CoExist

Deliverable 2.6

Technical report on data collection and validation

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1 Introduction

This document summarised the data collection, evaluation and validation process using two data sources. All used data were collected or produced within the CoEXist project in cooperation with consortium partners.

1.1 Why data collection is needed

From the modelling perspective, the WP2 should answer two key questions:

1) What are the differences between conventional and automated vehicles in terms of driving behaviour?
   The knowledge of the driving behaviour is key for the replication of the behaviour in virtual environment. Because automated vehicles are not yet wide spread in the traffic flow, data collection with own automated vehicles was needed. These vehicles were provided by TASS International and were equipped with the driving logic developed by TNO.

2) Is it possible to replicate the behaviour of automated vehicles using microscopic simulation software PTV Vissim?
   For this purpose, several simulation tests have been done in Vissim with different parameter & feature settings. The results of data evaluation in combination with the proposed concept of 4 different driving logics (see the *driving logic paper*[1]) led to new developments in PTV Vissim software (see D2.4 *Vissim extension - new features and improvements*).

1.2 Data Sources

1.2.1 Empirical data from the test track

These data were collected in real traffic environment with real automated vehicles in common traffic. Several driving scenarios were realised with 3 test vehicles. Several types of data have been collected by different type of devices: MOVE CAN interface, OXTS RTK-GPS, IBEO LiDAR reference system, Video capture (webcams). Collected data have been evaluated using script algorithms producing different kind of plots. See below for details.

1.2.2 Co-simulation outputs

Co-simulations outputs are represented by vehicle record files created by PTV Vissim software during co-simulations. Co-simulations are simulations where the control driving logic developed by VEDECOM is coupled with PreScan (providing the vehicle dynamics) and PTV Vissim – this allows to let the automated vehicle interact with surrounding conventional traffic provided by PTV Vissim. Vehicle record files contain

[1] The driving logic paper can be found in Appendix A of deliverable 1.4 *Scenario specifications for eight use cases*

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vehicle attributes (like speed, acceleration, following distance etc.) of each simulated vehicle for each simulated time step. See part 2 for more details.

2 Data collection

2.1 Introduction

This document includes a description of the vehicle setup regarding the measurement systems used for the data collection. Furthermore, it provides an overview of which data could be made available by what system.

2.2 Vehicle Setup

Three SAE level two partial automated research platforms have been used for the data collection. These vehicles are based on a Toyota Prius 3rd generation. The automated systems on the research vehicles in current setup all include lateral and longitudinal control systems which are listed in Table 1. The systems are ordered in descending order based on the level of automation.

Table 1: vehicle control systems

Longitudinal control		Lateral Control	
Abbr.:	**Description:**	**Abr.:**	**Description:**
CACC	Cooperative Adaptive Cruise Control	VF	Vehicle Following
dCACC	Degraded CACC	LK	Lane Keeping
ACC	Adaptive Cruise Control	Manual	Manual steering
CC	Cruise Control		
Manual	Manual (de)acceleration		

The vehicles have been driving in a predefined order during each test. This allows each combination of the operating modes as depicted in Figure 1. On top of the vehicle control systems, each research platform will be equipped with additional measurement systems to meet the data collection requirements for this project. The data acquisition systems available for CoEXist are:

1) MOVE CAN interface
2) OXTS RTK-GPS
3) IBEO LiDAR reference system
4) Video capture (webcams)

The order of vehicles depicted in Figure 1 knows two variants, one where the IBEO LiDAR system is in the vehicle in the middle, and one where this system is placed in the last vehicle.

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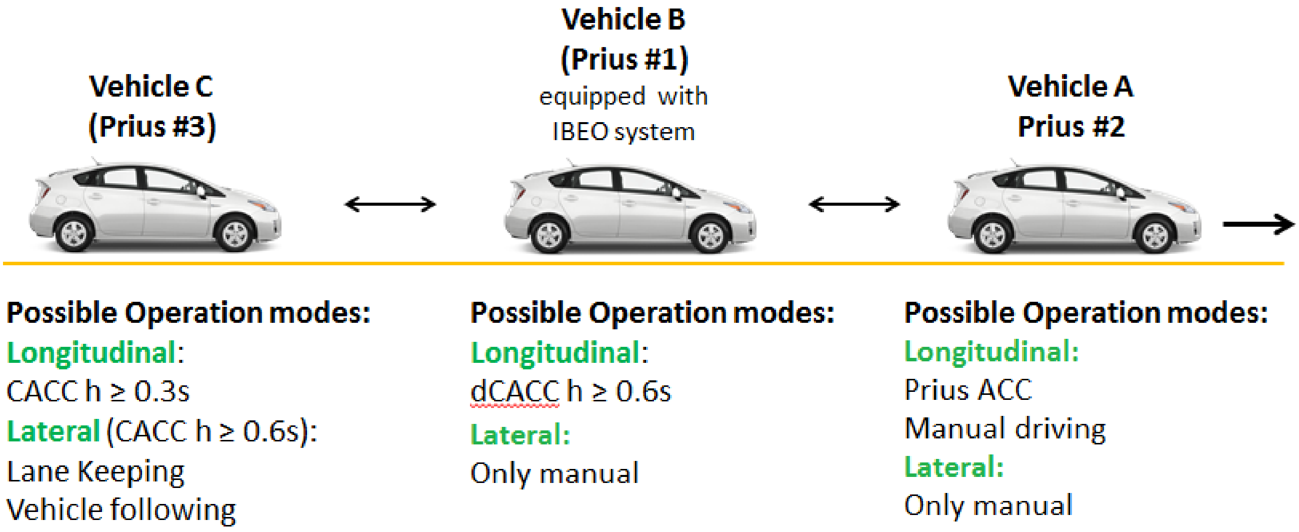

Figure 1: Vehicle operating modes

2.2.1 MOVE CAN interface

Each vehicle is equipped with a MOVE vehicle gateway allowing to interface between the vehicle CAN network and an external platform. The vehicle MOVE box provides accurate vehicle sensor data and contains several low-level controllers to guarantee safe operation. The available MOVE signals are (amongst others) shown in the Table 2 below:

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Table 2: Available MOVE signals

Group	Signal abbr.	Signal description
Vehicle Motion	vx	Longitudinal velocity
	ax	Longitudinal acceleration
	ay	Lateral acceleration
	psiD	Yaw rate
	delta	Steering angle
Vehicle State	Pct_trottle	Throttle pedal position
	BrakePressed	Brake pressed
	Gear	Gear (R,N,D,B)
	Fdrive	Current drivetrain force
	UserSteeringTorque	Applied steering torque by driver
	ControlStateLon	Longitudinal control state
	ControlModeLon	Current longitudinal control mode
	BrakeMode	Current brakemode
	MaxSetpReachedLon	Max. longitudinal set point reached
	MinSetpReachedLon	Min. longitudinal set point reached
	ThrottleOverrule	Throttle overrule
	BrakeOverrule	Brake overrule
	ControlStateLat	Lateral control state
	ControlModeLat	Current lateral control mode
	MaxSetpReachedLat	Max. lateral set point reached
	MinSetpReachedLat	Min. longitudinal set point reached
	SteeringOverrule	Steering overrule
	MaxSteeringRateReached	Max. steering rate reached
	MaxYawRateReached	Max. yaw rate reached
	SteeringMode	Steering mode

2.2.2 OXTS RTK-GPS

Vehicle B and vehicle C are both equipped with a highly accurate inertial and dual antenna GPS system for measuring position, orientation and motion. The system can provide highly accurate results even in urban or other 'covered' areas thanks to the combination of inertial and GPS measurements. Furthermore, it allows to generate system outputs at a fast update rate of 100 Hz. The dual antenna setup enables accurate heading measurements also under slow vehicle dynamics. The OXTS GPS units in the vehicles are connected to a real time kinematic (RTK) base station which broadcasts differential correction signals over the internet. RTK-GPS in the available setup for the CoEXist project will generate position measurements with an accuracy of 0.01 metre. A typical output configuration of this system is given in Table 3.

Table 3 OXTS signals, position, orientation and motion

Signal abbr.	Signal description
GpsNumSats	Number of visible satellites
GpsPosMode	Position mode descriptor
GpsVelMode	Velocity mode descriptor
GpsDiffAge	Time since last dGPS update
PosLat	Position in degrees latitude
PosLon	Position in degrees longitude
Altitude	Position in metres altitude
VelForward	Forward velocity
VelLateral	Lateral velocity
AccelX	IMU acceleration forward
AccelY	IMU acceleration lateral (right)
AccelZ	IMU acceleration vertical (down)
AngleHeading	Heading angle
AnglePitch	Pitch angle
AngleRoll	Roll angle
AngRateX	IMU angular rate X
AngRateY	IMU angular rate Y
AngRateZ	IMU angular rate Z
AngAccelX	IMU angular acceleration X
AngAccelY	IMU angular acceleration Y
AngAccelZ	IMU angular acceleration Z
LatStdev	The estimated accuracy of latitude
LonStdev	The estimated accuracy of longitude
AltStdev	The estimated accuracy of altitude
HeadingStdev	The estimated accuracy of heading
PitchStdev	The estimated accuracy of pitch
RollStdev	The estimated accuracy of roll

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2.2.3 IBEO LiDAR reference system

In addition to the OXTS system, the Toyota Prius #1 is equipped with an IBEO LiDAR system consisting of in total six IBEO LUX 4 LiDAR sensors. The six-sensor configuration allows a 360° view of the vehicle's surrounding and objects as depicted in Figure 2. Laser beams are sent from the LUX sensor and, based on the 'time of flight' measurement principle, the distance and direction of objects are measured with respect to the vehicle local coordinate system. Note that the object distance and direction can be translated into world coordinates as long as an accurate measurement of the vehicle's position and orientation is available. Thus, the measurement data from the OXTS GPS system can be used together with the relative object distances to convert from local vehicle to global coordinate system.

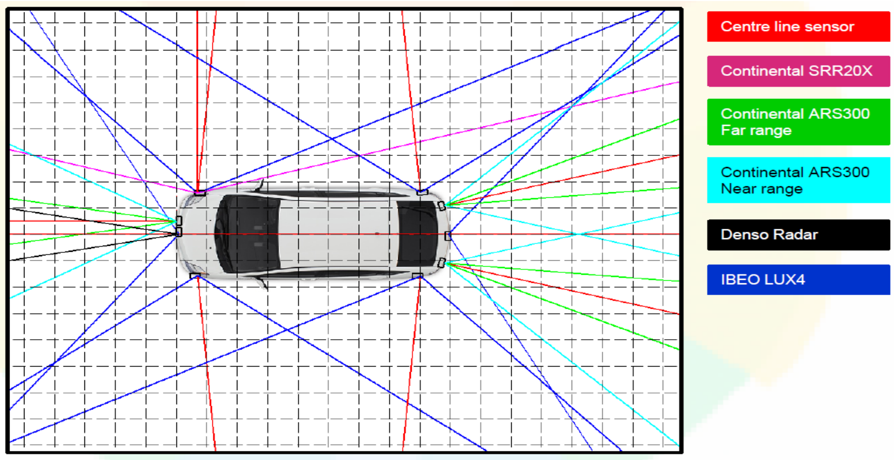

Figure 2: IBEO LUX4 scanner setup Toyota Prius #1

Typical object data from the IBEO LiDAR system consists of the signals given in Table 4. Note that the CoEXist data is filtered to include only dynamic objects from a user defined classification. i.e. an array is generated for each classification (e.g. 'cars' or 'trucks') and consists of original object ID, unique object ID, classification age and reference point location.

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Table 4: IBEO outputs

Signal abbr.	Signal description
nbObjects	Number of total objects
Id	IBEO Object identification number
IDnew	Unique object identification number
referencePoints	Distance from EGO vehicle to object in XY coordinates
Classifications	Object classification 0= unclassified 1= unclassified small 2= unclassified large 3= pedestrian 4= bike 5= car 6= truck
ClassificiationAges	Time since first classification of object
isMobile	Identifier for dynamic objects
xPos	IMU x position since initialization
yPos	IMU y position since initialization
courseAngle	IMU heading since initialization

The pre-processed CSV file has the following format (see Table 5):

Table 5: IBEO CSV format

GPS timestamp	Latitude	Longitude	Heading	No of objects (n)	IDS 1..n	Timestamps 1..n	Classification 1..n	Class_Age 1..n	ObjectType 1..n (Dynamic - 1 Static - 0)	(xPos, yPos) 1..n (local)

The MATLAB post-processing filters the detected objects and collect the two most relevant objects namely, cars and trucks into two carObj.mat and trcukObj.mat files which have the format shown in Table 6. The detection of these two objects are in general more reliable than others. However, classification of objects is not always fully accurate. For example, an object initially classified as car could later be misclassified as a truck and may even get a new id. Such anomalies must be filtered out manually.

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Table 6: Format of the carObj.mat/truckObj.mat files

GPS timestamp	ID	IDnew **(not used)**	Classification (= 5 for car)	Age	xPos (UTM)	yPos (UTM)	zPos (UTM)

2.2.4 Video Capture

Each of the vehicles are equipped with two Logitech C270 webcams facing to the front and back of the vehicle. The video streams can be used for quick observation and identification of the real-world scenario.

2.3 Data collection

Data collection was carried out from 28th August 2017 to 1st September 2017 by TASS International on the test track in Helmond.

Figure 3 CoEXist team and the three vehicles ready for data collection (photo taken on 29.08.2017)

The journey starts either from the Automotive Campus (A) or at the Shell station (H) and ends at one of these locations as shown in Figure 4. The station H was added to reduce the turn around time and avoid the left turn with 3 vehicles.

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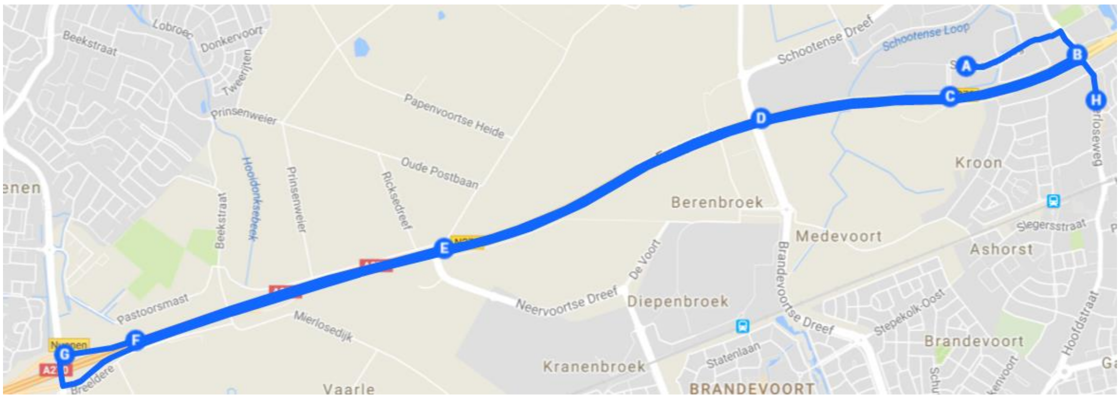

Figure 4: Route map of the data collection

The different points on the figure are referring to:

- A – parking lot in front of TASS International
- B-C – road section limited at 50 km/h
- C – intersection in front of the Automotive Campus
- C-D – road section limited at 70 km/h
- D-E – N270 limited at 100km/h
- At intersection D – 80 km/h limit
- D-E-F – A270, limited at 100 km/h
- H - Shell station

The automated driving mode is enabled between B and C and continues until F where it is disabled to take the exit. It is enabled back prior to entering the highway again. Each round took approximately 20-25 minutes of driving and 5-10 minutes of setting up/configuring the systems. Overall thirty scenarios were tested which are summarized in Table 8 with test parameters and their variations listed in Table 7.

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Table 7: Test parameters

Parameters	Variations			Comments
Merge/Diverge:	merge	diverge		Merge at the end of the chain (as a third vehicle) Merge in the middle of the chain (as a second vehicle)
Intersection behaviour	stop	drive through	-	No traffic light detection: first vehicle stops manually. Other vehicles respond on first vehicle. No prior planning.
Velocity (km/h)	50 → 70	70 → 80	80 → 100	
Communication	yes	no	transition	
Cut-in situation	take over	inject 4th vehicle	-	
Operating mode first vehicle	manual	Prius ACC		
Lateral control last vehicle	lane keeping	vehicle following	-	
Longitudinal control second vehicle	dCACC	-	-	
Longitudinal control last vehicle	dCACC	CACC	-	
IBEO System position	in second vehicle	in last vehicle	-	Different positioning of IBEO system allows either observation from vehicles behind or identification of cut-in vehicle
Time gap (last vehicle, in s)	0.3	0.6	1.2	
Emergency braking (m/s^2)	a > -6	a < -6	-	Possible on closed street only

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Table 8: Test scenarios

Scenario	Merge/ Diverge	Cut-in	Op. mode vehicle A	Lateral control vehicle C	Longitudinal control vehicle B	Longitudinal control vehicle C	Comm. b/w vehicle B & C	IBEO System position	Time gap (last vehicle, in s)
1	No	no	manual	manual	dCACC	CACC	on	vehicle B	0.3
2	No	no	manual	manual	dCACC	CACC	off*	vehicle B	0.3
3	No	no	prius ACC	manual	dCACC	dCACC	on	vehicle C	0.3
4	No	no	prius ACC	manual	dCACC	dCACC	off*	vehicle C	0.3
5	No	no	manual	vehicle following	dCACC	CACC	on	vehicle B	0.6
6	No	no	maual	lane keeping	dCACC	CACC	on	vehicle B	0.6
7	No	no	manual	vehicle following	dCACC	dCACC	off*	vehicle B	0.6
8	No	no	manual	lane keeping	dCACC	dCACC	off*	vehicle B	0.6
9	No	no	manual	vehicle following	dCACC	CACC	on	vehicle C	0.6
10	No	no	prius ACC	lane keeping	dCACC	CACC	on	vehicle C	0.6
11	No	no	prius ACC	vehicle following	dCACC	dCACC	off*	vehicle C	0.6
12	No	no	prius ACC	lane keeping	dCACC	dCACC	off*	vehicle C	0.6
13	No	no	manual	vehicle following	dCACC	CACC	on	vehicle B	1.2
14	No	no	manual	lane keeping	dCACC	CACC	on	vehicle B	1.2
15	No	no	manual	vehicle following	dCACC	dCACC	off	vehicle B	1.2
16	No	no	manual	lane keeping	dCACC	dCACC	off	vehicle B	1.2
17	No	no	prius ACC	vehicle following	dCACC	CACC	on	vehicle C	1.2
18	No	no	prius ACC	lane keeping	dCACC	CACC	on	vehicle C	1.2

19	No	no	prius ACC	vehicle following	dCACC	dCACC	off	vehicle C	1.2
20	No	no	prius ACC	lane keeping	dCACC	dCACC	off	vehicle C	1.2
21	Diverge	no	manual	manual	dCACC	CACC	on	in second vehicle	0.3
21*	Diverge	no	manual	lane keeping	dCACC	CACC	on	in second vehicle	0.6
22	No	no	manual	vehicle following	dCACC	CACC	on → off at 100 km/h and off→on again	in second vehicle	0.6
23	No	no	manual	vehicle following	dCACC	CACC	on → off at 70 km/h	in second vehicle	0.6
24	No	no	manual	vehicle following	dCACC	CACC	on → off at 50 km/h	in third vehicle*	0.6
25	No	overtake	manual	vehicle following	dCACC	CACC	on	in second vehicle	1.2
26	No	overtake	manual	vehicle following	dCACC	CACC	on	in second vehicle	0.6
27	No	overtake	manual	manual	dCACC	CACC	on	in second vehicle	0.3
28	No	inject 4th vehicle	manual	vehicle following	dCACC	CACC	on	in second vehicle	0.6
29	No	inject 4th vehicle	manual	vehicle following	dCACC	CACC	on	in second vehicle	0.3
30	No	inject 4th vehicle	manual	vehicle following	dCACC	CACC	on	in second vehicle	1.2

3 Data processing

3.1 Introduction

The aim of the data analysis at PTV was to extract the following behaviour of the automated vehicles and to adjust the following behaviour in PTV Vissim accordingly. The relevant aspects of the following behaviour depend on the modelling technique that is applied in the simulation. The car-following model implemented in Vissim, called Wiedemann model, uses the net distance to the leading vehicle for determining the acceleration in each timestep. Additionally, depending on the situation, the speed of the following vehicle or the speed of the leading vehicle and the speed difference between the two vehicles are considered. While the speed of each test vehicle is given directly from the sensor data, the net distances were not provided. Therefore, it was necessary to retrieve the net distances from the positional data of the test vehicles.

There are 4 different data sources:

- The ublox data: contains position data for Prius 3
- The MOVE data: contains information about the vehicles' motion and internal state for Prius 1, 2 and 3, respectively
- The OXTS data: contains information about the vehicles' position, orientation and motion for Prius 1 and 2, respectively
- The IBEO data: contains position data of the vehicles detected by Prius 1

3.2 Description of the data analysis

3.2.1 Preprocessing

The data was preprocessed by TASS International in the sense that the raw sensor data was filtered for random noise. For every test run, each of which contained one or two scenarios, there are 7 different data files, one for each data source and vehicle (see Figure 5). Therefore, the information which scenario the data belongs to had to be added. Then, the data from the different runs was combined so that one data set containing all data from one sensor for each vehicle was obtained.

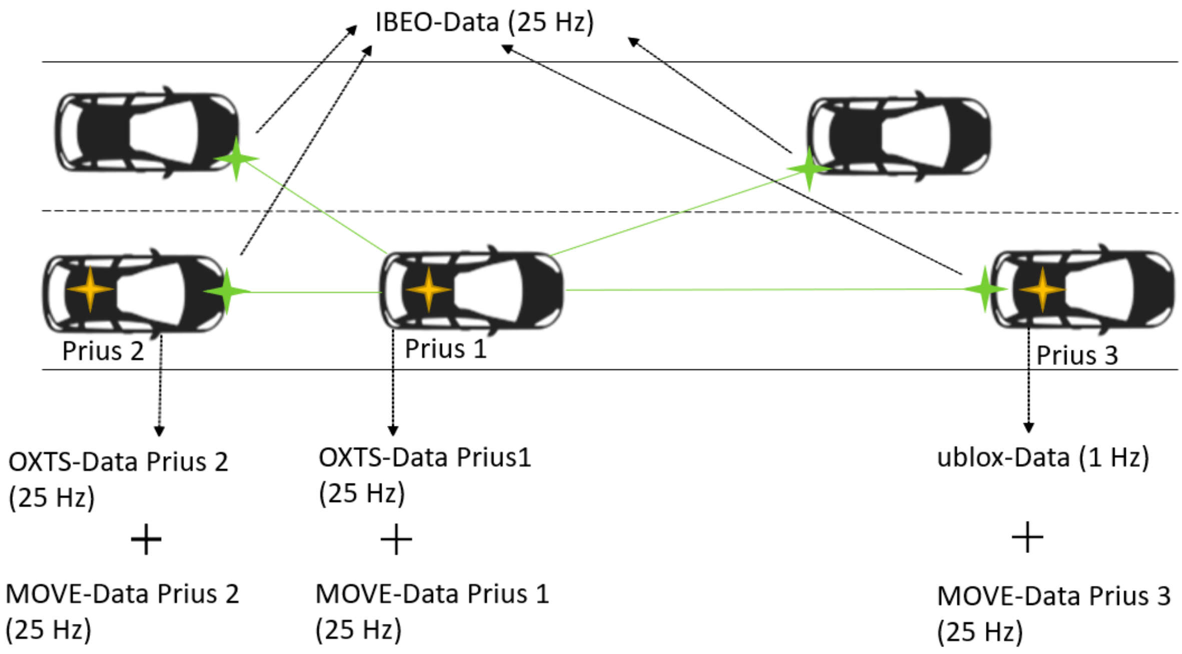

Figure 5: Different data sources from the test vehicles

3.2.2 Matching on the different data structures

The data from the different data sources was then combined into one data set per test vehicle. As the MOVE and the OXTS sensor had the same timestamps, data from these two sources could be combined by matching their timestamps. The ublox data was generated with a smaller frequency. The data was fitted to the MOVE/OXTS timestamps using linear interpolation. The IBEO data was processed in the next step independently from the other data sources.

3.2.3 Identification of the leading vehicle and the following vehicle

The net distances were calculated using the position data from the IBEO datasets, i.e. the distances to the surrounding vehicles as “seen” by Prius 1 (because the IBEO data is only available for this vehicle). As the test drives were conducted on a public road, i.e. in a normal traffic situation, the Prius 1’s sensor was detecting all vehicles travelling around it. This approach made it possible to assure that situations, when normal vehicles interfered with the test vehicles, were filtered out from the results (because normal vehicles positions appear in the data as well, not only the positions from the test vehicles). Consequently, it was necessary to filter the preceding vehicle and the following vehicle of the Prius 1 from the various vehicles detected. This was accomplished by using the heading angle β with regard to the UTM coordinate system which was given in the data (see Figure 6). The angle α between the heading angle vector β and the vector between Prius 1 and the surrounding vehicle was calculated. Using this angle α, the x- and y-components of the vector with respect to the driving direction of the Prius 1 could be calculated. Assuming small road curvatures, the y-components give direct information about the probability that both vehicles travelled on the same lane. Through filtering for small y-components considering the direction of the x-components, the vehicles travelling before and behind the test vehicles were defined. The position data of these vehicles was compared to the test vehicles’ position data so that the vehicles travelling in front and in the back could be identified as a test vehicle or an unknown vehicle.

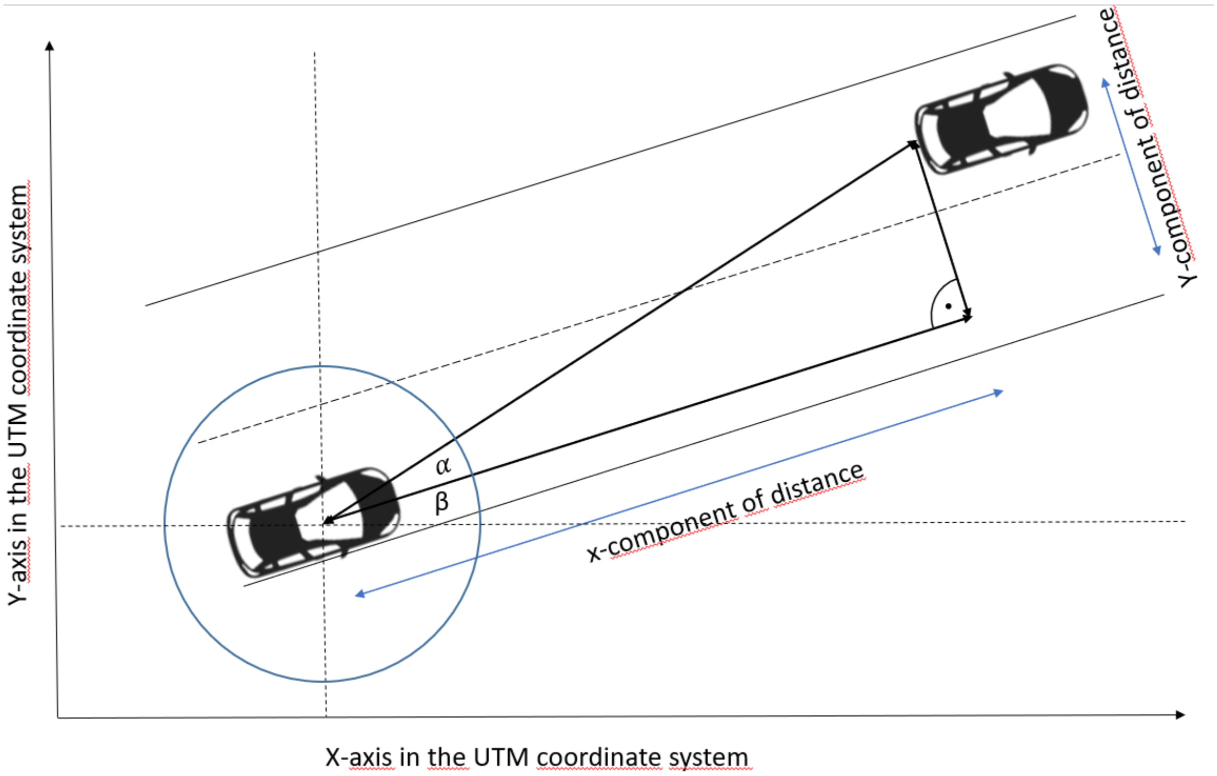

Figure 6: Vector components between Prius 1 and detected vehicle

3.2.4 Filtering of the data

To produce reliable results, the data sets from the preceding steps were filtered afterwards, so that only situations when the systems were running normally were considered. A "normal" situation can be defined as follows:

- Automated mode was switched on and working
- The system was not overridden by the human test driver
- The system is in "following mode" (e.g. the following vehicle is not "lost" at a traffic light)
- The following process is not interfered by another vehicle cutting in

This was accomplished by checking the internal state variables from the MOVE data sets, such as the SteeringOverrule or BrakeOverrule signals.

3.2.5 Data analysis

Using the above described database, several results were obtained:

- Standstill distances (distance between stopped vehicles): Through filtering for situations, when the automated vehicles were waiting at a traffic light, data about standstill distances could be analysed. This data was used for calibrating the parameter CC0[2].

[2] CC0 stands for standstill distance (m) in the Wiedemann 99 model. For more information on Widemann 99, see part 5.

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- Following behaviour in the course of time: Plotting the net distances over the speed of the following vehicle for each time step gave insights into the following behaviour on the complete test track. The results formed the basis for the qualitative adjustment of the parameters CC2-CC6[3].
- Mean queue discharge headway (time interval between two successive vehicles at a signalised intersection): for further analysis of the following behaviour at signalized intersections, the mean queue discharge headway was calculated for each vehicle at each intersection. This data provides reference for further calibration and development of Vissim models of automated driving behaviour in cities.

4 Data evaluation

4.1 Standstill distances

The standstill distance is an important factor in modelling following behaviour. It has a great influence on capacity at intersections. In contrast to the time headway, the driver can't adjust the standstill distance of the test vehicles. Consequently, the documentation provided no information about the target standstill distance.

The three figures below show the standstill distances found in the test drive data. This data was filtered by the different following situations when driving in automated mode. Figure 7 shows the relative number of stops per distance class when following an automated vehicle with communication (CACC mode). Figure 8 shows the same results when following another automated vehicle without communicating with it (dCACC mode). Figure 9 describes the standstill distances when following a manually driven car. The histograms for CACC and dCACC show a clear accumulation at about 4 metres and 6 metres, respectively. Thus, we assume that in CACC mode, the test vehicles aim at a standstill distance of 4 metres, while accepting a variance of about 1 metre. In dCACC mode, the target value seems to be 6 metres, with a similar variance to CACC mode. In both histograms, data occurs that seems to be misclassified (large distances in CACC and small distances in dCACC). We assume that the reason is that it was not possible to verify that communication was on from the data. Instead, this information had to be derived from the test drive scenarios, possibly leading to inaccuracies. When the vehicle in front is manually driven, the overall standstill distance seems to be higher and the variance is notably larger (neglecting the presumably misclassified data). This might be due either to less precise sensor data for calibrating the distance or to an unexpected behaviour (i.e. non-uniform braking behaviour when coming to a halt) of the vehicle in front. The target distance should be the same as in dCACC mode, however, the result seems to be different due to the differences in the driving behaviour of the leading vehicle.

[3] Parameter of the Widemann 99 model (for more information see part 5):
- CC1: Spacing time (s)
- CC2: Following variation (m)
- CC3: Threshold for entering „following (s)
- CC4: Negative “following” threshold (m/s)
- CC5: Positive “following” threshold (m/s)
- CC6: Speed dependency of oscillation (10^{-4} rad/s)

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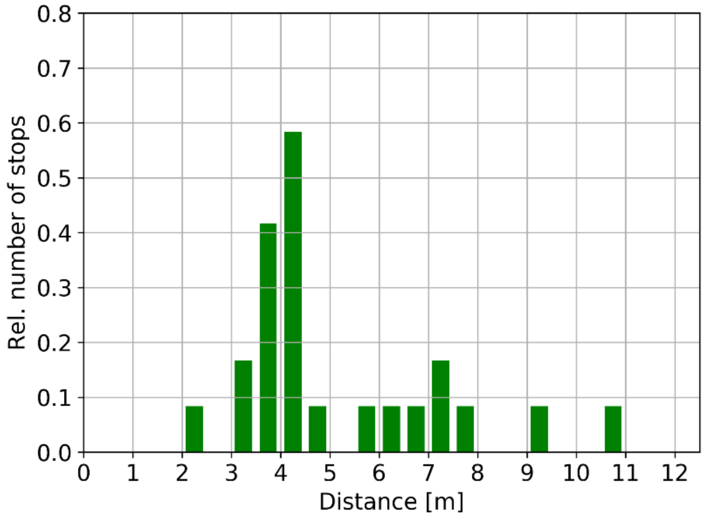

Figure 7: Standstill distance when following an automated car in CACC

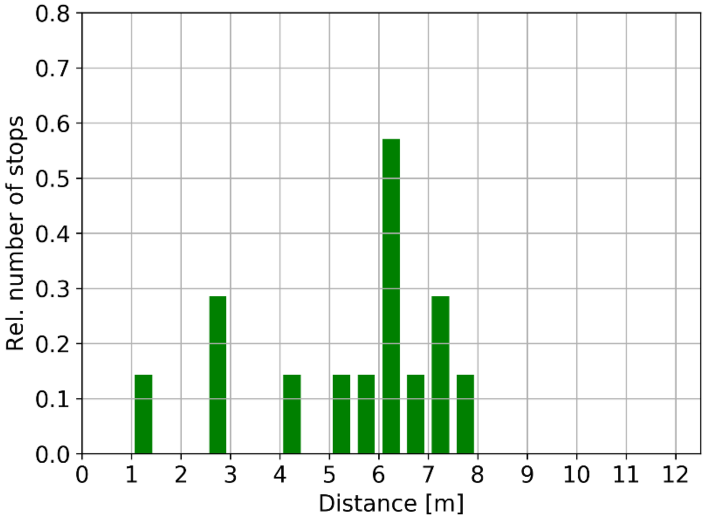

Figure 8: Standstill distance when following an automated car in dCACC

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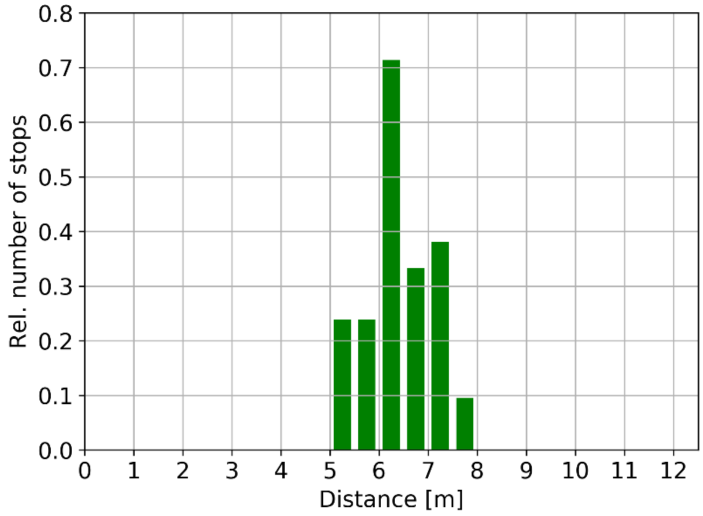

Figure 9: Standstill distances when following a manually driven car

4.2 Following behaviour

Using the above described results, two important factors for simulating the driving behaviour of automated vehicles are known: the standstill distances and the target value of the time headway, the latter being given from the documentation of the data collection. The remaining question is, how exactly the control logic of the automated vehicles work, i.e. in which situations the desired headway is not met and how much the behaviour can deviate from the standard behaviour. From a theoretical point of view, various reasons can be found for deviating from the target rules in certain situations, as there exists a variety of possible optimization objectives: e.g. safety, fuel saving, passenger comfort or stability of the traffic flow. Accordingly, we examined the course of the headway between the vehicles over a test run. The time headway is a theoretical parameter. It describes the time the following vehicle needs to reach the position of the vehicle in front at a given point in time (t) if the following vehicle continues to travel at the same speed. In other words, it describes the time-to-collision, assuming that the leading vehicle comes to a stop immediately at time t and that the follower does not break. Because this time-to-collision, called time headway in the following, cannot be measured directly, the net following distance and velocity were plotted for each time step. Dividing the distance by the speed in m/s gives the actual time headway. Thus, a linear relationship between the two parameters implies a constant time headway, when the standstill distance is neglected. All headways are given as net headways, which means that the reference points are the rear bumper of the leading and the front bumper of the following vehicle.

For making visible also the different driving situations of the test runs, e.g. braking in front of or accelerating after a traffic light, the speed differences between the leading and the following vehicle are expressed via the colours of the data points. The speed differences are denoted as $\Delta v = v_{following} - v_{leading}$. A negative Δv means that the following vehicle is slower. This usually happens if both vehicles accelerate due to a time lag in the reaction of the following vehicle. A positive Δv means that the following vehicle is faster, indicating that the vehicle in front brakes harder or earlier than the following vehicle.

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4.2.1 Following an automated vehicle with communication

When following another automated vehicle in CACC, the observed behaviour meets well the target values. Figure 10 shows the following at a time headway of 0.3 second, Figure 11 the following at 0.6 and 1.0 second respectively. The big “loop” in Figure 10 is due to a short communication shutdown.

The following distance in general is equal to the standstill distance plus the desired time headway transferred to metres. However, it can be seen from Figure 10 and Figure 11 that there is some variance in the time headways. The figure also shows that this variance stems mainly from different standstill distances and not from oscillations during following. This picture is in accordance with the findings from the analysis of standstill distances.

In conclusion, both figures show deviations from the target values. These deviations are small in magnitude and usually don’t appear when approaching the desired speed but occur at all speeds and also when coming to a halt.

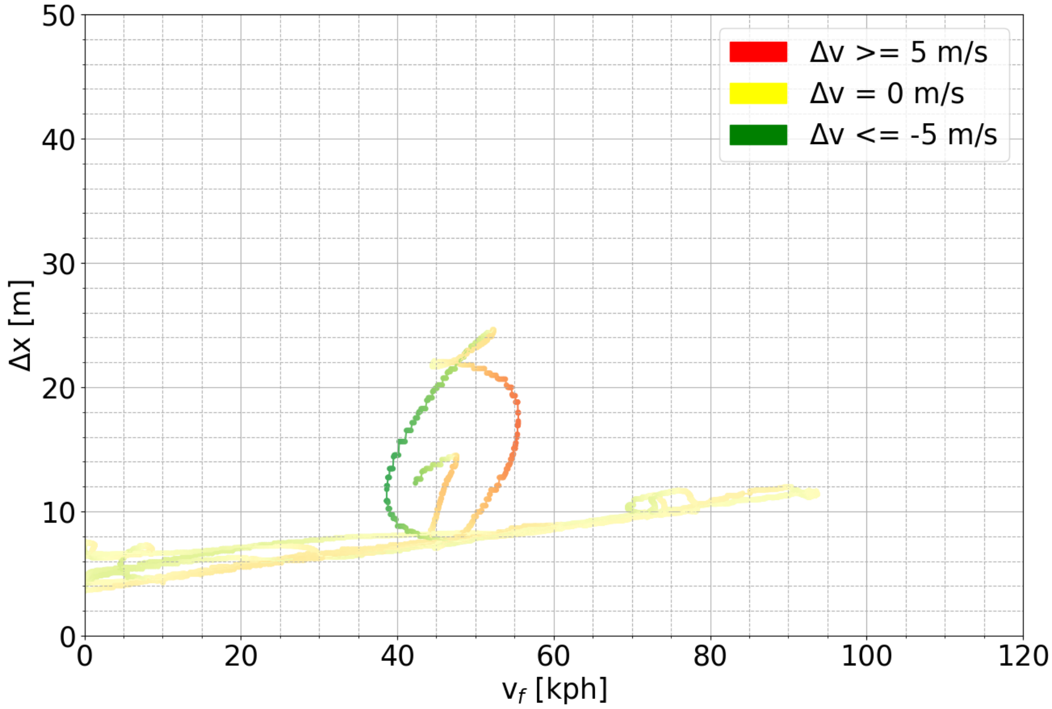

Figure 10: Distance in CACC at time headway of 0.3 s. kph stands for km/h

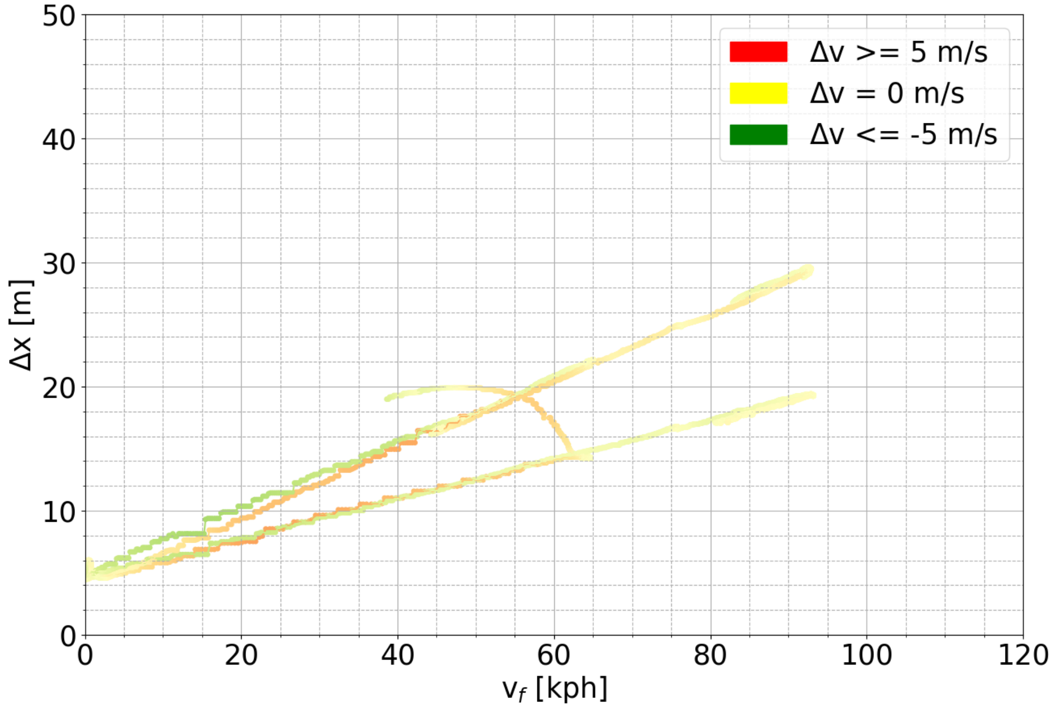

Figure 11: Distance in CACC at time headway of 0.6 s and 1.0 s. kph stands for km/h

4.2.2 Following an automated vehicle without communication

When following an automated vehicle in dCACC, the desired behaviour of maintaining a fixed time headway plus standstill distance cannot always be met. From Figure 12 it becomes clear that the vehicles show larger headways than the target value when the follower is faster. It shows lower headways when the vehicle is slower. When the differences in the velocities are small, the distance is very close to the expected headway.

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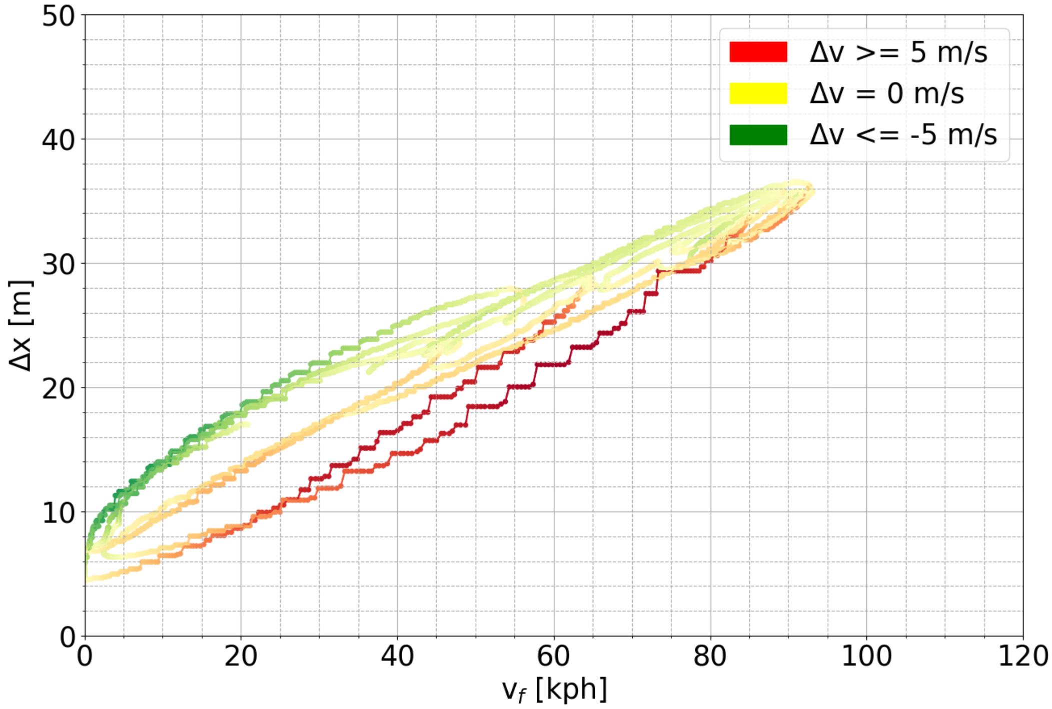

Figure 12: Following behaviour when following an automated vehicle in dCACC. kph stands for km/h

4.2.3 Following a manually driven vehicle

In general, the data doesn't show much difference between the following behaviour when following a manually driven vehicle and when following an automated vehicle in dCACC (see Figure 13). In contrast to following an automated vehicle, the expected headway is often not met also at small differences of the velocity. In general, these differences in distance headway are negligible. Therefore, in the following no differentiation between following a manually driven vehicle and following an automated vehicle in dCACC has been made.

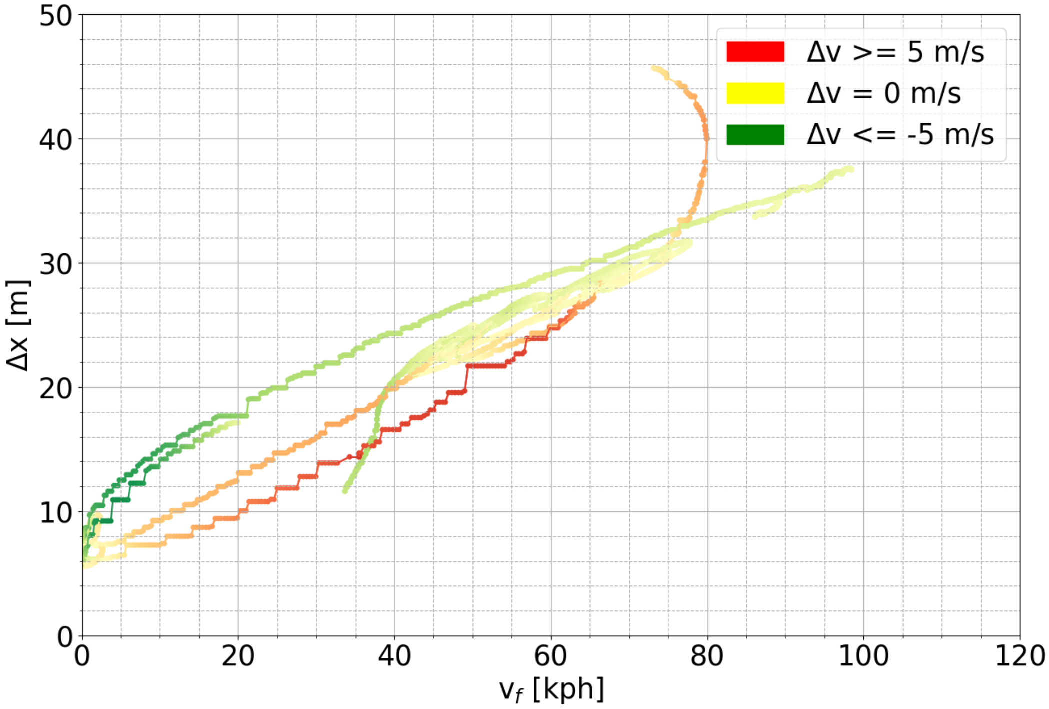

Figure 13: Following behaviour when following a manually driven vehicle. kph stands for km/h

5 Simulation & validation

Vissim provides two different car following models, Wiedemann 74 and Wiedemann 99. Both are so-called psycho-physical models, which means that the model considers human shortcomings in the perception of speeds and distances and in operating the car. That's why the distance oscillates around a target time headway. This human behaviour shall be adjusted to modelling the deterministic behaviour of the test vehicles.

Wiedemann 99 allows for changing many of the parameters used and assumes a linear relationship between speed and following distance (i.e., a constant time headway plus standstill distance). Furthermore, in contrast to Wiedemann 74, the vehicles keep their exact desired speed when no vehicle in front influences their behaviour. In conclusion, Wiedemann 99 is more suitable for simulating automated vehicles.

We have seen from the empirical data that especially in CACC mode, deviations from the target distance are small and are of a different nature than deviations from the target distances in Vissim. The typical oscillations that are produced by Vissim default behaviour (see Figure 14) should, thus, be omitted completely. For dealing with the stochastic behaviour creating the oscillations, a new feature, which makes it possible to turn off all implicit stochastic components in the Wiedemann model (tick-box "Use implicit

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stochastics"[4]) has been implemented. In a first step, the test vehicles have been simulated by using this feature and adjusting the parameters of the Wiedemann model. In a second step, deviations from the behaviour of the test vehicles were identified and adjustments of the acceleration behaviour were made. In a third step, we compared the adjusted driving behaviour again to the empirical data and evaluated the results.

Table 9 shows the settings used for the two different automated driving behaviours compared to the Vissim default settings.

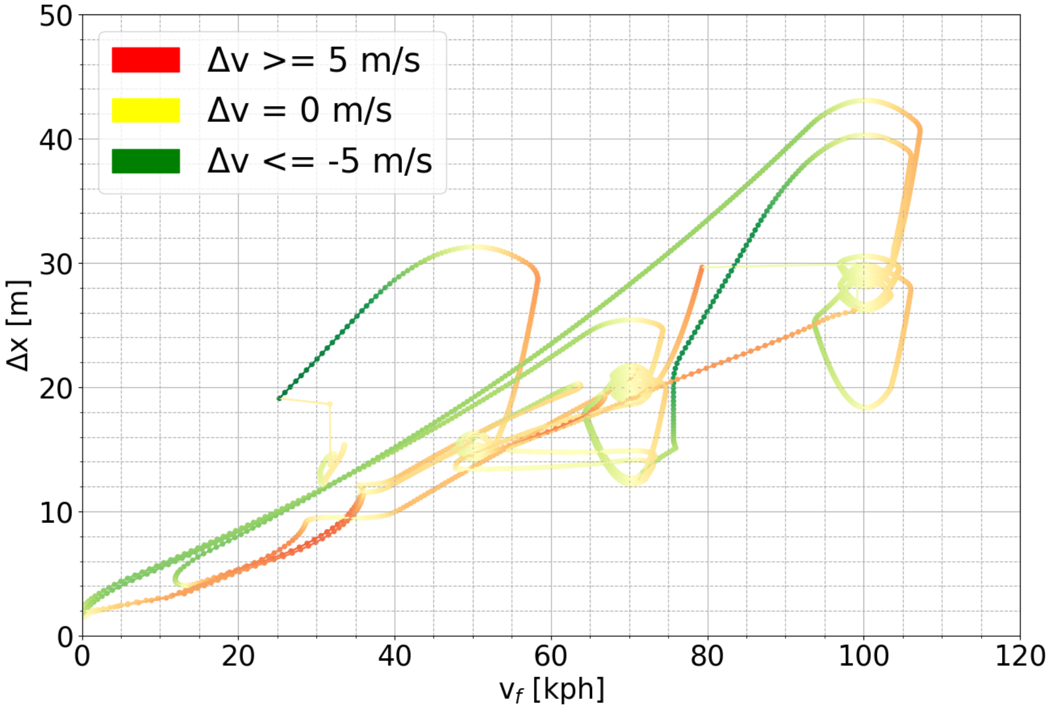

Figure 14: Default following behaviour in Vissim. kph stands for km/h

[4] For more details, please refer to D2.4 *Vissim extension – new features and improvements*

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Table 9: Used Wiedemann 99 parameter settings for automated vehicles

Parameter	Default behaviour	Automated CACC	Automated dCACC	Unit
CC0 – Standstill distance (m)	1.5	4	6	m
CC1 – Spacing time (s)	0.9	[0.3, 0.6, 1.0]	1.0	s
CC2 – Following variation (m)	4	0	0	m
CC3 – Threshold for entering “following” (s)	-8	-40	-40	s
CC4 – Negative “following” threshold (m/s)	-0.35	0	0	m/s
CC5 – Positive “following” threshold (m/s)	0.35	0	0	m/s
CC6 – Speed dependency of oscillation (10^{-4} rad/s)	11.44	0	0	$\frac{1}{m*s}$
CC7 – Oscillation acceleration (m/s^2)	0.25	0.25	0.25	$\frac{m}{s^2}$
CC8 – Standstill acceleration (m/s^2)	3.5	3.5	3.5	$\frac{m}{s^2}$
CC9 – Acceleration at 80 km/h (m/s^2)	1.5	1.5	1.5	$\frac{m}{s^2}$

Furthermore, some distributions and settings were adjusted:

- The distributions for desired acceleration and deceleration as well as for maximum acceleration and deceleration must be a linear function in accordance with the vehicle’s technical capabilities.
- Smooth close up must be enabled for all vehicles.
- The safety distance at traffic lights must not be reduced. In the default settings, it is reduced with a factor 0.6; this factor must be set to 1.0.

For analysing the Vissim behaviour, the test track in Vissim has been replicated. The following process has been modelled by opening only one lane for the vehicles and setting the desired speed of the two following vehicles higher than that of the first one. Because the vehicles’ behaviour is no longer of a stochastic nature but deterministic, it is not necessary to reproduce each scenario and to analyse the statistical measures resulting from the different experiments.

For analysing the simulation results, the distance headway against the velocity has been again plotted. The colours of the data points represent the different acceleration procedures in Vissim, called interaction states. In interaction state “Free”, the vehicle accelerates towards its desired speed. In interaction state “Follow”, the difference between target and actual headway is small and thus the acceleration is close to 0. In interaction state “Brake BX” and “Brake AX” the vehicles decelerates, as the distance to the leader is smaller than the target distance. In interaction state “Close up”, the vehicle detects a static obstacle (such as a traffic light) and decelerates towards it.

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5.1 Following an automated vehicle with communication

Figure 15 shows the following behaviour in Vissim with time headway 0.3 second after adjusting the Wiedemann parameters as given in Table 9. It becomes clear that in general, Vissim produces a good fit of the automated behaviour in CACC. The major problem is that when accelerating over a large distance, the following vehicle cannot keep up with the leading vehicle. The vehicle is not capable of accelerating to such an extent that it keeps the headway of 0.3 second. Therefore, the following vehicle accelerates above the speed of the leading vehicle when the latter reaches its desired speed. Consequently, the following distance becomes smaller than the desired headway, which makes the vehicle break again until it meets the desired headway. For larger time headways, this problem did not occur. As a possible solution, we increased the acceleration capabilities for vehicles following an automated vehicle type. Figure 16 depicts the resulting change in behaviour. Some deviations from the desired distance can still be observed, however, these are similar in magnitude to the deviations found in the empirical data. The biggest difference is that the standstill distance in Vissim is always exactly the value for CC0 while the standstill distances of the empirical data vary.

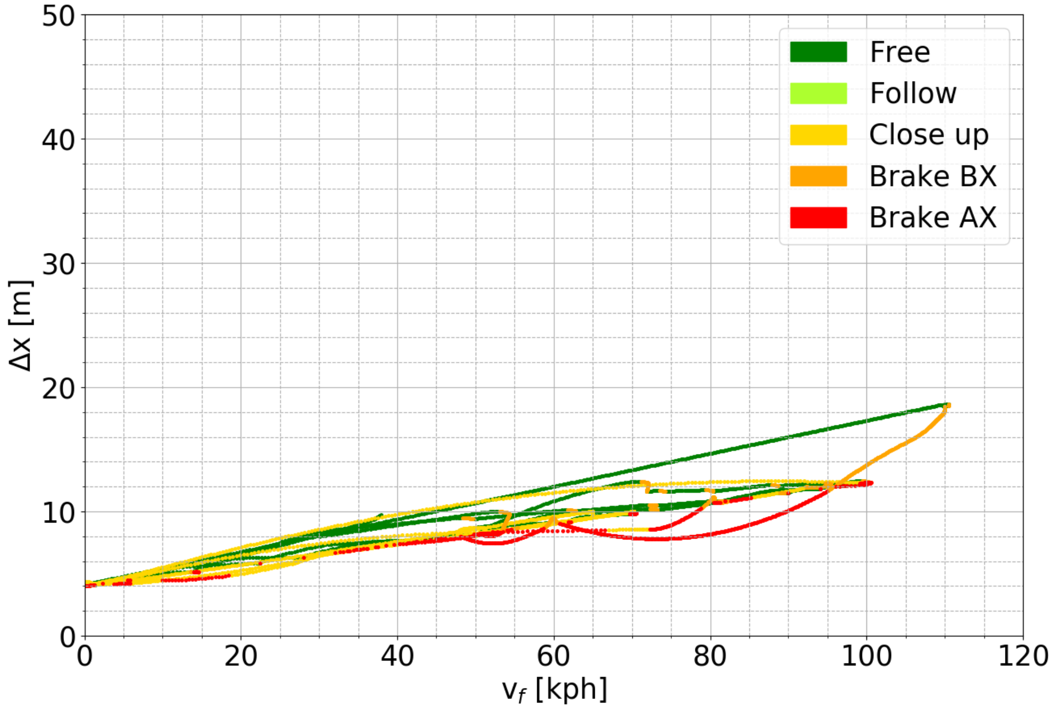

Figure 15: Vissim following behaviour with CACC parameter settings at 0.3 s headway. kph stands for km/h

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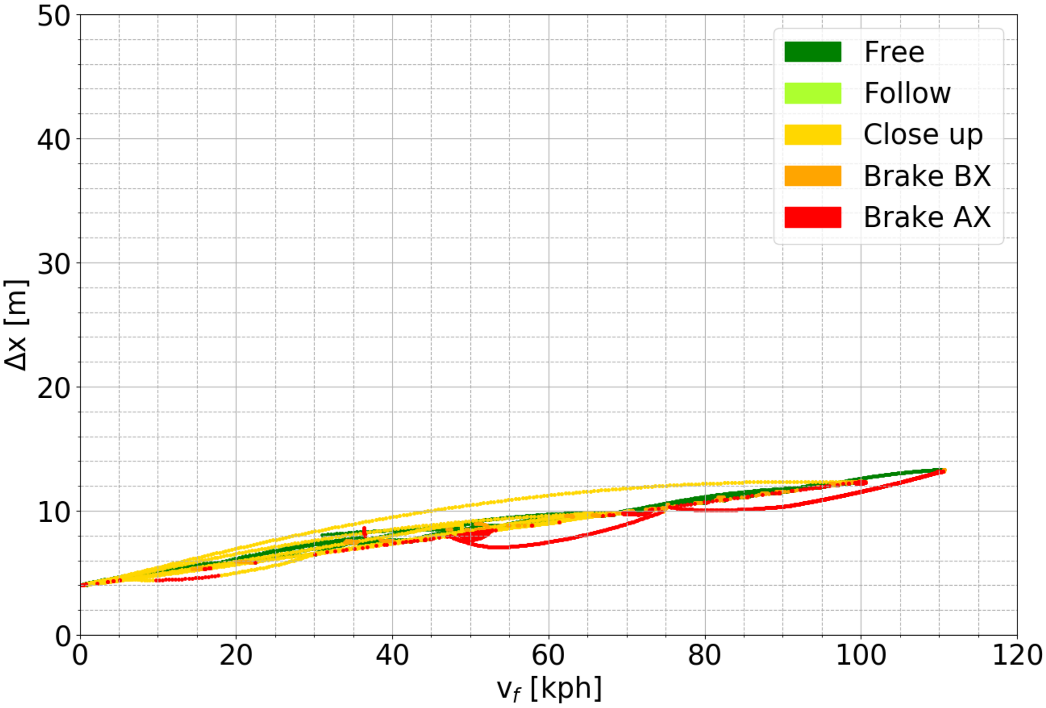

Figure 16: Following behaviour in Vissim when following an automated vehicle in CACC at time headway of 0.3s with adjusted acceleration. kph stands for km/h

5.2 Following an automated vehicle without communication or a manually driven vehicle

For the case of following another vehicle without communication, the picture is different. Reproducing the observed high deviations from the target headway realistically is difficult by adjusting the Wiedemann parameters. Exact match would require the implementation of a new acceleration and deceleration procedure. Especially the large headways when accelerating from standstill have tremendous effects on capacity at nodes. Figure 17 shows the following behaviour without communication (following either an automated or a manually driven car). It is equal to the following behaviour in CACC, with the only difference that the desired time headway is always 1.0 second.

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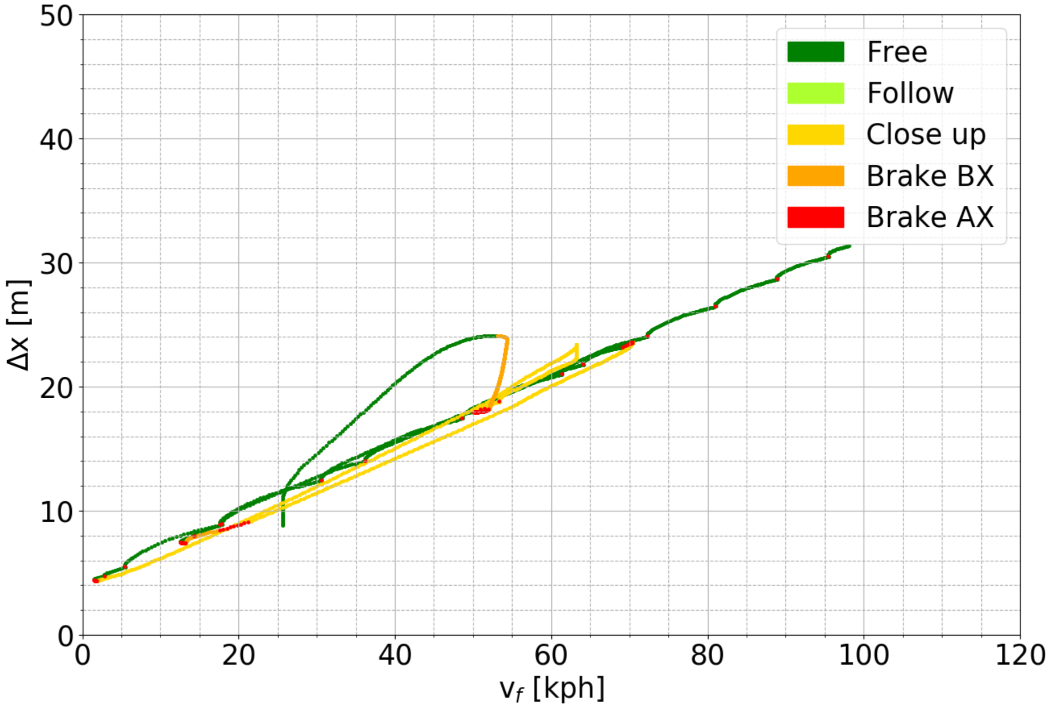

Figure 17: Following behaviour in Vissim when following an automated vehicle without communication or a manually driven vehicle, headway of 1.0 s. kph stands for km/h

6 Validation based on co-simulation data

Co-simulation is a process where one or several automated vehicles controlled by VEDECOM's driving logic is interacting with conventional traffic provided by PTV Vissim. The vehicle dynamics & sensors are provided by PreScan software. The whole process is also called nanosimulation. The technical details about the coupling between VEDECOM driving logic & Prescan & PTV Vissim using the driving simulator interface (drivingsimulator.dll) is described in deliverable D2.2 "Technical report on connecting CAV[5] control logic and CAV simulator".

The output of the co-simulation process is a vehicle record file. It has the following structure (the attributes to be recorded can be chosen in Vissim as needed):

[5] CAV stands for connected and automated vehicle

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```
$VISION
* File: C:\SimulationEnvironment\PreScan-8.3\ScenarioCoSim_XP4 - V2\Vissim\ScenarioSimple.inpx
* Comment:
* Date: 16/04/2018 10:30:46
* PTV Vissim: 10.00 [03]
*
* Table: Vehicles In Network
*
* SIMSEC: SimSec, Simulation second (Simulation time [s]) [s]
* NO: No, Number (Unique vehicle number)
* LANE\LINK\NO: Lane\Link\No, Lane\Link\Number (Unique link/connector number)
* LANE\INDEX: Lane\Index, Lane\Index (Unique number of the lane)
* POS: Pos, Position (Distance on the link from the beginning of the link or connector) [m]
* POSLAT: PosLat, Position (lateral) (Lateral position at the end of the time step. Value range 0 - 1:  0: at the right lane edge  0.5: middle of the lane  1: at the l
* COORDFRONT: CoordFront, Coordinate front (Coordinate of front end of vehicle at the end of the time step)
* COORDREAR: CoordRear, Coordinate rear (Coordinate of rear end position of vehicle at the end of the time step)
* DESSPEED: DesSpeed, Desired speed (Reference to the Desired speed distribution for the vehicle type) [km/h]
* SPEED: Speed, Speed (Speed at the end of the time step) [km/h]
* SPEEDTHEOR: SpeedTheor, Speed (theoretical) (Theoretical speed without hindrance) [km/h]
* SPEEDDIFF: SpeedDiff, Speed difference (Relative to the preceding vehicle in the time step (>0 = faster)) [km/h]
* ACCELERATION: Acceleration, Acceleration (Acceleration during the time step) [m/s2]
* ROUTENO: RouteNo, Route number (Number of route)
* ROUTDECNO: RoutDecNo, Routing decision no (Number of routing decision)
* ROUTDECTYPE: RoutDecType, Routing decision type (Type of routing decision (static, partial route, partial PT route, parking lot, dynamic, closure or managed lanes))
* SAFEDIST: SafeDist, Safety distance (Safety distance during the time step) [m]
* VEHTYPE: VehType, Vehicle type (Select Vehicle type from the list box)
* LENGTH: Length, Length (Minimum and maximum vehicle length (see "Using 2D/3D model distributions")) [m]
* LEADTARGTYPE: LeadTargType, Leading target type (Network object type of the relevant objects downstream (e.g.vehicle, signal head, conflict area))
* LEADTARGNO: LeadTargNo, Leading target number (Number of the relevant preceding vehicle, respectively preceding network object)
* INTERACTSTATE: InteractState, Interaction state (Short identifier for the state in the interaction procedure via which the acceleration or deceleration of the vehicl
* INTERACTTARGNO: InteractTargNo, Interaction target number (Number of the relevant interaction target object.)
* INTERACTTARGTYPE: InteractTargType, Interaction target type (Type of the relevant interaction target object.)
* FOLLOWDIST: FollowDist, Following distance (Distance to the interaction vehicle before the time step  (unit according to network settings [m] or [ft])) [m]
* HDWY: Hdwy, Headway (Distance to the preceding vehicle before the time step) [m]
* DRIVSTATE: DrivState, Driving state
*
* SimSec; No; Lane\Link\No; Lane\Index; Pos; PosLat; CoordFront; CoordRear; DesSpeed; Speed; SpeedTheor; SpeedDiff; Acceleration; RouteNo; RoutDecNo; RoutDecType; Safe
*
$VEHICLE:SIMSEC;NO;LANE\LINK\NO;LANE\INDEX;POS;POSLAT;COORDFRONT;COORDREAR;DESSPEED;SPEED;SPEEDTHEOR;SPEEDDIFF;ACCELERATION;ROUTENO;ROUTDECNO;ROUTDECTYPE;SAFEDIST;VEHT
0.10;1;1;1;1.98;0.50;1.980 0.000 0.000;-2.231 0.000 0.000;3.60;3.45;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
0.20;1;1;1;2.07;0.50;2.070 0.000 0.000;-2.141 0.000 0.000;3.60;3.20;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
0.30;1;1;1;2.16;0.50;2.155 0.000 0.000;-2.056 0.000 0.000;3.60;2.96;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
0.40;1;1;1;2.23;0.50;2.234 0.000 0.000;-1.977 0.000 0.000;3.60;2.72;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
0.50;1;1;1;2.31;0.50;2.306 0.000 0.000;-1.905 0.000 0.000;3.60;2.47;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
0.60;1;1;1;2.37;0.50;2.371 0.000 0.000;-1.840 0.000 0.000;3.60;2.23;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
0.70;1;1;1;2.43;0.50;2.430 0.000 0.000;-1.781 0.000 0.000;3.60;1.99;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
0.80;1;1;1;2.48;0.50;2.481 0.000 0.000;-1.730 0.000 0.000;3.60;1.72;3.60;0.00;0.00;;;;0.00;100;4.21;;;Free;;;0.00;0.00;Default
```

Figure 18 Example of vehicle record file

6.1 Simulation tests

The simulation tests are based on simple network, where the ego vehicle (automated vehicle controlled by VEDECOM's driving logic) is following a conventional vehicle simulated by Vissim. The desired speed of the ego vehicle is set higher than the highest driven speed of the conventional vehicle. This ensures, that the ego vehicle is in following state after certain simulation time. The simple network consists from one one-lane main link, the ego vehicle enters the network from left, the Vissim vehicle enters the network from the bottom link. The conventional (Vissim) vehicle changes the speed because of modelled objects like reduced speed areas, stop signs, speed decisions or signals. The ego vehicle does not react on mentioned Vissim objects, it reacts only on the leading vehicle in the following process. 500 metres before the end of the main link in the simple model the conventional vehicle leaves the network through the link on the top, the automated vehicle continues to the end of the main link. The length of the main link is 5 kilometres.

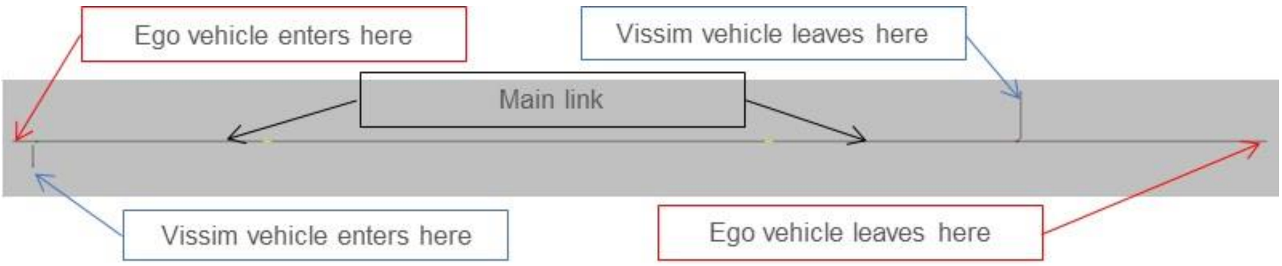

Figure 19 Basic test layout for co-simulations

For the Vissim simulation test, this feature setup has been used:

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Table 10 Feature setup used for the Vissim simulation tests

Feature	State
Enforce absolute braking distance	off
Use implicit stochastic	off unless otherwise noted
Increased acceleration	off unless otherwise noted
Signal control behaviour	Vissim default unless otherwise noted

6.1.1 Test 1

In this test layout two reduced speed areas (30 metres long) were implemented, where the conventional vehicle needs to reduce its speed to 20 km/h. When leaving the reduced speed area, the conventional vehicle accelerates to a desired speed of 50 km/h.

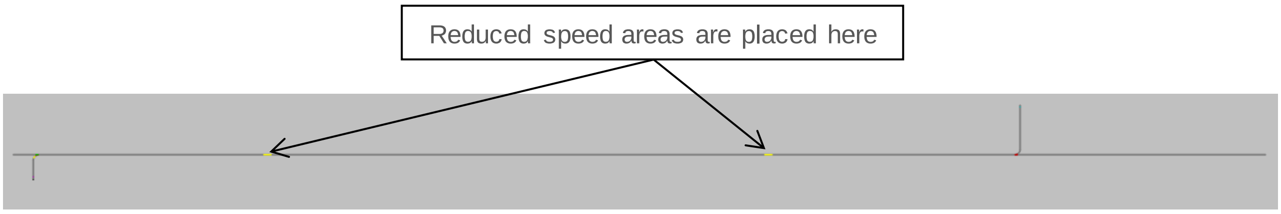

Figure 20: Layout of test 1

The following Vissim driving behaviour parameters (Wiedemann99 Model) have been used for test 1 (see Table 11):

Table 11: Vissim driving behaviour parameters used for test 1 (W99)

Parameter	CC0	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9
Value test 1	1.5	2	0	-8	-0.1	0.1	0	0.25	3.5	1.5
Unit	m	s	m	M	m/s	m/s	1/(m.s)	m/s^2	m/s^2	m/s^2

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research and innovation programme under grant agreement No. 723201

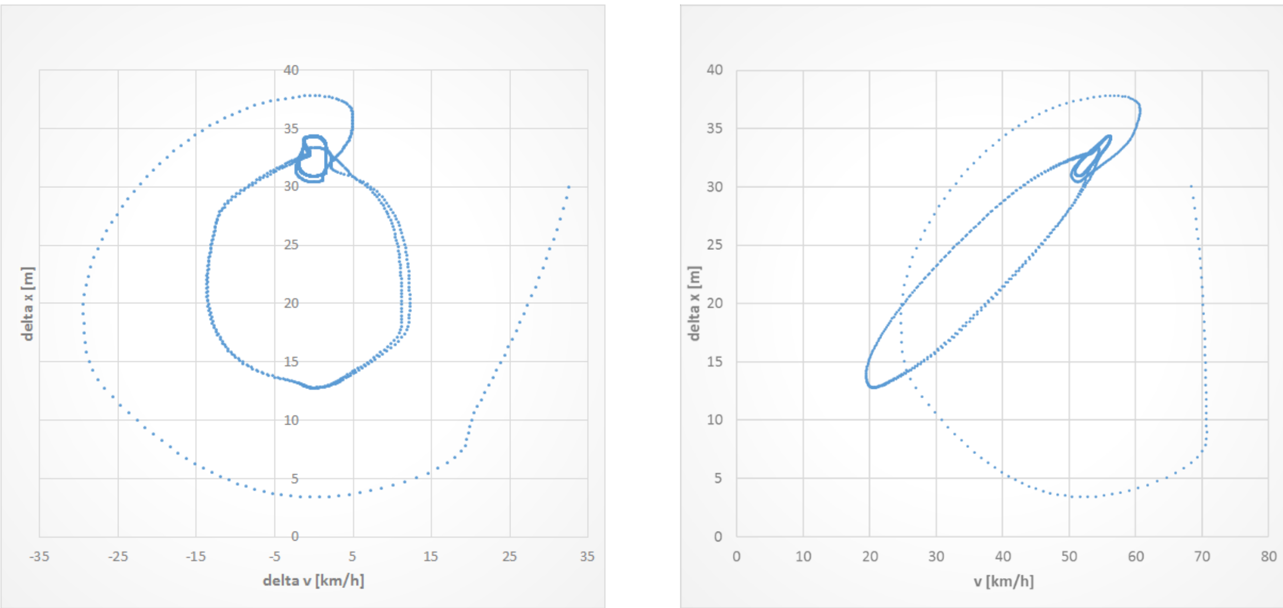

Figure 21: Co-simulation results of test 1 (VEDECOM's driving logic)

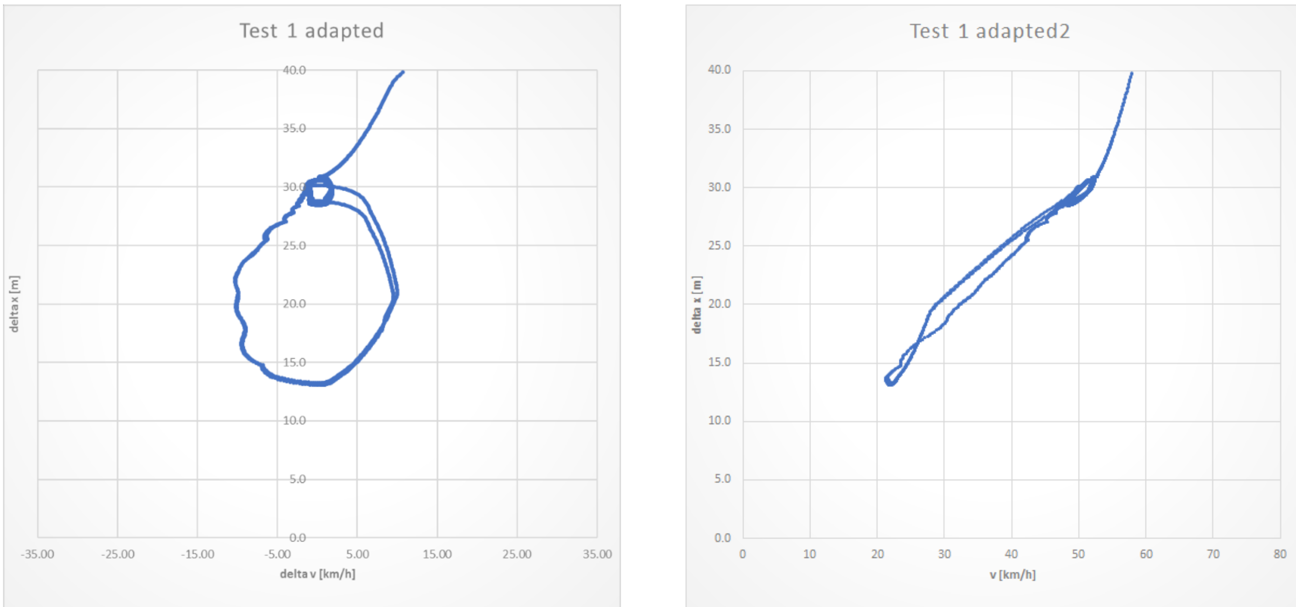

Figure 22: Vissim simulation results of test 1

As shown in Figure 21 and Figure 22, the shape of the dv/dx diagram (left-hand side of the figures) is not identical in co-simulation and Vissim simulation, but quite similar. The position of the small following circle between 30 and 35 metres distance in the co-simulation is slightly higher than in the Vissim simulation – this can be easily corrected by increasing the headway time parameter in Vissim. The bigger elliptical shape in v/dx diagram (right -hand side of the figures) was not achieved in Vissim simulation, but the range and angle are right, and the result is acceptable.

6.1.2 Test 2

In the second test, a stop sign is placed each 500 metres, where the conventional vehicle needs to stop for one simulation time step. After that, the conventional vehicle accelerates to its desired speed of 50 km/h. The automated vehicle does not react on the stop sign, just follows the conventional vehicle.

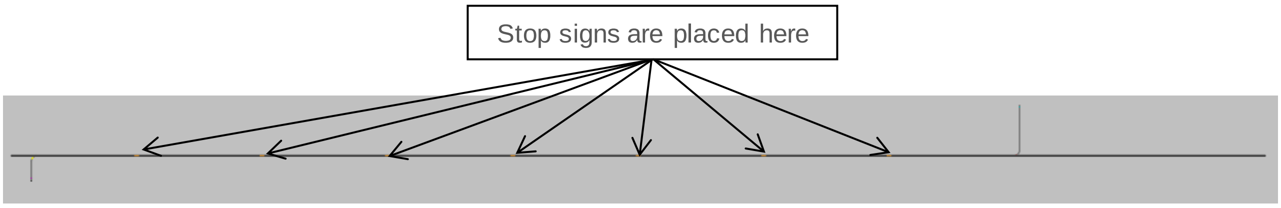

Figure 23: Layout of test 2

The following Vissim driving behaviour parameters (Wiedemann99 Model) have been used for test 2 (see Table 12):

Table 12: Vissim driving behaviour parameters used for test 2 (W99)

Parameter	CC0	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9
Value test 2a	1.5	2	0	-8	-0.1	0.1	0	0.25	3.5	1.5
Value test 2b*	1.5	2	0	-8	-0.1	0.1	0	0.25	3.5	1.5
Unit	m	s	m	m	m/s	m/s	1/(m.s)	m/s^2	m/s^2	m/s^2

* "increased acceleration" parameter set to 110%

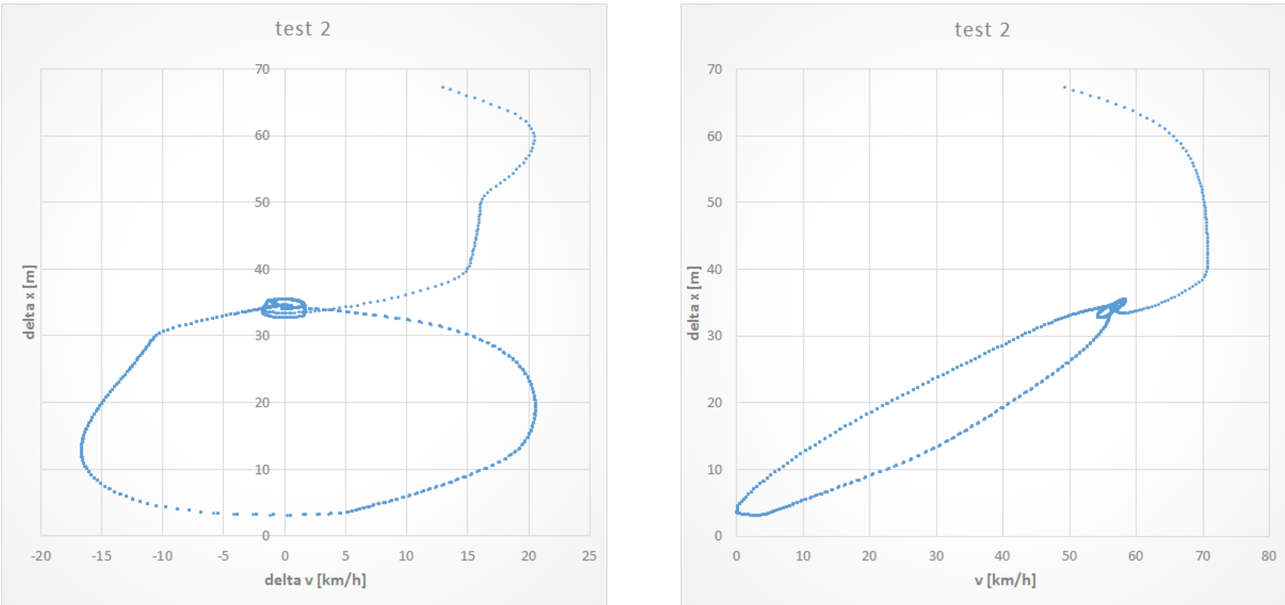

Figure 24: Co-simulation results test 2 (VEDECOM's driving logic)

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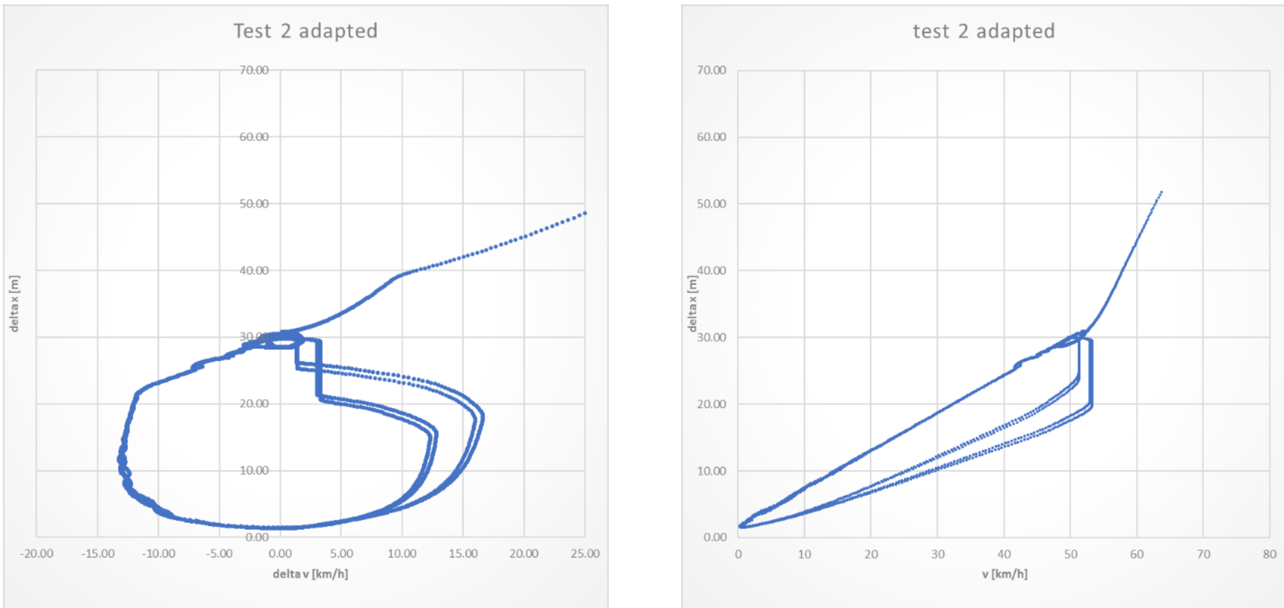

Figure 25: Vissim simulation results test 2a

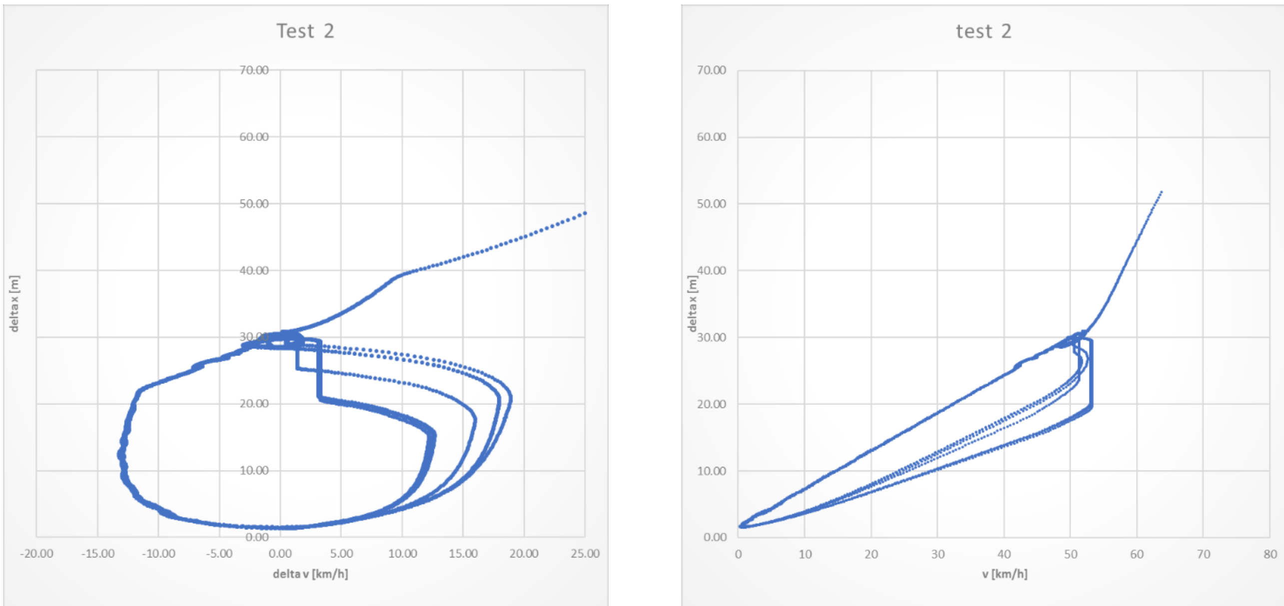

Figure 26: Vissim simulation results test 2b

As seen on the left-hand side of Figure 24, Figure 25, and Figure 26 the shape of the dv/dx diagram is not identical in the co-simulation and the Vissim simulation, but quite similar except of a couple of dx drops at small positive speed difference. The position of the small following circle around 35 metres distance in the co-simulation is slightly higher than in the Vissim simulation – this can be easily corrected by increasing the headway time parameter in Vissim. The bigger elliptical shape in v/dx diagram (right-hand side of the figures) was not achieved exactly in Vissim simulation, but the range and angle are right, and the result is acceptable. Setting the parameter “increased acceleration” to 110 % in test 2b shows slightly better results in dv/dx diagram than the test 2a.

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6.1.3 Test 3

In the third test, a stop sign is placed each 500 metres, where the conventional vehicle needs to react on the signal state e.g. stop and wait couple of seconds for a green signal. After that, the conventional vehicle accelerates to its desired speed of 50 km/h.

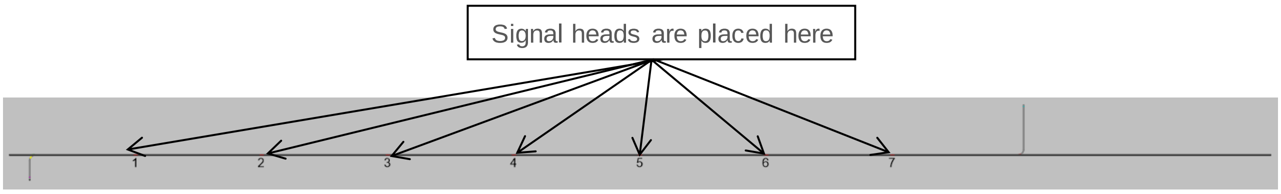

Figure 27: Layout of test 3

These Vissim driving behaviour parameters (Wiedemann99 Model) have been used for test 3 (see Table 13):

Table 13: Vissim driving behaviour parameters used for test 3 (W99)

Parameter	CC0	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9
Value test 3a	1.5	2	0	-8	-0.1	0.1	0	0.25	3.5	1.5
Value test 3b*	1.5	2	0	-8	-0.1	0.1	0	0.25	3.5	1.5
Unit	m	s	m	m	m/s	m/s	1/(m.s)	m/s2	m/s2	m/s2

* Factor “Reduced safety distance close to a stop line” (signal control tab) set to 1 (default = 0.6)

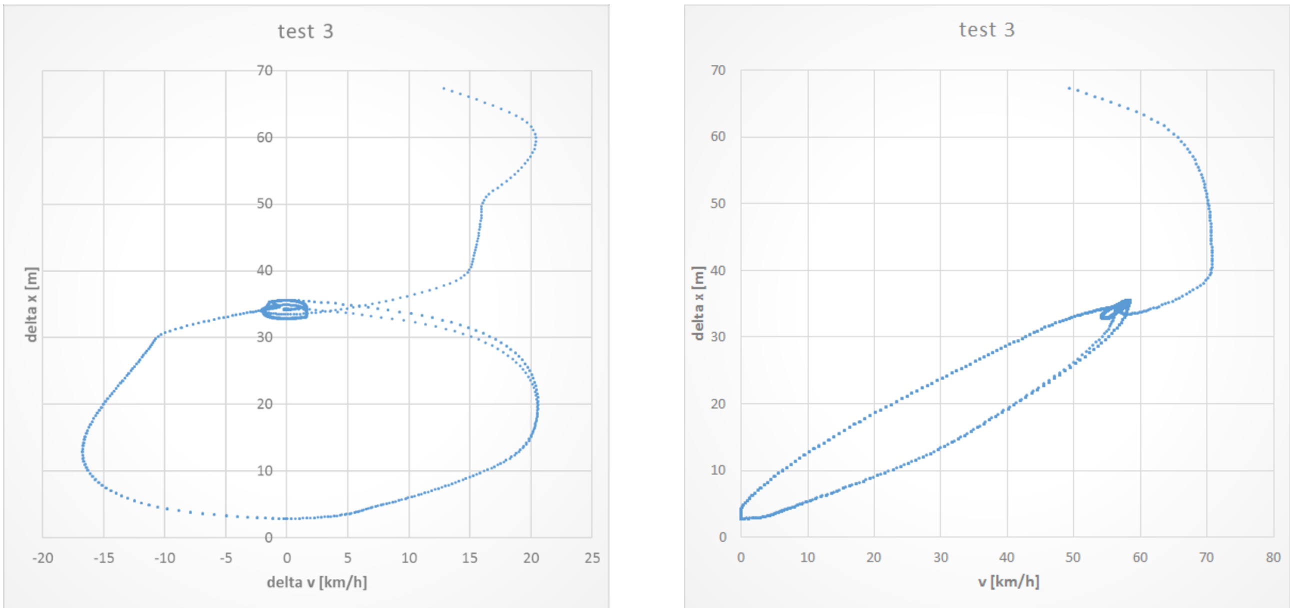

Figure 28: Co-simulation results test 3 (VEDECOM’s driving logic)

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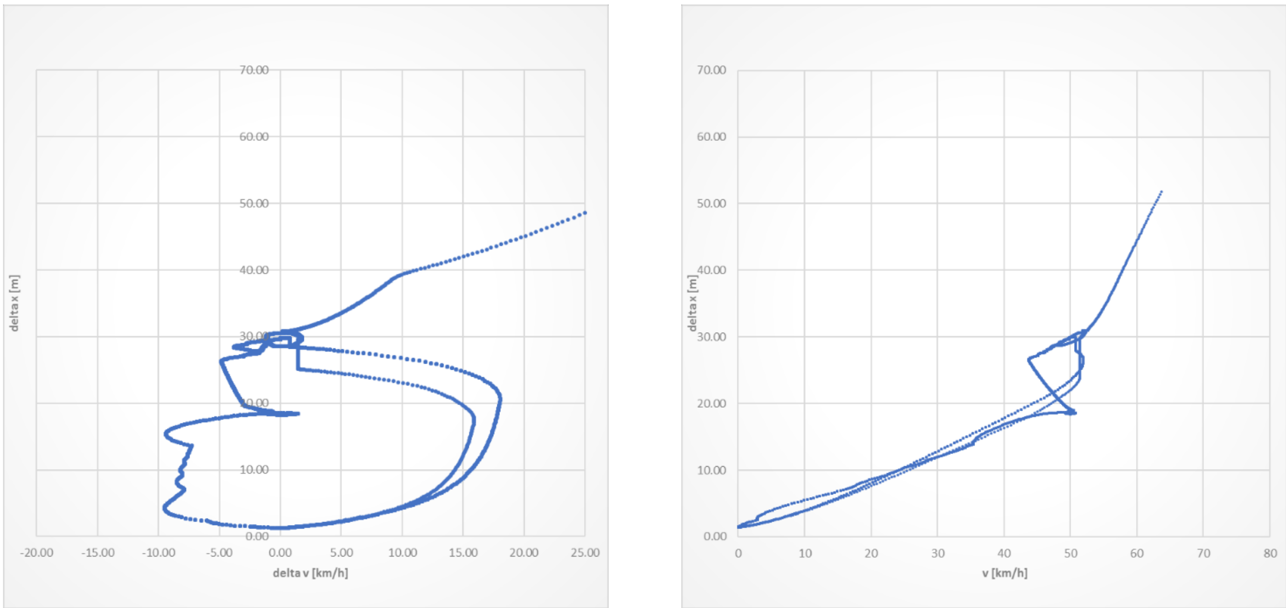

Figure 29: Vissim simulation results test 3a

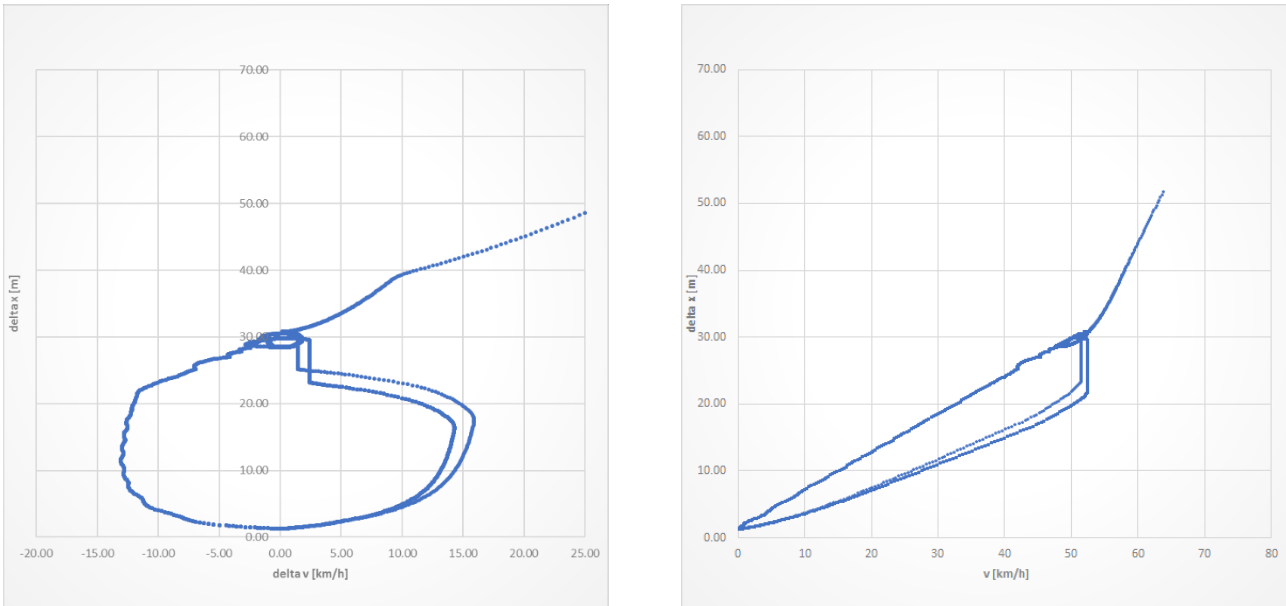

Figure 30: Vissim simulation results test 3b

As seen on Figure 28,Figure 29 and Figure 30 the shape of the dv/dx diagram (left-hand side of the figures) is not identical in the co-simulation and Vissim simulation test 3a because of the factor “Reduced safety distance close to a stop line”. By changing this factor to 1.0, a much better conformity can be achieved – like in the test 3b. The position of the small following circle around 35 metres distance in the co-simulation is slightly higher than in the Vissim simulation – this can be easily corrected by increasing the headway time parameter in Vissim. The bigger elliptical shape in v/dx diagram (right-hand side of the figures) was not achieved exactly in Vissim simulation, but the range and angle are right, and the result is acceptable in test 3b.

6.1.4 Test 4

In the fourth test, a desired speed decision is placed each 1000 m, where the conventional vehicle starts to accelerate to the new desired speed, which is higher than the previous desired speed.

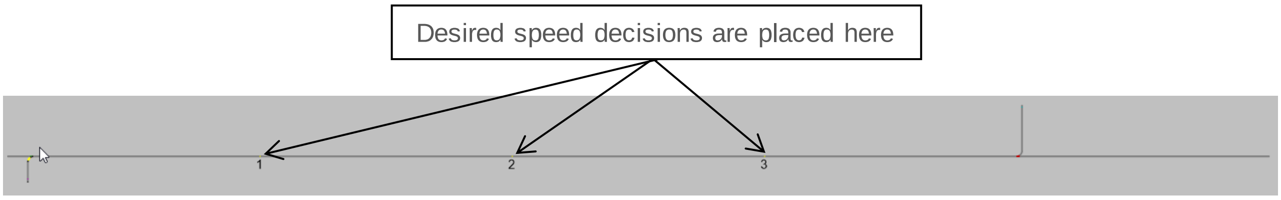

Figure 31: Layout of test 4

The following Vissim driving behaviour parameters (Wiedemann99 Model) have been used for test 4 (see Table 14):

Table 14: Vissim driving behaviour parameters used for test 4 (W99)

Parameter	CC0	CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8	CC9
Value test 4a*	1.5	2	4	-8	-0.35	0.35	11,44	0.25	3.5	1.5
Value test 4b	1.5	2	0	-8	-0.35	0.35	0	0.25	3.5	1.5
Value test 4c	1.5	1	0	-8	-0.35	0.35	0	0.25	3.5	1.5
Unit	m	s	m	m	m/s	m/s	1/(m.s)	m/s^2	m/s^2	m/s^2

* "Use implicit stochastic" is on

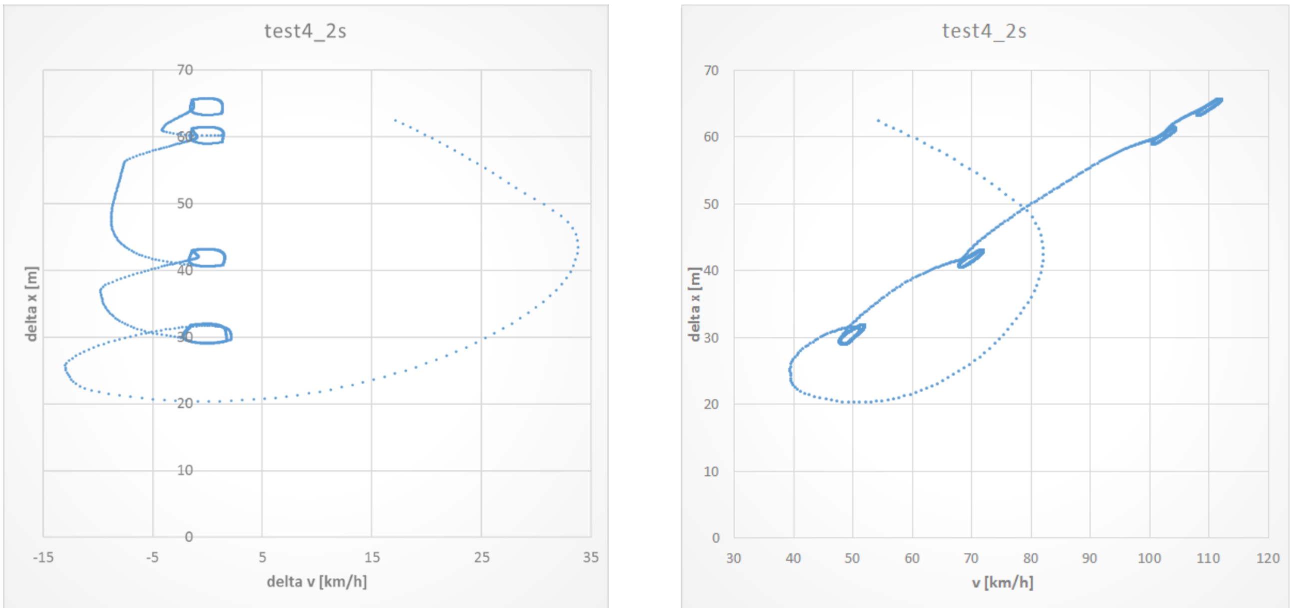

Figure 32: Co-simulations results test 4 (VEDECOM's driving logic), headway is set to 2s

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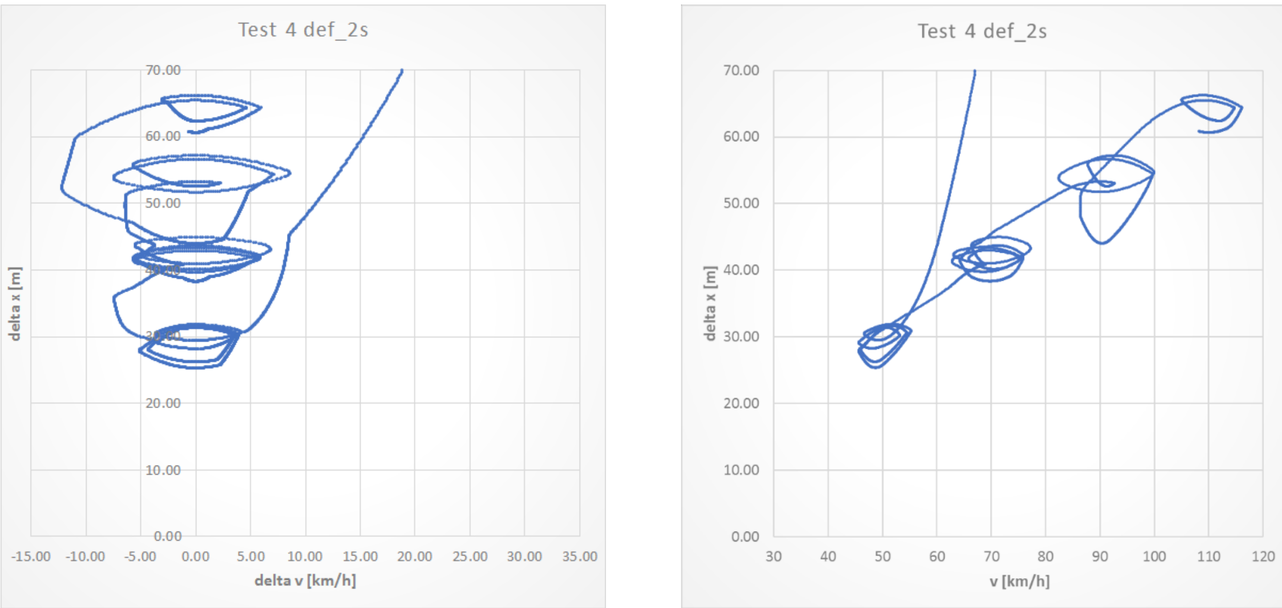

Figure 33: Vissim simulation result test 4a

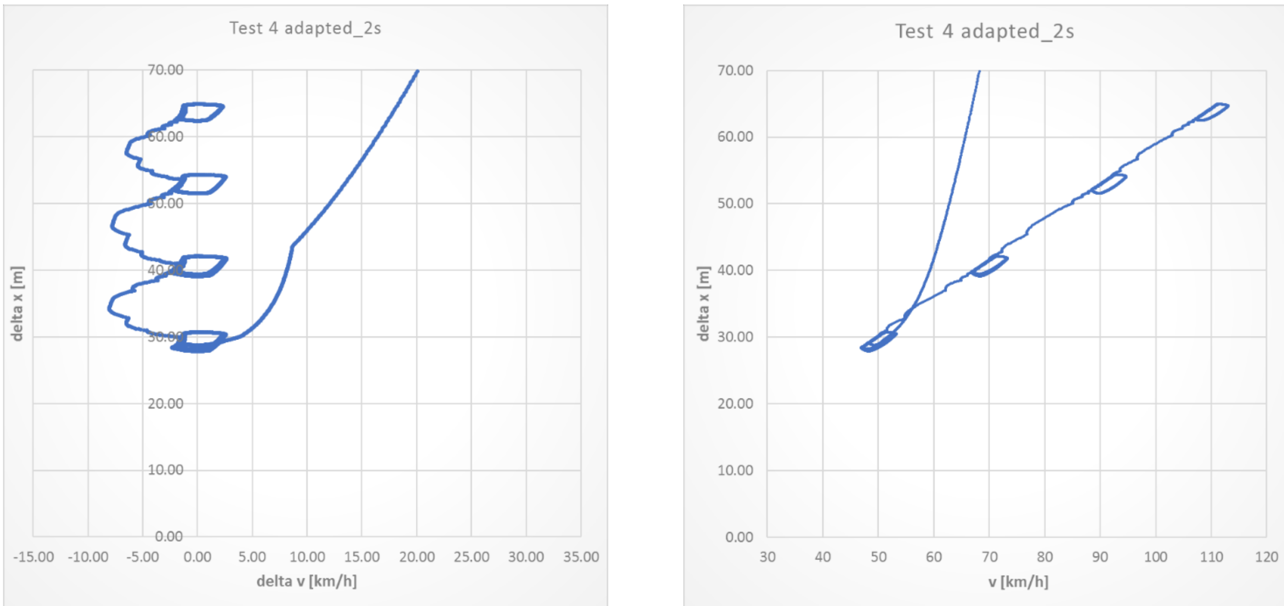

Figure 34: Vissim simulation result test 4b

Figure 33 shows the results of Vissim simulation with default driving parameters and settings. The difference to the co-simulation results depicted in Figure 32 is clear. Figure 34 shows the results with changed parameters and settings - the shape of the dv/dx and v/dx diagram is very similar to the co-simulation results. The vertical span between the small following circles differs because of different desired speeds in the co-simulation and the Vissim simulation – of course that can be unified and then would lead to even better conformity. Thus, the results are acceptable.

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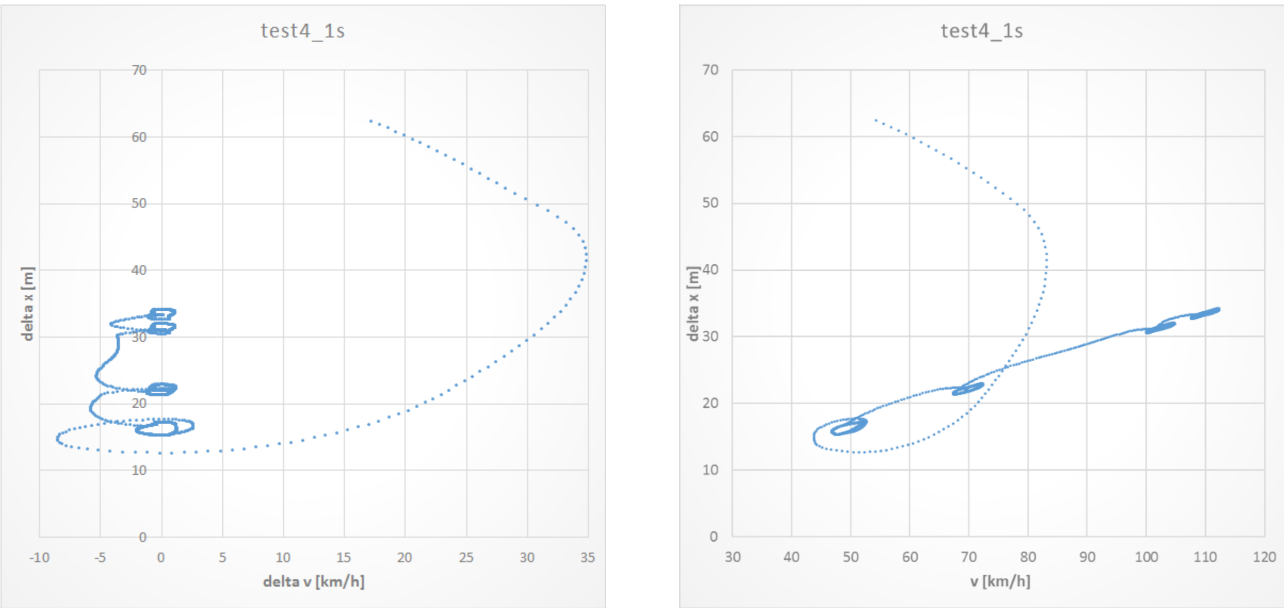

Figure 35: Co-simulation results test 4 (VEDECOM's driving logic), headway set to 1 s

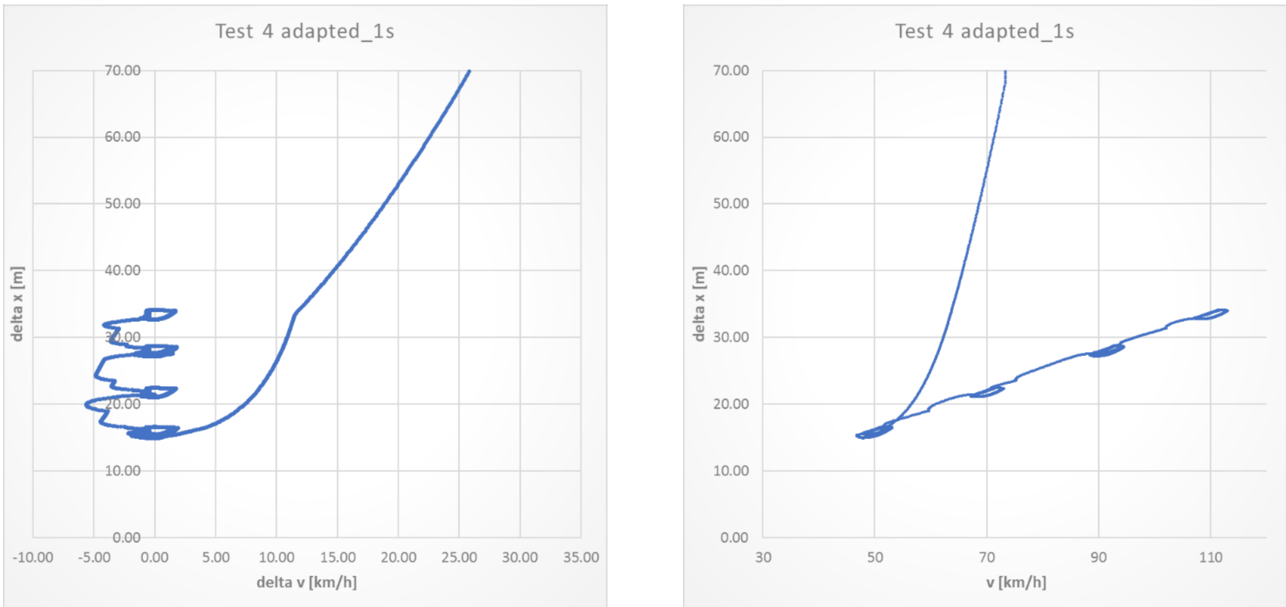

Figure 36: Vissim simulation results test 4c

Figure 35 shows the same test as Figure 32 but with different headway time: 1 second instead of 2 seconds. The similarity with the Vissim simulation results is obvious except for the vertical span of the small following circles because of different desired speeds in co-simulation and Vissim simulation – this can be easily unified and then would lead to even better conformity. Thus, the results are acceptable.

7 Results summary

7.1 Results from empirical data evaluation

Please note, that these results are abstracted from a data collected on one test-track with one specific driving logic (developed by TNO) and one specific vehicle type (Toyota Prius) with specific technical equipment (sensors). Only statement about the following process can be done. Another automated vehicle with different driving logic or technical equipment may lead to differences in results, but it is expected, that the principles remain.

- Linear deterministic relationship between headway and speed by following another automated vehicle with car to car (C2C) communication. Human imperfection while driving is replaced by higher precision and deterministic nature of technical equipment and algorithms.
- Almost linear relationship between headway and speed when following manually driven car or an automated car without C2C communication. The linear relationship is not as neat as with C2C communication but could be approximated.
- Oscillations during following process are small and without much variance in comparison with human drivers.
- Safety distance without C2C communication is much higher than in the communication case: With C2C communication the test vehicles were able to drive safely with 0.6 or 0.3 second headway. After the disconnection of the C2C communication the vehicle adapted to larger following distance because of safety reasons.
- Large safety distance in driveaway behaviour when there is no communication. When following from standstill, the test vehicle kept significantly larger safety distance in the case without C2C communication than with C2C.
- No stochastic variation in driveaway behaviour.
- When the vehicle followed another vehicle from a standstill (in front of a signal head), the following process did not show stochastic variations – the same behaviour applied each time.

7.2 Results from co-simulations

Please note, that these results are abstracted from co-simulation results with one driving logic (developed by VEDECOM). Only statement about the following process can be done. Sensors needed for following behaviour were simulated in PreScan software. Different driving logic may lead to differences in results.

- Relationship between headway and speed during following process is deterministic and has an elliptical shape
- Oscillation during following is smaller and without much variance in comparison with human driven vehicle

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7.3 Validation results

The test-track results and co-simulation results showed fundamental differences between automated vehicles and human driven vehicles in following behaviour. Modelling of such automated vehicles in PTV Vissim (directly within GUI without the need for use of interfaces & programming work) required not only change of existing driving behaviour parameters, but also adding some new features into PTV (see deliverable D2.4: "Vissim extension – new features and improvements"). Simulation test proved, that using new features and adapted driving behaviour parameters it is possible to model such behaviour with satisfactory level of accuracy.

Although PTV Vissim allows to simulate a lot of expected or assumed driving behaviours, some specific use cases, significantly different driving logics or complex strategies (especially communication and cooperation) might still require the use of exact algorithms (algorithm used by automated vehicles) with one of PTV Vissim interfaces – drivermodel.dll, drivingsimulator.dll or COM.

7.4 Use of results by PTV Group and the CoEXist consortium

- Development of new features
  - The findings from empirical data analysis and co-simulation results have been used to propose necessary new features in order to be able to simulate the behaviour of automated vehicles. All new features are described in D2.4 "Vissim extension – new features and improvements" and will be tested by the four CoEXist cities (Gothenburg, Helmond, Milton Keynes and Stuttgart) to assess the impact of automated and connected vehicles on their road networks.
- Definition of driving behaviour sets for automated vehicles
  The findings from empirical data analysis and co-simulation results have been also used to:
  - determine the direction of the change of driving behaviour parameters: from default values available in PTV Vissim for conventional vehicles to new values for automated vehicles. The "direction" says it the new value used for automated vehicles should be higher, smaller or same as the default value for conventional vehicles. Setting the direction is important, because there might be differences between particular automated vehicles in the future and one exact value might not fit for all of them. In such case, the user can specify several vehicle classes with different driving behaviour values;
  - propose the appropriate values for driving behaviour parameters for four driving logics of automated vehicles.

  All proposed driving behaviour sets are described in D2.3: "Default behavioural parameter sets".

7.5 Use of the results by other researchers

- Understanding the differences to conventional vehicles
  - The results are showing fundamental differences of automated vehicles in comparison with conventional with human driver. Please note, that the differences are related to used

vehicles & driving logics on the test-track (developed by TNO) and used driving logic in co-simulations (developed by VEDECOM). Other automated vehicles might differ less or more.

- Knowing the driving behaviour in specific tests
  - The driving behaviour was observed within several scenarios and test layouts. Please note, that not all possible layout or scenarios can be tested within one project.

8 Partners

Participation of partner on this deliverable:

- Preparation: Rupprecht, PTV Group, TASS international, University of Stuttgart
- Data collection: TASS international
- Data evaluation: PTV Group
- Co-simulations
  - Preparation of the software couplings: VEDECOM, Renault, PTV Group, TASS international
  - Preparation of co-simulation tests: PTV Group, VEDECOM
  - Running co-simulation test: VEDECOM
  - Evaluation of co-simulation outputs: PTV Group
- Validation: PTV Group

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