



CoEXist

D2.5

Micro-simulation guide for automated vehicles

Version: 1.0

Date: 31.10.18

Author: Peter Sukennik (PTV Group)

The sole responsibility for the content of this document lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the EASME nor the European Commission are responsible for any use that may be made of the information contained therein.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723201-2

Document Control Page

Title	Micro-simulation guide for automated vehicles		
Creator	Peter Sukennik (PTV Group)		
Editor	Charlotte Fléchon (PTV Group)		
Reviewer	Bernard Gyergyay (Rupprecht) Johan Olstam (VTI) Charlotte Fléchon (PTV Group) Jared Best (PTV Group)		
Brief Description			
Contributors			
Type (Deliverable/Milestone)	D2.5		
Format			
Creation date			
Version number	1.0		
Version date	31/10/2018		
Last modified by			
Rights			
Audience	<input type="checkbox"/> Internal <input checked="" type="checkbox"/> Public <input type="checkbox"/> Restricted, access granted to: EU Commission		
Action requested	<input type="checkbox"/> To be revised by Partners involved in the preparation of the Deliverable <input type="checkbox"/> For approval of the WP Manager <input type="checkbox"/> For approval of the Internal Reviewer (if required) <input type="checkbox"/> For approval of the Project Co-ordinator		
Deadline for approval			
Version	Date	Modified by	Comments

--	--	--	--



Table of contents

1	Purpose of this document	6
1.1	What is possible in PTV Vissim?	6
1.2	Communication and cooperation	6
1.3	The CoEXist project.....	7
2	AV characteristics & assumptions	7
2.1	Field data.....	8
2.2	AV Driving logic	8
2.3	Reduction of stochastics.....	9
2.3.1	Functions.....	9
2.3.2	Distributions.....	10
3	Simulation with PTV Vissim internally.....	11
3.1	Driving behaviour settings on a link level.....	11
3.1.1	Driving behaviour.....	11
3.1.2	Link behaviour types.....	12
3.1.3	Spatial extent.....	12
3.2	AV related features.....	13
3.2.1	Enforce absolute braking distance.....	14
3.2.2	Use implicit stochastics	15
3.2.3	Number of interaction objects and vehicles	16
3.2.4	Headway based on leader vehicle class	17
3.2.5	Increased acceleration	18
3.2.6	Occupancy distribution with zero passengers	19
3.2.7	Consider vehicles in dynamic potential	20
3.2.8	Platooning	20
3.3	Driving parameters	21
3.3.1	Following behaviour.....	21
3.3.2	Lane change behaviour	22
3.3.3	Lateral behaviour.....	22
3.3.4	Signal control behaviour	23
3.4	AV – Penetration rates	23
3.5	Future adaptation of human drivers.....	23
3.6	Safety aspects	23
3.7	Examples.....	24
4	Simulation with PTV Vissim externally.....	24

4.1 PTV Vissim interfaces 25

4.1.1 COM.....25

4.1.2 DriverModel.....26

4.1.3 DrivingSimulator27

4.2 Vehicles Dynamics & sensors (nano-simulation)..... 29

5 Next steps..... 29



1 Purpose of this document

This document was created as part of the project CoEXist¹. The intent of this document is to provide a comprehensive description on modelling of automated vehicles with PTV Vissim 11 or later versions. Adjustments to different types of models, in simulation software other than PTV Vissim, can be inferred from the recommendations given here, but caution must be taken especially when the driving behaviour parameters are based on a different type of model (e.g. models apart from Wiedemann).

1.1 What is possible in PTV Vissim?

Automated vehicles can have different automation levels², different automation functions, different sensor equipment, and different driving logics. The modelling technique depends on the scope of information you have about the automated vehicles.

With driving logics algorithms

If the driving logics algorithms are known or under development, one of PTV Vissim's interfaces can be used to couple the algorithms with PTV Vissim. This allows direct testing of algorithms, giving the ability to visualize and compare the interaction between automated vehicles equipped with the algorithms and conventional vehicles provided by the PTV Vissim model. This process is described in 'D2.2 Technical Report on connecting AV control logic and AC Simulator' available on the CoEXist website.

Without driving logics algorithms

If the algorithms are not known, the driving behaviours offered by PTV Vissim can be used as a starting point for the model. The expected driving behaviour of automated vehicles should be always considered. Saying e.g. **automation level 4** is insufficient for microscopic simulation because it requires knowledge or assumptions about the behaviour when following lane changing, reacting on signals or resolving conflicts, e.g. gaps, thresholds, etc. Using the human driver as a benchmark, expected behaviour of automated vehicles in terms of desired speed or acceleration can be defined (following headway, its variability, etc.). Some suggestions are provided by in 2 AV characteristics & assumptions for more information.

1.2 Communication and cooperation

Basic cooperation features are implemented in PTV Vissim already. However, these have been introduced to replicate how humans cooperate. Cooperation beyond that scope needs to be reflected another way.

¹ See <https://www.h2020-coexist.eu/>

² See SAE Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (J3016) <https://www.sae.org/standards/>

The screenshot shows the 'Driving Behaviour' window for a vehicle named 'AV_allknowing (CoEXist)' with ID '103'. The 'Lane Change' tab is selected. The 'General behavior' is set to 'Free lane selection'. The 'Necessary lane change (route)' section contains parameters for 'Own' and 'Trailing vehicle' vehicles, including maximum deceleration, distance, and accepted deceleration. The 'Waiting time before diffusion' is 60.00 s. The 'Min. net headway (front to rear)' is 0.50 m. The 'To slower lane if collision time is above' is 11.00 s. The 'Safety distance reduction factor' is 0.75. The 'Maximum deceleration for cooperative braking' is -6.00 m/s². The 'Cooperative lane change' section is highlighted in yellow, showing 'Maximum speed difference' as 10.80 km/h and 'Maximum collision time' as 10.00 s. The 'Advanced merging' checkbox is checked and highlighted in yellow. The 'Rear correction of lateral position' is unchecked. The 'Active during time period from' is 1.00 s until 10.00 s after lane change start.

Figure 1 Driving behaviour window from Vissim 11, where advanced merging and the parameters for cooperative lane change are highlighted

Communication and cooperation might be a complex process with complex or simple outputs and impacts. For example, if the impact of communication between vehicles leads to small headways between them, you might achieve this by changing the driving behaviour parameters, especially CC0, CC1, CC2, CC6. See general [PTV Vissim help for parameter description - Defining the Wiedemann 99 model parameters](#).

If the communication leads to complex longitudinal and lateral maneuverers, then you would likely need to use one of the PTV Vissim interfaces and describe the manoeuvres as an algorithm. Communication in vehicle platoons including joining or leaving the platoon will be provided as feature in future service pack of PTV Vissim. See section 3.2.8 Platooning for more information.

1.3 The CoEXist project

Many AV-related enhancements and new features in PTV Vissim have been implemented within the project CoEXist. CoEXist is a European project (May 2017 – April 2020) which aims at preparing the transition phase during which automated and conventional vehicles will coexist on cities' roads. For more information see <https://www.h2020-coexist.eu/>.

2 AV characteristics & assumptions

2.1 Field data

Field data from the test track in Helmond (NL) collected as part of CoEXist³ has shown for tested automated vehicles:

- Almost a linear relationship between headway and speed when following a manually driven car or an automated car without car-to-car (C2C) communication.
- A linear deterministic relationship between headway and speed when following another automated vehicle with car-to-car (C2C) communication.
- Oscillations during vehicle following are small with little variation in comparison with human drivers.
- No stochastic variation in driveaway behaviour. That was observed when vehicle accelerated on green signal at the intersection.

To reproduce the behaviour observed on the test track, it is necessary to change the driving behaviour parameters based on Wiedemann 99 model and use additional features developed for this purpose. See section 3.2 AV related features for more information.

2.2 AV Driving logic

Each automated vehicle uses a driving logic. Instead of distinguishing between car manufacturer's or company's driving logics, CoEXist works with 4 fundamental driving logics described by their major principles and capabilities. The logics are named **rail safe**, **cautious**, **normal**, and **all-knowing**.

The driving logics **cautious**, **normal** and **all-knowing** are part of the PTV Vissim default.inpx file as separate driving behaviours. They are based on the Wiedemann 99 car-following model with adjusted driving behaviour parameters and additional features developed for PTV Vissim 11. See section 3.2 AV related features for more information.

The **rail safe** driving logic is not included in PTV VISSIM DEFAULT.INPX file because of its special nature and application area.

Rail safe

This driving logic requires the appropriate parameters in addition to a special modelling approach to be in line with the driving logic principles. The **rail safe** driving logic describes a deterministic behaviour that represents the closed, controlled environment found at ports or within factories. It is characterized by the presence of physically separate lanes or large lateral distances, a pre-defined path that the vehicles follow, no lane change, and no unsignalized intersection. Furthermore, the brick wall stop distance always remains activated, see the feature **enforce absolute braking distance**, section 3.2.1 3.2.1Enforce absolute braking distance. The modeller needs to keep all these specific details in mind.

Cautious

³ See "D2.6 Technical report on data collection and validation process" for additional information about the data collection process. Report available on www.h2020-coexist.eu.

The vehicle observes the road code and always adopts a safe behaviour. The brick wall stop distance is always active, see the feature **enforce absolute braking distance** and unsignalized intersections and lane changes are possible, but the vehicle will maintain large gaps. See section 3.2.1 Enforce absolute braking distance for more information.

Normal

The vehicle behaves like a human driver with the additional capacity of measuring distances and speeds of the surrounding vehicles with its range of sensors.

All-knowing

The vehicle has profound awareness and predictive capabilities, leading mainly to smaller gaps for all manoeuvres and situations. A kind of cooperative behaviour is expected.

2.3 Reduction of stochastics

Stochastics have been implemented into PTV Vissim to reflect the randomness of human driving behaviour. Two types of stochastics are available in PTV Vissim:

Explicit stochastics

Is defined by functions and distributions which the user can change directly.

Implicit stochastics

Is hard-coded and cannot be changed by the user. However, starting with PTV Vissim 11, this can be switched off (is on by default) in the dialog or list of driving behaviours (tab Following). See section 3.2.2 **Use implicit stochastics** for more information.

2.3.1 Functions

Functions are accessible through the main menu: **Base Data > Functions**.

It is expected that automated vehicles will behave deterministically instead of stochastically like human drivers. This might have implications on the acceleration and deceleration behaviours. Based on this assumption, the modeler can reduce the spread of values for individual vehicles for:

- Desired acceleration
- Desired deceleration
- Maximum acceleration
- Maximum deceleration

The reduction can be done by simply changing the max and min curves, bringing them closer to the median curve or putting them on the median curve:

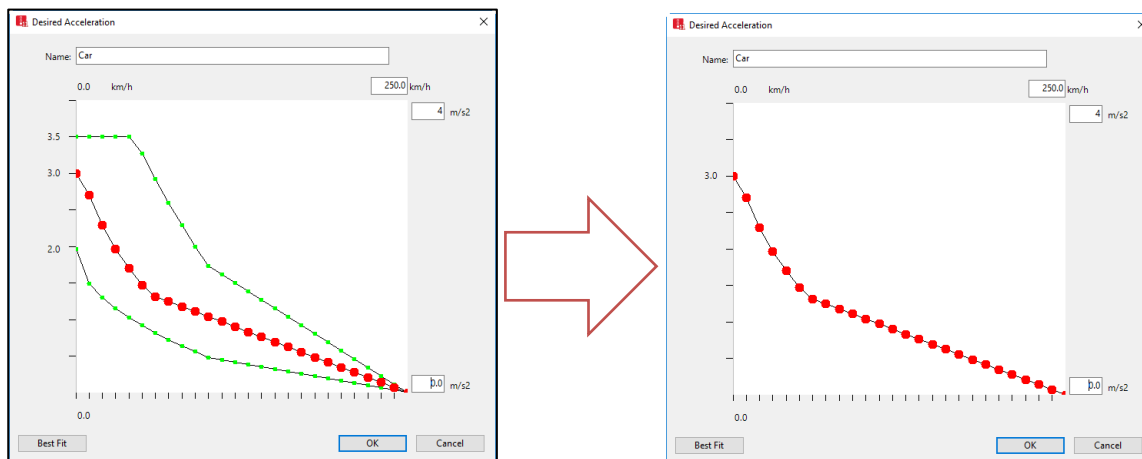


Figure 2 Example of a possible modification of the desired acceleration curve

To make this change, the modeller can use the list of correspondent function with the coupled list **Data Points** and copy the Y value to yMin and yMax, multiply them by an appropriate factor, or change them manually:

Maximum Acceleration Functions / Data Points				
Select layout...				
Count: 6	No	Name		
1	1	Car		
2	2	HGV		
3	3	Bus		
4	4	Tram		
5	5	Pedestrian		
6	6	Bike		

Count: 26	X	Y	yMin	yMax
1	0.00	3.50	1.96	3.50
2	10.00	3.20	1.49	3.50
3	20.00	2.79	1.30	3.50
4	30.00	2.47	1.15	3.50
5	40.00	2.20	1.03	3.50
6	50.00	1.96	0.92	3.27
7	60.00	1.75	0.82	2.92
8	70.00	1.55	0.72	2.59

Figure 3 Illustration of how to modify the maximum acceleration function

2.3.2 Distributions

Distributions are accessible through the main menu: **Base Data > Distributions**.

2.3.2.1 Desired speed

The distribution function of desired speeds is a particularly important parameter since it has an impact on link capacity and achievable travel times. The desired speed is the speed the driver wants to drive. The real speed is a result from interaction with other drivers and objects in the simulation, and each vehicle is assigned an individual desired speed from a distribution. With human drivers, a large spread of desired speeds can be observed. However, automated vehicles may operate with a much lower spread because they likely obey speed limits. Therefore, the automated vehicles might get different desired speed distributions than the conventional vehicles.

To do so, create a new speed distribution used by automated vehicles only and set appropriate boundaries.

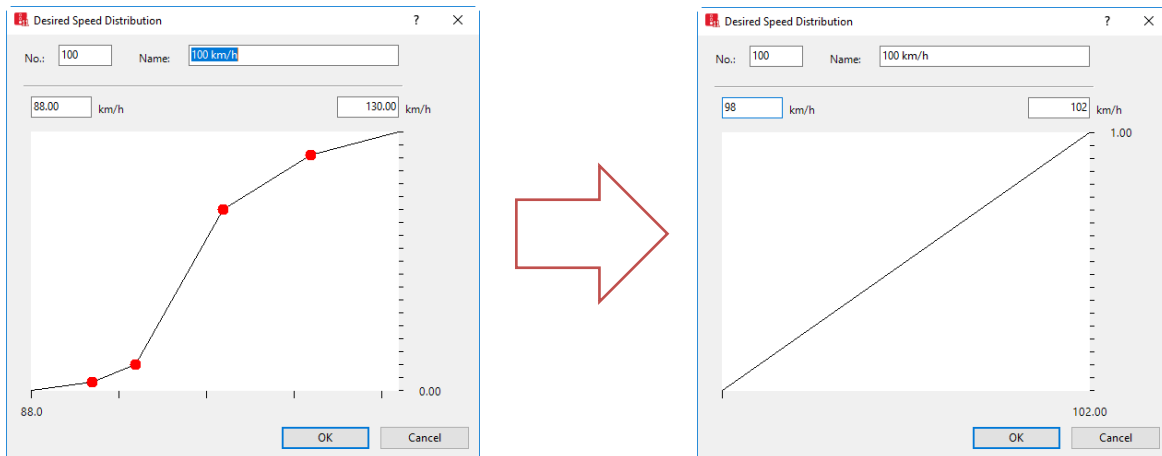


Figure 4 Example of a modification of the desired speed distribution

2.3.2.2 Time

Time is an important distribution because it is used to define the CC1 driving parameter. The time has impact on the capacity, see PTV Vissim Help Defining the Wiedemann 99 model parameters for details. CC1 is a time distribution of the speed-dependent part of desired safety distance. Each time distribution may be empirical or normal. Each vehicle has an individual, random safety variable. PTV Vissim uses this random variable as a fractile for the selected time distribution CC1. The randomness can be switched off by deactivating **use implicit stochastic**. See section 3.2.2 **Use implicit stochastics** for more information.

The appropriate value(s) for the time distribution for CC1 parameter depends on the expected behaviour of the automated vehicle. The value might be larger value for cautious vehicles or smaller value for all-knowing vehicles in comparison with the value used for conventional vehicles by default (0.9 s).

3 Simulation with PTV Vissim internally

3.1 Driving behaviour settings on a link level

PTV Vissim allows to define vehicle class-specific driving behaviours for each link or connector in the network. This means different vehicles can behave differently on the same link/connector, e.g. cars and HGVs or conventional cars and automated cars.

3.1.1 Driving behaviour

PTV Vissim offers predefined driving behaviours, which can be easily adjusted by the user. We recommend duplicating a specific driving behaviour(s), adjusting them if necessary, and then using it in your simulation.



Note: The driving behaviours for automated vehicles are not extensively tested and compared with the real world yet because of a simple fact. There are only few automated vehicles on the roads as of 2018 and they are capable of only the simpler part of the driving tasks (following). Driving parameter values proposed by PTV are based on empirical studies and co-simulation data collected within CoExist (following behaviour only) as well as on several assumptions. If your assumptions differ, consider changing the parameter values and features settings.

3.1.2 Link behaviour types

In the list of **Link behavior types**, you can specify which driving behaviour will be used by default and in the coupled right-hand-side-list **Driving behaviors** you can specify additionally driving behaviours for individual vehicle classes. This will allow e.g. a vehicle from vehicles class Car_AV_cautious behave differently compared to a conventional car.

Link Behavior Types / Driving Behaviors By Vehicle Class			
Select layout...			
Count: 5	No	Name	DrivBehavDef
1	1	Urban (motorized)	1: Urban (motorized)
2	2	Right-side rule (motorized)	2: Right-side rule (motorized)
3	3	Freeway (free lane selection)	3: Freeway (free lane selection)
4	4	Footpath (no interaction)	4: Footpath (no interaction)
5	5	Cycle-Track (free overtaking)	5: Cycle-Track (free overtaking)

Count: 3	VehClass	DrivBehav
1	101: Car_AV_cautious	101: AV_cautious
2	102: Car_AV_normal	102: AV_normal
3	103: Car_AV_allknowin	103: AV_allknowing

Figure 5 Example of how to set different driving behaviour to the vehicle classes

3.1.3 Spatial extent

In the real world or in a scenario, the study area might be spatially divided into several zones where different driving logics are required. For example, there might be an AV-friendly part of the city, where the vehicles could use normal or all-knowing driving logic, but also another part of the city where a cautious driving logic is needed. To achieve this, you need to define link behaviour types to cover all possible behaviours of your automated vehicle and then assign this link behaviour type to links in the corresponding part of your model. As a result, the same vehicle can use different driving logics in different parts of the network.

Link Behavior Types / Driving Behaviors By Vehicle Class			
Select layout...			
Count: 7	No	Name	DrivBehavDef
1	1	Urban (motorized)	1: Urban (motorized)
2	2	Right-side rule (motorized)	2: Right-side rule (motorized)
3	3	Freeway (free lane selection)	3: Freeway (free lane selection)
4	4	Footpath (no interaction)	4: Footpath (no interaction)
5	5	Cycle-Track (free overtaking)	5: Cycle-Track (free overtaking)
6	6	Freeway AV-friendly	3: Freeway (free lane selection)
7	7	Freeway AV-challenging	3: Freeway (free lane selection)

Count: 6	LinkBehavType/Name	VehClass	DrivBehav
1	Freeway AV-friendly	101: Car_AV_cautious	101: AV_cautious
2	Freeway AV-friendly	102: Car_AV_normal	102: AV_normal
3	Freeway AV-friendly	103: Car_AV_allknowin	103: AV_allknowing
4	Freeway AV-challenging	101: Car_AV_cautious	101: AV_cautious
5	Freeway AV-challenging	102: Car_AV_normal	101: AV_cautious
6	Freeway AV-challenging	103: Car_AV_allknowin	101: AV_cautious

Figure 6 Example of how to set different driving behaviour for different link types

Analogically, a highly developed automated vehicle can drive with **all-knowing** driving behaviour through the network but act as a rail safe or cautious vehicle in a parking garage or shared space.

Example from the CoExist project:

The scenario includes 3 different AV vehicle classes, and each vehicle class uses a specific driving logic for a specific road type (see the Table 1 below). In this case, you can define four link behaviour types (motorway, arterial, urban street, shared space) combined with four driving behaviours (cautious, normal, all-knowing, manual – for each of them an urban and freeway option is defined because of differences in lane change parameters) for three AV vehicle classes (basic AV, intermediate AV, advanced AV)⁴.

Table 1 Specification of which driving logic basic AVs, intermediate AVs and advanced AVs could use in different road environments.

Road type	Driving logic: (Cautious (C), Normal (N), All-Knowing (AK), Manual (M))		
	Basic AV	Intermediate AV	Advanced AV
Motorway	C	N	AK
Arterial	C	C / N	AK
Urban street	M	C	N
Shared space	M	M	C

Link Behavior Types / Driving Behaviors By Vehicle Class			
Select layout...			
Count	No	Name	DrivBehavDef
1	1	Motorway	5: Manual (freeway)
2	2	Arterial	9: Manual (urban)
3	3	Urban street	9: Manual (urban)
4	4	Shared space	9: Manual (urban)

Count	LinkBehavType	VehClass	DrivBehav
1	1: Motorway	20: Basic AV	2: Cautious (freeway)
2	1: Motorway	30: Intermediate AV	3: Normal (freeway)
3	1: Motorway	40: Advanced AV	4: All-knowing (freeway)
4	2: Arterial	20: Basic AV	6: Cautious (urban)
5	2: Arterial	30: Intermediate AV	7: Normal (urban)
6	2: Arterial	40: Advanced AV	8: All-knowing (urban)
7	3: Urban street	20: Basic AV	9: Manual (urban)
8	3: Urban street	30: Intermediate AV	6: Cautious (urban)
9	3: Urban street	40: Advanced AV	7: Normal (urban)
10	4: Shared space	20: Basic AV	9: Manual (urban)
11	4: Shared space	30: Intermediate AV	9: Manual (urban)
12	4: Shared space	40: Advanced AV	6: Cautious (urban)

Figure 7 Scenario including 3 different AV vehicle classes, and each vehicle class uses a specific driving logic for a specific road type

3.2 AV related features

Multiple additional attributes are available in the driving behaviour dialogs since PTV Vissim 11. Most are required mainly for modelling of CAV (connected and/or automated vehicles), but many can also be used for calibration of human behaviour. The added attributes are explained in the following chapters.

⁴ For more information, please refer to deliverable 1.4 “Scenario specification for eight use cases”

Figure 8 The driving behaviour window with the relevant attributes highlighted in yellow

Table 2 Recommended settings for the AV-related features

driving logic	recommended setting for new features			
	enforce absolute breaking distance (EABK)	use implicit stochastics	number of interaction vehicles*	increased desired acceleration
rail safe	ON	OFF	1	100%
cautious	ON	OFF	1	100%
normal	OFF	OFF	1	100-110%
all knowing	OFF	OFF	>1	110%
* for advanced sensors and/or communicating vehicles choose more than 1 if information from more than one vehicle ahead is available				

3.2.1 Enforce absolute braking distance

If the attribute **Enforce absolute braking distance** (a.k.a. brick wall stop distance) is checked, vehicles using this driving behaviour will always make sure that they could brake without a collision, even if the leading vehicle comes to an immediate stop (turns into a brick wall).

This condition applies also:

- to lane changes for the vehicle itself on the new lane and for the trailing vehicle on the new lane and
- to conflict areas for the following vehicle on the major road.
- Following:



Figure 9 Illustration of the definition of the following distance

- Lane change:

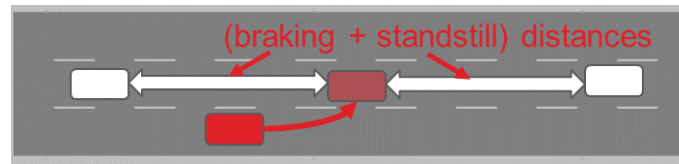


Figure 10 Illustration of the distances involved in the lane changing process

- Gap acceptance⁵ at intersections (conflict areas only):

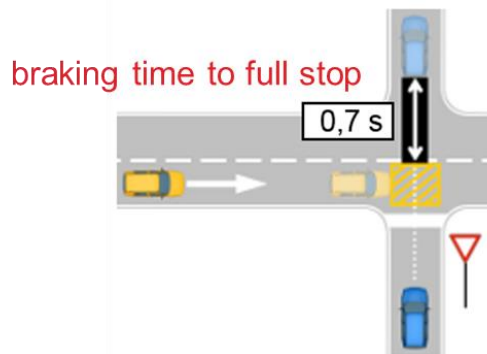


Figure 11 Illustration of the rear gap

Activating **Enforce absolute braking distance** is recommended for rail safe and cautious driving logic vehicles.

3.2.2 Use implicit stochastics

If the attribute **Use implicit stochastics** is unchecked (default is checked), a vehicle using this driving behaviour does not use any internal stochastic variation that is meant to model the imperfection of human drivers. For all distributions that cannot be explicitly set by the user, a median value is used instead of a random value.

This affects:

- the safety distances
- the desired acceleration
- the desired deceleration
- the estimation uncertainty for braking decisions

The three former variables are partially defined by attributes/functions accessible to the user, so this

⁵ Rear gap = time to brake to full stop 1 m in front of the conflict area

part is still valid, but the additional stochastic spread included in the internal model is reduced to zero.

Deactivating **Use implicit stochastic** is recommended for all automated vehicles or for that part of the infrastructure, where the vehicle drives in automated mode.

3.2.3 Number of interaction objects and vehicles

The attribute **observed vehicles** from PTV Vissim 10 has been split into two attributes:

- **Number of interaction objects** refers to vehicles and internal objects (reduced speed areas, stop signs, priority rules, red signal head)
- **Number of interaction vehicles** refers only to real vehicles

The number of interaction vehicles defines an upper limit for the observed leading vehicles, therefore, for example, this could be set to 1 for automated vehicles with a sensor equipment that cannot see through the leading vehicle. A red signal downstream of the leading vehicle would still be observed, but not the second real vehicle downstream.

Examples

Number of interaction objects: 3 (first three objects are **visible** for the red car)

Number of interaction vehicles: 1 (only one vehicle is **visible** for the red car)

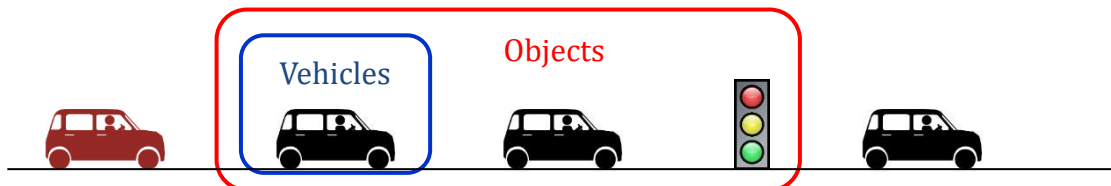


Figure 12 Example of the use of the new attributes: number of interaction objects and number of interaction vehicles

Another situational examples:

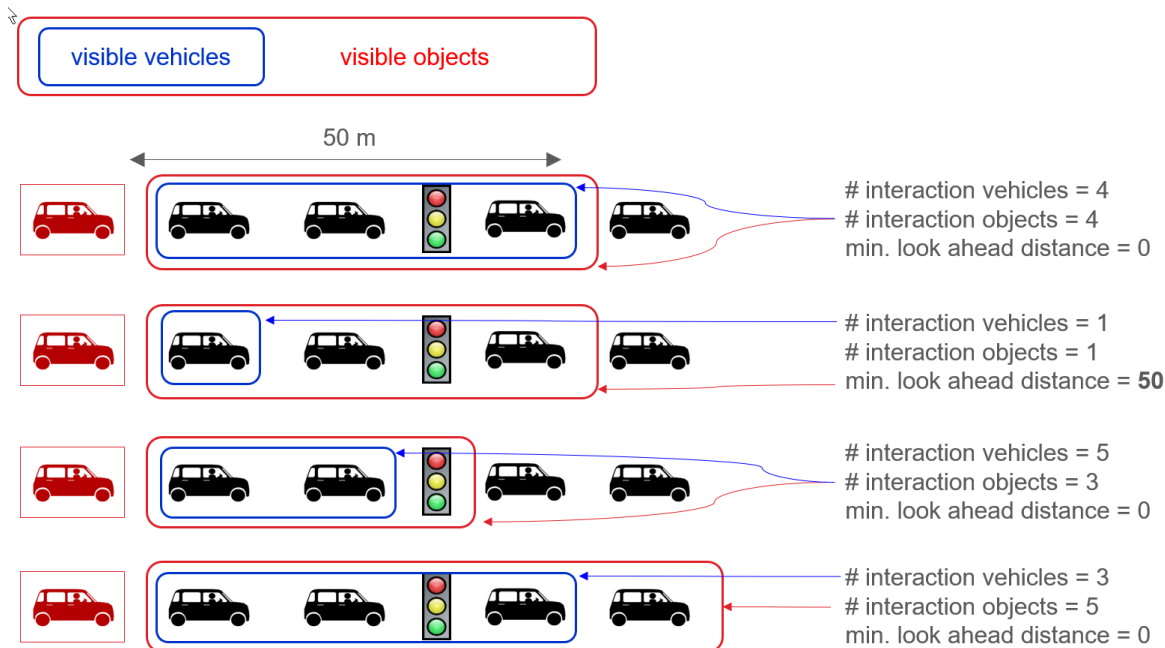


Figure 13 Additional examples of the use of the new attributes: number of interaction objects and number of interaction vehicles.

Per default, within the Wiedemann 99 model, the number of interaction objects is set to 2 and the number of interaction vehicles is set to 99, which is the maximum possible value.

It is possible to enter a higher number of interaction vehicles than objects; however, the number of interaction objects is always the limiting factor.

If the number of interaction vehicles is equal or higher than the number of interaction objects, you get the same setup as in PTV Vissim 10 or earlier releases.

If you set the number of interaction vehicles lower than the number of interaction objects, you will limit the number of visible vehicles within the visible objects.

3.2.4 Headway based on leader vehicle class

On the new tab page **Car following model** in the driving behavior dialog or in the coupled list **Vehicle Class Following Behavior**, some of the parameter values affecting the desired safety distance can be specified per vehicle class of the leading vehicle now, in addition to the value for all other vehicles.

This can be used, for example, for having connected vehicles using a smaller safety distance when following another connected vehicle but a larger safety distance when following a human driver or a bike.

Driving Behavior

No.: 103 Name: AV_allknowing

Following Car following model Lane Change Lateral Signal Control Meso

Wiedemann 99

Model parameters

CC0 (Standstill Distance): 1.00 m CC5 (Positive 'Following' Threshold): 0.10

CC1 (Headway Time): 103: 0,6 s CC6 (Speed dependency of Oscillation): 0.00

CC2 ('Following' Variation): 0.00 m CC7 (Oscillation Acceleration): 0.10 m/s²

CC3 (Threshold for Entering 'Following'): -6.00 CC8 (Standstill Acceleration): 4.00 m/s²

CC4 (Negative 'Following' Threshold): -0.10 CC9 (Acceleration with 80 km/h): 2.00 m/s²

Following behavior depending on the vehicle class of the leading vehicle:

Count: 2	VehClass	W74ax	W74bxAdd	W74bxMult	W99cc0	W99cc1Distr
1	10: Car	2.00	2.00	3.00	1.20	2: 0.9 s
2	60: Bike	2.00	2.00	3.00	1.50	104: 1,2 s

OK Cancel

Figure 14 Example of different headway settings depending on the vehicles class of the leading vehicle

Driving Behaviors / Vehicle Class Following Behaviors

Select layout...

<

Figure 15 List of vehicle class following behavior where some of the parameter values affecting the desired safety distance can be specified per vehicle class of the leading vehicle

3.2.5 Increased acceleration

This attribute is accessible through the **Driving behaviors** list and can be set in dependency on leading vehicle class in the coupled list **Vehicle class following**.

The normal human acceleration behaviour cannot use reliable information about the future behaviour of the leading vehicle, and therefore, normal Vissim vehicles tend to fall behind when the leading vehicle is accelerating. But automated vehicles, especially if using car-to-car (C2C) communication, can use a tight coupling with small headways.

If the attribute **Increased acceleration** is set to a higher value than 100%, a vehicle using this driving behaviour can accelerate with the given percentage of its normal desired acceleration, but not exceeding its maximum acceleration if the leading vehicle is faster and accelerating.

Driving Behaviors / Vehicle Class Following Behaviors									
Select layout...									
Count	No	Name	NumInteractObj	CarFollowModType	IncrsAccel	Count	VehClass	W74ax	W74bxAdd
1	1	Urban (motorized)	4	Wiedemann 74	100.0 %	1	10: Car	2.00	2.00
2	2	Right-side rule (motorized)	2	Wiedemann 99	100.0 %	2	60: Bike	2.00	2.00
3	3	Freeway (free lane selection)	2	Wiedemann 99	100.0 %				
4	4	Footpath (no interaction)	2	No interaction	100.0 %				
5	5	Cycle-Track (free overtaking)	2	Wiedemann 99	100.0 %				
6	101	AV_cautious	2	Wiedemann 99	100.0 %				
7	102	AV_normal	2	Wiedemann 99	105.0 %				
8	103	AV_allknowing	2	Wiedemann 99	110.0 %				

Figure 16 The driving behaviors / Vehicle class following behaviors list in which the increased acceleration can be set

3.2.6 Occupancy distribution with zero passengers

For empty automated vehicles (without passengers), it is now possible to define an empirical occupancy distribution which contains zero passengers. You can do so in the coupled list **Data points**.

Occupancy Distributions / Data Points									
Select layout...									
Count	No	Name	Type	LowerBound	UpperBound	StdDev	Mean	Count	X
1	1	Single Occupancy	Normal	1.00	1.00	0.00	1.00	1	0.00
2	2	Zero occupancy	Empirical	0.00	0.00	0.00	1.00	2	0.00

Figure 17 The occupancy distributions / Data points list

Occupancy Distribution

No.: 2

Name: Zero occupancy

0.0

0.0

0.00

0.00

OK

Cancel

Figure 18 Occupancy distribution is set to zero

3.2.7 Consider vehicles in dynamic potential

The interaction between vehicles and pedestrians is mainly modelled as conflict areas, which do block a certain area if a vehicle or pedestrian is within the area or approached it. In this case, others are not allowed to use this area.

Vehicles blocking a conflict area can now be considered in the dynamic potential for conflicting pedestrians. If this option has been activated on a pedestrian link, pedestrians will not stop at a blocked conflict area, but will try to walk around it through the gaps between queued vehicles. For this, the lanes of a pedestrian link need to be sufficiently narrow. For example, lane widths of 0.6 m only, so that at least one lane conflict remains open between queued cars. Dynamic potential for pedestrian routes needs to be active.

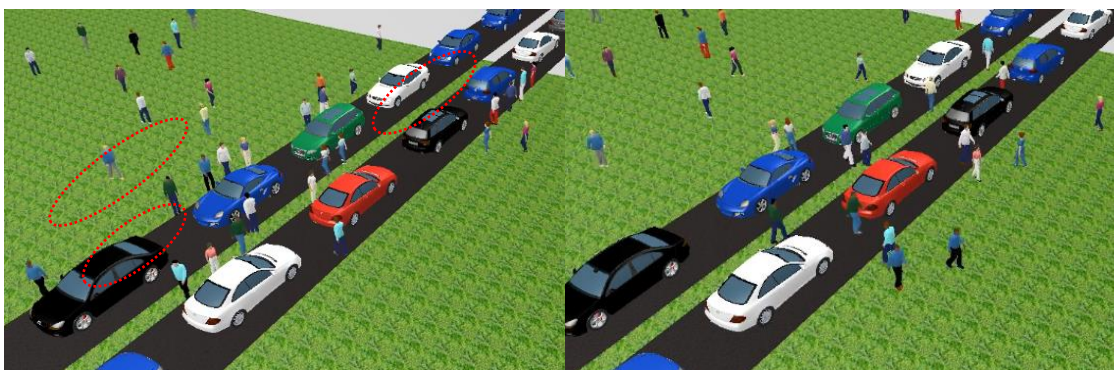


Figure 19 Left-hand side: interaction pedestrians-vehicles when dynamic potential is deactivated, the pedestrians are waiting in front of the standing vehicles; right-hand side: interaction pedestrians-vehicles when dynamic potential is activated, the pedestrians are actively looking for and using the gaps between the standing vehicles

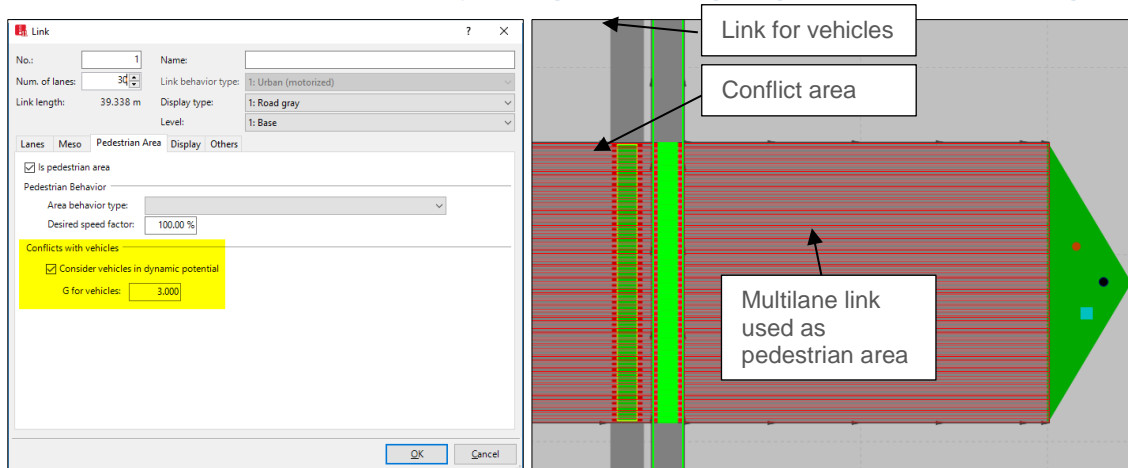


Figure 20 Left-hand side: link dialog: activation of “consider vehicles in dynamic potential”; right-hand side network objects needed

The parameter **G for vehicles in dynamic potential** affects the general strength of vehicles (default value: 3). This attribute also influences the oncoming lane.

3.2.8 Platooning

Platooning as a parametrized feature in PTV VISISM GUI is planned to be implemented in the last quarter of 2018 and should be available for PTV Vissim users with a service pack in 2019. A script-

based platooning example is available already within the PTV Vissim installation.

3.3 Driving parameters

The tables in the following subchapters recommend the direction of change for the driving behaviour parameters to model CAVs. Specific numeric values proposed within CoEXist, which can be used as a starting setting, are available as three additional driving behaviours directly in the default network file, so they appear in the driving behaviour list after opening PTV Vissim or creating a new file, if you did not save your own default network file before without these new driving behaviours.



Note: The specific parameter values available within cautious, normal and all-knowing driving behaviour are not the only possible values. The development on the field of automated vehicles is fast and the resulting driving behaviour is influenced by many factors like legislation, legal aspects, hardware and software equipment, weather and visibility conditions.

3.3.1 Following behaviour

Because of deterministic behaviour of automated vehicles and to reflect much smaller oscillation in vehicle following:

- CC2 can be reduced up to zero
- CC4 and CC5 can be significantly reduced
- CC6 can be reduced up to zero

Table 3 General recommendations for the Wiedemann following behaviours and the rail safe, cautious, normal and all-knowing driving logics

	model	parameter**	control logic			
			rail safe	cautious	normal	all knowing
following behavior	Wiedemann 99	CC0	def	def	def	smaller
		CC1	def/higher*	def/higher*	def	smaller
		CC2	def/smaller	def/smaller	smaller	smaller
		CC3	def/higher	def/higher	def	def
		CC4	Smaller	def/smaller	def/smaller	smaller
		CC5	Smaller	def/smaller	def/smaller	smaller
		CC6	def/smaller	def/smaller	def	smaller
		CC7	def/smaller	def/smaller	def/smaller	smaller
		CC8	Smaller	smaller	def	def
		CC9	Smaller	smaller	def	def
	W74	ax	def	def	def	smaller
		bxadd	def/higher*	def/higher*	def	smaller
		bxmult	def/higher*	def/higher*	def	smaller

* if EABD is on, brick wall stop distance is guaranteed ** see PTV Vissim manual for detailed description



Note: Although the table above also contains the parameters for the Wiedemann 74 model, it is recommended to use Wiedemann 99 to simulate automated vehicles because of more options to control the behaviour through the driving parameters.

3.3.2 Lane change behaviour

For the lane change behaviour, the most important parameter is the **Safety distance reduction factor**, which is set to 0.6 by default in PTV Vissim. That means vehicles accept smaller gaps for lane change as for following.



Note: For automated vehicles, this parameter might be higher or lower in value in comparison to the default value based on the driving logic or assumed behaviour in lane change manoeuvres. There are different default values for urban and freeway driving behaviours. To include automated vehicles in a model, we recommend using two driving behaviours: one for urban roadways and another for freeway type of infrastructure.

Table 4 General recommendation for lane changing behaviours

parameter for necessary lane change*	rail safe		cautious**		normal		all knowing	
	own	trailing vehicle	own	trailing vehicle	own	trailing vehicle	own	trailing vehicle
maximum deceleration	n.a.	n.a.	smaller/def	smaller/def	def	smaller/def	def	higher/def
- 1 m/s per distance	n.a.	n.a.	smaller/def	smaller / def	def	def	def	smaller/def
accepted deceleration	n.a.	n.a.	smaller/def	smaller/def	def	def	def	higher/def

*necessary lane change means a lane change which is necessary in order to follow a defined route (it is not overtaking because of higher own desired speed)

** EABD (enforce absolute breaking distance) must be on

n.a. = not applicable

Table 5 General recommendation for lane changing behaviour functionalities

behavioral functionality	control logic			
	rail safe	cautious**	normal	all knowing
Advanced merging*	n.a.	on***/off	on***	on
Cooperative lane change*	n.a.	on***/off	on***	on
Safety distance reduction factor	n.a.	higher+EABD	def/smaller	def/smaller
min. headway (front/rear)	n.a.	higher	def	def
max. deceleration for cooperative braking	n.a.	smaller***	smaller***/def	def

*depends on technical equipment and implemented connectivity & cooperation functions

** EABD (enforce absolute breaking distance) must be on

*** If the AV cannot detect that the other vehicle wants to change lanes, the value should be off/zero

n.a. = not applicable

3.3.3 Lateral behaviour

There are no suggestions regarding lateral behaviour from CoEXist. Automated vehicles will likely try to keep the lateral position in the middle of the lane. There might be requirements for lateral distance to other road space users, especially to vulnerable road users. These can be defined class dependent on the tab **Lateral** in the driving behaviour dialog according to expected behaviour of the automated vehicle.

3.3.4 Signal control behaviour

For the signal control behaviour, defining the reduced safety distance factor in an appropriate way is important. This parameter is set to 0.6 by default. For automated vehicles, this can be set to 1 if it is expected that they do not change the safety distances in the proximity of a signalized intersection.

On the other hand, if it is expected that automated vehicles will also reduce the safety distances in proximity to signalized intersections, then set this value lower than 1. The proximity itself is described by **reduced safety start (end) up (down) stream of stop line**.

Table 6 General recommendation for signal control behaviour

attribute	driving logic			
	rail safe*	cautious**	normal	all knowing
behavior at amber signal	continuous check	continuous check	one decision***	one decision
behavior at red/amber signal	stop	stop	stop/go	stop/go
reaction time distribution	-	-	-	-
reduced safety distance factor	higher+EABD	higher+EABD	def	def/lower
reduced safety start upstream of stop line	lower/def	lower/def	def	def/higher
reduced safety end upstream of stop line	lower/def	lower/def	Def	def/higher

*only protected phase possible in AV-certified environment

** probably protected phases only, EABD must be on

*** requires that the AV can remember that it has made a decision for that particular signal head already, else: continuous check

3.4 AV – Penetration rates

While testing the future scenarios with automated vehicles, different penetration rates of different kinds of automated vehicles or driving logics are often of interest. To address this, it is possible to simply change the vehicle composition with the corresponding share of automated vehicle types. For example, to model 50% conventional, 30% cautious, and 20% normal, the settings should be:

Vehicle Compositions / Relative Flows			
Select layout... Relative flows			
Count: 1	No	Name	
1	1	My Example Composition	
Count: 3	VehType	DesSpeedDistr	RelFlow
1	100: Car	100: 100 km/h	50.000
2	1001: Car_AV_cautious	101: 100±2 km/h	30.000
3	1002: Car_AV_normal	101: 100±2 km/h	20.000

Figure 21 Example of the settings for a model with the following share of driving behaviour: 50% conventional, 30% cautious, and 20% normal

3.5 Future adaptation of human drivers

With a growing share of automated vehicles in the traffic flow, the behaviour of other human drivers might also change. Because of lack of empirical data and real experience with higher penetration rates of automated vehicles as of 2018, specific recommendation cannot be provided, except that this aspect should not be overseen and should be taken into account when listing the assumptions of the model..

3.6 Safety aspects

For conventional vehicles with human drivers, the safety aspects can be investigated using the

SSAM model (Surrogate Safety Assessment Model⁶). According to the SSAM software user manual,

“it provides guidance on the installation and use of the software, which is used to perform surrogate safety analysis of a traffic facility, such as a signalized intersection. It does so by processing vehicle trajectory data from a given microscopic traffic simulation to identify the frequency of conflicts-where two vehicles are on a collision course and one vehicle must make an evasive maneuver to avoid a collision. Such surrogate measures have been shown to correlate to some degree with the historical frequency of crashes at intersections.”

Unfortunately, due to the lack of data on the frequency of crashes at intersections with automated vehicles, there is no experience in applying such techniques for automated vehicles and the results should be handled with precaution. It is not clear whether the thresholds used in SSAM for defining conflicts and severity of conflicts are also valid for automated vehicles, especially for the all-knowing driving logic, which might be able to drive with short safety distances without being unsafe or at least not as unsafe as a human driver would be in the same situation.

3.7 Examples

All AV-related examples are available in ...\\EXAMPLES TRAINING\\AUTOMATED VEHICLES (AV) folder. Each example is described in detail in a PDF document explaining the goal and modelling technique.

Base network AV

This file can be used as a template to start a new model or read additional network object types for basic automated vehicle settings and three CoEXist automated vehicles driving logics.

Lateral Space

Demonstration of possible consequences of automated vehicles on road capacity at signals and weaving sections. A simplistic approach where a typical driving behaviour of automated vehicles (AV) can be described based on some basic AV characteristics.

Simple Intersection

Demonstration of possible consequences of automated vehicles in simple intersection in terms of delay and queue length. Automated vehicles are modelled in a simple way as a vehicle class with modified driving behaviour parameters. Driving behaviour parameters were modified with couple of simple assumptions about the behaviour of automated vehicles.

4 Simulation with PTV Vissim externally

Simulation with PTV Vissim externally means using PTV interfaces. This approach is needed when one wants to use its own or third-party algorithms and/or tools, e.g.:

⁶ See <https://www.fhwa.dot.gov/publications/research/safety/08049/> for additional information

- couple PTV Vissim to a driver/cyclist/pedestrian training simulator
- control vehicle(s) with own driving logics algorithms
- simulate vehicle dynamics
- simulate sensors

4.1 PTV Vissim interfaces

4.1.1 COM

The Component Object Model (COM) describes how binary components of different programs collaborate. COM gives access to data and functions contained in other programs. Since Vissim version 4.0, data contained in Vissim can be accessed via the COM interface using Vissim as an automation server. The Vissim COM interface is automatically included when the software is installed. Since Vissim version 4.30, COM scripts can be called directly from the Vissim main menu.



Note: The Vissim COM interface is not included in the Demo version.

COM does not depend on a certain programming language. COM objects can be used in a wide range of programming and scripting languages, including VBA, VBS, Python, C, C++, C#, Delphi, and MATLAB. In the following examples, VBA is used most often. Exceptions using the programming language Python are marked explicitly.

- **Advantage:** The COM script has access to all data inside Vissim which can be made visible in a list window (and some more).
- **Restriction:** The COM script cannot affect the lateral movement of the vehicle. No direct lane change can be performed (only a desired lane change). And COM may be slow.

Executing a script

There are two options to execute a script directly within Vissim, if it is written in VBS (Visual Basic Script), Java-Script or Python:

- Direct, single call of a script file: SCRIPTS - RUN SCRIPT FILE...
- Event-based scripts: SCRIPTS - EVENT-BASED SCRIPTS

Further information

For further information about COM, see these information sources:

- VISSIM 11 - COM INTRO.PDF in the Doc directory
- COM-Help in the PTV Vissim menu: **Help > COM-Help**
- COM-webinar in the webinar archive: <http://vision-traffic.ptvgroup.com/en-us/community/webinar-archive/>
- COM BASIC COMMANDS ENG.PDF in ...\\EXAMPLES TRAINING\\COM\\BASIC COMMANDS

4.1.1.1 Examples

All COM examples can be found in: ...\\EXAMPLES TRAINING\\AUTOMATED VEHICLES (AV)

Path Addition + Assignment.COM

A taxi vehicle serves random requests from an origin (pick-off) to a destination (drop-off). Once there is a new request (randomly created), the vehicle will first be sent to the pick-up point and then drive to the drop-off point.

Platooning.COM

Vehicles on a highway may form platoons, which means they travel at an identical speed and maintain a short and steady headway. This example includes the generation of platoons at the edge of the network as well as platoon operations such as vehicles closing the gap if a vehicle leaves the platoon and vehicles opening a gap to allow another vehicle to enter the platoon.

Speed At Signals - C2X.COM

Vehicles to infrastructure communication (C2X) for adjusting driving speed to arrive at signals at green. Connected automated vehicles (CAVs) receive the information about the upcoming signal and adjust their speed to arrive at green without stopping.

4.1.2 DriverModel

The External DriverModel DLL Interface of Vissim provides the option to replace the internal driving behaviour by a fully user-defined behaviour for some or all vehicles in a simulation run. The user-defined algorithm must be implemented in a DLL written in C/C++ which contains specific functions, as specified below.

During a simulation run, Vissim calls the DLL code for each affected vehicle in each simulation time step to determine the behaviour of the vehicle. Vissim passes the current state of the vehicle and its surroundings to the DLL and the DLL computes the acceleration/deceleration of the vehicle and the lateral behaviour, mainly for lane changes and passes the updated state of the vehicle back to Vissim.

The external driver model can be activated for each vehicle type separately in the dialog box **Vehicle Type** by checking the checkbox **Use external driver model** on the tab page **External Driver Model** and selecting a driver model DLL file and optionally a parameter file to be used. If this option is checked, the driving behaviour of all vehicles of this vehicle type will be calculated by the selected DLL. A subdirectory DRIVERMODELDATA\ must exist in the directory of VISSIM.EXE to avoid a warning message when Vissim is started.

- **Advantage:** Vissim passes only information of the nearby vehicles and about the upcoming road along the vehicle's route to the DLL, so the DLL doesn't need to know the network.
- **Restriction:** Information about priority rules and conflict areas is not passed to the DLL, so behaviour at intersections cannot be modelled. Routing cannot be changed but lateral behaviour and lane changes must be decided by the DLL.

For additional detail see INTERFACE_DESCRIPTION.PDF in: ...\\PTV VISION\\PTV VISSIM 11\\API\\DRIVERMODEL_DLL

DRIVERMODEL.DLL INTERFACE

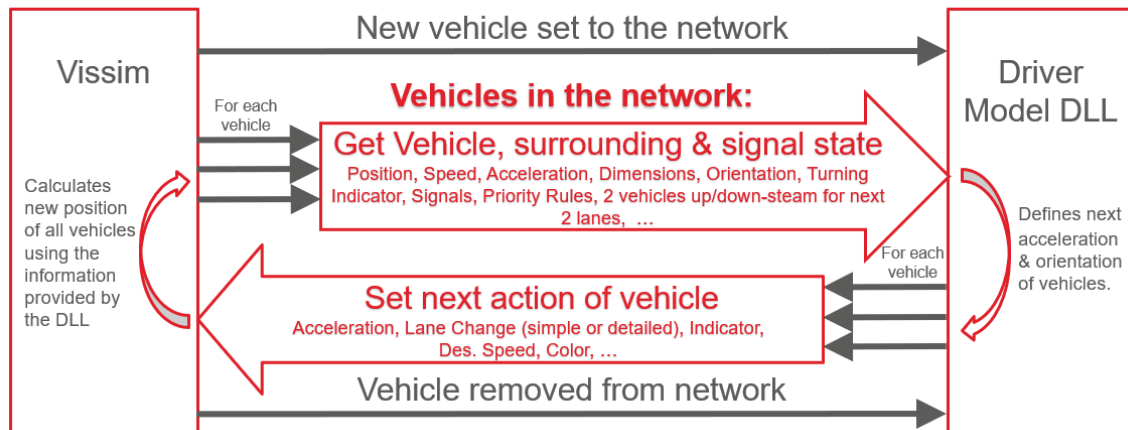


Figure 22 Diagram of the exchange of information between Vissim and the drive model dll

4.1.2.1 Examples

There is not a full example available, but PTV provides supporting project files in ...\\PTV VISION\\PTV VISSIM 11\\API\\DRIVERMODEL_DLL

DRIVERMODEL.H

Header file for a driver model DLL. This file should not be changed. It contains the definitions of all **type** and **number** constants used by Vissim in calls of the **DriverModel*** DLL functions which are declared here, too.

DRIVERMODEL.CPP

Main source file of a driver model DLL. This file is the place where calculations or calls of functions of the driving behavior model algorithm should be added.

DRIVERMODEL.VCPROJ

Visual C++ 2010 project file for a driver model DLL. This file can be used if the DLL is to be created with Microsoft Visual C++.

4.1.3 DrivingSimulator

The PTV Vissim add-on module **Driving Simulator Interface** allows to connect Vissim to a driving, cycling or walking simulator (DS). That DS can either be a simulator hardware used by a human or a piece of software representing the algorithms of a CAV or multiple CAVs.

Vissim provides the surrounding traffic (vehicles, bicycles, pedestrians) to be visualized in the DS, and the DS passes back the current position and orientation of the simulator vehicle(s) (bicycle(s) / pedestrian(s)). The vehicles and pedestrians in the Vissim network react to this simulator data as to

all other vehicles and pedestrians in the microscopic simulation model. In addition, Vissim passes traffic signal states to the DS for visualization, and the DS can set detectors in Vissim explicitly to affect the signalization.

The DS does not need to know the Vissim data model where the network is modelled from links, connectors, areas, ramps and obstacles. The DS needs to have its own world model (for simulation and visualization). As all vehicle and pedestrian positions are exchanged in cartesian world coordinates (x/y/z), the DS must be able to provide/use such coordinates, and the coordinates of the networks on both sides (Vissim / DS) must match precisely.

For additional details, see PTV VISSIM API - DRIVING SIMULATOR INTERFACE.PDF in ...\\PTV VISION\\PTV VISSIM 11\\API\\DRIVINGSIMULATOR_DLL\\DOC

DRIVINGSIMULATOR.DLL INTERFACE

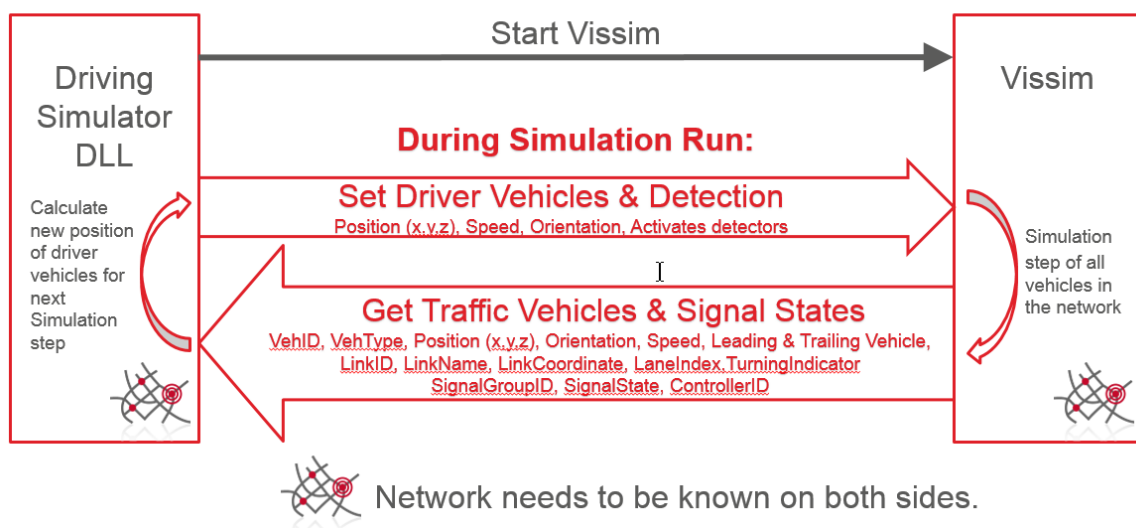


Figure 23 Diagram of the exchange of information between Vissim and the driving simulator dll

4.1.3.1 Examples

All examples can be found in: ...\\PTV VISION\\PTV VISSIM 11\\API\\DRIVINGSIMULATOR_DLL\\EXAMPLE

Driving simulator text client

A simple example **DrivingSimulatorTextClient** is provided with the API package, including the example network file **DRIVING_SIMULATOR_TEST.INPX** and some additional files.

Unity (game engine)

This example demonstrates how PTV Vissim can be used to receive realistic traffic in Unity from PTV Vissim. When starting the Unity application, PTV Vissim opens, a network defined in PTV Vissim opens in Unity and vehicles controlled by PTV Vissim are displayed in Unity. In addition, one vehicle can be controlled by Unity like in a driving simulator.

4.2 Vehicles Dynamics & sensors (nano-simulation)

Simulation of detailed vehicle dynamics like power train, suspension, gear box, etc. or/and any kind of sensors is possible using a coupling (using DRIVINGSIMULATOR.DLL) with some external software providing such capabilities like PreScan, CarMaker, CarSim, dSPACE, or others.

5 Next steps

Within the CoEXist project, the new Vissim features will be demonstrated in five use cases in three CoEXist partner cities (Gothenburg, Milton Keynes and Helmond). For a detailed overview of the use cases, please check 'D3.1 Completed experimental setup templates for eight use cases and AV-ready alternative design' available on www.h2020-coexist.eu.

