is lower than observed at IDIADA, while warning time in this case (as in all other cases, see above) is comparable.
13. Standard deviations for the TNO test vehicle C are fairly low, which indicates a robust test set up. (Test vehicle C represents the TNO car lab, which was designed to react in a very simple and robust manner)
14. Speed reduction with static target (with and without driver reaction) is for test vehicle A consistent between TNO and ADAC, however significantly higher compared to the results obtained at BASt and IDIADA. The reason for this might be issues with the vehicle calibration or side-wind effects at the IDIADA and BASt testing (see 3). For test vehicle B, no consistent results could be obtained.

It should be noted, that as the timing for initiating the braking was found to be inconsistent, a consistent speed reaction throughout the tests and test houses was not to be expected.

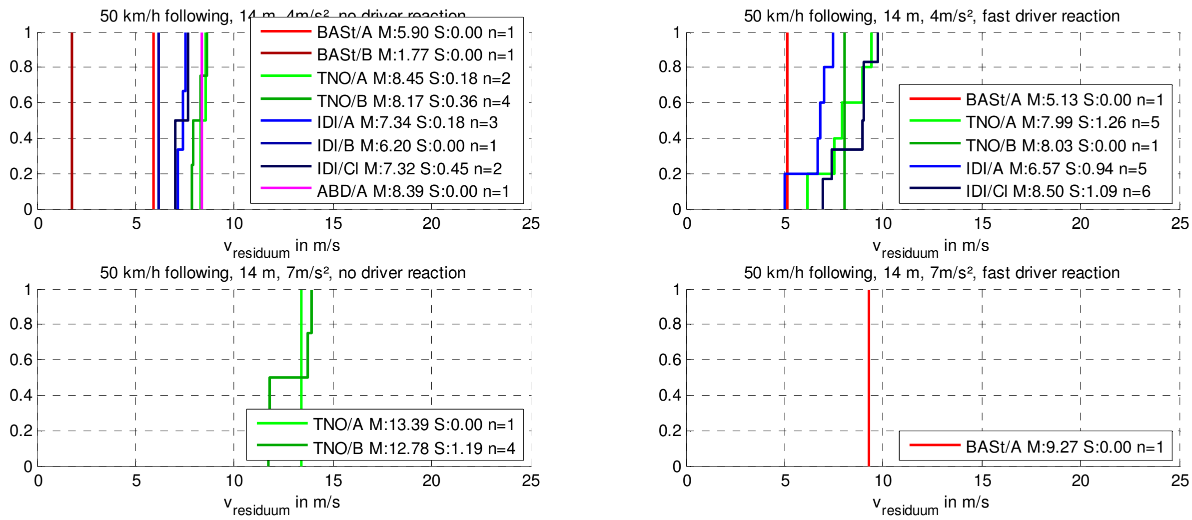


Figure 5-12: residual speed (speed of VuT minus speed of target at impact) for manoeuvres with target braking (no data available for other manoeuvres)

As can be seen in Figure 5-12, the results of all labs are not consistent for the case of manoeuvres with braking lead vehicle, however there is only little data available. It should also be noted again, that these manoeuvres were difficult to conduct in a safe manner at the outdoor test tracks, hence they were mostly aborted at a certain stage.

The following – more or less general - conclusions could be drawn from the data analysis at this point:

15. The repeatability for test runs without driver reaction within one test lab is relatively good (standard deviation below 10% of mean value) for those labs that managed to perform repeated tests.
16. The repeatability with driver reaction is approximately twice as high.

17. The reproducibility (between labs) is not as consistent as with the other manoeuvres.

5.2.2 Reproducibility of Brake Pedal actuation

As already mentioned above, repeatable and reproducible brake pedal actuation was found to be problematic in gradient as well as in timing. Figure 5-13 shows the brake force for all those test runs where the data was available, normalized for the first point in time where the brake pedal force exceeds 20 N. Figure 5-14 shows the brake force normalized to the first acoustic warning. The target values are indicated by a black dotted line.

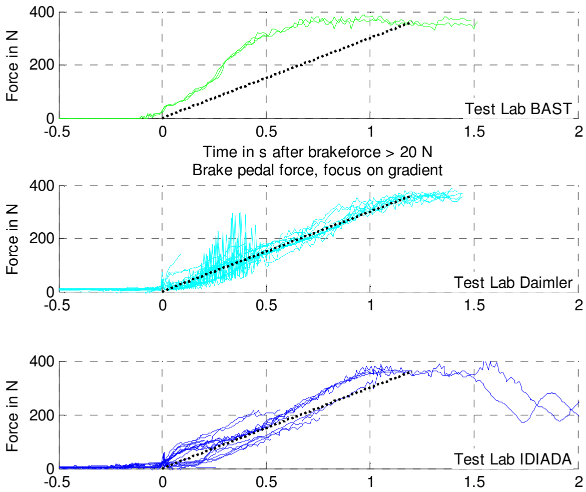


Figure 5-13: Brake force gradient

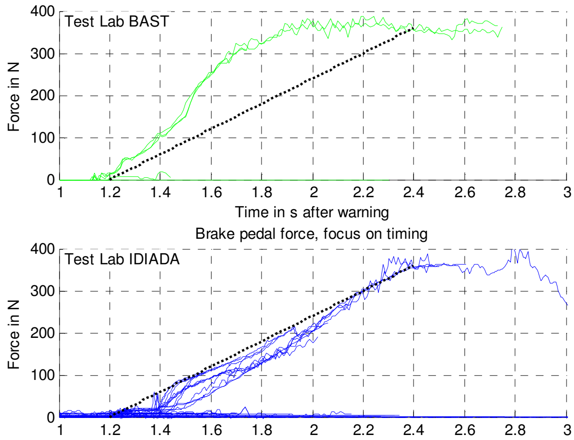


Figure 5-14: Brake force timing

First of all, it seems to be difficult to achieve the desired values for gradient as well as timing. The brake robots at all test sites were used in closed-loop force control mode. This control mode is sensitive to elastic parts in the force flow.
The measured brake force curves of BAST and IDIADA are the result of heavy trial-and-error tuning of the brake robot.

Second, even with good approximations of the desired brake pedal force values as can be seen at IDIADA and DAIMLER, there is still the issue of the first control cycle or the first ramp-up. How much this behaviour influences the AEB system performance depends on the control strategy of the brake system of the tested car, especially the threshold that is needed to activate any brake support functions.

Taking all this into account, it seems that the idea of reproducing driver brake action with a brake robot in different test labs, with the given desired gradient and timing for a brake actuation is not easily achievable. The main reason for this is the high sensitivity of the test result to slight deviations in brake pedal force with the current state-of-the-art of brake actuators. It would be possible to overcome this problem with even more time-consuming tuning of the brake robot or by mounting the actuator fixed to the chassis instead of a driver seat, thus removing any elastic parts. The first option will very likely increase the test costs by a large amount; the second option could not treat the vehicle as a black box anymore.

The ASSESS consortium agrees on the importance of introducing driver reaction into the testing since driver warning is considered to result in a large benefit in accident avoidance and mitigation. However, feasible options to overcome the repeatability problem are needed.

The following options should be considered for further investigation:

- Different implementation of driver reaction (e.g. with a high gradient, so variations in gradient etc. will be very low, or with a position-controlled force actuation),
- A separate evaluation of driver reaction that would take out the influence of a spread in warning TTC.

5.2.3 Deceleration over TTC

AEB control strategies are usually defined via a specific deceleration value over TTC (defined as distance between vehicles divided by relative speed). Thus, deceleration-over-TTC-plots show the AEB control strategy (see Figure 5-15).

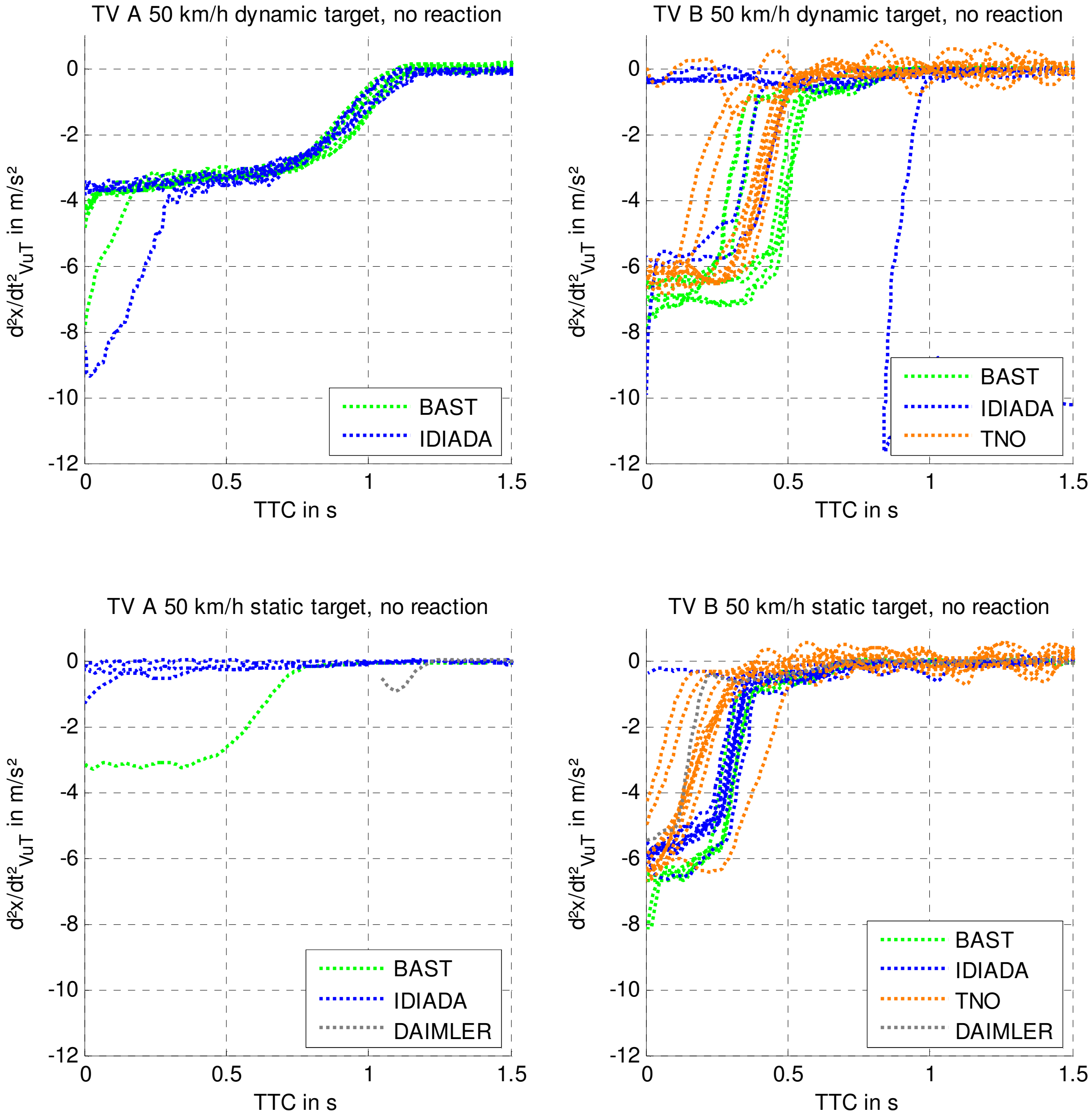


Figure 5-15: VuT deceleration over TTC for manoeuvres A1A1 (top) and A3A1 (bottom)

The following observations were made:

18. This type of plot shows that the brake system of Test Vehicle A has a divided control strategy: Starting from a TTC of approximately 1.2 s, the deceleration ramps up to a final value of just below 4 m/s². This is true for static as well as for dynamic targets, with braking TTCs later and less consistent for static targets.
19. Test vehicle A's full braking stage is not triggered in all cases and if triggered, not at consistent TTC levels.
20. Test Vehicle B increases deceleration slowly up to 1 m/s² (which could be related to brake prefill action).
21. When autonomous braking is triggered, TV B brakes harder, up to 7 m/s², but less consistent and at different trigger times.
    For dynamic targets, the trigger times for TV B are between TTC = 0.6s and 0.4s, for static target, TTCs become more consistent but also late. At IDIADA and BASt the observed TTC lies around 0.4s. The tests at TNO show a relative high spread. As at TNO all tests are done based on the principle of relative motion, the target vehicle is always moving towards the VUT with the respective relative speed. Some of the tests with test vehicle B were conducted in an open loop configuration. This could have had an influence on the test results as from the perspective of the VUT the target starts moving during the test in such a configuration. For the closed loop tests conducted at TNO with this vehicle at the time of testing there were still some unwanted delay times in the system. This could have confused the AEB system of Test vehicle B as well and could possibly have resulted in inconsistent braking behaviour. Further improvements of the TNO set up after testing test vehicle B have in the meantime brought closed loop delay times down to 20ms. Hence such wide spread is not expected anymore for future testing.

5.3 Conclusions

The acceptance of a test procedure depends on whether it is valid, repeatable and reproducible. The performance of Test Vehicles should not be affected by the specific circumstances and test setups at three labs.

The test results for Test Vehicle A are in general found to be consistent between the test houses.; no contradictions could be found throughout the already available test data. Where repetitions were made, the standard deviations were always low (e.g. some 5 to 10 % of the mean values). Tests at TNO and ADAC did for some tests show results closer to the system specifications then tests at BASt and IDIADA. Tests at TNO and ADAC were conducted at a later stage of the project where more detailed information was available on the calibration of the sensor system which turned out to be needed before each test. Additionally, it was observed that the ASSESSOR would tend to sway slightly in case cross wind was present during testing which could have influenced the system performance. This problem does not occur with the ADAC target or an indoor test facility such as VeHIL. Other differences found between test labs and test runs with driver reaction can be explained by technical difficulties with the application of the driver reaction, see section 5.2.2, page 44.
Therefore, different circumstances as listed below in the three test labs are considered to have only a neglectable influence on test results:

- Different propulsion systems,
- Relative or absolute motions,
- Lateral deviations up to ± 0.2 m between the vehicles,
- Artificial steering activations introduced by driving robots.

It is important to avoid significant steering input during an experiment since this can overrule autonomous braking systems. Consistency between the labs could be improved for manoeuvres with a braking lead vehicle – in these cases, test results are highly sensitive to initial distances and brake swell times. Even the requirements defined within the ASSESS project (see D4.2) are not sufficient yet.

It was found, that at TNO where the initial distance between the 2 vehicles can be set up very precisely, repeatable test results can be obtained. As maintaining the initial following distance as precisely on a test track is not possible, an improvement of the test procedure for these braking (A2) manoeuvres could include a predefined approach of the lead vehicle (e.g. relative speed < 5 km/h, braking trigged when a specified distance has been reached) rather than requiring a constant following distance.

It is believed that the spread observed in the test results from Test Vehicle B was due to incompatibilities with the ASSESSOR reflective properties. After the tests at IDIADA, vehicle B algorithms were upgraded. By this, it presented a better performance in the other labs. Thus, test results from vehicle B at IDIADA cannot be compared directly with results at other labs.

The methodology itself is considered verified against the specifications defined within the ASSESS project. A further validation of the full test method including tools (e.g. target, propulsion systems, etc) would require measuring the Test Vehicles' performance in tests with real cars. To investigate this issue briefly, some reference A1A1 tests using a real car as test target were conducted with test vehicle A by BASt. Please note, that after the warning signal was registered, the test was aborted as a real car is not crash forgiving. It was seen, that warnings obtained using a real car as target vehicle were in line with the warnings obtained in this manoeuvre at all test houses using either the ASSESSOR or the ADAC target. (see conclusion 7 on page 40)

6 Repeatability and reproducibility analysis

6.1 Introduction

The ASSESS project is developing test and assessment procedures for collision warning and Autonomous Emergency Braking Systems (AEBS) for passenger cars.

The *test* scenarios developed by the project assess technical system performance and are simplified versions of the *accident* scenarios which result in greatest monetised casualty cost, according to the analysis conducted in work package 1 of the project. ASSESS tests focus on "front to rear" accidents only (Test scenario A), because current systems are only able to respond in these situations. In the future, other test scenarios as defined in D4.1 and D4.2 could be added. ASSESS test scenarios are described again in section 6.2.1.

In order to quantify the robustness of the procedures developed by the ASSESS project, it was necessary to quantify test repeatability and reproducibility. This will be used to guide proposals for the number of tests in the final test protocol so that the results are accurate, fair, and are repeatable and representative.

The main aim of Task 1.4 was to analyse the test results to quantify the repeatability and reproducibility, therefore quantifying the robustness of the ASSESS test procedures. This was achieved by comparing, using statistical analysis, the variation in:

- test conditions and test results from repeated tests at the same test house; and
- test conditions and test results for the same vehicle in the same test at different test houses

In addition to this analysis, the relationships between the KPIs (Key Performance Indicators) and the test parameters were investigated to understand which of the test parameters had most effect on the test outcome (KPIs). This information was also useful to understand which initial test parameters require close control.

6.1.1 Approach used in the assessment of reproducibility

In order to understand the detailed testing procedures and identify potential sources of variation, TRL visited the facilities and witnessed examples of testing at each test house. This had dual aims of understanding the reasons for variations observed in the results and to help co-ordinate and harmonise the procedures at the different test houses to reduce the influence of any differences in the tests. TRL used a test checklist and the draft test protocol to monitor how closely the protocol was being followed, and to identify any differences in the approach or implementation of the protocol's instructions between test houses.

TRL contributed to the development of the draft test protocol as well as proposing a baseline document containing the test matrix for the repeatability tests so that all test houses involved in testing had defined instructions for which tests to include in repeatability and reproducibility testing.

6.1.2 Approach used in the assessment of repeatability

Not all tests in the ASSESS test programme can be repeated because to do so would be time and cost prohibitive. However, as part of the research, an assessment of repeatability was completed to demonstrate the robustness of the final test procedures which may be based on a single test, or reduced number of tests. Consequently, the tests recommended for inclusion in Task 1.4 were selected carefully to ensure that the full range of test conditions (vehicle speed, overlap, braking level etc.) were included in the evidence base. Furthermore, consideration was given to the types of tests that are within the capabilities of the test houses – i.e. those tests selected for assessment should be able to be carried out at each test house.

6.2 Methodology

6.2.1 ASSESS rear end test scenarios (Scenario A)

Three main test types of front to rear accidents have been considered in testing:

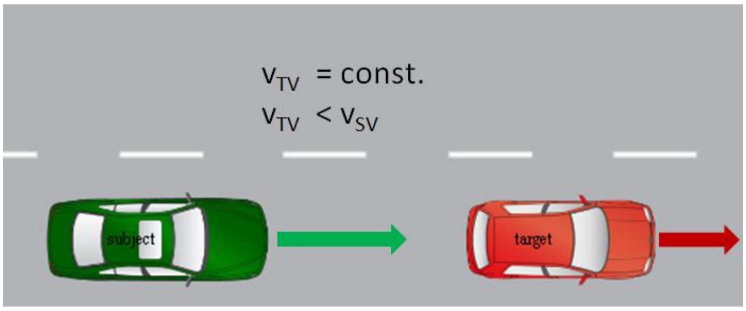


Figure 6-1. A1A1 – Slower lead (target) vehicle

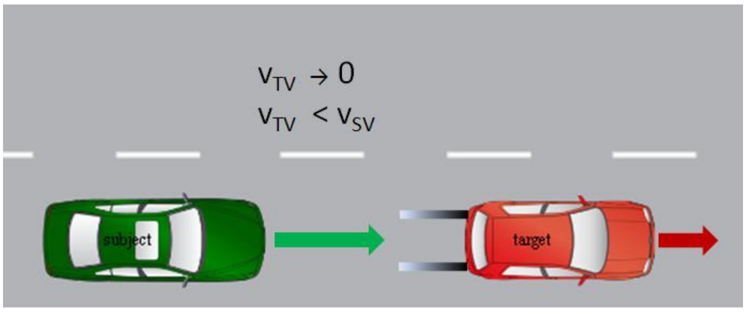


Figure 6-2. A1A2 – Decelerating lead (target) vehicle

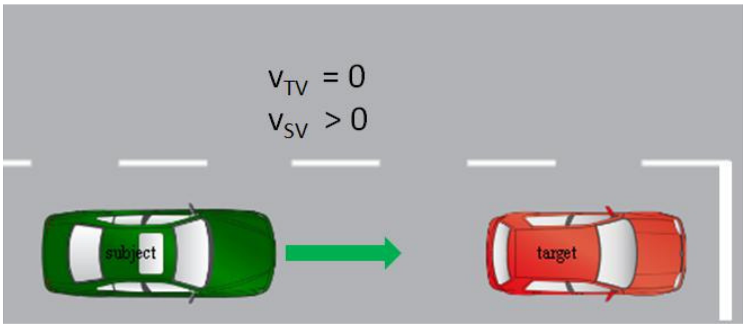


Figure 6-3. A1A3 – Stationary lead (target) vehicle

Within each of these test types, there were differences in the overlap of the lead and following vehicle (either 50% or 100%), the response of the driver to the warning provided by the system (no response or fast response), and the level of braking of the lead vehicle in the A1A2 scenario, see Table 6-1 ($4ms^{-2}$ or $7ms^{-2}$). The response times of the driver were derived from results from simulator experiments in work package 3, which showed that the mean brake reaction time of a distracted driver to an audible warning signal was 1.2 seconds.

In order to investigate repeatability and reproducibility it was necessary to repeat a number of test runs to build up statistical information on the results. TRL recommended that the following programme of repeated tests be carried out by the project partners involved in the test activities in work package 4. The recommended number of repeats is shown in Table 6-1. These repeats were selected carefully so that only one of the main test parameters was changed at a time so that its influence of could be considered in the analysis.

Table 6-1. Test matrix showing ASSESS tests and those recommended for inclusion in Task 1.4

Scenario					SV	TV					Driver reaction
					Initial speed [km/h]	Initial speed [km/h]	initial lateral overlap [%]	Braking [m/s^2]	time to perform lane-change [s]	final intended lateral overlap [%]	
A	**Rear end**										
		A1		**Slower lead vehicle**							
		A1	A1	Urban scenario 1	50	10	100	no braking	n/a	n/a	no
		A1	A3	Urban scenario 1	50	10	100	no braking	n/a	n/a	fast
		A1	B1	Urban scenario 2	50	10	50	no braking	n/a	n/a	no
		A1	B3	Urban scenario 2	50	10	50	no braking	n/a	n/a	fast
		A1	C1	Motorway (Traffic jam)	100	20	100	no braking	n/a	n/a	no
		A1	C3	Motorway (Traffic jam)	100	20	100	no braking	n/a	n/a	fast
		A2		**Decelerating lead vehicle (until stopped)**							
		A2	A1	Urban normal driving	50	50	100	4	n/a	n/a	no
		A2	A3	Urban normal driving	50	50	100	4	n/a	n/a	fast
		A2	B1	Urban emergency braking	50	50	100	7	n/a	n/a	no
		A2	B3	Urban emergency braking	50	50	100	7	n/a	n/a	fast
		A2	C1	Motorway normal driving	80	80	100	4	n/a	n/a	no
		A2	C3	Motorway normal driving	80	80	100	4	n/a	n/a	fast
		A2	D1	Motorway emergency braking	80	80	100	7	n/a	n/a	no
		A2	D3	Motorway emergency braking	80	80	100	7	n/a	n/a	fast
		A3		**Stopped lead vehicle**							
		A3	A1	Urban scenario 1	50	0	100	no braking	n/a	n/a	no
		A3	A3	Urban scenario 1	50	0	100	no braking	n/a	n/a	fast
		A3	B1	Urban scenario 2	50	0	50	no braking	n/a	n/a	no
		A3	B3	Urban scenario 2	50	0	50	no braking	n/a	n/a	fast
		A3	C1	Motorway (Traffic jam)	80	0	100	no braking	n/a	n/a	no
		A3	C3	Motorway (Traffic jam)	80	0	100	no braking	n/a	n/a	fast

The table above presents the specifications for each test in the A test scenario group, and highlights (in orange) the tests proposed for inclusion in the repeatability and reproducibility assessment. It was proposed by TRL that each test selected for Task 1.4 was repeated 10 times at each test house.

Initially, only the "no driver reaction" tests were selected because this excludes any potential variation from the use of the braking robot. However, after information from the test houses that some "no driver reaction" tests result in impacts with the target at relatively high velocities, some tests (A1B and A2 test scenarios) were changed so that the "fast driver reaction" tests were repeated. This proposal was made to reduce the risk of damage to the test target, damage to which would have severe logistical implications for the testing phase of the project.

6.2.2 Key Performance Indicators (KPIs)

The results were analysed with respect to the following KPIs:

- Time to Collision (TTC) of warning – the time in seconds between the system warning and the time of collision

- Time to Collision (TTC) of braking – time in seconds between the braking activation and the time of collision
- Velocity reduction – the velocity (km/h) lost between the initial value and that at the time of collision

6.2.3 Analysis method

The aim of the analysis was to quantify how repeatable and reproducible the results are and also and to investigate the sources of variation with a view to determine whether the tolerance values specified in the draft test protocol (see Appendix A) are appropriate or should be reconsidered.

Analysis was carried out using the statistical software package SPSS and considered test results from work package 4, the data files from which were compiled by BASt..

6.3 Results

6.3.1 Test overview

Three labs: BASt, IDIADA and TNO completed 256 tests on four different vehicles across the set of test combinations shown in Table 6-2. These test combinations relate to test characteristics shown in section 6.2.1. Vehicle C tests were only completed at IDIADA and Vehicle D tests were only completed at TNO. As each test combination was completed for a different number of repeats across labs and vehicles, results are based on subsets of the completed tests. For each analysis, the subset has been specified at the start of the section.

Table 6-2: Number of tests completed by lab, vehicle and test

	Vehicle A			Vehicle B			Vehicle C			Vehicle D		
	BASt	IDIADA	TNO	BASt	IDIADA	TNO	BASt	IDIADA	TNO	BASt	IDIADA	TNO
A1A 1	8	5	10	7	7	10	0	8	0	0	0	3
A1A 2	1	0	0	0	0	0	0	0	0	0	0	0
A1A 3	1	5	5	5	1	10	0	6	0	0	0	2
A1B 1	0	2	0	0	1	1	0	0	0	0	0	2
A1B 3	1	2	0	0	0	1	0	0	0	0	0	1
A1C 3	0	0	1	0	0	0	0	0	0	0	0	0
A2A 1	1	3	2	1	1	4	0	2	0	0	0	0
A2A 2	1	0	0	0	0	0	0	0	0	0	0	0
A2A 3	1	5	5	0	0	1	0	6	0	0	0	0
A2B 1	0	0	1	0	0	4	0	0	0	0	0	0
A2B 3	1	0	0	0	0	0	0	0	0	0	0	0
A3A 1	1	3	0	5	10	10	0	10	0	0	0	2
A3A 2	1	0	0	0	0	0	0	0	0	0	0	0
A3A 3	1	1	5	5	0	1	0	3	0	0	0	0
A3B	1	5	0	1	8	10	0	8	0	0	0	8

1												
A3B 2	1	0	0	0	0	0	0	0	0	0	0	0
A3B 3	1	3	0	1	0	1	0	2	0	0	0	1
A3C 1	1	0	0	0	0	0	0	0	0	0	0	0
A3C 3	1	0	0	0	0	0	0	0	0	0	0	0

Three key performance indicators (KPIs) were measured in each test – the time to the collision of the warning (TTC warning), the time to collision of braking (TTC brake) and velocity reduction, as defined in Section 6.2.2.

Some tests did not record the relevant KPIs due to the system not providing a response in the test. The numbers of tests for each vehicle and laboratory where each KPI was recorded are shown in Table 6-3. In general around 95%-100% of BASt and TNO tests had KPIs and in around 70% of IDIADA tests the KPIs were recorded.

Table 6-3: Number of tests and completeness of KPIs by vehicle and lab

Vehicle	Lab	Number of tests	Completeness of TTC warn	Completeness of TTC brake	Completeness of velocity reduction
Vehicle A	BASt	23	23	22	22
	IDIADA	34	24	26	26
	TNO	31	31	31	31
Vehicle B	BASt	25	25	24	24
	IDIADA	28	18	15	15
	TNO	53	53	48	48
Vehicle C	BASt	0	0	0	0
	IDIADA	45	31	37	36
	TNO	0	0	0	0
Vehicle D	BASt	0	0	0	0
	IDIADA	0	0	0	0
	TNO	19	19	17	17
All	BASt	48	48	46	46
	IDIADA	107	73	78	77
	TNO	103	103	96	96

This first step is important because it indicates the number of tests for which the system did not provide the response expected: a “failed test”. The reasons for this are discussed later, but Table 6-3 indicates that there was some variability in the overall system response between test labs. At some test labs, the results did not contain recorded KPIs, suggesting that the system did not function appropriately in the test.

Subsequent analyses were based on tests where the appropriate KPI was recorded. This means that, in some cases, analyses based on TTC warn and TTC brake were based on different subsets of tests.

6.3.2 Example trace plots

Velocity trace plots were derived from the data and examined to reveal any abnormalities. An example velocity trace plot is shown in Figure 6-4 for Vehicle B in A1A1 tests (SV initial speed 50 km/h, TV initial speed 10 km/h, 100% lateral overlap and no driver reaction). This shows the velocity of the subject vehicle from the start of each test to a point after braking commences. Lines hanging off the top axis represent the time of the warning.

A number of features are observed for this particular test combination and vehicle:

- The starting velocity for all tests is between 48 km/h and 51 km/h.
- Velocity traces on initial tests completed at TNO show a different pattern because the velocity control was affected by the capabilities of the winch motor to maintain the desired velocity. Despite this effect, the velocity was controlled closely. Furthermore, revisions to the winch system were made and the significantly improved velocity control can be observed in Figure 6-6.
- Most tests at IDIADA warned later than other test houses.
- Some tests at TNO and IDIADA did not warn at all.
- Tests at IDIADA where the TTC warning was late, resulted in no or little braking and therefore little velocity reduction; however some of these are still valid tests, as their KPIs exist.

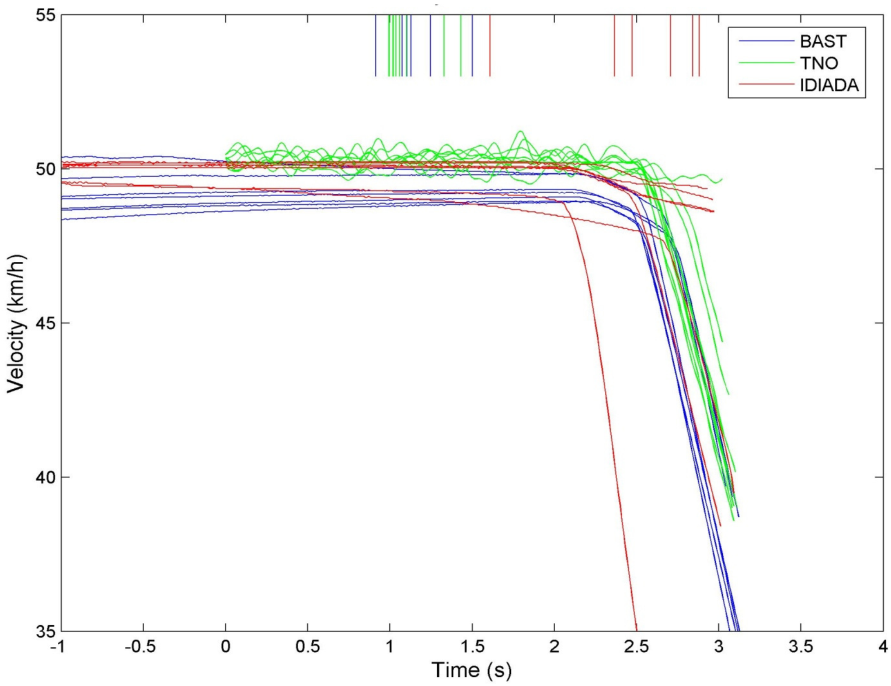


Figure 6-4: Velocity trace plot for Vehicle B- A1A1 tests

Figure 6-5 shows the velocity trace plot for Vehicle D in A3B1 tests. This shows a different shape trace which, due to a continuous decreasing trend in speed, makes it difficult to derive a braking point. Therefore, results for Vehicle D were removed from any analysis. It should be noted, that the 2 different shapes of the velocity trace in this plot result from changing the parameters of the implemented pre-crash algorithm for this car lab during the testing.

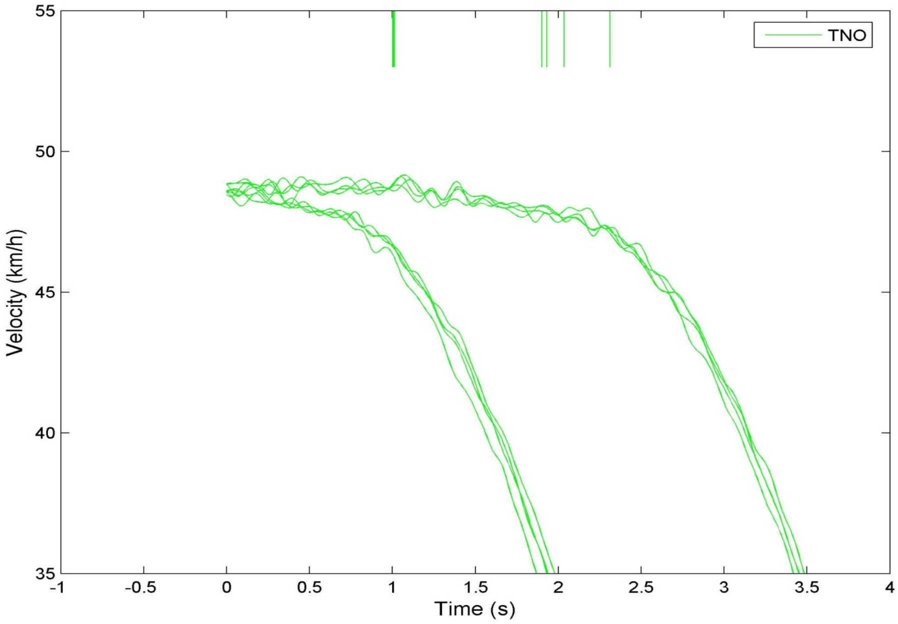


Figure 6-5: Velocity trace plot for Vehicle D - A3B1 tests

Finally Figure 6-6 shows the velocity trace plot for Vehicle A in A1A1 tests. This shows a good, consistent set of results although there is some variability in the warning times at TNO and the initial velocity is slightly lower than 50 km/h for the tests conducted at BASt. Please note, that the offset in time of 1 second between the TNO tests and the BASt and IDIADA tests is only artificial. In some tests at TNO early warnings were registered. Therefore, TNO data was provided with t=0 set to TTC = 4 sec instead of 3 sec.

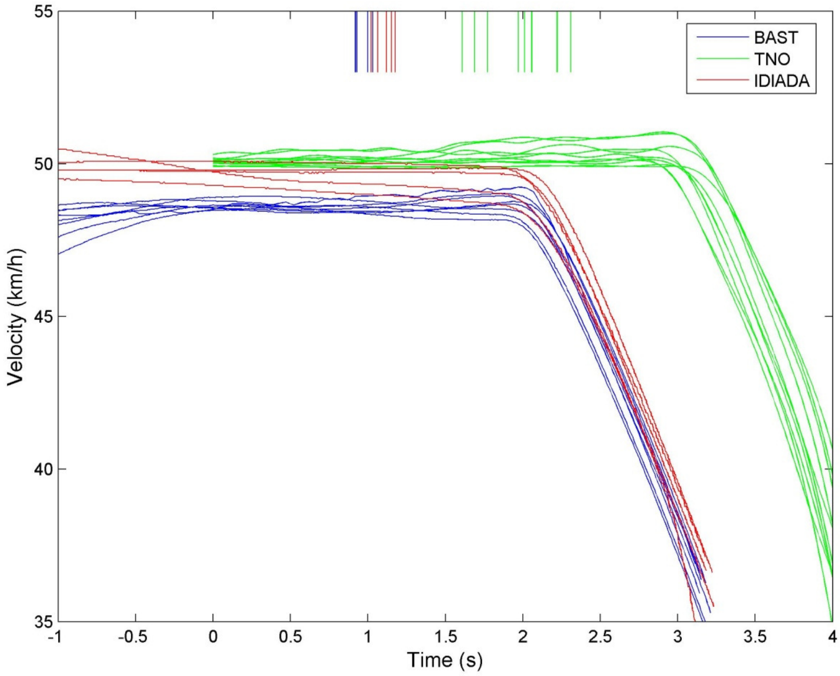


Figure 6-6: Velocity trace plot for Vehicle A A1A1 tests

6.3.3 Overview of test results for Vehicle A and Vehicle B

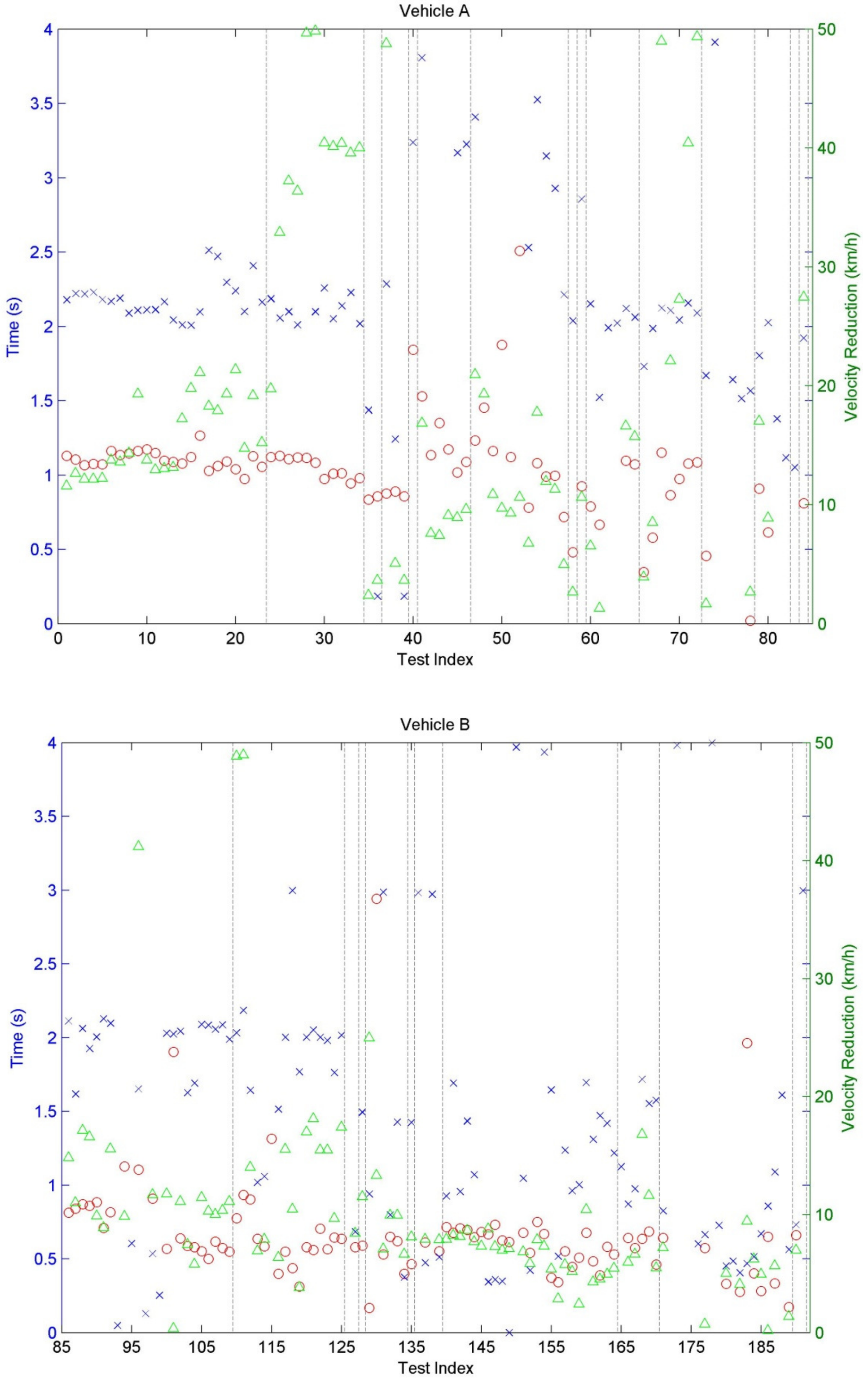


Figure 6-7. Overview of test results for Vehicle A and Vehicle B, TTC of warning (blue crosses), TTC of braking (red circles), velocity reduction (green triangles)

The figure above shows the test results for vehicle A and vehicle B for all test houses. The test results are in order from test A1A1 at left hand side and progress to the last tests of the test matrix at the right hand side. The vertical dashed lines on the graph show the transition between the test scenarios. TTC of warning (blue crosses) and TTC of braking (red circles) should be read using the left hand y-axis; velocity reduction (green triangles) should be read using the scale on the right hand y-axis.

These diagrams show the generally better repeatability of vehicle A tests (especially in the A1 scenarios) and also provide a visual depiction of the variability of the KPIs. This is in line with the findings from section 5.2.1.

6.3.4 Repeatability and reproducibility

Testing identical pieces of equipment under identical conditions does not usually result in identical results. This is due to variability inherent in every testing procedure. This random or systematic variability may be due to many factors including measurement error, environmental changes (temperature, for example) or slight deviations from initial conditions. It is important to determine the amount of variability inherent in testing in order to interpret the results correctly – differences in the results of two different test combinations may solely be due to random variability in the data.

Repeatability and reproducibility values quantify variability in test results. Repeatability is a measure of the variability inherent in tests completed by the same operator, on the same vehicle in the same lab with the same equipment. Reproducibility measures the variability in tests done in different labs by different people on a comparable vehicle and under the same conditions. BS ISO 5725-2:1994 / British Standard BS5497:1987 details calculation of repeatability and reproducibility values for inter-laboratory testing and we have followed the methodology for uniform-level experiments with unequal number of replicates per cell. These calculations use information about the number of tests, their values and variability to compute statistical values that provide a measure of the repeatability and reproducibility of the test. The interpretation of these values is defined in the Standard as:

> **Repeatability value:** the difference between two single results run in one laboratory under the same conditions with the same vehicle and operator would be expected to exceed the repeatability value 1 out of 20 times.
>
> **Reproducibility value:** the difference between two single results run in two laboratories under the same conditions on an identical vehicle but with a different operator would be expected to exceed the reproducibility value 1 out of 20 times.

In other words, these values represent the maximum difference expected between two selected test results, with a 95% degree of confidence. Therefore, small values (in relation to the mean) indicate that we can be very confident of the repeatability and reproducibly of the result.

Repeatability and reproducibility values are based on identical conditions, and therefore each test combination must be evaluated separately. The following sections contain repeatability and reproducibility values for the three different KPIs and three different vehicles for test combinations where there were sufficient repeats to allow calculation.

6.3.4.1 Vehicle A tests

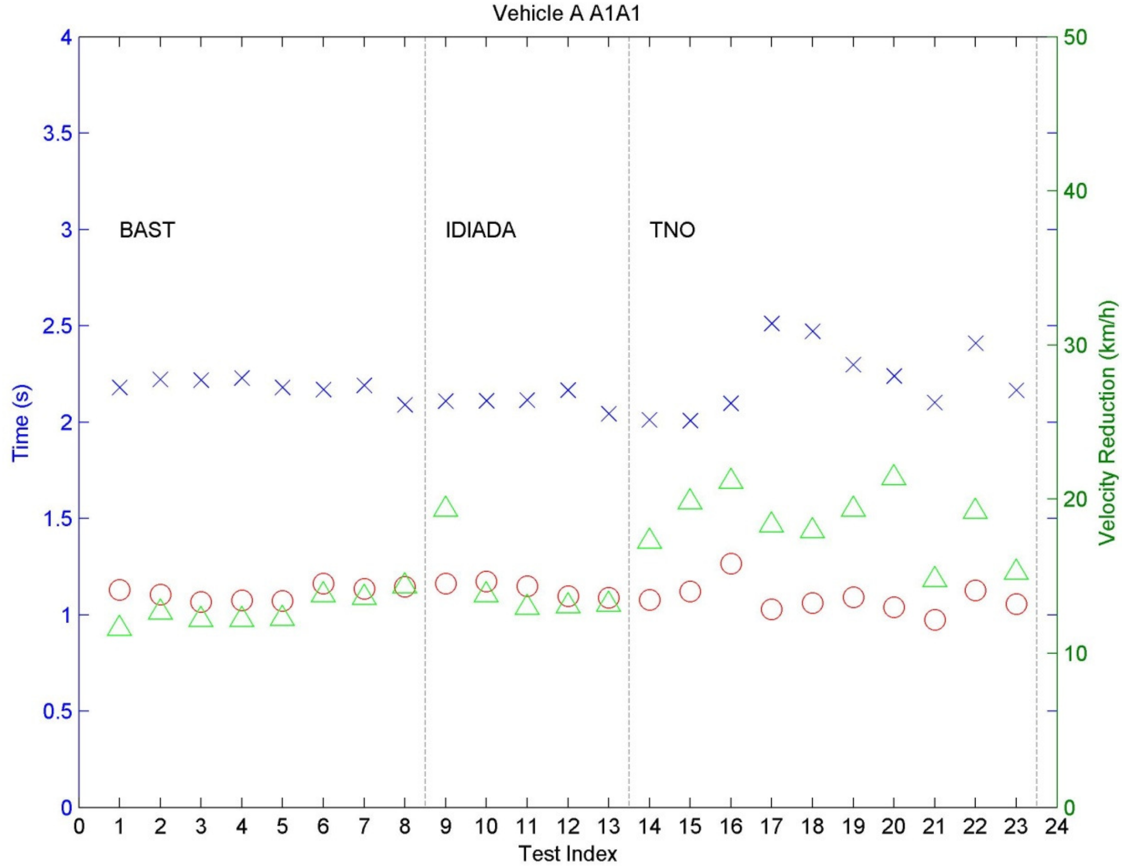


Figure 6-8. Vehicle A: Scenario A1A1, TTC of warning (blue crosses), TTC of braking (red circles), velocity reduction (green triangles)

Table 6-4: Repeatability and reproducibility values: Vehicle A A1A1 tests

		TTC warn (s)	TTC brake (s)	Velocity reduction (km/h)	Number of tests
Repeatability	BASt	0.13	0.10	2.7	8
	IDIADA	0.12	0.11	7.7	5
	TNO	0.52	0.22	6.2	10
	All	0.36	0.17	5.6	23
Reproducibility		0.37	0.17	10.3	
Mean[2]		2.2	1.1	15.6	

There was one test combination completed with Vehicle A which had sufficient cases to calculate and interpret repeatability and reproducibility values:

[2] Mean of all tests in specific test scenario which had KPIs recorded

A1A1 – Urban scenario 1: SV initial speed 50, TV initial speed 10, 100% lateral overlap and no planned driver reaction (23 valid tests for TTC warn and brake and velocity reduction)
This test condition worked well as KPIs were recorded for all the tests. The repeatability and reproducibility values are shown in Table 6-4. Results at BASt appear to be repeatable, with a TTC warn and TTC brake repeatability values which are less than 10% of the overall mean. This suggests that two TTC warning and two TTC brake results from BASt are highly likely to be different by less than 0.13s and 0.1s respectively. Likewise velocity reductions were relatively consistent and all fell between 11.6 and 14.4 km/h.

The tests at IDIADA produced similarly repeatable results for warning and braking, although the variation in velocity reduction was greater; however this is because of one test where this value was 19.3 km/h, the other tests all produced velocity reductions of around 13 km/h.

The results at TNO show increased variability in TTC warn and TTC brake although the results are still indicative of a repeatable test. The larger repeatability value for TTC of warning can be seen from Figure 6-6 where some tests triggered slightly earlier which is in line with the specifications of the pre-crash system of this car. The same tendency was also found for the tests with the ADAC test target.

Overall, the similarity between repeatability and reproducibility values, particularly for TTC warn and TTC brake, suggests that the majority of the variability is due to variability within the test house and not between test houses. There is some variability between test houses for velocity reduction with values at TNO tending to be higher - around 18 km/h compared to around 14 km/h for BASt and IDIADA (see Table 5-1, Table 5-2 and Table 5-3).

6.3.4.2 Vehicle B tests

There were four test combinations completed with Vehicle B which had sufficient cases to calculate and interpret repeatability and reproducibility values:

- A1A1 – Urban scenario 1: SV initial speed 50, TV initial speed 10, 100% lateral overlap and no planned driver reaction (23 valid tests for TTC warn and 20 valid tests for TTC brake and velocity reduction);
- A1A3 – Urban scenario 1: SV initial speed 50, TV initial speed 10, 100% lateral overlap and fast planned driver reaction (15 valid tests for TTC warn and 16 valid tests for TTC brake and velocity reduction);
- A3A1 – Urban scenario 1: SV initial speed 50, TV initial speed 0, 100% lateral overlap and no planned driver reaction (23 valid tests for TTC warn and 24 valid tests for TTC brake and velocity reduction);
- A3B1 – Urban scenario 2: SV initial speed 50, TV initial speed 0, 50% lateral overlap and no planned driver reaction (16 valid tests for TTC warn and 10 valid tests for TTC brake and velocity reduction).

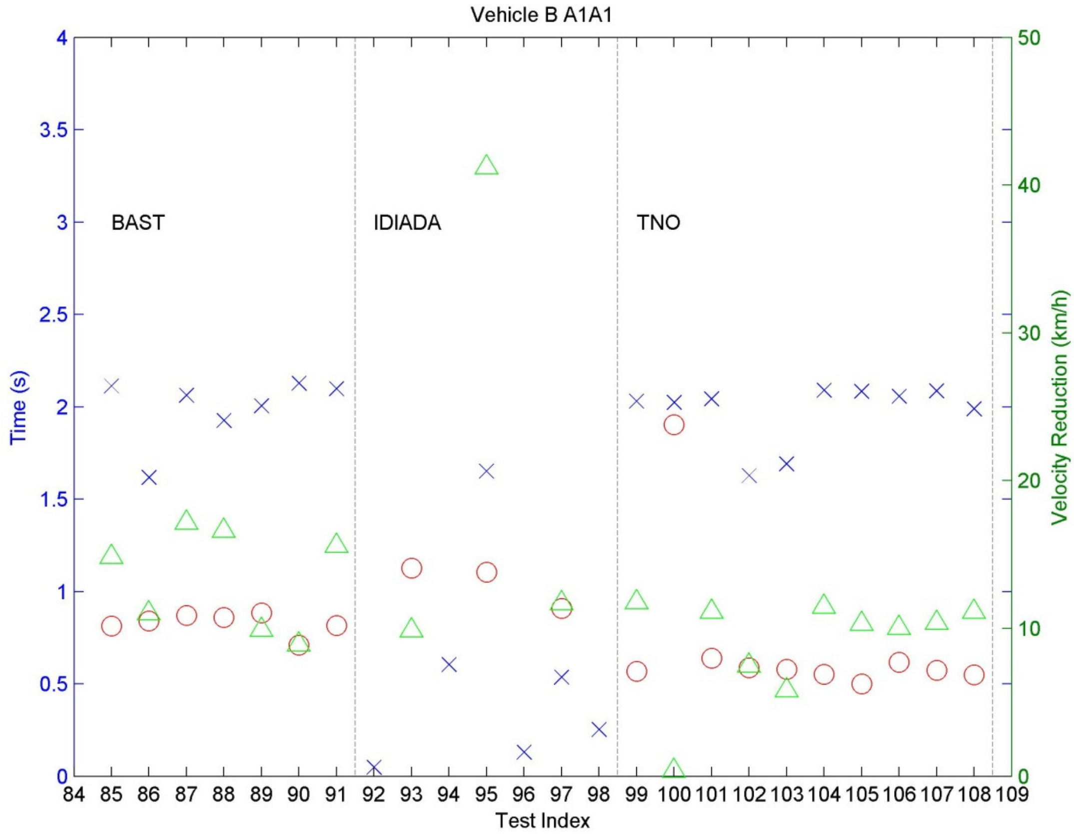


Figure 6-9. Vehicle B: Scenario A1A1, TTC of warning (blue crosses), TTC of braking (red circles), velocity reduction (green triangles)

Table 6-5 shows the repeatability and reproducibility values for Vehicle B for test scenario A1A1. Low values (relative to the mean) suggest that there is little variability in the results. Results at BASt appear to be repeatable, with a TTC brake repeatability 20% of the overall mean. This suggests that two TTC brake results from BASt are highly likely to differ by less than 0.16s. This small repeatability value is reflected in the small range of results for BASt shown in Table 14-1; for example, 0.71 - 0.88s for TTC brake.

At IDIADA the results for TTC warn and velocity reduction were much more variable, resulting in higher repeatability values – TTC warn on 6 tests had a range from 0.05s to 1.65s. A TTC warn of 0.05s suggests a test in which the system did not function as intended, and indeed the results of this test (and three others) were not complete for TTC brake and velocity reduction. One test had TTC brake and velocity reduction results but no TTC warn result.

At TNO repeatability values for TTC warn and velocity reductions were similar to those derived for BASt, and therefore represent fairly repeatable results. The large repeatability value for TTC brake is due to one test where the TTC brake was 1.9s and the velocity reduction was 0.37km/h (i.e. the vehicle did not brake), whereas all other tests had a TTC brake between 0.50 and 0.64s.

Reproducibility values for TTC brake and velocity reduction were similar to the overall repeatability values which suggests that variability between laboratories is small and the majority of the variability comes from within laboratories, mainly due to tests where the system did not respond as intended.

Table 6-5: Repeatability and reproducibility of Vehicle B A1A1 tests

		TTC warn (s)	TTC brake (s)	Velocity reduction (km/h)	Number of tests
Repeatability	BASt	0.50	0.16	9.5	7
	IDIADA	1.65	0.34	49.2	3*
	TNO	0.47	1.18	10.0	10
	All	0.92	0.87	19.2	20**
Reproducibility		2.36	0.90	23.0	20**
Mean		1.60	0.050.80 2.13	12.3	20**

* 6 tests in TTC warn ** 23 tests in TTC warn

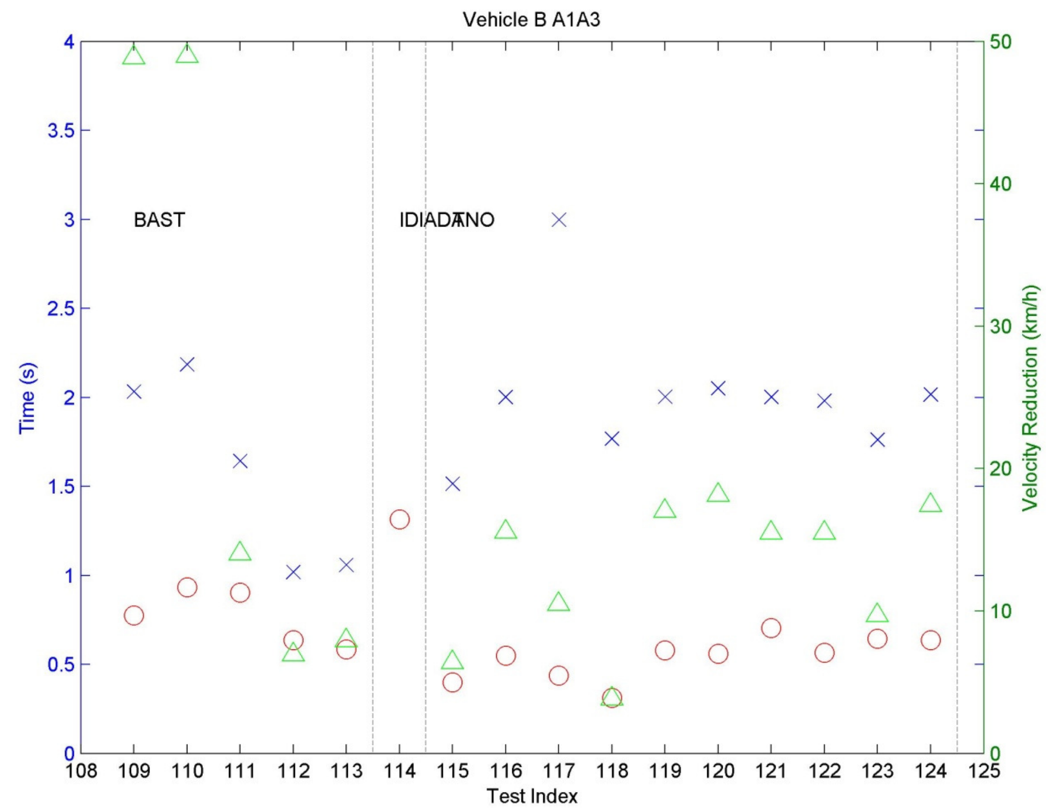


Figure 6-10. Vehicle B: Scenario A1A3, TTC of warning (blue crosses), TTC of braking (red circles), velocity reduction (green triangles)

Table 6-6: Repeatability and reproducibility of Vehicle B A1A3 tests

		TTC warn (s)	TTC brake (s)	Velocity reduction (km/h)	Number of tests
Repeatability	BASt	1.51	0.44	60.7	5
	IDIADA	N/A	N/A	N/A	1*
	TNO	1.08	0.34	14.0	10
	All	1.23	0.37	35.6	15
Reproducibility		1.41	0.57	41	15
Mean		1.9	0.7	19.1	15

* 0 tests in TTC warn

Repeatability and reproducibility values for Vehicle B A1A3, shown in Table 6-6, are substantially worse than A1A1 tests. For example, the velocity reduction repeatability for BASt is three times the size of the overall mean. Over the five tests, the repeatability of TTC warn is just less than the overall mean, and of TTC brake is around 50% of the overall mean. It is not possible to produce repeatability values for IDIADA as there was only one test completed on this test combination. Results at TNO were slightly more repeatable, in particular for velocity reduction, where the repeatability was around 75% of the overall mean. Large repeatability values suggest a mixture of failed (i.e. late warning or braking) and successful tests.

Reproducibility across the two laboratories was larger than the overall repeatability for TTC brake which suggests that there was some variability in mean results between the two laboratories. The reproducibility for velocity reduction was around 25% larger than the repeatability suggesting some variability in these means.

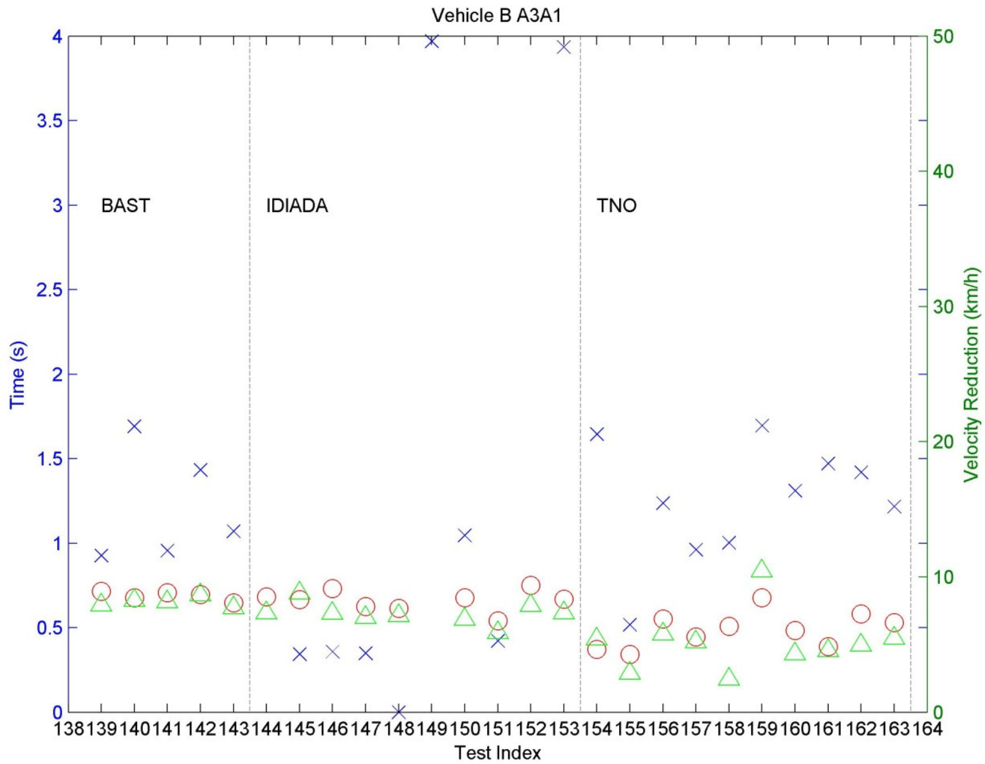


Figure 6-11. Vehicle B: Scenario A3A1, TTC of warning (blue crosses), TTC of braking (red circles), velocity reduction (green triangles)

For Vehicle B A3A1 tests (see Table 6-7) the picture is similar to the A3A1 tests – there are some KPIs which appear to be more repeatable than others: TTC brake and velocity reduction at BASt appear to be the best. There were large repeatability values at IDIADA for TTC warn due to two tests (one which did not have associated TTC brake and velocity reduction values) with early warnings – at 3.97s and 3.93s. Reproducibility values were similar to the overall repeatability value suggesting, once again, that the major source of variability is not between laboratories, but due to variability in response of the vehicle system.

Velocity reduction repeatability values were low for track tests (1-2 km/h; 15-35% of overall), but were higher in the laboratory (100% of overall mean).

Table 6-7: Repeatability and reproducibility of Vehicle B A3A1 tests

		TTC warn (s)	TTC brake (s)	Velocity reduction (km/h)	Number of tests
Repeatability	BASt	0.93	0.08	1.0	5
	IDIADA	4.65	0.18	2.2	9*
	TNO	0.99	0.29	6.1	10
	All	2.86	0.22	4.2	24**
Reproducibility		2.66	0.38	5.9	24**
Mean		1.30	0.61	6.6	24**

* 7 tests in TTC warn ** 22 tests in TTC warn

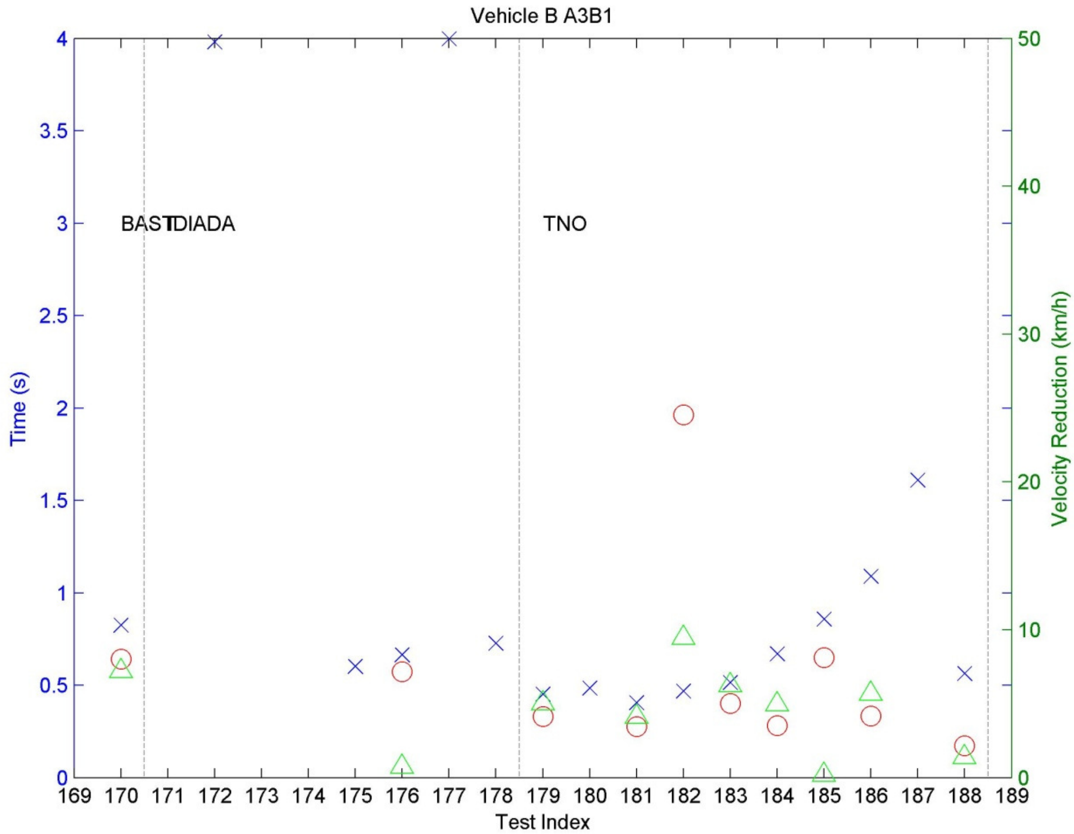


Figure 6-12. Vehicle B: Scenario A3B1, TTC of warning (blue crosses), TTC of braking (red circles), velocity reduction (green triangles)

For Vehicle B A3B1 tests (see Table 6-8) there were insufficient tests completed at BASt and IDIADA to complete the repeatability values. For those where sufficient cases were available, the repeatability values were considerably bigger than the overall mean, suggesting that these results are not very repeatable when considering all test results including obvious outliers.

Table 6-8: Repeatability and reproducibility of Vehicle B A3B1 tests

		TTC warn (s)	TTC brake (s)	Velocity reduction (km/h)	Number of tests
Repeatability	BASt	N/A	N/A	N/A	1
	IDIADA	5.10	N/A	N/A	1*
	TNO	1.07	1.64	8.0	8**
	All	2.97	1.64	8.0	8**
Reproducibility		3.73	N/A	N/A	8**
Mean		1.06	0.60	4.5	8**

* 5 tests in TTC warn ** 10 tests in TTC warn

6.3.4.3 Vehicle C tests

Table 6-9: Repeatability of Vehicle C tests

	Test	TTC warn (s)	TTC brake (s)	Velocity reduction (km/h)
Repeatability	A1A1	0.45	0.63	6.1
	A1A3	0.55	0.13	4.8
	A3A1	0.56	0.07	32.8
	A3B1	1.93	0.28	1.2
Mean	A1A1	1.6	0.8	12.7
	A1A3	1.7	0.6	13.6
	A3A1	1.4	0.6	17.2
	A3B1	0.7	0.4	5.7

The repeatability results for the tests conducted with a Vehicle C at IDIADA are shown in Table 6-9. These results suggest good repeatability of TTC warn for tests A1A1, A1A3 and A3A1 but not A3B1. This may be a result of the A3B1 test being the only one of the group conducted with 50% overlap (as opposed to 100%). The results for TTC brake and velocity reduction suggest good repeatability across the tests with the exception of velocity reduction in test A3A1. This result for A3A1 is heavily influenced by two runs where the velocity reduction was around 39 km/h, the rest of the runs had a velocity reduction of around 12 km/h.

6.3.4.4 Vehicle A tests with alternative targets

The A1A1 condition was repeated at BASt with two alternative target vehicles:

- An ADAC test target
- A 2011 VW Passat to test the warning trigger on a real car before swerving to avoid collision

The repeatability and reproducibility values from these tests are shown in Table 6-10. The repeatability values in the first line are those applicable to the original Vehicle A A1A1 tests conducted at BASt and shown in Table 6-4. In this analysis the reproducibility values reflect tests conducted with different target vehicles and not tests conducted at different laboratories.

The results using an ADAC target show increased variance, particularly for TTC brake, although this value is heavily influenced by one test where braking occurred early at 1.8s the other tests had a TTC brake value of between 1.1 and 1.2s.

The results with the VW Passat as a target vehicle show good repeatability with respect to TTC warn with all values between 2.1 and 2.2s.

Overall the results with respect to TTC warn suggest good repeatability, with less repeatability apparent in TTC brake and velocity reduction. The similarity between repeatability and reproducibility values, particularly for TTC warn and TTC brake, suggest that the majority of the variability is due to variability within tests using the same target vehicle and not between target vehicles.

Table 6-10: Repeatability and reproducibility of Vehicle A A1A1 tests

	Target	TTC warn (s)	TTC brake (s)	Velocity reduction (km/h)
Repeatability	ASSESS	0.13	0.10	2.7
	ADAC	0.15	0.59	4.7
	PASSAT	0.08	N/A	N/A
	All	0.13	0.45	4.0
Reproducibility		0.13	0.47	8.4
Mean		2.2	1.2	14.9

6.3.4.5 Summary

In summary, there have been mixtures of successful and failed tests, where a failed test is defined as one where the warning or braking system did not operate or where the system reacted earlier or later than expected. Failed tests were considered to have occurred because of either differences in the radar characteristics of the target to the sensing system because of repeated impacts or because of inconstancy of detection by the sensing systems.

In groups of tests where the system functioned correctly, results range from being relatively repeatable (e.g. Vehicle A: TTC brake at BASt on A1A1) to quite variable (e.g. Vehicle B: velocity reduction at BASt on A1A3), and in groups of tests where some failed tests were included, repeatability values were considerably larger than the mean. Overall, this suggests that KPI results from these tests are inconsistent and not reliable. However these inconsistencies are most likely due to variability in the system under test rather than the testing methodology itself.

Comparisons between 'crashable' targets and a real car showed that TTC of warning was not significantly different.

For further comparison of the test results, please also refer to section 5.2.

6.3.5 Detecting variability within factors

In Section 6.3.4, it has been shown that there is a degree of variability in the test results. We have combined all test combinations together for two vehicles: Vehicle A and Vehicle B, where there were sufficient cases to analyse the variability.

For the purposes of the analyses, tests where the KPI was missing have not been included and the following tests were also removed as there were insufficient cases:

- 2 cases where initial speed of the Subject vehicle was 80km/h (A3C1, A3C3)
- 1 case where initial speed of the Target vehicle was 20km/h and initial speed of the Subject vehicle was 100km/h (A1C3)
- 4 cases where planned driver reaction was slow (A1A2, A2A2, A3A2, A3B2)
- 5 cases where braking of target vehicle was 7km/h (A2B1, A2B3)

On this reduced subset of data, ANalysis Of VAriance (ANOVA) models have been used to partition the variability and determine which input test variables[3] are contributing the most to the variability in the outcome measures (KPIs). In total there are 44 tests at BASt, 107 tests at IDIADA and 98 tests at TNO. The number of tests split by each input test variable is shown in Table 6-11.

Table 6-11: Number of tests for each test variable

		BASt	IDIADA	TNO
Planned driver reaction	fast	17	34	34
	no	26	73	64
TV braking	0 m/s^2	40	90	86
	4 m/s^2	3	17	12
TV initial speed	0 km/h	18	53	40
	10 km/h	22	37	45
	50 km/h	3	17	12
TV initial lateral overlap	50%	5	31	25
	100%	38	76	73

For the purposes of the analysis we work with the natural log of the KPIs, as the analysis technique requires the KPI to be distributed approximately normally.

6.3.5.1 Vehicles combined

The relevant results from the ANOVA analysis for all laboratories and both vehicles (Vehicle A and Vehicle B) on one KPI (TTC brake) are shown in Table 6-12. The complete ANOVA is shown in the Appendix. There are three important concepts to define:

- 'Significance' shows the chance that this factor does not contribute to the explanation of any variability in the data; i.e. a small value ($p<0.05$) suggests that there is some significant variability within that variable.
- 'Partial eta squared' is the proportion of the variability in the KPI which could be explained by that particular variable.
- 'R squared' is the total proportion of variability in the KPI which can be explained by the model. An adjusted R squared value adjusts the R squared value relative to the sample size and so these values are comparable between models.

[3] Input test variables are TV initial speed, TV braking, TV initial lateral overlap and SV planned driver reaction

These definitions will be required throughout this section. In ANOVA tables we present models which contain significant main effects and interactions and any main effects which are not significant but are contained in a significant interaction term for the purposes of interpretation. The precise Significance values are shown when p>0.10 (i.e., for non-significant variables, denoted also by ns) while for the significant variables, the lowest possible level of p<0.01, p<0.05 or p<0.10 is displayed. For example, p<0.05 in the table means that the corresponding p-value is between 0.01 and 0.05.

Table 6-12 shows that each of the variables except 'Planned driver reaction' are significant in the model (have a Significance of p<0.10) and explain some of the variability (Partial eta squared) in the KPI: TTC of braking. The partial eta squared shows that the largest individual influence (49%) of the known variability is explained by the variable 'vehicle'.

Table 6-12: ANOVA analysis for log(TTC of braking)[4]

Source	Significance	Partial Eta Squared
Corrected Model	p<0.01	53%
Intercept	ns: p=0.68	
Lab	p<0.10	3%
Vehicle	p<0.01	49%
TV initial speed	p<0.05	5%
TV lateral overlap	p<0.01	6%
Planned driver reaction	ns: p=0.43	0%

R Squared = 0.53 (Adjusted R Squared = 0.51)

Further investigation is required to determine whether the significant results from the ANOVA are due to the variables we have tested or whether the unbalanced nature of the trials means that a few important variables are influencing others, e.g. certain laboratories may have carried out certain tests which resulted in a significantly shorter TTC of braking. This will show as a significantly shorter overall TTC of braking for that lab.

In the following sections we analyse a subset of tests which are a balanced set which match approximately across the different test types. Analyses have been split by vehicles as results from different vehicles would not be combined in practice.

6.3.5.2 Vehicle A

Vehicle A results can only be compared between labs when valid tests are present for all three laboratories. In the case of TTC warn results, the tests used in the following analysis include A1A1, A1A3, A3A1 and A3A3. TTC brake and velocity reduction results are available for two additional tests: A2A1 and A2A3. Hence, comparisons cannot be made between TTC warn and TTC brake results since these tests are based on different data samples.

The subset of complete data on Vehicle A for TTC warn totals 46 tests including 11 tests from BASt, 13 tests from IDIADA and 22 from TNO. The complete data for TTC brake and velocity reduction consists of 62 tests; 13 from BASt, 20 from IDIADA and 29 from TNO. These tests have been weighted to ensure equal influence for each category (e.g. 0 km/h, 10 km/h) within each variable (e.g. TV initial speed) across the laboratories.

[4] A full ANOVA is shown in **Error! Reference source not found.**

Table 6-13: Number of KPI TTC warn valid results and weighted count for Vehicle A tests split by test input variables

		Count			Weighted count		
		BASt	IDIADA	TNO	BASt	IDIADA	TNO
Planned driver reaction	Fast	2	5	10	2	2	2
	No	9	8	12	2	2	2
TV braking	0 m/s	11	13	22	4	4	4
TV initial speed	0 km/h	2	4	7	2	2	2
	10 km/h	9	9	15	2	2	2
SV initial speed	50 km/h	11	13	22	4	4	4
TV lateral ovelap	100%	11	13	22	4	4	4

Table 6-14: Number of KPI TTC brake and velocity reduction valid results and weighted count for Vehicle A tests split by test input variables

		Count			Weighted count		
		BASt	IDIADA	TNO	BASt	IDIADA	TNO
Planned driver reaction	Fast	3	11	15	3	3	3
	No	10	9	14	3	3	3
TV braking	0 m/s^2	11	12	22	4	4	4
	4 m/s^2	2	8	7	2	2	2
TV initial speed	0 km/h	2	2	7	2	2	2
	10 km/h	9	10	15	2	2	2
	50 km/h	2	8	7	2	2	2
SV initial speed	50 km/h	13	20	29	6	6	6
TV initial lateral overlap	100%	13	20	29	6	6	6

More detailed analysis of the distribution of tests has shown that there is a confound between TV initial speed and TV braking for TTC brake and velocity reduction (see Table 6-15) i.e. all tests that were carried out with TV braking of $4ms^{-2}$ were also done at a TV initial speed of 50km/h. This means, for example, that any effect attributed to the variability within TV braking could also be due to variability in initial speed and it is not possible to separate these effects in a single analysis. As a result, TV braking was not included as an input variable in the analysis and this confound will be considered in the interpretation of the results.

Table 6-15: Number of KPI TTC brake and velocity reduction valid results for Vehicle A tests split by TV braking and TV initial speed

		TV initial speed (km/h)		
		0	10	50
TV braking	$0ms^{-2}$	11	34	0
	$4ms^{-2}$	0	0	17

a) TTC of warning

Table 6-16 shows the ANOVA analysis for TTC warn on Vehicle A. For TTC warn, there is a significant effect of Lab and of TV initial speed. Firstly, there appears to be significant differences between Labs and in particular, the weighted mean of TTC warn is significantly larger for TNO than IDIADA which has been explained in section 5.3. Secondly, there are significant differences between TV initial speeds; the weighted mean of TTC warn is significantly larger for 10 km/h than 0 km/h.

Table 6-16: ANOVA table for log(TTC warn) for Vehicle A

Source	Sig.	Partial Eta Squared
Corrected Model	$p<0.01$	35%
Intercept	$p<0.01$	
TV initial speed	$p<0.01$	27%
Lab	$p<0.05$	14%

Figure 6-13 shows the weighted means and ranges of TTC warn for Vehicle A over the main test input variables (figures are given in Table 14-6). The mean TTC of warning for BASt is not significantly different to IDIADA or TNO. However, there is a significant difference between IDIADA and TNO. The mean TTC of warning for TV initial speed of 0km/h and 10km/h are significantly different.

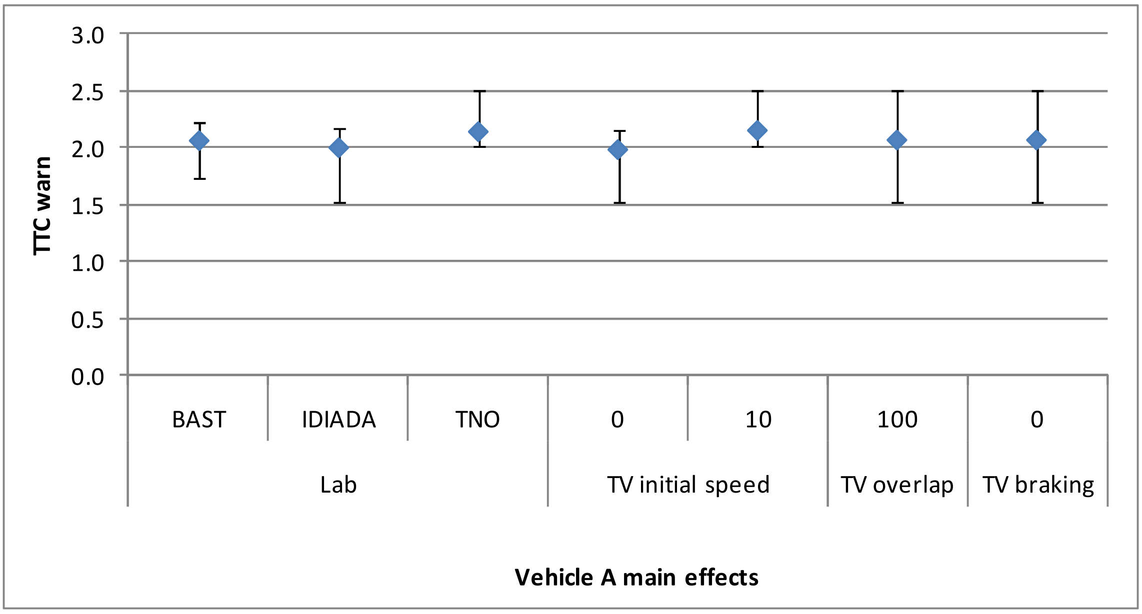


Figure 6-13: Weighted mean and range of TTC warn (s) for Vehicle A

b) TTC of braking

Table 6-17 shows the ANOVA analyses for TTC brake on Vehicle A. For TTC brake, there is a significant effect of TV initial speed and driver reaction. That is, there appear to be significant differences between each of the pairwise TV initial speeds and between the fast and no driver reactions. Three interaction effects are significant in the ANOVA: driver reaction and lab; TV initial speed and driver reaction and TV initial speed and lab. The interaction between TV initial speed and lab accounts for 71% of the variability in the dataset (see Figure 6-14).

Table 6-17: ANOVA table for log(TTC brake) for Vehicle A

Source	Sig.	Partial Eta Squared
Corrected Model	p<0.01	88%
Intercept	ns: p=0.20	
TV initial speed	p<0.01	79%
Driver reaction	p<0.01	24%
Lab	ns: p=0.11	9%
Driver reaction * Lab	p<0.01	28%
TV initial speed * Driver reaction	p<0.01	24%
TV initial speed * Lab	p<0.01	71%

Figure 6-14 shows the relationship between laboratory and TV initial speed which was detected as significant in Table 6-17. The TTC to braking increased as the TV initial speed increased for tests carried out at both BASt and IDIADA. Tests carried out at TNO showed little difference in the mean TTC to braking at different TV initial speeds. The reasons for this are unknown, but possible explanations are that for the relative motion laboratory facility, the target effectively has a velocity which fluctuates very slightly around zero for “standstill”tests and this might be sufficient to improve detection compared to a static target on the track. Furthermore, TNO do not directly measure the deceleration of the car, but derive it from the velocity of the chassis dynamometer. Data filtering may explain the lower value for the TTC brake at 50km/h.

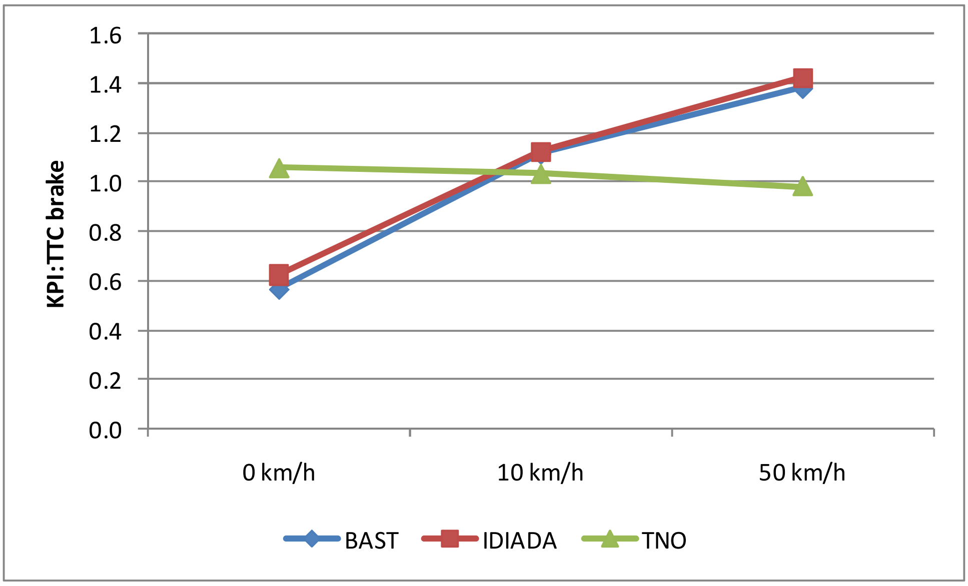


Figure 6-14: Weighted mean of TTC brake (s) for Vehicle A by Lab and TV initial speed

Figure 6-15 shows the weighted means and ranges of TTC brake for Vehicle A over the main test input variables (figures are given in Table 14-7). The mean TTC of braking for TV initial speed of 0km/h is significantly different to that at 10km/h and 50km/h. There is also a significant difference between 10km/h and 50km/h. The mean TTC of braking for fast and no driver reaction are significantly different. TV braking is confounded with TV initial speed (see Table 6-15). As a result, TV braking was not included in the ANOVA and conclusions cannot be drawn about differences in the mean TTC brake for this variable.

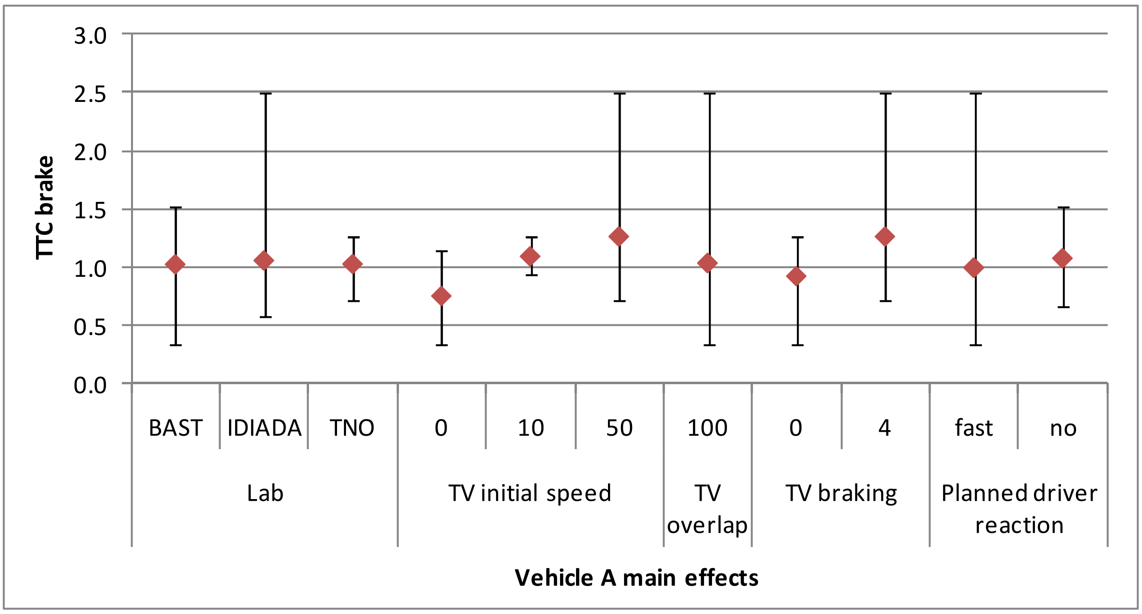


Figure 6-15: Weighted mean and range of TTC brake (s) for Vehicle A

c) Velocity reduction

Table 6-18 shows the ANOVA analyses for velocity reductions on Vehicle A. For velocity reduction, there is a significant effect of TV initial speed, driver reaction and Lab. Three interaction effects are significant in the ANOVA: driver reaction and lab; TV initial speed and driver reaction and TV initial speed and lab. The interaction between TV initial speed and lab accounts for 76% of the variability in the dataset (see Figure 6-16). The interaction between driver reaction and lab accounts for 41% of the variability in the dataset (see Figure 6-17).

Table 6-18: ANOVA table for log(velocity reduction) for Vehicle A

Source	Sig.	Partial Eta Squared
Corrected Model	p<0.01	91%
Intercept	p<0.01	
TV initial speed	p<0.01	75%
Driver reaction	p<0.01	54%
Lab	p<0.01	56%
Driver reaction * Lab	p<0.01	41%
TV initial speed * Driver reaction	p<0.01	19%
TV initial speed * Lab	p<0.01	76%

Figure 6-16 shows the relationship between laboratory and TV initial speed which was detected as significant in Table 6-18. This indicates that greater velocity reduction is achieved when the target is moving and when there is a “fast” driver reaction. It also suggests that the laboratory at which the tests are conducted also explains a significant amount of the variation in final velocity reduction, although some of this effect can be explained by the interaction terms involving 'laboratory'. These main effects of TV initial speed and driver reaction can be seen in the following figures.

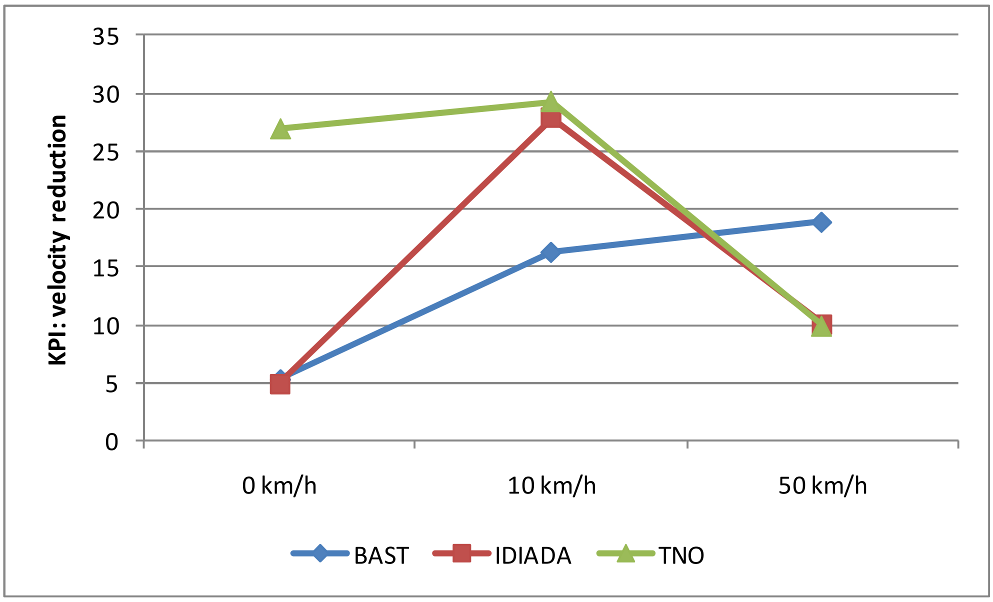


Figure 6-16: Weighted mean of velocity reduction for Vehicle A by Lab and TV initial speed

Figure 6-17 shows the relationship between laboratory and driver reaction which was detected as significant in Table 6-18. As expected, there is a decrease in velocity reduction with no planned driver reaction compared to fast driver reaction for all laboratories; however this drop is much less for the tests completed at BASt compared to the other two test houses. BASt results with a fast driver reaction are only based on three tests with one particularly low velocity reduction (3.92) i.e. the braking occurred too close to the subject vehicle. Therefore, this interaction is significant because of this single test.

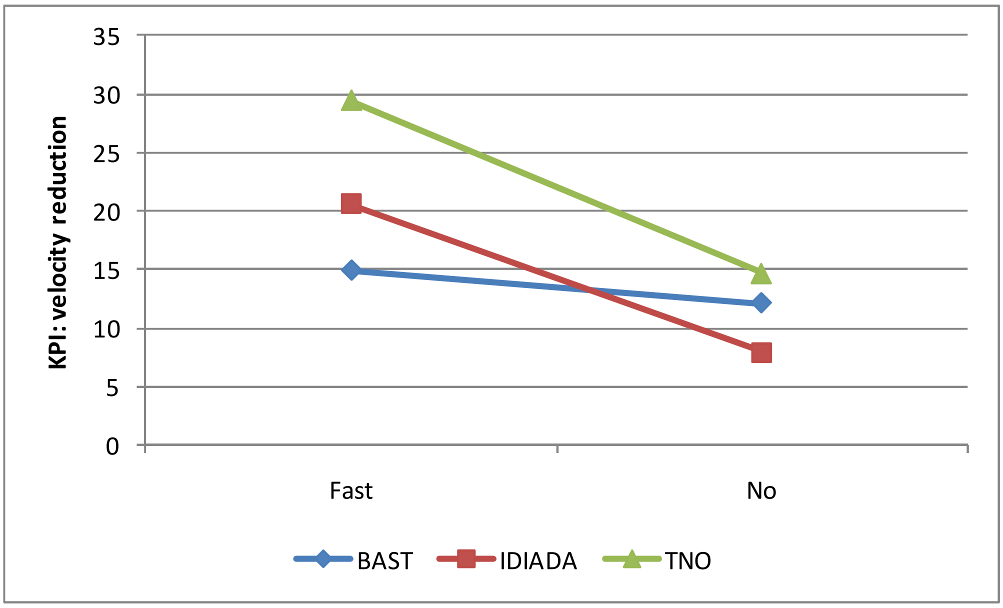


Figure 6-17: Weighted mean of velocity reduction for Vehicle A by Lab and driver reaction

Figure 6-18 shows the weighted means and ranges of TTC brake for Vehicle A over the main test input variables (figures are given in Table 14-8). The mean velocity reduction for BASt is significantly different to IDIADA and TNO. There is also a significant difference between IDIADA and TNO. The mean velocity reduction for TV initial speed of 0km/h is significantly different to that at 10km/h and 50km/h. There is also a significant difference between 10km/h and 50km/h. The mean velocity reductions for fast and no driver reaction are significantly different. TV braking is confounded with TV initial speed (see Table 6-15).

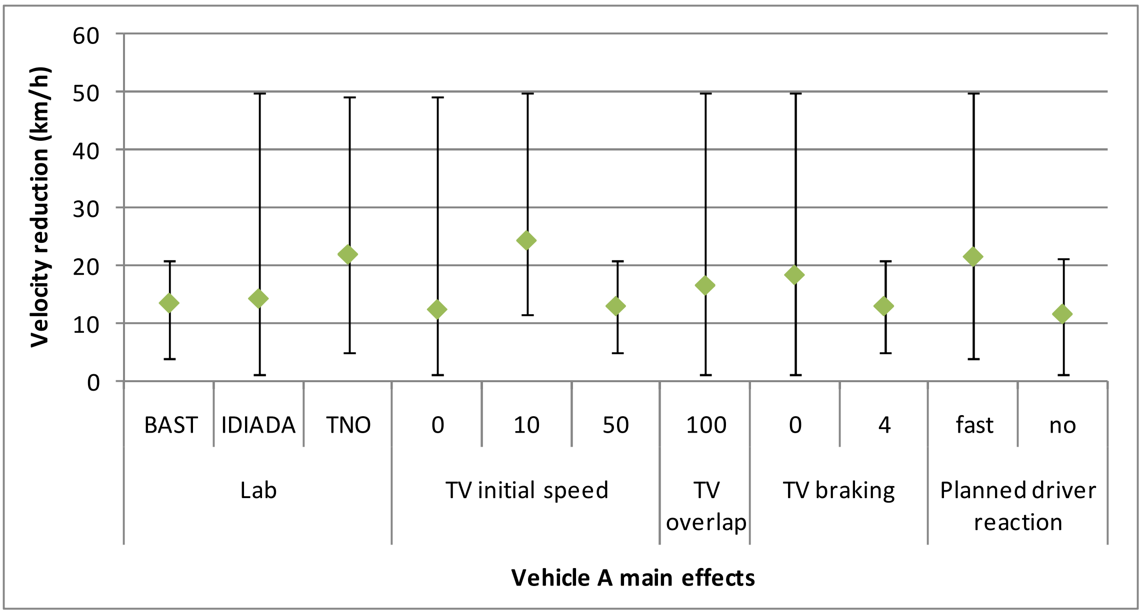


Figure 6-18: Weighted mean and range of velocity reduction for Vehicle A

6.3.5.3 Vehicle B

The subset of complete data based on Vehicle B totals 90 tests including 19 tests from BASt, 27 IDIADA tests and 44 tests from TNO. Some of these tests did not result in three KPI results. These tests have been weighted to ensure equal influence for each category within each variable across the laboratories.

Table 6-19: Number of tests and weighted count for Vehicle B tests split by test input variables

		Count			Weighted count		
		BASt	IDIADA	TNO	BASt	IDIADA	TNO
Planned driver reaction	Fast	5	1*	10	1	1	1
	No	15	14****	32**	4	4	4
TV braking	0 ms^{-2}	19	14****	38**	4	4	4
	4 ms^{-2}	1	1*	4	1	1	1
TV initial speed	0 km/h	6	10**	18**	2	2	2
	10 km/h	13	4**	20	2	2	2
	50 km/h	1	1*	4	1	1	1
SV initial speed	50 km/h	20	15***	42**	5	5	5
TV initial lateral overlap	50%	1	1*	10	1	1	1
	100%	19	14****	32**	4	4	4

* 1 fewer in TTC warn ** 2 more in TTC warn *** 3 more in TTC warn **** 4 more in TTC warn

More detailed analysis of the distribution of tests has shown that there is a confound between TV initial speed and TV initial overlap (see Table 6-20); i.e. all tests that were carried out at 50% lateral overlap were also done at a TV initial speed of 0 km/h. This means, for example, that any effect attributed to the variability within lateral overlap could also be due to variability in initial speed and it is not possible to separate these effects in a single analysis. Therefore, two separate analyses have been carried out to evaluate two subsets of the data:

- subset A: to evaluate initial speed, we take tests done with 100% overlap
- subset B: to evaluate lateral overlap, we take tests done at TV initial speed = 0km/h

Table 6-20: Number of tests for Vehicle B tests split by TV initial speed and lateral overlap

Lab	TV initial speed	TV lateral overlap	
		50%	100%
BASt	0 km/h	1	5
	10 km/h	0	13
	50 km/h	0	1
IDIADA	0 km/h	8	10
	10 km/h	0	8
	50 km/h	0	1
TNO	0 km/h	10	10
	10 km/h	0	20
	50 km/h	0	4

In addition there is some confounding of TV braking with other variables: tests where TV braking was 4m/s are all carried out at TV initial speed of 50km/h, TV initial overlap of 100% and with no planned driver reaction. For this reason, TV braking will not be included as an input variable in the analysis and this confound will be considered in the interpretation of the results.

a) TTC of warning and braking

Table 6-21 shows the ANOVA analyses for TTC warn on Vehicle B. For TTC warn, subset A, there is a significant effect of Lab and a significant interaction between Lab and TV initial speed. That is, firstly, there appear to be significant differences between labs, and in particular the weighted mean of TTC warn in subset A is significantly smaller for IDIADA than for BASt and TNO. Secondly, the significant interaction of lab and TV initial speed suggests that the effect of TV initial speed on TTC warn is different for different labs. For TTC warn, subset B, the interaction between Lab and TV initial lateral overlap is approaching significance however there is no significant difference in the means of TTC warn for Labs or TV overlap and the overall R squared value is very low suggesting that there is a substantial amount of variability in the results which cannot be explained with the test input variables. That is, test results appear to be quite variable for unknown reasons, and much of this is expected to be due to failed tests, as discussed in Section 0. The repeatability and reproducibility results in Section 0 also suggest very variable results for TTC of warning.

Table 6-21: ANOVA table for log(TTC warn) for Vehicle B

Subset A

Source	Sig.	Partial Eta Squared
Corrected Model	p<0.01	47%
Intercept	ns: p=0.58	
TV initial speed	ns: p=0.11	7%
Lab	p<0.01	33%
TV initial speed * Lab	p<0.01	18%

R Squared = 0.47 (Adjusted R Squared = 0.41)

Subset B

Source	Sig.	Partial Eta Squared
Corrected Model	ns: p=0.23	19%
Intercept	ns: p=0.78	
Lab	ns: p=0.72	2%
TV overlap	ns: p=0.40	2%
Lab * TV overlap	p<0.10	14%

R Squared = 0.19 (Adjusted R Squared = 0.06)

Figure 6-19 shows the relationship of lab and TV initial speed. There is no significant difference between the mean TTC warnings across the different TV initial speeds on this subset. Note that IDIADA carried out no tests at 50km/h in this subset, and that tests done at 50 km/h at BASt and TNO were completed with a TV braking of 4 m/s rather than 0 m/s for the other TV initial speed categories. The pattern of interest which the ANOVA analysis detected is the increase in TTC warn with speed for BASt and TNO and a reduction for IDIADA. This drop is likely to be due to a few failed tests where the warning was immediately before the collision and no braking occurred.

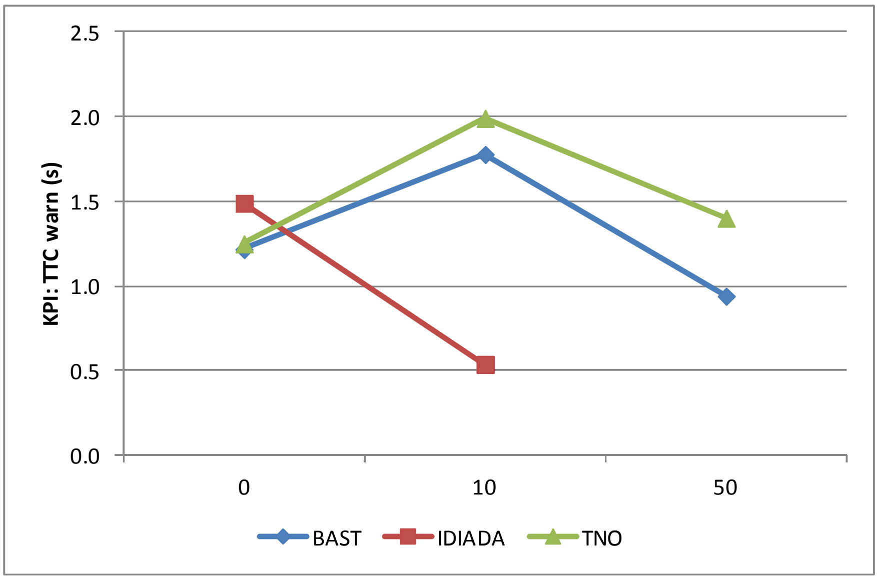


Figure 6-19: Weighted mean and range of Vehicle B TTC warn by lab and TV initial speed (subset A)

Table **6-22** shows the equivalent ANOVA analysis for TTC brake, which in general shows that it is substantially easier to explain variability in the TTC brake result in relation to the test input variables. For subset A, significant differences between tests completed at different speeds and tests completed at different labs have significantly different TTC brake results. In particular, Figure 6-21 shows that there were significant differences between test results from IDIADA and the two other labs. Once again the interaction between lab and TV initial speed was significant and this pattern is shown in Figure 6-20.

This divergence of TTC brake at 50 km/h is due to the results at IDIADA which is based on one single test where the TTC warn does not exist (i.e. the system did not work fully).

Table 6-22: ANOVA table for log(TTC brake) for Vehicle B

Subset A

Source	Sig.	Partial Eta Squared
Corrected Model	p<0.01	94%
Intercept	p<0.01	
TV initial speed	p<0.01	28%
Lab	p<0.01	83%
Planned driver reaction	ns: p=0.74	0%
Lab * Planned driver reaction	p=0.05	11%
TV initial speed * Lab	p<0.01	88%

R square 0.98 (adjusted R squared = 0.93)

Subset B

Source	Sig.	Partial Eta Squared
Corrected Model	p<0.01	28%
Intercept	p<0.01	
Lab	p<0.01	28%

R square 0.28 (adjusted R squared = 0.24)

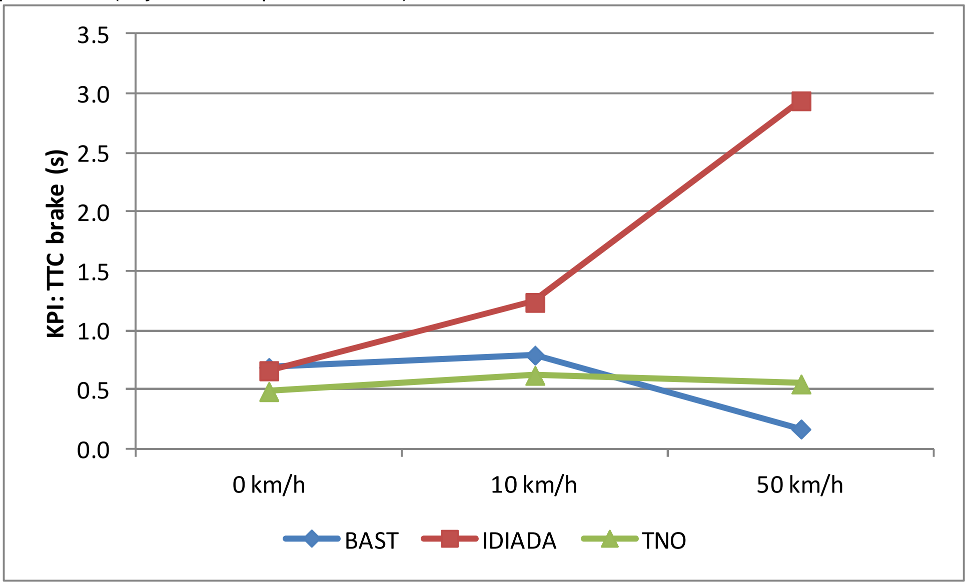


Figure 6-20: Weighted mean of Vehicle B TTC brake by lab and TV initial speed (subset A)

Figure 6-21 and Figure 6-22 show the weighted means and ranges of TTC warn and brake results for Vehicle B over the main test input variables (figures are given in Table 14-13 and

Table 14-14). In general the range of TTC brake results are smaller (i.e. less variable) than the equivalent TTC warn results, and this reflects the smaller repeatability and reproducibility values shown in Section 0.

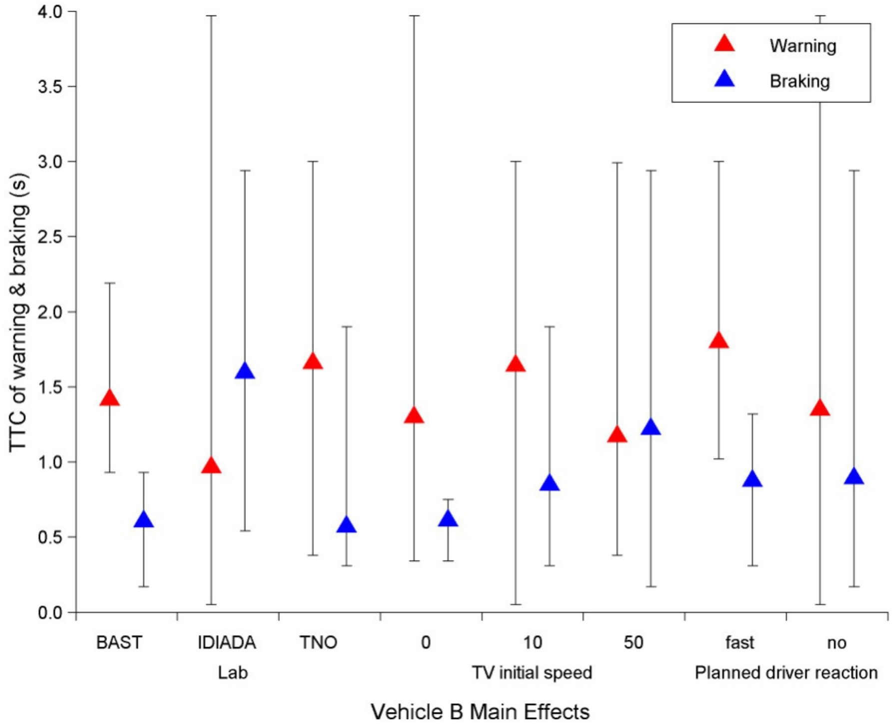


Figure 6-21: Weighted mean and range of Vehicle B main effects (subset A)

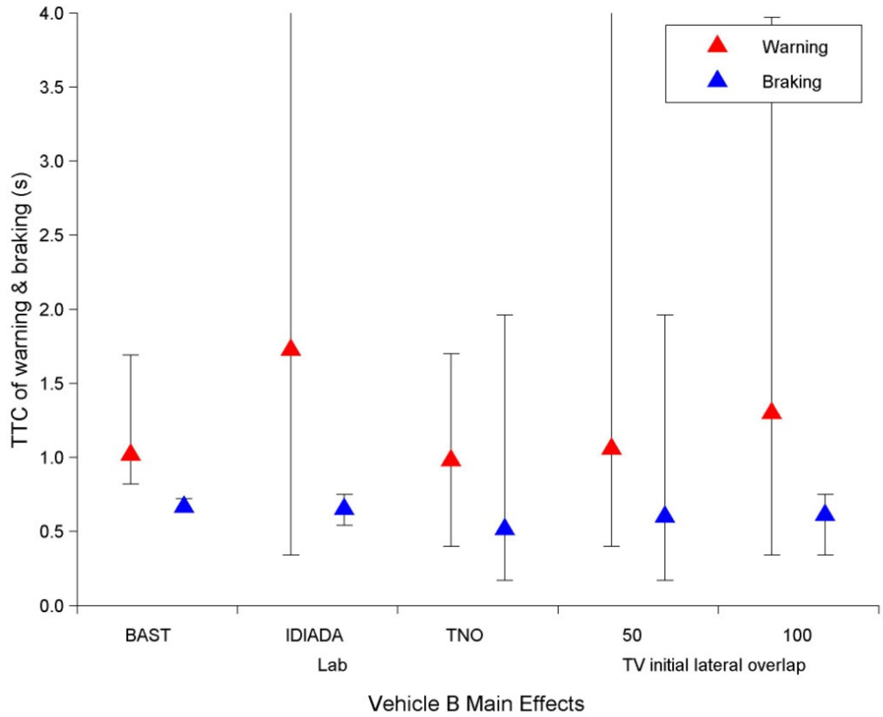


Figure 6-22: Weighted mean and range of Vehicle B main effects (subset B

)

b) Velocity reduction

Table 6-23 contains the results of the ANOVA analysis on Vehicle B for velocity reduction. For both subsets each relevant test input variable is significant in the models, i.e. there were significant differences detected between categories in each variable. The highest amount (36%-37%) of the variability in the overall dataset could be attributed to the differences between the labs in subset A and B, followed by TV initial speed and TV initial lateral overlap in subset A and B respectively.

Table 6-23: ANOVA table for log(velocity reduction) for Vehicle B

Subset A

Source	Sig.	Partial Eta Squared
Corrected Model	p<0.01	62%
Intercept	p<0.01	
Lab	p<0.01	36%
TV initial speed	p<0.01	25%
Driver reaction	p<0.01	20%
Lab * Driver reaction	p<0.01	19%

R square 0.62 (adjusted R squared = 0.58)

Subset B

Source	Sig.	Partial Eta Squared
Corrected Model	p<0.01	46%
Intercept	p<0.01	
Lab	p<0.01	37%
TV lateral overlap	p<0.01	33%
Lab * TV lateral overlap	p<0.05	26%

R square 0.46 (adjusted R squared = 0.37)

Figure 6-23 and Figure 6-24 show the means and ranges for each variable for subset A and B (figures are given in Table 14-17 and

Table 14-18). . The mean velocity reduction results in subset A for each of the three laboratories are significantly different from the other two laboratories. In subset B, the results from BASt are significantly higher than those from TNO and IDIADA. Tests in subset B at BASt had a considerably smaller range than the tests at the other two laboratories and this is reflected in the repeatability values in Section 0. In subset A, tests at a TV initial speed of 0 km/h resulted in a mean velocity reduction which was significantly smaller than those at 10km/h and 50km/h. Note that tests completed at 50km/h were also subject to 4m/s braking. The mean velocity reduction in tests where there was fast planned driver reaction was significantly higher than those where there was no planned driver reaction.

In subset B, tests where the TV lateral overlap was 50% resulted in a significantly smaller velocity reduction than those with a 100% overlap.

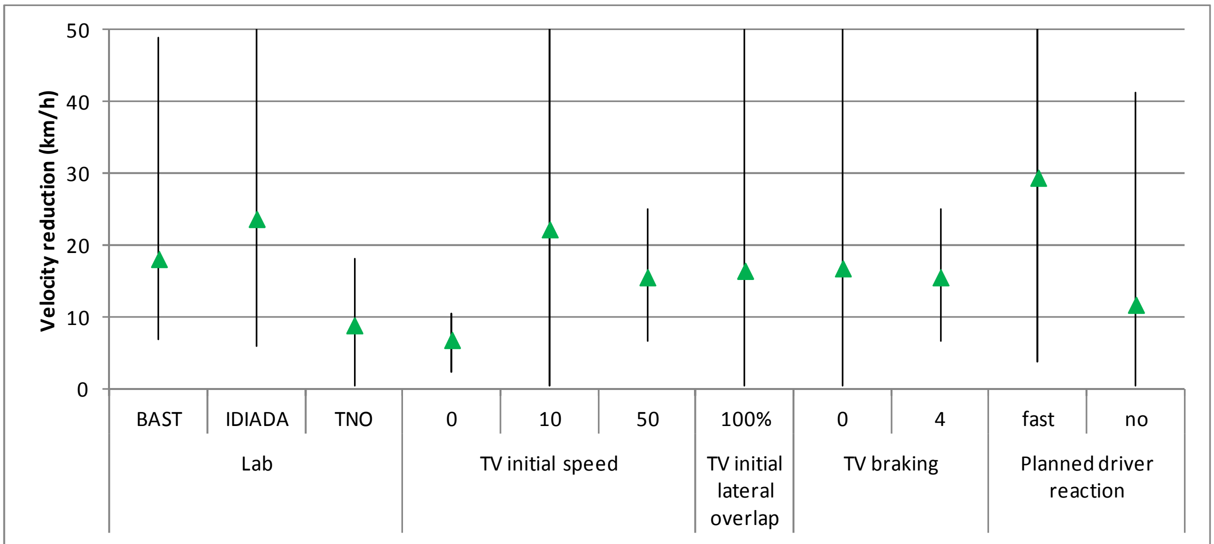


Figure 6-23: Weighted mean and range of velocity reduction for Vehicle B main effects (subset A)

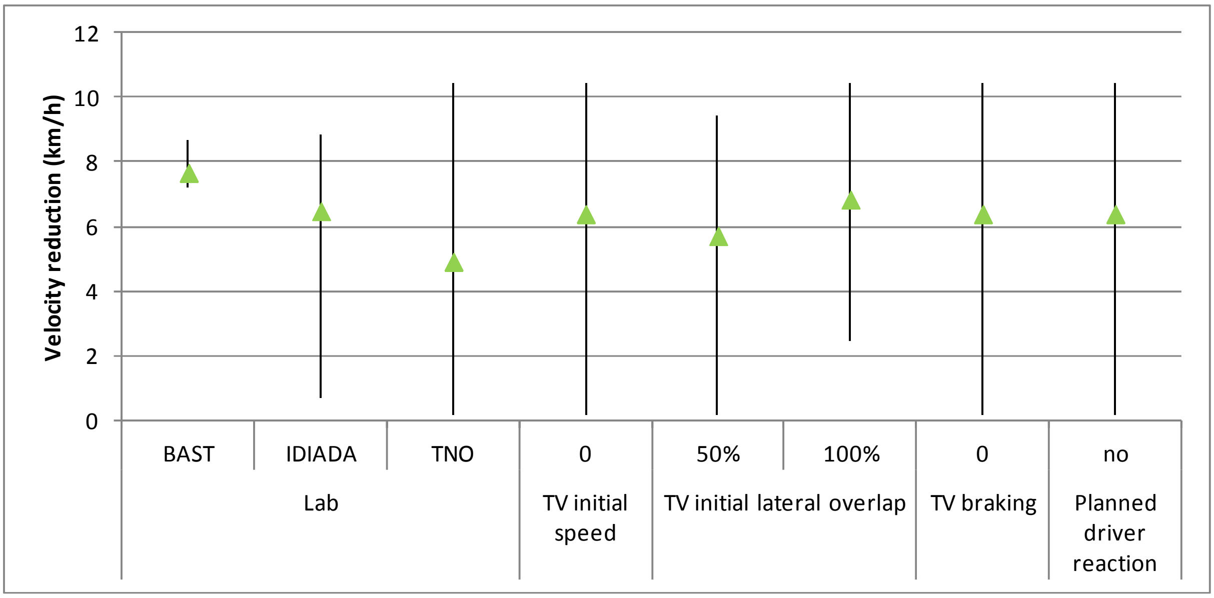


Figure 6-24: Weighted mean and range of velocity reduction for Vehicle B main effects (subset B)

In the two subsets there are also two interactions which contribute to explaining variability in the model. For subset A, the interaction between lab and planned driver reaction is significant, and is shown in Figure 6-25. As expected, there is a decrease in velocity reduction with no planned driver reaction compared to fast driver reaction for all laboratories, however this drop is much bigger for the tests completed at IDIADA compared to the other two laboratories. There was only one test in this subset of tests at IDIADA with a fast planned driver reaction, where TTC warn did not exist and TTC brake was recorded at 1.3s – this is much sooner than other similar test done at BASt and TNO and suggests that this may be skewing the results. Variability in the fast driver reaction may be as a result of the difficulties in achieving a consistent driving robot response, more specifically with achieving a mounting position that allows repeatable application of the brake.

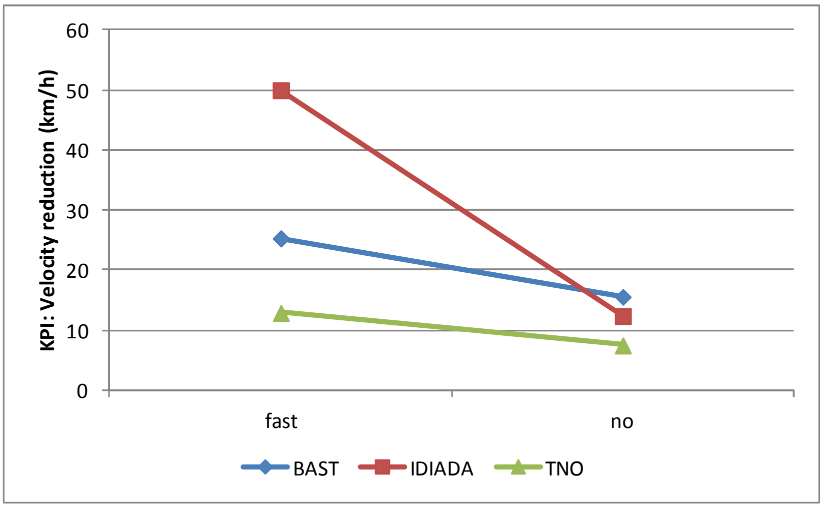


Figure 6-25: Weighted mean of Vehicle B velocity reduction by lab and driver reaction (subset A)

Figure 6-26 shows the relationship between laboratory and TV lateral overlap for subset B which was detected as a significant interaction in Table 6-23. The velocity reduction is, in general, higher for 100% overlap than 50% tests, and this difference is much greater for the IDIADA tests. Once again, there was only one test (out of eight in this subset) completed at IDIADA where the TV lateral overlap was 50% and the velocity reduction KPI exists. Therefore this interaction is significant due to one failed test.

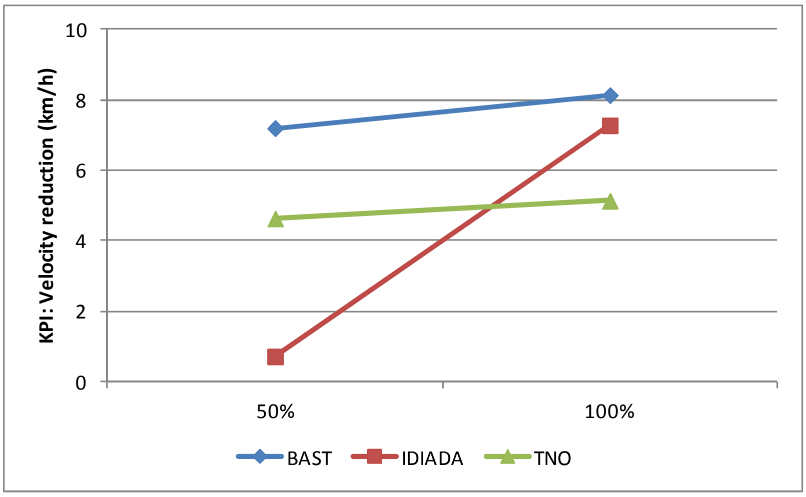


Figure 6-26: Weighted mean of Vehicle B velocity reduction by lab and TV lateral overlap (subset B)

6.3.5.4 ADAC and PASSAT tests

A number of additional tests were carried out by BASt which involved changing the target vehicle. Two additional targets were tested; the ADAC target and a real vehicle (Passat). Each additional test was conducted using the Vehicle A subject vehicle. Note: Passat tests only collected TTC warn data. Table 6-24 displays the number of additional tests carried by test scenario.

Table 6-24: Number of additional tests by test scenario

	ADAC	Passat
A1A1	10	8
A3A1	10	0
Total	20	8

Originally, nine tests were conducted by BASt using the ASSESS target; 8 were A1A1 tests and one was A3A1.

Since only one A3A1 test with the ASSESS target was available as a comparison; the analysis in this section uses only A1A1 data. Comparisons are first made between the TTC warn, TTC brake and velocity reduction results for the ADAC and ASSESS targets ("crashable targets") using a t-test. Secondly, ANOVA is used to partition the variability and determine whether the target vehicle used is contributing significantly to the variability in the outcome measures (KPIs).

The following t–tests determine whether there is a significant difference between the mean of each KPI for the ADAC and ASSESS targets. For the purposes of the analysis, we work with the natural log of the KPIs, as the analysis technique requires the KPI to be distributed approximately normally.

Table 6-25: Mean KPI for ASSESS and ADAC targets and t-test significance for log(KPI)

KPI	Assess (mean)	ADAC (mean)	Sig.
TTC warn	2.18	2.14	p<0.10
TTC brake	1.11	1.22	p<0.01
Velocity reduction	12.83	4.62	ns: p=0.15

The following ANOVA tests whether the target vehicle used contributes significantly to the variability in TTC warn (Table 6-26). The target vehicle is not significant overall.

Table 6-26: ANOVA table for log(TTC warn)

Source	Sig.	Partial Eta Squared
Corrected Model	ns: p=0.12	17%
Intercept	p<0.01	
Target vehicle	ns: p=0.12	17%

Figure 6-27 displays the mean and range of TTC warn for each of the three targets. The mean TTC of warning for Passat is not significantly different to ASSESS or ADAC. There is a significant difference between ASSESS and ADAC (as shown in Table 6-25 and explained in section 5.3).

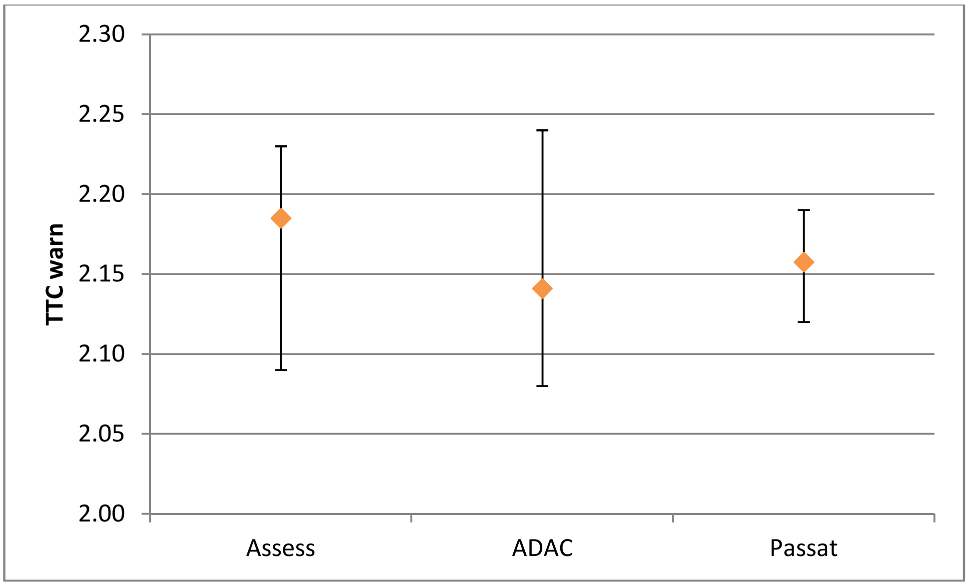


Figure 6-27: Mean and range of TTC warn for different target vehicles

6.3.6 The effect on KPIs of diversion from intended speed and overlap

During testing there were some deviations from the planned input variable specification. This included SV initial speeds which deviated from the planned speed by, on average, less than 1 km/h, and very little deviation from the TV lateral overlap in tests for which there was accurate GPS data. Figure 6-28 shows the distribution of the SV initial speeds at the time of the warning. Apart from two extreme tests (one Vehicle B test at 18km/h – not shown and one at 42km/h) the variability around the actual input speed compared to the planned input speed was closely controlled. The trace plots in Section 6.3.2 show that variability around input speed does not have an effect on whether the test works or not.

These deviations do not appear to contribute to explaining variability in the model – the actual inputs were never significant in the ANOVA models. This is due to the extreme variability caused by a substantial proportion of tests which either failed completely or failed partially due to one or more of the KPIs not being recorded, as discussed throughout the report. We hypothesise that if each test had worked correctly and produced all three KPIs successfully, and the combination of tests had been more balanced then it may have been possible to detect the effect of these deviations from the intended input variables.

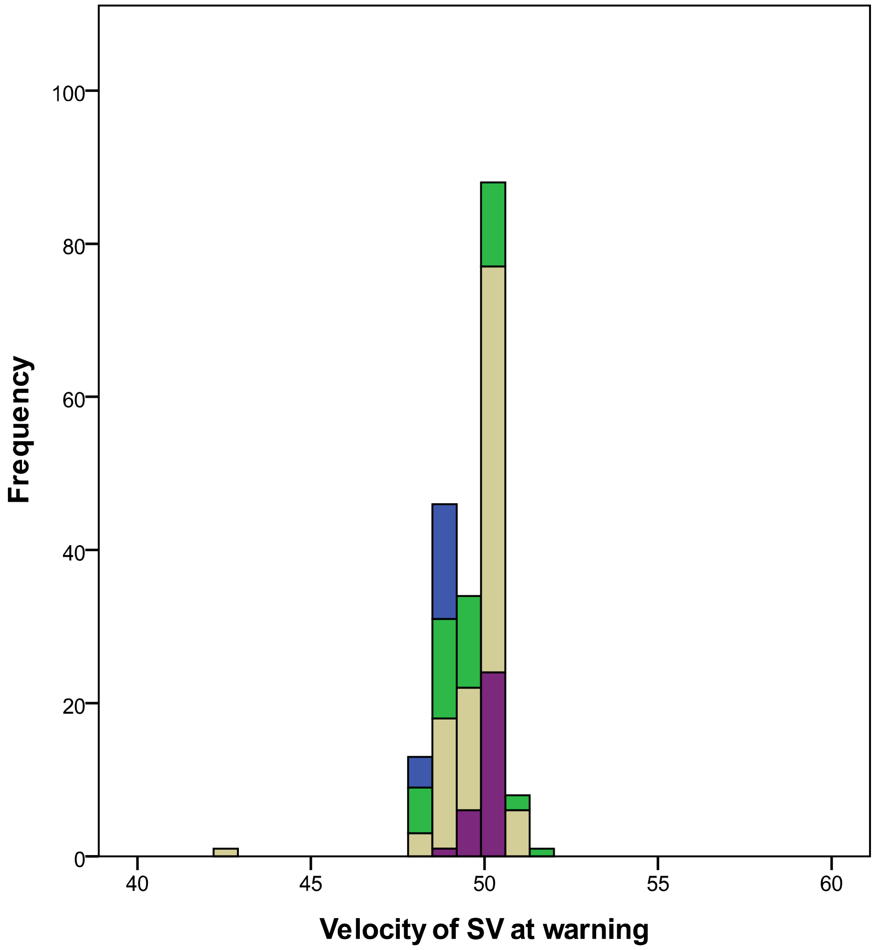


Figure 6-28: Distribution of actual velocity of SV at warning (km/h)
Green: Vehicle A, Brown: Vehicle B, Purple: Vehicle C, Blue: Vehicle D

6.4 Conclusions

This analysis shows that in some test situations for a more 'robust' system (e.g. Vehicle A A1A1):

- Repeatability and reproducibility of TTC warning and braking was ~10% of mean
- Repeatability and reproducibility of velocity reduction was ~35% of mean

This suggests that, since repeatability and reproducibility of TTC warning and TTC braking are similar, that the main variability can be attributed to the response of the system rather than the implementation of the test methodology. It also shows that the velocity reduction is more variable than other KPIs, both within and between test houses.

This, and the results from other test scenarios, demonstrate that the ASSESS *test methodology* can be considered robust and that a limited number of tests will generally provide a reasonable performance estimate. However, the final protocol should include an approach which accurately characterises the performance of the system; in particular a greater number of tests are required to accurately characterise the velocity reduction until such time as improvements to the test target or sensing systems result in improved repeatability. The final protocol should also improve the consistency of the fast driver braking response.

The results highlight that there are differences in the consistency of response of current systems. This means that in the same test scenario, a system may respond as intended, or under near identical conditions, provide a varied response, or no response at all. For these tests, repeatability and reproducibility were consequently much greater. There are a range of explanations for this, including the number and specification of radar sensors implemented in the vehicle (and the system in general) and changes in the radar cross section of the test target due to being impacted in testing. This is an area which requires further investigation, since if the system is responsible for the main variability, any rating based on a single test may not be representative. This means that a system could achieve a good result, but have poor real world performance; something which would undermine the credibility of any assessment.

For vehicle B a greater variability in system response was noted, and in particular at IDIADA. The main reason for having differences in the tests with vehicle B at IDIADA is that vehicle B sensor algorithms were upgraded after the non-optimum tests at IDIADA. Unfortunately, due to time constraints, it was not possible to repeat the tests with the upgraded software in vehicle B. Additionally, because of differences in the ASSESS target characteristics (particularly orientation of the radar corner reflector) as a result of being impacted. It is considered that, the effect of using a "rabbit vehicle" can be excluded as a contributory factor because results at IDIADA for vehicle A were repeatable with a good system response.
It also should be noted that there were Vehicle B some limitations to analysis due to an unbalanced set of tests and also because of the (in some cases) inconsistent success rate of tests.

Limited testing to compare the ADAC and ASSESS targets showed that there were significant differences with respect to TTC brake, but no significant differences with respect to TTC warning or velocity reduction. The mean TTC of warning in tests with a VW Passat as the target vehicle was not significantly different to tests using the ASSESS or ADAC target, supporting the conclusion that the "crashable" targets are representative targets.

Repeatability and reproducibility analysis showed that results from track and laboratory settings yielded similar variability showing that either facility type were capable of producing repeatable results providing the system under test was robust.
ANOVA analysis show that several expected trends can be confirmed which affect the KPIs:

- Lower overlap (50% instead of 100%) results in later warning and braking and consequently lower velocity reductions.
- A fast driver response achieves earlier TTC braking and greater velocity reductions, showing the benefit for such systems to provide effective warnings.
- A moving target vehicle results in earlier warning and braking (especially when the relative speed differences are large).

An analysis of the intended and actual initial test conditions showed that there was good control on the initial conditions during ASSESS testing, although some were outside the tolerances specified in the draft protocol. The actual initial conditions had negligible effects on the KPIs; had the initial conditions been controlled to the specification of the draft protocol, the influence on the test outcome could be expected to have been even smaller.

7 Conclusions and recommendations

The acceptance of a test procedure depends on whether it is valid, repeatable and reproducible. The performance of Test Vehicles should not be affected by the specific circumstances and test setups at three labs.

The test results for Test Vehicle A are in general found to be consistent between the test houses. No contradictions could be found throughout the available test data. Where repetitions were made, the standard deviations were always low (e.g. some 5 to 10 % of the mean values). Tests at TNO and ADAC did for some tests show results closer to the system specifications then tests at BASt and IDIADA. Tests at TNO and ADAC were conducted at a later stage of the project where more detailed information was available on the calibration of the sensor system which turned out to be needed before each test. Additionally, it was observed that the ASSESSOR would tend to sway slightly in case cross wind was present during testing which could have influenced the system performance. This problem does not occur with the ADAC target or an indoor test facility such as VeHIL. Other differences found between test labs and test runs with driver reaction can be explained by technical difficulties with the application of the driver reaction, see section 5.2.2, page 44.

It was found, that at TNO where the initial distance between the 2 vehicles can be set up very precisely, repeatable test results can be obtained. As maintaining the initial following distance as precisely on a test track is not possible, an improvement of the test procedure for these braking (A2) manoeuvres could include a predefined approach of the lead vehicle (e.g. relative speed < 5 km/h, braking trigged when a specified distance has been reached) rather than requiring a constant following distance.

Repeatability and reproducibility analysis showed that results from track and laboratory settings yielded similar variability, showing that either facility type were capable of producing repeatable results providing the system under test was robust.

An analysis of the intended and actual initial test conditions showed that there was good control on the initial conditions during ASSESS testing, although some were outside the tolerances specified in the draft protocol. The actual initial conditions had negligible effects on the KPIs; had the initial conditions been controlled to the specification of the draft protocol, the influence on the test outcome could be expected to the even smaller.

For vehicle B a greater variability in system response was noted, and in particular at IDIADA. The main reason for having differences in the tests with vehicle B at IDIADA is that vehicle B sensor algorithms were upgraded after the non-optimum tests at IDIADA. Unfortunately, due to time constraints, it was not possible to repeat the tests with the upgraded software in vehicle B. Additionally, because of differences in the ASSESS target characteristics (particularly orientation of the radar corner reflector) as a result of being impacted. It is considered that, the effect of using a “rabbit vehicle” can be excluded as a contributory factor because results at IDIADA for vehicle A were repeatable with a good system response.
It also should be noted that there were Vehicle B some limitations to analysis due to an unbalanced set of tests and also because of the (in some cases) inconsistent success rate of tests.

The methodology itself is considered verified against the specifications defined within the ASSESS project. A further validation of the full test method including tools (e.g. target, propulsion systems, etc) would require measuring the Test Vehicles’ performance in tests with real cars. To investigate this issue briefly, some reference A1A1 tests using a real car as test target were conducted with test vehicle A by BASt. Please note, that after the warning signal was registered, the test was aborted as a real car is not crash forgiving. It was seen, that warnings obtained using a real car as target vehicle were in line with the warnings obtained in this manoeuvre at all test houses using either the ASSESSOR or the ADAC target. (see conclusion 7 on page 40)

A simulation study to investigate the sensitivity of certain parameters as initial velocity or time delays on the potential outcome of the WP4 tests was conducted on top the physical tests. The study was conducted using Matlab and not PreScan as initially intended. This was done, as no in-depth system or hardware information was available that could be implemented. Additionally, a more general approach that was independent of a specific system was considered more valuable for this study. It should be noted, that if detailed system information were available, this could have been used to additionally investigate scenarios numerically instead of by means of testing. At this stage no numerically simulations were included into the methodology itself, as these would require in-depth information on the system under test which is in general available to the system manufacturer, but not to an organisation evaluating the system in a black box approach as done within ASSESS.

To assure an appropriate dissemination of the project results, WP4 communicated with other related initiatives as AEB, vFSS or ADAC amongst others via the Harmonisation Platforms that were set up. A draft test procedure (Appendix A) as well as information on the target and test houses gathered via HP2 (Appendix F) was provided to Euro NCAP for further consideration for the definition of the upcoming Euro NCAP AEB protocols.

8 Risk Register

Risk No.	What is the risk	Level of risk[5]	Solutions to overcome the risk
1	Acceptance of the results by policy makers in different regions of the world. Although related to the overall ASSESS project this risk is mainly related to WP6 Dissemination	2	The establishment of the Supervisory Board with high level representatives from governments, OEMs and research. Furthermore the ASSESS is cooperating closely with all other relevant projects in this field, including vFFS, AEB and US CAMP. This is formalised in the so called Harmonisation platforms on topics: 1. Test target definition, 2. Scenario definition and 3 Effectiveness analysis.

The work-package is finished, hence no risks exist for the proceeding of this work-package any longer.

[5] Risk level: 1 = high risk, 2 = medium risk, 3 = Low risk

9 References

Bartels O., Langner T., Aparicio A., et al: ASSESS deliverable D4.1 : "Action plan pre-crash evaluation", 2010

British Standards Institution, 1987. *BS 5497:1987 Part 1 Precision of test methods: Guide for the determination of repeatability and reproducibility for a standard test method in inter-laboratory tests*. Milton Keynes: BSI.

BS ISO 5725-2:1994 *Accuracy (trueness and precision) of measurement methods and results – Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

Hair-Buijssen S, Rodarius C., "Potential Results of AEB systems in rear end scenarios", Active Test Workshop Presentation, Aachen, September 2011

Rodarius C., Hair-Buijssen S., Seiniger P. et al: ASSESS deliverable D4.2: "Draft test and assessment protocol for the pre-crash evaluation of integrated safety systems based on existing, updated and standardized test methods", 2011

10 Appendix A: Draft Test procedure

Preface

This document contains the ASSESS WP4 test protocol in its final version. Please note that certain paragraphs of this test protocol are considered to benefit from further refinement that could not be realized or validated anymore within this part of the project. These sections are indicated in [ ].

In addition to the settings specified in this protocol, the following information will be required from the manufacturer of the car being tested in order to facilitate the vehicle preparation. A vehicle handbook should be provided to the test laboratory prior to preparation.

Table 10-1 Manufacturer specified settings

Manufacturer – Specified Settings	
Adjustment	**Section Reference**
Sensor system used by pre-crash system (radar, camera, lidar, etc) and necessary characteristics for detection of another car	
Fuel Tank Capacity	Manufacturer's Handbook
Unladen Kerb Weight	Manufacturer's Handbook
Tyre Pressures	Manufacturer's Handbook
Driver Airbag Removal Instructions (if needed for installation of robot)	
List of passive safety features that should be activated in each of the tests (if applicable)	
Information on how to calibrate the sensor system prior to testing (if applicable)	10.6.1.4

Introduction

This test-protocol specifies performance and equipment requirements for pre-crash collision avoidance and mitigation systems. The purpose of these tests is to reduce the number of injuries and deaths from car-to-car crashes where the vehicle equipped with the system sustains a frontal collision by assessing the system performance in critical situations. The assessment of collisions with VRUs, or motor vehicles other then cars is not included in this protocol.

2 different proposals for evaluation of these tests are presented within ASSESS deliverable D4.2. The overall assessment incooperating also ASSESS WP4 results is part of the work done by WP1.

10.1. Definitions

For the purpose of this procedure the following definitions shall apply:

10.1.1. **Pre-crash collision mitigation or avoidance system** means a system that has at least one of the following attributes:

(a) That warns an inattentive driver about an imminent dangerous situation that would result in a crash in the case that the driver fails to react.
(b) That assists the driver with the collision avoidance or mitigation action taken by the driver.
(c) That pre-triggers passive protection systems to ensure optimized protection during a following crash.
(d) That reacts autonomously to mitigate the collision once the risk reaches a critical level in the case that the driver failed to react.

10.1.2. **Vehicle under test (VUT)** means the vehicle tested according to this protocol with the pre-crash collision mitigation or avoidance system on board

10.1.3. **Target vehicle (TV)** means the target used for the testing: ASSESSOR, which was developed within the ASSESS project.

10.1.4. **Warning**: a warning issued by a system can be optical, haptic or acoustic. Combinations of 2 (or all 3) different warning types that occur at the same time are considered as one warning, only. Warnings that are not continuous (for example beeps issued at a certain frequency) are also considered as one warning only, unless a significant amount of time elapses between the sequences or the warning itself changes (for example significant increase of volume of the beeps).

10.1.5. **Impact speed** means the absolute speed with which the VUT hits the TV

10.1.6. Relative speed at Impact (RSaI) means the difference in speed upon crash between the VUT and the TV. This measure is NOT equivalent to the □v obtained in an actual car-to-car crash.

10.1.7. **Virtual centreline** of a test: means a virtual line in x direction laid through the data points of both VuT and TV in the last 5 seconds of each test or projected forward as an elongation of the centreline of the VUT at the beginning of the test.

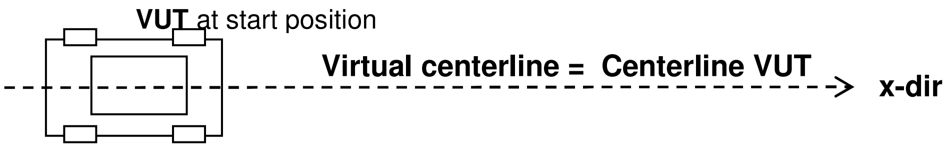


Figure 2-10-1: virtual centreline of the test as elongation of the VUT centreline at the beginning of the test

10.1.8. **Time to Collision (TTC)** means the remaining time before the VUT strikes the TV assuming that both, VUT and TV would continue to travel with the speed they travel at that moment. No decelerations are taken into account for this calculation:

$TTC_i = \Delta s / (v_{VUT} - v_{TV})$

with
v_{VUT} = velocity of vehicle under test [m/s]
v_{TV} = velocity of target vehicle [m/s]
Δs = headway distance between vehicle under test and target vehicle [m].
i = event for which TTC is established (for example “occurrence of first warning”)

10.1.9. **Headway distance Δs**: means the distance between the front bumper of the VUT and the rear bumper of the TV measured on the virtual centerline of the test. It is defined as 0 as soon as contact between the front bumper of the VUT and the rear bumper of the TV is established. If the VUT is heading straight forward (as intended), the headway distance corresponds to the longitudinal range and the lateral offset to the lateral range.

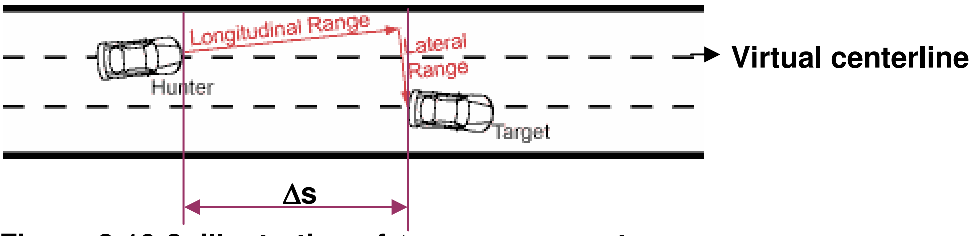


Figure 2-10-2: illustration of Δs measurement

10.1.10. **Lateral Offset**: is a lateral overlap between VUT and TV. It is defined wrt the VUT. 100% offset mean that VUT and TV can just pass each other without contact between the two. To establish a lateral offset of 50% one side of the TV is aligned with the virtual centerline of the VUT as illustrated in Figure 2-10-3.

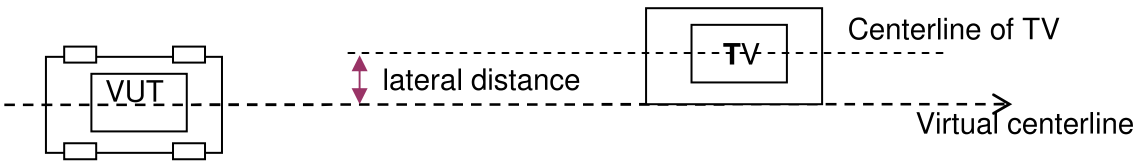


Figure 2-10-3: 50% offset situation

10.1.11. **Lateral distance:** is defined as the distance between either VuT or TV centreline and the virtual centreline.

10.1.12. **Centre of Gravity (CoG):** means the mean location of all the mass in the vehicle at kerb weight and with a full fuel load. In case the CoG height is not available or supplied by the OEM, it will be approximated as 38% of maximum roof height.

10.2. Reference System

The coordinate system used must be an ordinate Cartesian coordinate system with 90º between the axes and the sign convention detailed in Table 10-2 and Figure 3-10-4.

Table 10-2 Coordinate system

Measure	Reference
Positive X	Horizontally forward, in the longitudinal symmetry plane
Positive Y	To the driver's left hand side
Positive Z	Vertically upward

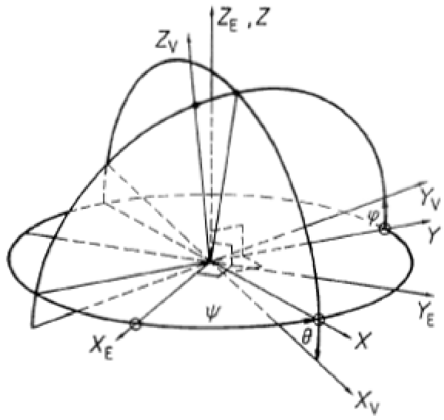


Bild B.1: Winkeldefinitionen
Figure B.1: Definitions of angles

Die in diesem Bild dargestellten Winkel sind positiv.
All angles shown positive.

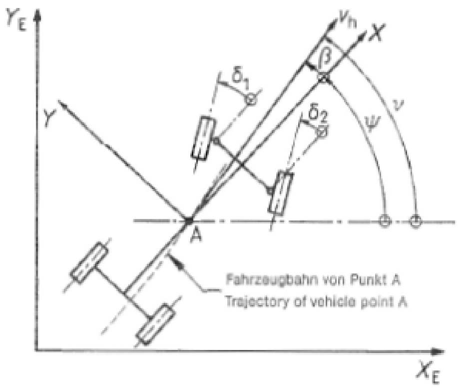


Bild B.2: Lenkung
Figure B.2: Steering

Figure 3-10-4 Coordinate system according to ISO 8855 and Centre of Gravity and inertial sensor reference

10.3. Variables and measurements

The following measurements and variables shall be conducted and determined for each test:

1.) **Speed** over elapsed time of the **VUT** throughout each test
2.) **Speed** over elapsed time of the **TV** throughout each test
3.) **Position** (latitude, longitude) over elapsed time of the **VUT** throughout each test, relative to one stationary reference point on the test track.
4.) **Position** (latitude, longitude) over elapsed time of the **TV** throughout each test, relative to one stationary reference point on the test track.
5.) **Lateral distance** between VUT centerline and TV centerline throughout each test, with respect to the virtual centerline of each test run. (see Figure 2-10-3)
6.) **Acceleration** over elapsed time of the VUT throughout each test
7.) **Acceleration** over elapsed time of the TV throughout each test (if applicable)
8.) **Activation of all passive safety features as stated by OEM (Y/N)?**
9.) **TTC at activation** of each passive safety features (if applicable)

10.) **Collision avoidance (Y/N)?**
11.) **RSaI** (if applicable)

For systems that include a driver warning, the following measurements shall be taken:

12.) **Type of warning** (visual, haptic, acoustic, etc)
13.) **TTC** at first warning
14.) **TTC** of each subsequent warning (if applicable)

For tests including a driver reaction, the following measurements shall be taken:

15.) **Type of assistance** (braking, steering, etc), if applicable
16.) **TTC of activation** of brake and / or steering robot
17.) Braking force over time for the brake robot
18.) [Brake pedal velocity]

For systems that include an autonomous action, the following measurements shall be taken:

19.) **Warning triggered prior to any intervention (Y/N)**.
20.) **Type of autonomous action** (single or two phase braking, steering, etc)
21.) **TTC** at trigger point of each phase or action

The time base for all measurements needs to be synchronized to allow the determination of TTC's, relative x and y distance between VUT and TV as well as deviations of all measurements form the given target values. De-synchronizations of more then 10 ms are not allowed. For tests on a test track for example GPS time can be used as easy synchronization signal.

10.4. Measuring equipment

The variables to be determined in accordance with Chapter 10.3 shall be measured by means of appropriate transducers. Their time histories shall be recorded on a multi-channel recording system having a time base. The typical operating ranges and recommended specifications are given in the table below:

Variable to be measured	**Range**	**Resolution and accuracy**
Velocity (VUT and TV)	0 to 100 km/h	Accuracy ± 0.1 km/h
Position of VUT and TV (longitudinal and lateral)	-	Accuracy ± 0.03 m
Longitudinal accelerations (VUT, TV if applicable)	-[15] m/s^2 to [15] m/s^2	Accuracy ± 0.1m/s^2
Time	-	Sampling time ≤ 10 ms

The following table summarizes the main specifications of the test equipment required for the testing:

Equipment	**Specifications**
Data acquisition system	[Sampling rate: real 100 Hz Signal conditioning for analogue sensors: amplification, anti-alias filtering, digitizing (not applicable for integrated measurement systems). Amplifier gains for analogue sensors: selected to

	maximize the signal-to-noise ratio of the digitized data (not applicable to integrated measurement)] systems).
Filtering	**[From ISO 7401 (as an example): 6.3.3.6 Digital filtering** For filtering of sampled data in data evaluation, phaseless (zero-phase-shift) digital filters shall be used, in accordance with the following: • the passband shall range from 0 Hz to 5 Hz; • the stopband shall begin at between 10 Hz and 15 Hz; • the filter gain in the passband shall bẹ 0,005 (100 - 0,5) %; • the filter gain in the stopband shall be u 0,01 (u 1 %).]
Braking and acceleration robot	[response time: 0.05s Maximum Brake force: 360 N Brake velocity: ?? N]
Pressure or contact sensor (if needed)	On front bumper of the VUT or rear bumper of TV
Microphone + fast frequency analyzer (or equivalent hardware / software to detect warning)	Capable of detecting frequency within 3ms
Electrical connection between vehicle restraint system fuse and IMU / Datalogger	
Target vehicle	See Section 10.1.3
Optional automated steering machine	[Suitable for testing within given corridors]

10.5. Test conditions

Limits and specifications for the ambient wind and vehicle test conditions are established in this chapter and shall be maintained throughout each test. Any deviations shall be shown in the test report.

10.5.1. Test track

10.5.1.1. The tests shall be conducted on a smooth, clean, dry, uniform, solid-paved surface. Surfaces with irregularities and undulations, such as dips and large cracks, are unsuitable.

10.5.1.2. The test surface shall have has a consistent slope between level and 1%.

10.5.1.3. The road test surface shall have a minimal peak braking coefficient (PBC) of 0.9, when measured using the method specified in (ASTM) E1136-93 (1993) standard reference test tyre, in accordance with ASTM Method E 1337-90 (reapproved 1996).

10.5.2. Weather conditions

10.5.2.1. During the measurements, the ambient temperature shall be between >7° C and 35° C and there shall be dry weather conditions. If the peak braking coefficient criteria is still fulfilled, tests can also be conducted at temperatures between 0 and 7 degrees.

10.5.2.2. During the measurements, ambient wind velocity shall not exceed 10 m/s regardless of wind direction.

10.5.2.3. All tests shall be conducted under normal lighting conditions. Testing during twilight or at night is only permitted where the OEM clearly states that this has no influence on the system performance.

10.5.2.4. The visibility range must at all times be such, that the target-detection is not impaired. Testing under weather conditions that impair the general visibility range (for example fog) is only permitted, where the OEM clearly states, that this has no influence on the system performance.

10.5.2.5. For each test, weather conditions shall be recorded in the test report. A single recording per test day is considered sufficient, given that the weather conditions do not change during the test day.

10.6. Test vehicle

10.6.1. Driver assistance systems

10.6.1.1. The pre-crash collision mitigation and / or avoidance system is enabled for all testing.

10.6.1.2. All other driver assistance systems shall be set to their default on or off setting

10.6.1.3. If possible to change, the vehicle will be tested with the default (normal) pre-crash system mode

10.6.1.4. Where needed, the OEM shall be contacted for information on how to calibrate the sensor system.

10.6.2. Tyres

10.6.2.1. The test shall be performed with the tyres fitted on the test vehicle (according to the manufacturer's specifications). It is allowed to change to tyres which are acquired at an official car dealer, if those tyres are identical make, model, size, speed and load rating to original.

10.6.2.2. The tyres shall be inflated to the vehicle manufacturer's recommended cold tyre inflation pressure(s) e.g. as specified on the vehicle's placard or the tyre inflation pressure label. Inflation pressures should be those corresponding to least loading condition. Tubes may be installed to prevent tyre de-beading.

10.6.2.3. The tyres shall be run in according to the paragraph 10.7.3 tyre conditioning. After running in, the tyres shall be maintained at the same position on the vehicle throughout the tests.

10.6.3. Vehicle loading conditions

10.6.3.1. The fuel tank shall be full and, in the course of the measurement sequence, the indicated fuel level should not drop below “half-full”. The total load of the driver plus instrumentation should not exceed [200] kg. If necessary, higher loads up to 400 kg are acceptable, given that the maximum total weight as well as the maximum allowed axe load of the VUT is not exceeded. If the vehicle is to be tested in any other load condition (e.g. GVM), then the additional payload shall be evenly distributed such that cross-axle variations do not exceed 50 kg

10.6.4. Vehicle Preparation

10.6.4.1. Fit the on-board test equipment and instrumentation in the vehicle. Also fit any associated cables, cabling boxes and power sources.

10.6.4.2. Any items added should be securely attached to the car.

10.6.4.3. With the driver in the vehicle, weigh the front and rear axle loads of the vehicle to make sure that the maximum axle and total weights are not exceeded. Record the final axle loads in the test details.

10.6.4.4. Make sure, that contact between VUT and TV can be detected in a reliable manner. This can be done for example by attaching a pressure sensor on the front bumper of the VUT. Another option could be the usage of a sufficiently accurate position measurement for TV and VUT.

10.6.4.5. In case the VUT is driven by a test driver attach a pressure sensor to brake pedal to ensure no manual braking was conducted during the test.

10.6.5. Vehicle Width and Overlap

10.6.5.1. Determine the widest point of the vehicle ignoring the rear-view mirrors, side marker lamps, tyre pressure indicators, direction indicator lamps, position lamps, flexible mud-guards and the deflected part of the tyre side-walls immediately above the point of contact with the ground.

10.6.5.2. Record this width in test details.

10.6.5.3. Determine the centre-line of the vehicle and mark it on the bonnet and bumper. Tests will be conducted with either 100% or 50% overlap for all scenarios. For tests with 50% overlap, the side of the TV should be aligned with this mark at the beginning of the test. The mark should stay in line with the virtual centreline of the test during the test.

10.6.6. Target preparation

10.6.6.1. Inflate the target according to its specifications.

10.6.6.2. Fit the necessary on-board test equipment and instrumentation in the target. Also fit any associated cables, cabling boxes and power sources.

10.6.6.3. Make sure, the target is equipped with all necessary features needed by the sensor system used on the VUT.

10.6.7. Check that all measurement systems are time synchronized

10.6.8. **Test tolerances:** The tolerances in Table 10-3 need to be met to achieve a valid test:

Table 10-3 test accuracy (limits for test execution)

Parameter	Controllability	Measurement accuracy
Test Velocity	± 1.0 km/h	± 0.1 km/h
Distance (longitudinal)	± 0.50 m	± 0.03 m
Distance (lateral)	± 0.20 m	± 0.03 m
Acceleration / Deceleration	± 0.5 m/s^2	± 0.1 m/s^2
[Brake robot force	+- 20 N	+- 1 N]

10.7. Test procedure

10.7.1. General considerations

10.7.1.1. The tests described in Section 10.7.4 to 10.7.7 shall only be conducted, if the car manufacturer confirms that the pre-crash system in question is able to address the respective scenario.

10.7.1.2. In case the manufacturer states that the system can only address part of the tests defined within a scenario, only that specific sub-set of tests shall be conducted. An overview on all tests per scenario including the initial conditions per test is provided in Appendix

10.7.1.3. Testing shall always be conducted starting with the test with the lowest expected RSaI building up towards higher RSaI's. This order can be different for different systems.

10.7.1.4. The condition of the target shall be checked before each run. Follow the guidelines provided with the target.

10.7.2. Driver reaction

10.7.2.1. A slow driver reaction is defined as braking action initiated 1.9 seconds after the commencement of the warning.

10.7.2.2. A fast driver reaction is defined as braking action initiated 1.2 seconds after the commencement of the warning.

10.7.2.3. The throttle shall be released at least 0.1 second before the braking robot acts on the brake pedal, and the pedal release shall not lower the vehicle's velocity more than 0.5 km/h.

10.7.2.4. [The brake robot is to brake for each driver reaction such that the effort applied to the brake pedal rises to a value that represents [x%] of maximum braking power in less than Y seconds].

10.7.3. **[Brake Conditioning**: the brake temperature shall be above 100 degrees during testing. To achieve this, the vehicle brakes may be conditioned using the method described in 10.7.3.1 to 10.7.3.4. Using another method to achieve an appropriate brake temperature is fine as well. The conditioning shall be conducted prior to the first pre-crash test and shall be repeated in the case that there are long breaks between tests which allow the brake system to cool down below 100 degrees. Overheating the brakes however must be avoided at all times.

10.7.3.1. Ten stops are performed from a speed of approximately 56 km/h, with an average deceleration of approximately 0.5g.

10.7.3.2. Immediately following the series of approximately 56 km/h stops, three additional stops are performed from 72 km/h at higher deceleration.

10.7.3.3. When executing these 3 stops, sufficient force is applied to the brake pedal to activate the vehicle's antilock brake system (ABS) for a majority of each braking event.

10.7.3.4. Following completion of the final stop in paragraph 7.1.2, the vehicle is driven at a speed of approximately 72 km/h for five minutes to cool the brakes.]

10.7.4. **Scenario A – rear end**

10.7.4.1. All tests from this scenario will result in a frontal impact for the VUT and a rear impact for the TV if the crash cannot be avoided.

10.7.4.2. Set up the TV and VUT. Both vehicles may be set up far away from each other without the need to meet the initial boundary conditions right away. For track testing it is advised, to first move the TV far away and start approaching it with the VUT to the desired boundary conditions of the respective test.

10.7.4.3. Accelerate both vehicles (VUT and TV) to their respective test speed. This can be done either by using an acceleration robot, a test driver, or setting the SLD (if available) to the required test speed.

10.7.4.4. Ensure that the initial distance and required offset between VUT and TV is correct prior to the start of the test.

10.7.4.5. The test shall start at T0. Should the car already take action before T0 is reached, these actions should be noted. They will however be disregarded for the evaluation of the respective test. T0 is defined as the point in time where TTC = 3 seconds for the first time. At T0 all initial boundary conditions need to be met:

a) Initial speed of TV

b) Initial speed of VUT

c) Offset between VUT and TV

d) Relative distance between VUT and TV (A2 maneuvers).

10.7.4.6. For all A2 maneuvers, the deceleration of the TV shall be initiated only after all boundary conditions specified under 10.7.4.5 are reached. For these tests, T0 is defined at the point in the absolute timeframe, when the TV starts braking. When exactly the deceleration of the TV is initiated is up to the test house.

10.7.4.7. The end of a test is considered to be reached, if one of the following conditions is met:

a) VUT has stopped moving

b) $v_{VUT} \leq v_{TV}$

c) Contact established between VUT and TV.

10.7.5. **Scenario B – Intersection**

10.7.5.1. All tests from this scenario will result in a frontal impact for the VUT and side impact for the TV if the crash cannot be avoided. In that case, the middle of the front end of the VUT shall be aligned with the middle of the side face of the TV during impact.

10.7.5.2. Set both, TV and VUT perpendicular to each other at their respective starting positions. Ensure that both vehicles are set up and can be controlled in a manner that they will meet each other in the position defined under 10.7.5.1 in case the VUT fails to react within the test

10.7.5.3. Accelerate both vehicles (VUT and TV) to their respective test speed. This can be done either by using an acceleration robot, a test driver, or setting the SLD (if available) to the required test speed.

10.7.5.4. The test shall start at T0. Should the car already take action before T0 is reached, these actions should be noted. They will however be disregarded for the evaluation of the respective test. T0 is defined as the point in time where TTC = 3 seconds for the first time. At T0 all initial boundary conditions need to be met

a) Initial speed of TV

b) Initial speed of VUT

10.7.5.5. The end of a test is considered to be reached, if one of the following conditions is met:

a) VUT has stopped moving

b) Contact established between VUT and TV

c) VUT and TV crossed each other’s path without making contact

10.7.6. **Scenario C – Oncoming traffic**

10.7.6.1. All tests from this scenario will result in a frontal impact for both, VUT and TV. Within this test, no collision avoidance can be established by the pre-crash system. Only mitigation effects will be established.

10.7.6.2. Set up the target vehicle and VUT. Both vehicles may be set up far away from each other without the need to meet the initial boundary conditions right away. For track testing it is advised, to first move the TV far away and start approaching it with the VUT to the desired boundary conditions of the respective test

10.7.6.3. Ensure that the initial distance between VUT and TV is sufficient prior to the start of the test.

10.7.6.4. Accelerate both, VUT as well as TV towards the respective test speed. This can Accelerate both vehicles (VUT and TV) to their respective test speed. This can be done either by using an acceleration robot, a test driver, or setting the SLD (if available) to the required test speed.

10.7.6.5. The test shall start at T0. Should the car already take action before T0 is reached, these actions should be noted. They will however be disregarded for the evaluation of the respective test. T0 is defined as the point in time where TTC = 3 seconds for the first time. At T0 all initial boundary conditions need to be met:

d) Initial speed of TV

e) Initial speed of VUT

f) Offset between VUT and TV

10.7.6.6. The end of a test is considered to be reached, if one of the following conditions is met:

g) VUT has stopped moving

h) Contact established between VUT and TV.

10.7.7. **Scenario D – Cut – in**

10.7.7.1. All tests from this scenario will result in a frontal impact for the VUT and a rear or frontal impact for the TV if the crash cannot be avoided.

10.7.7.2. Set up the target vehicle in front of the VUT taking into account that there should be no initial offset for tests of this scenario

10.7.7.3. Ensure that the initial distance between VUT and TV is sufficient to allow both vehicles to get into the appropriate start position.

10.7.7.4. Accelerate both vehicles (VUT and TV) to their respective test speed. This can be done either by using an acceleration robot, a test driver, or setting the SLD (if available) to the required test speed.

10.7.7.5. The test shall start at T0. Should the car already take action before T0 is reached, these actions should be noted. They will however be disregarded for the evaluation of the respective test. T0 is defined as the point in time where TTC = 3 seconds for the first time. At T0 all initial boundary conditions need to be met:

i) Initial speed of TV

j) Initial speed of VUT

k) Relative distance between VUT and TV

10.7.7.6. The TV should start the cut-in sequence as both vehicles are located at the relative distance needed to perform the intended cut-in manoeuvre.

10.7.7.7. The end of a test is considered to be reached, if one of the following conditions is met:

l) VUT has stopped moving

m) $v_{VUT} \leq v_{TV}$

n) Contact established between VUT and TV.

10.8. Data Post Processing: Calculations for performance metrics

10.8.1. All data shall be sampled at 100 Hz.

10.8.2. All velocity, position and acceleration signals shall use the same time base. For track testing, GPS time is recommended as time synchronization signal

10.8.3. Lateral displacement should be determined using DGPS data or other direct measurements that can supply the required accuracy.

10.9. Photographic and video requirements

10.9.1. Event Recording

10.9.1.1. Each test vehicle shall be photographed in test condition prior to the start of the tests: these photographs should effectively show positioning of the test equipment within the vehicle and good general reference photographs of all sides of the exterior of the vehicle. Where applicable a photographic record of the chassis plate including Vehicle Identification Number should also be made. If no damage occurred to the VUT and the instrumentation is not changed during the commencement of the tests, there is no need to take these photographs more than once per test sequence.

10.9.1.2. Each test run should be filmed from an external position to effectively record any behavioural characteristics of the vehicle for each run. This should be filmed in a way to best allow a clear and repeatable view of all test runs and camera location shall not alter once testing has commenced, although camera “panning” can be used.

10.9.1.3. On-board cameras can be used to further record vehicle behaviour from inside the vehicle or mounted on the vehicle exterior as long as these do not exceed the vehicle mass as detailed in paragraph 10.6.4.3 or effect driver or vehicle behaviour through positioning of mass or influencing vehicle movements.

10.9.1.4. Any damages to the TV or VUT should be documented together with the test they occurred in.

11 Appendix B: Overview on test scenarios

Overview on the test scenarios and the respective initial boundary conditions

Table B-11-1: Scenario A – rear end

	SV		TV						
	Initial speed [km/h]	Initial speed [m/s]	Initial speed [km/h]	Initial speed [m/s]	braking [m/s*s]	initial distance to SV [m]		initial lateral overlap [%]	time to perform change
l vehicle									
rio 1	50	13,9	10	2,8	0	based on TTC >> 3 sec	33	100	n/a
rio 1	50	13,9	10	2,8	0	based on TTC >> 3 sec	33	100	n/a
rio 1	50	13,9	10	2,8	0	based on TTC >> 3 sec	33	100	n/a
rio 2	50	13,9	10	2,8	0	based on TTC >> 3 sec	33	50	n/a
rio 2	50	13,9	10	2,8	0	based on TTC >> 3 sec	33	50	n/a
rio 2	50	13,9	10	2,8	0	based on TTC >> 3 sec	33	50	n/a
ffic jam)	100	27,8	20	5,6	0	based on TTC >> 3 sec	67	100	n/a
ffic jam)	100	27,8	20	5,6	0	based on TTC >> 3 sec	67	100	n/a
ffic jam)	100	27,8	20	5,6	0	based on TTC >> 3 sec	67	100	n/a
g lead vehicle (until stopped)									
l driving	50	13,9	50	13,9	4	14 m (1sec following dist.)	14	100	n/a
l driving	50	13,9	50	13,9	4	14 m (1sec following dist.)	14	100	n/a
l driving	50	13,9	50	13,9	4	14 m (1sec following dist.)	14	100	n/a
ency braking	50	13,9	50	13,9	7	14 m (1sec following dist.)	14	100	n/a
ency braking	50	13,9	50	13,9	7	14 m (1sec following dist.)	14	100	n/a
nal driving	80	22,2	80	22,2	4	45 m (2sec following dist.)	44	100	n/a
nal driving	80	22,2	80	22,2	4	45 m (2sec following dist.)	44	100	n/a
nal driving	80	22,2	80	22,2	4	45 m (2sec following dist.)	44	100	n/a
ergency braking	80	22,2	80	22,2	7	45 m (2sec following dist.)	44	100	n/a
ergency braking	80	22,2	80	22,2	7	45 m (2sec following dist.)	44	100	n/a
ld vehicle									
rio 1	50	13,9	0	0,0	0	based on TTC >> 3 sec	42	100	n/a
rio 1	50	13,9	0	0,0	0	based on TTC >> 3 sec	42	100	n/a
rio 1	50	13,9	0	0,0	0	based on TTC >> 3 sec	42	100	n/a
rio 2	50	13,9	0	0,0	0	based on TTC >> 3 sec	42	50	n/a
rio 2	50	13,9	0	0,0	0	based on TTC >> 3 sec	42	50	n/a
rio 2	50	13,9	0	0,0	0	based on TTC >> 3 sec	42	50	n/a
ffic jam)	80	22,2	0	0,0	0	based on TTC >> 3 sec	67	100	n/a
ffic jam)	80	22,2	0	0,0	0	based on TTC >> 3 sec	67	100	n/a
ffic jam)	80	22,2	0	0,0	0	based on TTC >> 3 sec	67	100	n/a

Table B-11-2: Scenario B – intersection

	TV			
al ed s]	Initial speed [km/h]	Initial speed [m/s]	braking [m/s*s]	initial distance to SV [m]
13,9	10	2,8	0	No reaction SV –> side
13,9	10	2,8	0	No reaction SV –> side
13,9	10	2,8	0	No reaction SV –> side
13,9	10	2,8	0	No reaction SV –> side
13,9	10	2,8	0	No reaction SV –> side
13,9	50	13,9	0	No reaction SV –> side
13,9	50	13,9	0	No reaction SV –> side
13,9	50	13,9	0	No reaction SV –> side
13,9	50	13,9	0	No reaction SV –> side
13,9	50	13,9	0	No reaction SV –> side

Table B-11-3: Scenario C – Oncoming traffic and Scenario D – Cut-in

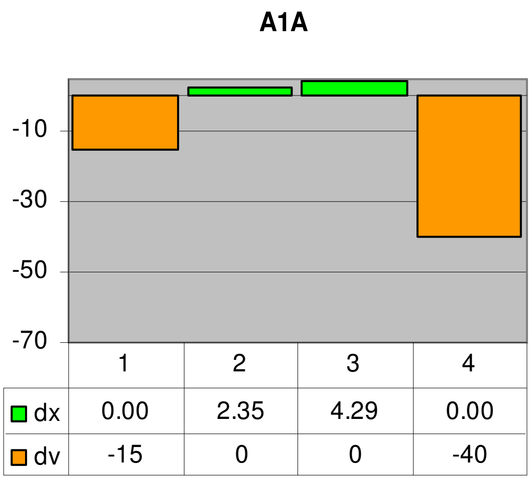
SV		TV					
Initial speed [km/h]	Initial speed [m/s]	Initial speed [km/h]	Initial speed [m/s]	braking [m/s*s]	initial distance to SV [m]		ini lat ov [%
40	11,1	40	11,1	0	based on TTC >> 3 sec	67	
40	11,1	40	11,1	0	based on TTC >> 3 sec	67	
40	11,1	40	11,1	0	based on TTC >> 3 sec	67	
64	17,8	64	17,8	?	based on TTC >> 3 sec	107	
64	17,8	64	17,8	?	based on TTC >> 3 sec	107	
64	17,8	64	17,8	?	based on TTC >> 3 sec	107	
50	13,9	10	2,8	0	> cut - in distance (28)	35	
50	13,9	10	2,8	0	> cut - in distance (28)	35	
50	13,9	10	2,8	0	> cut - in distance (28)	35	
50	13,9	10	2,8	0	> cut - in distance (14)	30	
50	13,9	10	2,8	0	> cut - in distance (14)	30	
50	13,9	10	2,8	0	> cut - in distance (14)	30	
80	22,2	40	11,1		> cut - in distance (44)	70	
80	22,2	40	11,1		> cut - in distance (44)	70	
80	22,2	40	11,1		> cut - in distance (44)	70	
80	22,2	40	11,1		> cut - in distance (22)	35	
80	22,2	40	11,1		> cut - in distance (22)	35	
80	22,2	40	11,1		> cut - in distance (22)	35	

12 Appendix C: all Phase II test results

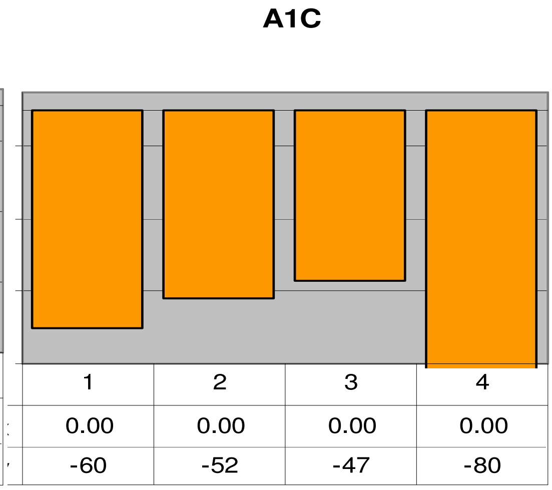
This appendix which is provided as separate document "ASSESS D4.3 Appendix C.pdf" includes the test results of all tests conducted throughout the phase II testing of ASSESS WP4.

13 Appendix D: TNO simulation study results

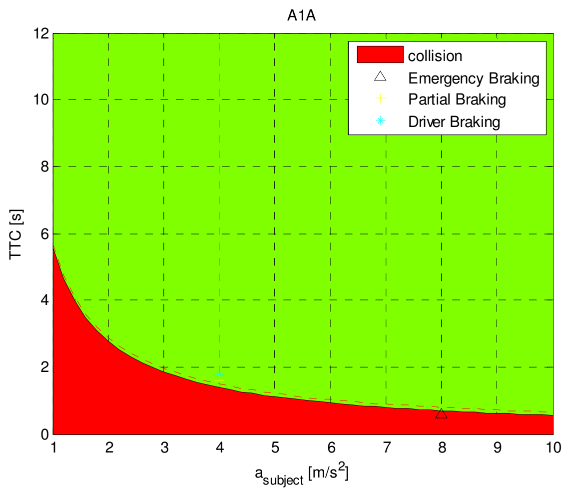
A1A (SV 50 km/h, TV 10 km/h) and A1C (SV 100 km/h, TV 20 km/h)

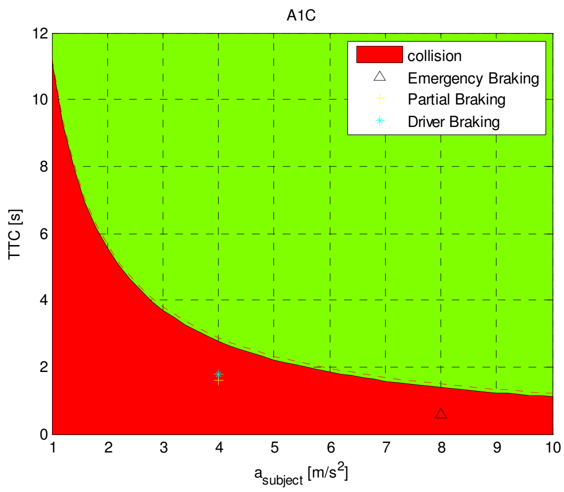


	1	2	3	4
dx	0.00	2.35	4.29	0.00
dv	-15	0	0	-40

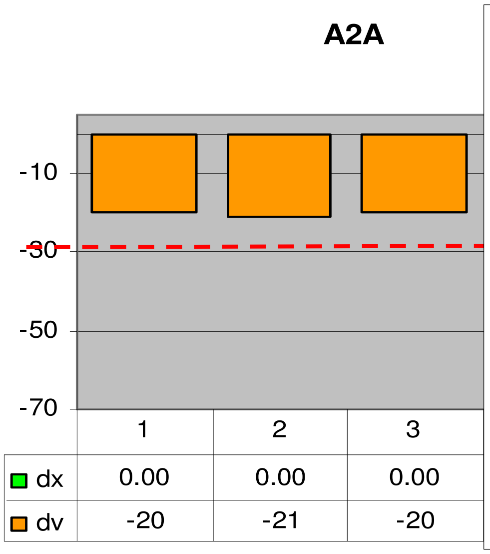


	1	2	3	4
dx	0.00	0.00	0.00	0.00
dv	-60	-52	-47	-80

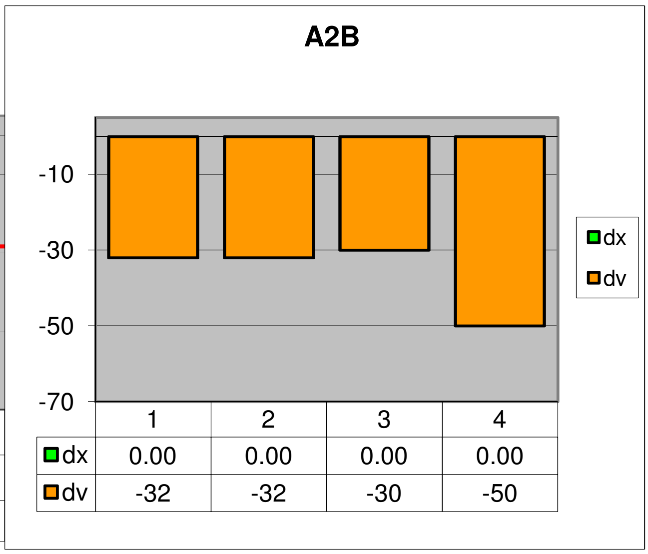




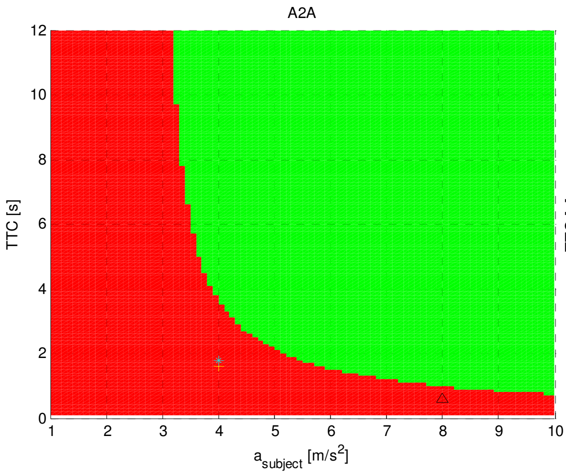
A2A and A2B (decelerating lead vehicle, TV = SV = 50 km/h, a_{TV} = 4 and 7 m/s2)

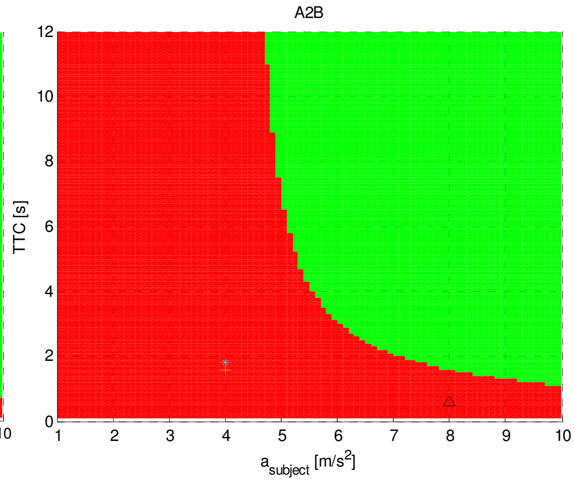


	1	2	3
dx	0.00	0.00	0.00
dv	-20	-21	-20

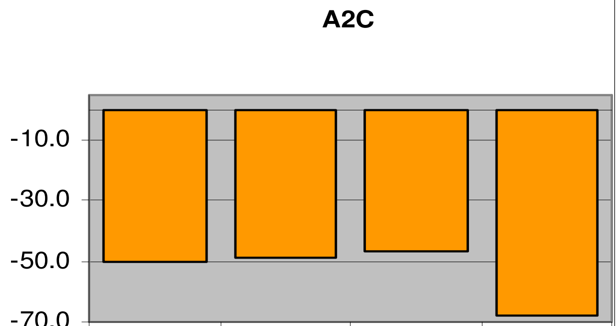


	1	2	3	4
dx	0.00	0.00	0.00	0.00
dv	-32	-32	-30	-50

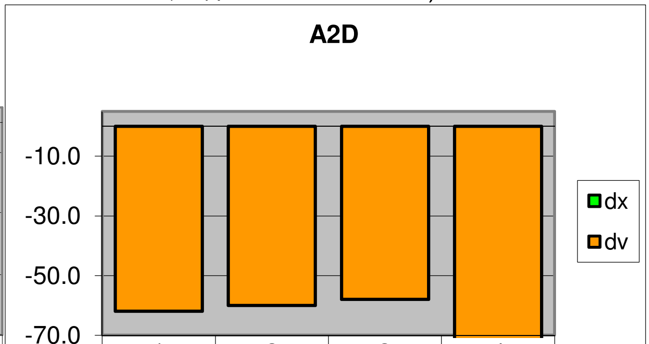




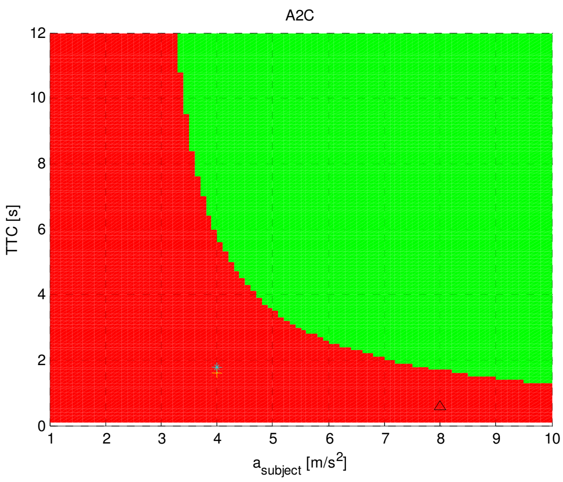
A2C and A2D (decelerating lead vehicle, TV = SV = 80 km/h, a_{TV} = 4 and 7 m/s2)

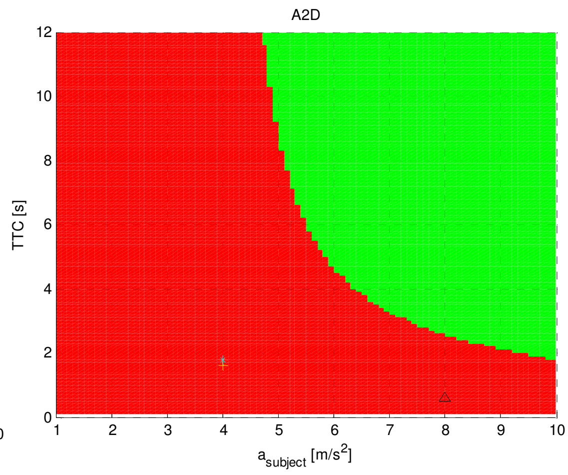


	1	2	3	4
dx	0.00	0.00	0.00	0.00
dv	-50.0	-49.0	-47.0	-68.0



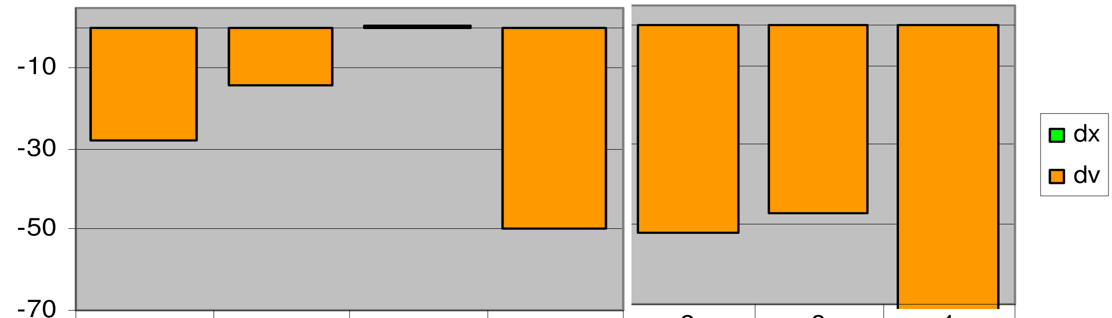
	1	2	3	4
dx	0.00	0.00	0.00	0.00
dv	-62.0	-60.0	-58.0	-80.0



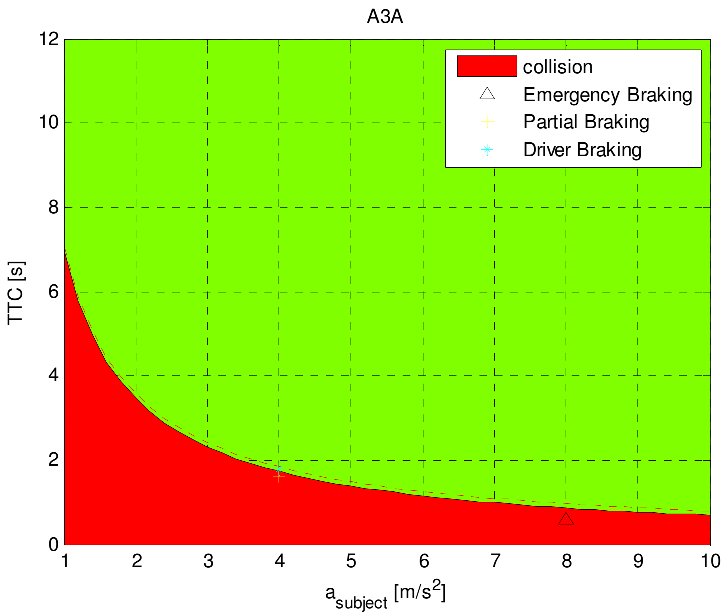


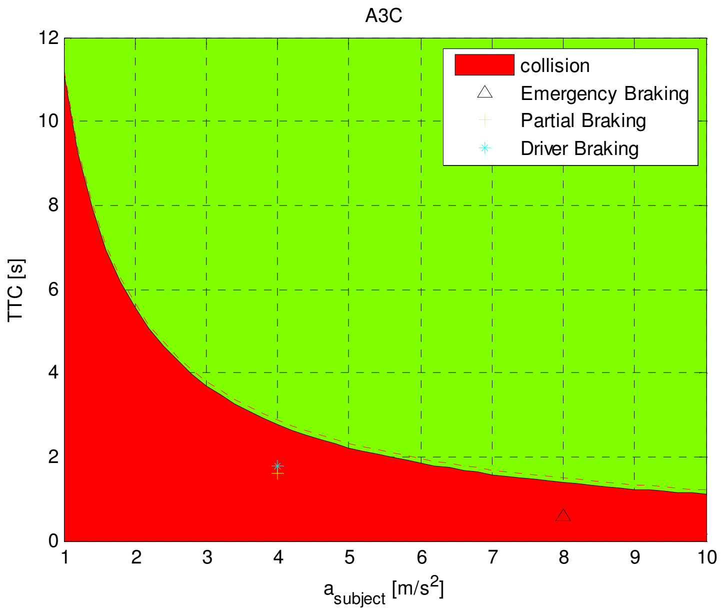
A3A and A3C (stopped lead vehicle, SV = 50 km/h and 80 km/h)

A3A **A3C**

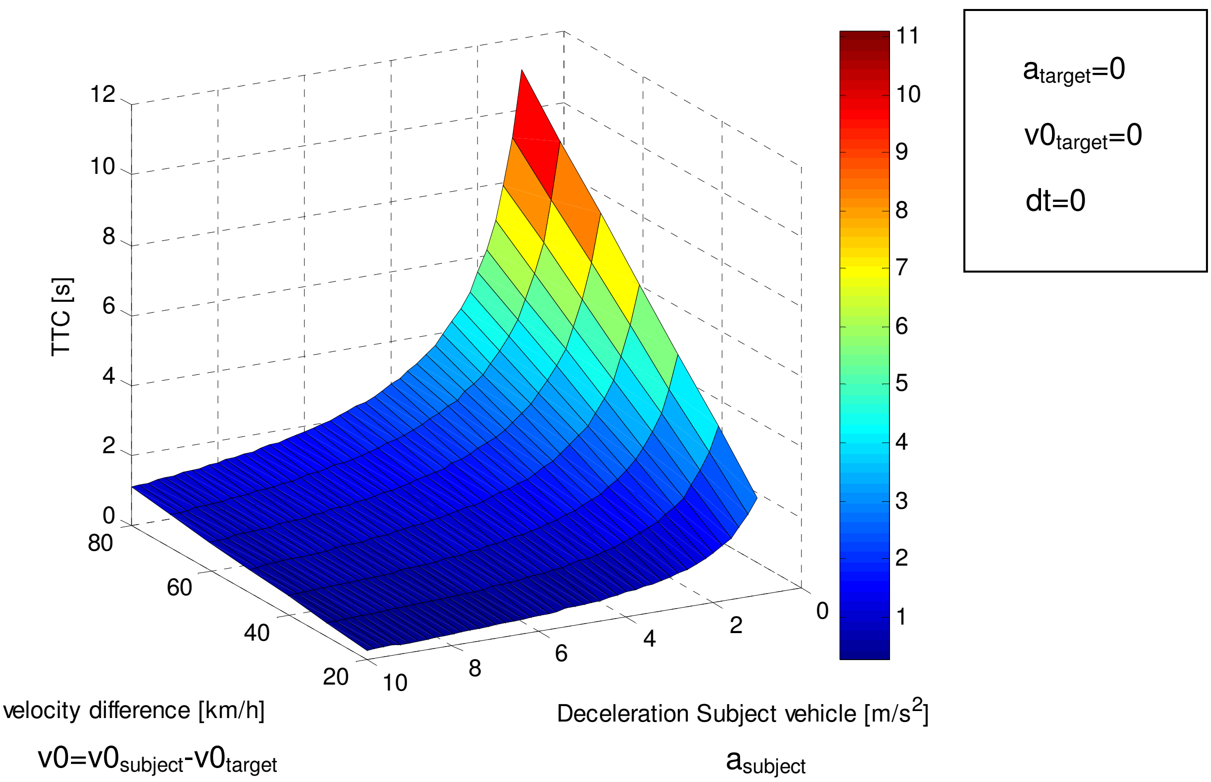


	A3A 1	A3A 2	A3A 3	A3A 4	A3C 2	A3C 3	A3C 4
dx	0.00	0.00	0.89	0.00	0.00	0.00	0.00
dv	-28	-14	0	-50	-52	-47	-80





Influence on initial velocity



14 Appendix E: Reproducibility data

		KPI - Time to collision of warning (s)				
		Count	Valid N	Mean	Minimum	Maximum
Vehicle A	A1A1	13	13	2.16	2.04	2.23
	A1A2	1	1	2.14	2.14	2.14
	A1A3	6	5	2.09	2.01	2.19
	A1B1	2	2	0.81	0.18	1.44
	A1B3	3	3	1.24	0.18	2.29
	A2A1	4	1	3.81	3.81	3.81
	A2A2	1	1	3.62	3.62	3.62
	A2A3	6	1	3.41	3.41	3.41
	A2B3	1	1	2.86	2.86	2.86
	A3A1	4	4	1.92	1.52	2.15
	A3A2	1	1	2.13	2.13	2.13
	A3A3	2	2	1.86	1.73	1.99
	A3B1	6	5	2.06	1.51	3.91
	A3B2	1	1	2.17	2.17	2.17
	A3B3	4	4	1.58	1.12	2.03
	A3C1	1	1	1.05	1.05	1.05
	A3C3	1	1	1.92	1.92	1.92
Vehicle B	A1A1	24	23	1.60	0.05	2.13
	A1A3	16	15	1.87	1.02	3.00
	A1B1	2	1	0.68	0.68	0.68
	A1B3	1	1	1.49	1.49	1.49
	A2A1	6	5	1.31	0.38	2.99
	A2A3	1	1	1.42	1.42	1.42
	A2B1	4	4	1.73	0.47	2.98
	A3A1	25	22	1.32	0.34	3.97
	A3A3	6	6	1.30	0.87	1.72
	A3B1	19	16	1.12	0.40	4.00
	A3B3	2	2	1.87	0.73	3.00
Vehicle C	A1A1	8	8	1.56	1.25	1.80
	A1A3	6	6	1.70	1.48	1.95
	A2A1	2	0	.	.	.
	A2A3	6	0	.	.	.
	A3A1	10	10	1.40	1.05	1.62
	A3A3	3	3	1.45	1.24	1.63
	A3B1	8	3	0.68	0.25	1.48
	A3B3	2	1	0.35	0.35	0.35
Vehicle D	A1A1	3	3	3.21	3.20	3.22
	A1A3	2	2	3.29	3.27	3.30
	A1B1	2	2	3.56	3.11	4.00
	A1B3	1	1	3.13	3.13	3.13
	A3A1	2	2	2.96	2.93	2.99
	A3B1	8	8	3.53	2.96	4.00
	A3B3	1	1	3.04	3.04	3.04

		KPI - Time to collision of braking (s)				
		Count	Valid N	Mean	Minimum	Maximum
Vehicle A	A1A1	13	13	1.12	1.07	1.17
	A1A2	1	1	1.13	1.13	1.13
	A1A3	6	6	1.11	1.08	1.13
	A1B1	2	2	0.85	0.83	0.86
	A1B3	3	3	0.88	0.86	0.89
	A2A1	4	4	1.30	1.13	1.53
	A2A2	1	1	1.19	1.19	1.19
	A2A3	6	6	1.56	1.12	2.51
	A2B3	1	1	0.93	0.93	0.93
	A3A1	4	2	0.73	0.67	0.79
	A3A2	1	1	0.13	0.13	0.13
	A3A3	2	2	0.47	0.35	0.58
	A3B1	6	2	0.24	0.02	0.46
	A3B2	1	1	0.29	0.29	0.29
	A3B3	4	2	0.77	0.62	0.91
	A3C1	1	0	.	.	.
	A3C3	1	1	0.81	0.81	0.81

		KPI - Time to collision of braking (s)				
		Count	Valid N	Mean	Minimum	Maximum
Vehicle B	A1A1	24	20	0.80	0.50	1.90
	A1A3	16	16	0.66	0.31	1.32
	A1B1	2	1	0.58	0.58	0.58
	A1B3	1	1	0.59	0.59	0.59
	A2A1	6	6	0.89	0.17	2.94
	A2A3	1	1	0.46	0.46	0.46
	A2B1	4	2	0.58	0.55	0.61
	A3A1	25	24	0.60	0.34	0.75
	A3A3	6	5	0.60	0.46	0.69
	A3B1	19	10	0.56	0.17	1.96
	A3B3	2	1	0.66	0.66	0.66
Vehicle C	A1A1	8	8	0.76	0.48	1.24
	A1A3	6	6	0.61	0.55	0.66
	A2A1	2	2	0.52	0.45	0.58
	A2A3	6	4	0.35	0.06	0.92
	A3A1	10	10	0.63	0.59	0.68
	A3A3	3	3	0.63	0.61	0.66
	A3B1	8	3	0.36	0.25	0.45
	A3B3	2	1	0.43	0.43	0.43
VEHICLE D	A1A1	3	3	2.32	2.09	2.54
	A1A3	2	2	2.80	2.57	3.03
	A1B1	2	2	2.57	2.01	3.13
	A1B3	1	1	2.83	2.83	2.83
	A3A1	2	2	2.06	2.00	2.11
	A3B1	8	6	3.00	1.95	3.76
	A3B3	1	1	3.07	3.07	3.07

		KPI - velocity reduction (km/h)				
		Count	Valid N	Mean	Minimum	Maximum
Vehicle A	A1A1	13	13	13.5	11.6	19.3
	A1A2	1	1	10.8	10.8	10.8
	A1A3	6	6	37.6	19.8	49.9
	A1B1	2	2	3.0	2.4	3.7
	A1B3	3	3	19.2	3.7	48.8
	A2A1	4	4	10.3	7.5	16.9
	A2A2	1	1	8.6	8.6	8.6
	A2A3	6	6	13.5	9.3	21.0
	A2B3	1	1	10.6	10.6	10.6
	A3A1	4	2	3.9	1.3	6.6
	A3A2	1	1	0.1	0.1	0.1
	A3A3	2	2	6.2	3.9	8.5
	A3B1	6	2	2.2	1.7	2.7
	A3B2	1	1	6.1	6.1	6.1
	A3B3	4	2	13.0	8.9	17.0
	A3C1	1	0	.	.	.
	A3C3	1	1	27.5	27.5	27.5
Vehicle B	A1A1	24	20	12.3	0.4	41.2
	A1A3	16	16	19.1	3.8	50.0
	A1B1	2	1	8.4	8.4	8.4
	A1B3	1	1	11.5	11.5	11.5
	A2A1	6	6	12.0	6.7	25.0
	A2A3	1	1	8.1	8.1	8.1
	A2B1	4	2	7.9	7.9	7.9
	A3A1	25	24	6.6	2.4	10.4
	A3A3	6	5	9.3	5.5	16.8
	A3B1	19	10	4.5	0.2	9.5
	A3B3	2	1	7.0	7.0	7.0

		KPI - velocity reduction (km/h)				
		Count	Valid N	Mean	Minimum	Maximum
Vehicle C	A1A1	8	8	12.7	8.1	15.1
	A1A3	6	6	13.6	11.2	16.3
	A2A1	2	2	8.5	7.9	9.1
	A2A3	6	3	3.8	0.5	7.9
	A3A1	10	10	17.2	8.3	39.2
	A3A3	3	3	12.0	11.2	12.9
	A3B1	8	3	5.7	5.3	6.2
	A3B3	2	1	6.1	6.1	6.1
Vehicle D	A1A1	3	3	43.5	43.3	43.6
	A1A3	2	2	43.4	43.2	43.7
	A1B1	2	2	42.3	41.0	43.7
	A1B3	1	1	44.1	44.1	44.1
	A3A1	2	2	48.3	48.2	48.4
	A3B1	8	6	46.0	43.7	48.0
	A3B3	1	1	47.6	47.6	47.6

Table 14-1: Mean KPIs for Vehicle B by lab and test combination

Test	Lab	KPI - Time to collision of warning (s)				KPI - Time to collision of braking (s)				KPI - velocity reduction (km/h)			
		Valid N	Mean	Minimum	Maximum	Valid N	Mean	Minimum	Maximum	Valid N	Mean	Minimum	Maximum
A1A1	BASt	7	1.99	1.62	2.13	7	0.83	0.71	0.88	7	13.42	8.91	17.14
	IDIADA	6	0.54	0.05	1.65	3	1.05	0.91	1.13	3	20.91	9.86	41.18
	TNO	10	1.97	1.63	2.09	10	0.71	0.50	1.90	10	8.98	0.37	11.76
A1A3	BASt	5	1.59	1.02	2.19	5	0.76	0.58	0.93	5	25.34	6.95	48.96
	IDIADA	0				1	1.32	1.32	1.32	1	50.00	50.00	50.00
	TNO	10	2.01	1.51	3.00	10	0.54	0.31	0.70	10	12.95	3.82	18.12
A1B1	BASt	0				0				0			
	IDIADA	0				0				0			
	TNO	1	0.68	0.68	0.68	1	0.58	0.58	0.58	1	8.42	8.42	8.42
A1B3	BASt	0				0				0			
	IDIADA	0				0				0			
	TNO	1	1.49	1.49	1.49	1	0.59	0.59	0.59	1	11.53	11.53	11.53
A2A1	BASt	1	0.94	0.94	0.94	1	0.17	0.17	0.17	1	24.97	24.97	24.97
	IDIADA	0				1	2.94	2.94	2.94	1	13.32	13.32	13.32
	TNO	4	1.40	0.38	2.99	4	0.55	0.40	0.65	4	8.42	6.65	9.95
A2A3	BASt	0				0				0			
	IDIADA	0				0				0			
	TNO	1	1.42	1.42	1.42	1	0.46	0.46	0.46	1	8.12	8.12	8.12
A2B1	BASt	0				0				0			
	IDIADA	0				0				0			
	TNO	4	1.73	0.47	2.98	2	0.58	0.55	0.61	2	7.90	7.87	7.93
A3A1	BASt	5	1.22	0.93	1.69	5	0.69	0.65	0.72	5	8.14	7.70	8.66
	IDIADA	7	1.49	0.34	3.97	9	0.66	0.54	0.75	9	7.28	5.87	8.82
	TNO	10	1.25	0.52	1.70	10	0.49	0.34	0.68	10	5.14	2.44	10.42
A3A3	BASt	5	1.25	0.87	1.72	4	0.64	0.57	0.69	4	10.28	5.99	16.81
	IDIADA	0				0				0			
	TNO	1	1.58	1.58	1.58	1	0.46	0.46	0.46	1	5.49	5.49	5.49
A3B1	BASt	1	0.82	0.82	0.82	1	0.64	0.64	0.64	1	7.20	7.20	7.20
	IDIADA	5	1.99	0.60	4.00	1	0.57	0.57	0.57	1	0.72	0.72	0.72
	TNO	10	0.71	0.40	1.61	8	0.55	0.17	1.96	8	4.63	0.19	9.46
A3B3	BASt	1	0.73	0.73	0.73	1	0.66	0.66	0.66	1	7.00	7.00	7.00
	IDIADA	0				0				0			
	TNO	1	3.00	3.00	3.00	0				0			

Table 14-2: Test of between subject effects for log(TTC of braking) all vehicles

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	45.6	10	4.6	22.8	p<0.01	.532
Intercept	0.05	1	0.05	0.3	ns: p=0.62	.001
Lab	1.1	2	0.6	2.8	p<0.10	.027
Vehicle	39.2	3	13.1	65.4	p<0.01	.494
TV_initial	2.1	3	0.7	3.5	p<0.05	.050
TV_lat_over	2.4	1	2.4	112.0	p<0.01	.056
Driver_react1	0.1	1	0.1	0.6	ns: p=0.42	.003
Error	40.2	201	0.2			
Total	97.8	212				
Corrected Total	85.8	211				

R Squared = .532 (Adjusted R Squared = .509)

Table 14-3: ANOVA table for log(TTC to warning) for Vehicle A

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	0.03	3	.010	7.5	p<0.01	35%
Intercept	6.28	1	6.276	4515.8	p<0.01	
TV_initial	0.02	1	.021	15.4	p<0.01	27%
Lab	0.01	2	.005	3.5	p<0.05	14%
Error	0.06	42	.001			
Total	6.37	46				
Corrected Total	0.09	45				

R Squared = .349 (Adjusted R Squared = .302

Table 14-4: ANOVA table for log(TTC to braking) for Vehicle A

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.03	13	.156	27.0	p<0.01	88%
Intercept	0.01	1	.010	1.7	ns: p=0.20	
TV_initial	1.04	2	.522	90.6	p<0.01	79%
Driver_react1	0.09	1	.087	15.1	p<0.01	24%
Lab	0.03	2	.013	2.3	ns: p=0.11	9%
Driver_react1 * Lab	0.11	2	.053	9.3	p<0.01	28%
TV_initial * Driver_react1	0.09	2	.045	7.7	p<0.01	24%
TV_initial * Lab	0.67	4	.168	29.2	p<0.01	71%
Error	0.28	48	.006	27.1		
Total	2.31	62		1.7		
Corrected Total	2.30	61				

R Squared = .880 (Adjusted R Squared = .847)

Table 14-5: ANOVA table for log(velocity reduction) for Vehicle A

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	11.3	13	0.9	35.0	p<0.01	91%
Intercept	114.5	1	114.4	4610.4	p<0.01	
TV_initial	3.5	2	1.8	70.8	p<0.01	75%
Driver_react1	1.4	1	1.4	56.9	p<0.01	54%
Lab	1.5	2	0.7	30.2	p<0.01	56%
Driver_react1 * Lab	0.8	2	0.4	16.7	p<0.01	41%
TV_initial * Driver_react1	0.3	2	0.1	5.8	p<0.01	19%
TV_initial * Lab	3.8	4	0.9	38.1	p<0.01	76%
Error	1.2	48	0.02			
Total	127.0	62				
Corrected Total	12.5	61				

R Squared = .905 (Adjusted R Squared = .879)

Table 14-6: Weighted mean, minimum and maximum of TTC warn for Vehicle A

		TTC warning			Test configurations
		Mean	Max	Min	
Vehicle	Vehicle A	2.07	2.51	1.52	A1A1, A1A3, A3A1, A3A3
Lab	BASt	2.06	2.23	1.73	A1A1, A1A3, A3A1, A3A3
	IDIADA	2.00	2.17	1.52	A1A1, A1A3, A3A1, A3A3
	TNO	2.14	2.51	2.01	A1A1, A1A3, A3A1, A3A3
TV initial speed	0	1.98	2.16	1.52	A3A1, A3A3
	10	2.15	2.51	2.01	A1A1, A1A3,
TV initial lateral overlap	100%	2.07	2.51	1.52	A1A1, A1A3, A3A1, A3A3
TV braking	0	2.04	2.26	1.73	A1A1, A1A3, A3A1, A3A3
Planned driver reaction	fast	2.06	2.23	1.73	A1A1, A3A1
	no	2.00	2.17	1.52	A1A3, A3A3

Table 14-7: Weighted mean, minimum and maximum of TTC brake for Vehicle A

		TTC braking			Test configurations
		Mean	Max	Min	
Vehicle	Vehicle A	1.03	2.51	0.35	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
Lab	BASt	1.02	1.53	.35	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
	IDIADA	1.06	2.51	.58	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
	TNO	1.03	1.27	.72	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
TV initial speed	0	.75	1.15	.35	A3A1, A3A3
	10	1.09	1.27	.94	A1A1, A1A3,
	50	1.26	2.51	.72	A2A1, A2A3,
TV initial lateral overlap	100%	1.03	2.51	.35	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
TV braking	0	.92	1.27	.35	A1A1, A1A3, A3A1, A3A3
	4	1.26	2.51	.72	A2A1, A2A3
Planned driver reaction	fast	.99	2.51	.35	A1A1, A2A1, A3A1
	no	1.07	1.53	.67	A1A3, A2A3, A3A3

Table 14-8: Weighted mean, minimum and maximum of velocity reduction (km/h) for Vehicle A

		Velocity reduction (km/h)			Test configurations
		Mean	Max	Min	
Vehicle	Vehicle A	16.59	49.86	1.30	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
Lab	BASt	13.48	20.95	3.92	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
	IDIADA	14.26	49.86	1.30	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
	TNO	22.04	49.36	4.98	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
TV initial speed	0	12.36	49.36	1.30	A3A1, A3A3
	10	24.47	49.86	11.60	A1A1, A1A3,
	50	12.95	20.95	4.98	A2A1, A2A3,
TV initial lateral overlap	100%	16.59	49.86	1.30	A1A1, A1A3, A2A1, A2A3, A3A1, A3A3
TV braking*	0	18.42	49.86	1.30	A1A1, A1A3, A3A1, A3A3
	4	12.95	20.95	4.98	A2A1, A2A3
Planned driver reaction	fast	21.63	49.86	3.92	A1A1, A2A1, A3A1
	no	11.55	21.36	1.30	A1A3, A2A3, A3A3

Table 14-9: ANOVA table for log(TTC warning) for Vehicle B (subset A)

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.474[a]	7	.353	7.260	.000	.471
Intercept	.016	1	.016	.319	.575	.006
TV_initial	.219	2	.110	2.253	.114	.073
Lab	1.370	2	.685	14.070	.000	.331
TV_initial * Lab	.624	3	.208	4.271	.009	.184
Error	2.775	57	.049			
Total	5.517	65				
Corrected Total	5.249	64				

R Squared = .471 (Adjusted R Squared = .406)

Table 14-10: ANOVA table for log(TTC warning) for Vehicle B (subset B)

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	0.36	5	0.07	1.46	ns: p=0.23	19%
Intercept	0.00	1	0.00	0.08	ns: p=0.78	
Lab	0.03	2	0.02	0.33	ns: p=0.72	2%
TV lateral overlap	0.04	1	0.04	0.73	ns: p=0.40	2%
Lab * TV lateral overlap	0.25	2	0.13	2.51	p<0.10	14%
Error	1.59	32	0.05			
Total	1.97	38				
Corrected Total	1.96	37				

R square 0.186 (adjusted R squared = 0.059)

Table 14-11: ANOVA table for log(TTC braking) for Vehicle B (subset A)

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4.87	11	0.44	74.76	p<0.01	94%
Intercept	0.89	1	0.89	150.21	p<0.01	
TV initial speed	0.12	2	0.06	10.40	p<0.01	28%
Lab	1.57	2	0.79	132.61	p<0.01	83%
Planned driver reaction	0.00	1	0.00	0.11	ns: p=0.74	0%
Lab * Planned driver reaction	0.04	2	0.02	3.17	p=0.05	11%
TV initial speed * Lab	2.38	4	0.60	100.52	p<0.01	88%
Error	0.32	54	0.01			
Total	6.64	66				
Corrected Total	5.19	65				

R square 0.983 (adjusted R squared = 0.926)

Table 14-12: ANOVA table for log(TTC braking) for Vehicle B (subset B)

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	0.18	2	0.09	6.06	p<0.01	28%
Intercept	1.35	1	1.35	92.87	p<0.01	
Lab	0.18	2	0.09	6.06	p<0.01	28%
Error	0.45	31	0.01			
Total	2.16	34				
Corrected Total	0.63	33				

R square 0.281 (adjusted R squared = 0.235)

Table 14-13: Weighted mean and range for TTC warn and TTC brake for Vehicle B (subset A)

		TTC warning			TTC braking			Test configurations
		Mean	Range		Mean	Range		
Vehicle	Vehicle B	1.44	3.92		0.89	2.77		A***
Lab	BASt	1.42	1.26		0.61	0.76		A***
	IDIADA	0.96	3.92		1.59	2.40		A***
	TNO	1.66	2.62		0.57	1.59		A***
TV initial speed	0	1.30	3.63		0.61	0.41		A3**
	10	1.64	2.95		0.85	1.59		A1A*, A1B*
	50	1.17	2.61		1.22	2.77		A2A*, A2B*
TV braking	0	1.52	3.92		0.77	1.59		A1**, A3**
	4	1.17	2.61		1.22	2.77		A2A*
Planned driver reaction	fast	1.80	1.98		0.87	1.01		A**3
	no	1.35	3.92		0.89	2.77		A**1

Table 14-14: Weighted mean and range for TTC warn and TTC brake for Vehicle B (subset B)

		TTC warning			TTC braking			Test configurations
		Mean	Range		Mean	Range		
Vehicle	Vehicle B	1.18	3.66		0.61	1.79		A***
Lab	BASt	1.02	0.87		0.67	0.08		A***
	IDIADA	1.73	3.66		0.65	0.21		A***
	TNO	0.98	1.30		0.52	1.79		A***
TV initial lateral overlap	50%	1.06	3.60		0.60	1.79		A3**
	100%	1.30	3.63		0.61	0.41		A1A*, A1B*
TV braking	0	1.18	3.66		0.61	1.79		A1**, A3**
	4							A2A*
Planned driver reaction	fast	1.18	3.66		0.61	1.79		A**3
	no	1.06	3.60		0.60	1.79		A**1

Table 14-15: ANOVA table for log(velocity reduction) for Vehicle B (subset A)

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4.3	7	0.61	13.7	p<0.01	62%
Intercept	41.2	1	41.15	926.7	p<0.01	
Lab	1.4	2	0.71	16.1	p<0.01	36%
TV initial speed	0.9	2	0.44	9.9	p<0.01	25%
Driver reaction	0.6	1	0.63	14.1	p<0.01	20%
Lab * Driver reaction	0.6	2	0.30	6.8	p<0.01	19%
Error	2.6	58	0.04			
Total	77.0	66				
Corrected Total	6.8	65				

R square 0.62 (adjusted R squared = 0.58)

Initial speed = 0km/h Subset B

Table 14-16: ANOVA table for log(velocity reduction) for Vehicle B (subset B)

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1.09	5	0.22	4.82	p<0.01	46%
Intercept	5.31	1	5.31	118.02	p<0.01	
Lab	0.75	2	0.37	8.32	p<0.01	37%
TV lateral overlap	0.61	1	0.61	13.58	p<0.01	33%
Lab * TV lateral overlap	0.43	2	0.22	4.80	p<0.05	26%
Error	1.26	28	0.05			
Total	16.58	34				
Corrected Total	2.35	33				

R square 0.463 (adjusted R squared = 0.367)

Table 14-17: Means of velocity reduction (km/h) for Vehicle B (subset A)

		Mean	Min	Max
Vehicle	Vehicle B	16.5	0.4	50.0
Lab	BASt	18.1	7.0	49.0
	IDIADA	23.7	5.9	50.0
	TNO	8.9	0.4	18.1
TV initial speed	0	6.8	2.4	10.4
	10	22.2	0.4	50.0
	50	15.6	6.7	25.0
TV braking	0	16.8	0.4	50.0
	4	15.6	6.7	25.0
Planned driver reaction	fast	29.4	3.8	50.0
	no	11.7	0.4	41.2

Table 14-18: Means of velocity reduction (km/h) for Vehicle B (subset B)

		Mean	Min	Max
Vehicle	Vehicle B	6.4	0.2	10.4
Lab	BASt	7.7	7.2	8.7
	IDIADA	6.5	0.7	8.8
	TNO	4.9	0.2	10.4
TV initial lateral overlap	50%	5.7	0.2	9.5
	100%	6.8	2.4	10.4
TV braking	0	6.4	0.2	10.4
	4			
Planned driver reaction	fast			
	no	6.4	0.2	10.4

Table 14-19: ANOVA table for log(TTC warning) for additional data (ADAC target & VW Passat target vehicle)

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	<0.01	2	<0.01	2.4	ns: p=0.12	17%
Intercept	15.2	1	15.2	35606.5	p<0.01	
Target_veh1	<0.01	2	<0.01	2.3	ns: p=0.12	17%
Error	0.01	23	. <0.01			
Total	15.4	26				
Corrected Total	0.01	25				

Tests of Between-Subjects Effects

Dependent Variable:log_KPI_ttcwarn

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.002[a]	2	.001	2.371	.116	.171
Intercept	15.230	1	15.230	35606.465	.000	.999
Target_veh1	.002	2	.001	2.371	.116	.171
Error	.010	23	.000			
Total	15.381	26				
Corrected Total	.012	25				

a. R Squared = .171 (Adjusted R Squared = .099)

15 Appendix F: HP2 report

This Appendix is provided as separate document.