MICROSCOPIC SIMULATION AND IMPACT ASSESSMENT OF THE COEXISTENCE OF AUTOMATED AND CONVENTIONAL VEHICLES IN EUROPEAN CITIES

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1. ABSTRACT

This article reports progresses made within the European project CoEXist on the simulation and modelling of the coexistence of conventional cars and automated cars both in microscopic and macroscopic traffic and transport models as well as its impact assessment. The paper focuses on the respective enhancements of PTV's microscopic software solution Vissim (PTV Vissim) and the ongoing project work on developing a methodology for assessing the impacts of automated driving on road safety.

Keywords: microscopic traffic flow simulation, connected and automated car, impact assessment.

2. INTRODUCTION

As the introduction of connected and automated vehicles (CAVs) is promising to reduce road space demand and improve traffic flows and safety, an adapted transport and infrastructure planning is becoming mandatory for the development of cities. Surprisingly, some big European cities are still not mentioning CAVs in their strategic urban mobility plans [GY18] showing the necessity for an increase of awareness of the stakeholders. That is the gap the European project CoEXist[1] is aiming to fill by enabling mobility stakeholders to become "automation-ready".

For this purpose, the availability of adapted simulation software is necessary, and new features facilitating the simulation and modelling of CAVs have been developed within the project. A connection between control logics of CAVs and vehicle simulator has been established for analysing the ego vehicle (the CAV) behaviour. Based on these analyses the microscopic simulation model of PTV Vissim has been modified accordingly. Empirical data collected on test tracks with real automated cars have been used to calibrate the behaviour of the CAVs within the model and to provide default behavioural parameter sets for CAVs. The results of the validated CAV-ready microsimulation model will also be used to create assumptions for the supply-side of macroscopic models.

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So far socio-economic impacts of automated driving are still discussed by experts of the international community [SH12]. For example, in terms of road safety, the predicted impacts range from 90 % reduction of road accidents due to human errors avoided [KA17] to an increasing number of accidents during the transition period when conventional vehicles and CAVs would share the road [SI15]. The examples mentioned show that the boundary conditions anticipated when predicting impacts of autonomous driving are of greatest importance. Therefore, within CoEXist assessment tools are to be developed which allow assessing the impacts of automated driving for a specific road site under consideration of the local conditions.

Besides the enhancement on simulation and modelling software as well as the development of assessment tools CoEXist includes a proof of concept. To that end, eight use cases have been identified all around Europe. The enhanced software and developed tools will be applied on these use cases which try to cover the whole variety of influencing conditions like road type, traffic load, penetration rates of CAVs, etc. The paper gives an overview about the use cases and their main characteristics.

3. SIMULATION AND MODELLING SOFTWARE

3.1. Driving logics

There are different ways of classifying automated cars. Probably the most well-known, is the one published in 2014 by SAE international [SA14] which defines six levels of automation. This classification relies on driver intervention and attentiveness required rather than vehicle capabilities. However, in the case of CoEXist and microscopic traffic flow models, the definition of driving behaviours seems more adapted, and even though not all of them are necessarily “realistic” they are needed for comparison and research purposes. A new classification has therefore been elaborated which aims at representing the whole span of possible behaviours[2]: This classification should be seen as independent from the SAE classification, without any correspondence between the SAE levels and the driving logics described below.

The *rail safe* driving logic is mimicking the behaviour of a train on tracks, which means the vehicle is following a predefined path. The vehicle is keeping enough safety distance to be able to brake without causing accidents at any time, it is called the brick wall stop distance. Furthermore, the vehicle radars its back and sides too and adjusts its velocity in case objects on the potential collision course are detected. Such driving behaviour is more adapted to closed or low speed environments (such as harbours, factories and urban areas).

The *cautious* driving logic describes a logic in which the vehicle operates safely. In this logic the brick wall distance should also be respected to calculate safety distances, leading to bigger gaps than an average human driver would use. Unlike the rail safe driving logic, the vehicle takes into account only what is

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happening on its path and not the whole surrounding environment such as pedestrians walking in longitudinal traffic on the pavement.

The *normal* driving logic replicates the average human driver in addition to the capacity for evaluating distances and velocity accurately. This leads to a higher road safety than with human drivers because lack of attention, tiredness and misestimations are eliminated.

Finally, the *all-knowing* driving logic represents an omniscient driving exploiting its capability to achieve the best possible performances while respecting traffic regulations.

These four driving logics aim at studying the effect CAVs could have on the road, by simulating the extremes of the broad driving behaviour spectrum CAVs can adopt. The development of the microscopic simulation is, among others, allowing the user to implement these four driving logics.

3.2. Further development of the microscopic simulation tool PTV Vissim

3.2.1. Data sources

The microscopic simulation tool PTV Vissim relies on several approaches and provides specifically two psycho-physical car following models developed by Wiedemann [WI74]. Psycho-physical models take into account human shortcomings in the perception of speed and distance and in operating the car.

As part of the project, answers to the following questions are investigated: Are there differences between conventional and automated vehicles in driving behaviour? If yes, which ones? And can they be modelled based on PTV Vissim existing approaches? Which modifications of these approaches are necessary? Which parameter(s) would change compared to the human behaviour?

To answer these questions, three sources of information have been used:

An interface between the control logics of automated cars from the project partners Renault, VEDECOM and the CAV simulator PreScan[3] has been established. PreScan and PTV Vissim can also be connected thanks to an already existing interface. Thereby, PreScan provides the vehicle dynamics, Renault and VEDECOM the decision algorithms (driving behaviour) and PTV Vissim the surrounding traffic (vehicles and eventually pedestrians). Based on these interfaces it is possible to run co-simulations and analyse them with PTV Vissim.

Besides applying high level informatic software, information provided by project partners has also turned out to be a useful source for answering the above-mentioned questions. The information consists of data but also of the experience and opinion of developers of control logics on decisive parameters and behaviours.

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On top of the challenge of adapting the simulation software for CAVs based on the two sources explained above, comes the challenge of getting reliable data to calibrate and validate the developments. Even though connected and automated cars are currently being tested in many cities, very few data are available. For this reason, TASS International organised a data collection in real traffic environment on a test track in Helmond (The Netherlands). Two CAVs following a conventional car were studied for different scenarios, the data have then been analysed and used for the validation of the PTV Vissim development [ZE18] [CO18].

3.2.2. Data Evaluation

Based on the data collected in Helmond, several parameters for the simulation of CAV could be evaluated: the relationship between following distance and velocity, the relationship between following distance and difference in velocity, standstill distance (distance between two successive vehicles stopped) and target headway (distance between two successive vehicles driving). The automated vehicles are equipped with cooperative advanced cruise control (CACC) which can be on, off or in degraded mode (dCACC) which is CACC without vehicle to vehicle (V2V) communication. The difference between ACC and dCACC is that in dCACC the following vehicle is estimating the acceleration of its predecessor instead of communicating with it. Data from sensors such as LiDAR, GPS and MOVE CAN interface have been collected and the results of their analysis for conventional vehicles, automated vehicles with CACC and dCACC have been compared.

As one could expect, automated vehicles with activated V2V communication are able to keep lower standstill distances and headways than without. The same applies to the comparison between CAVs with activated V2V communication and conventional vehicles. The relationship between headway and velocity is in every case (conventional, automated car with CACC and dCACC) linear or almost linear. With V2V communication and in following mode, the automated vehicles could keep 0.3 or 0.6 second headway safely. Furthermore, oscillations in the velocity of the automated car during following process are small in comparison to conventional vehicles. In the same way, stochastic variation in driveway or standstill are almost suppressed.

The co-simulations, run in cooperation with VEDECOM, revealed similar results: the relationship between headway and velocity during following process is deterministic and oscillation during following process is smaller and without much variance in comparison with conventional vehicle[4].

3.2.3. Further development of PTV Vissim

The test-track and co-simulation results showed fundamental differences between CAVs and conventional vehicles in following behaviour. Modelling the behaviour of automated vehicles in PTV Vissim (directly within the graphic user interface (GUI) without the need for use of interfaces & programming work)

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required not only change of existing driving behaviour parameters, but also adding some new features to the software. In addition to the results of the data evaluation, the driving logics described above and numerous discussions between the CoEXist consortium members have been considered for the development of new features for PTV Vissim 11[5] which are shown in Table 1:

Table 1 Description[5] of the new PTV Vissim features for the simulation of CAVs (released in Vissim 11)

Feature	Description	Relevant driving logic (see part 3.1)
Application programming interfaces (API)	APIs can be used to simulate vehicles with one's own algorithms, to connect and exchange information with an external simulator but also to simulate communication and cooperation strategies or any other feature that is not directly available in the graphic user interface from Vissim. Dynamic link libraries for the driver model and the driving simulator (drivemodel.dll and drivingsimulator.dll) have been improved[6].	All
Enforce absolute breaking distance	The vehicle can stop safely anytime (without a crash), even if the leading vehicle stops instantly ("turns into brick wall"). This ensures that the brick wall stop distance is always kept.	Rail Safe Cautious
Zero passenger /Empty trips	For simulating the highest level of automation, it is needed to allow "empty trips" which mean vehicles with no people inside.	All
Use implicit stochastics	The stochastic imperfection of human driving is replaced by deterministic machines and computers. If this attribute is false, a deterministically instead of a stochastically distributed value is used. The values which cannot be influenced by the users of PTV Vissim e.g. via an adjustable distribution and which are expected to be unaffected by human perception in CAVs. are affected	All
Class dependent safety distance in following behaviour	The headway to the followed vehicle depends on the followed vehicle class. This feature allows to set different following distances to conventional vehicles, automated vehicles, connected and automated vehicles, cyclists etc.	All
Number of interaction objects & vehicles	The attribute "observed vehicles" from 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 heads), and "Number of interaction vehicles" refers only to real vehicles. The number of interaction vehicles defines an	All

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	upper limit for the observed leading vehicles, therefore, for example, this could be set to 1 for autonomous 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.	
Consider vehicles in dynamic potential	The interaction between vehicles and pedestrians in crossing conflict (e.g. on shared space areas) has been improved by considering vehicles in dynamic potential. The pedestrians are able to find and use gaps between standing or slow-moving vehicles dynamically, so their behaviour is more intelligent and closer to real behaviour.	All
Increased acceleration in following	This new parameter allows to set higher acceleration in following process in order to “stay in touch” when the speed of the leading vehicle increases significantly. To mimic such behaviour, this parameter can be set a value above 100% for a specific vehicle class and in dependence of the leading vehicle class as well.	Normal All-knowing
Labels for vehicles	This feature allows to show any vehicle attribute in a label. The label is moving with the vehicle during 2D visualisation. This is useful for debugging or analysing the model, showing results, etc.	All

3.2.4. Validation

One of the psycho-physical car following models included in PTV Vissim (Wiedemann 99) turned out to be well suited to model CAVs because of its high flexibility. One can vary parameters easily, and it assumes a linear relationship between velocity and following distance (i.e., a constant time headway plus standstill distance) as it has been observed for CAVs in the data evaluation. Furthermore, the vehicles keep their exact desired speed when no vehicle in front influences their comportment.

To validate the improvement and give guidelines to the users, simulation with PTV Vissim have been carried out and compared to the data from the test track and the co-simulation. By adjusting the different parameters of the car following model, satisfactory fits could be achieved.

From the validation results, recommendations on the values the user might use for each driving logics have been evaluated. Qualitative and quantitative indications for different traffic situations have been gathered and made available to the partners of the project[7].

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4. DEVELOPMENT OF THE IMPACT ASSESSMENT

In general, CoEXist offers simulation and modelling solutions as well as assessment tools which should help local authorities quantifying the effects of the introduction of CAVs for specific road sites and boundary conditions. Thereby road authorities can evaluate whether a certain road site is AV-ready or whether any measures should be implemented to avoid negative impacts. The specification of the road site and the boundary conditions of the analysis is done by applying templates for describing the use case and its scenario (see Figure 1). The template for describing the use case includes information about the traffic environment of a specific road site, incorporated infrastructure, data, models, etc. For each use case to be analysed a scenario is specified. The scenario template allows describing further boundary conditions which are necessary to model and simulate the use case appropriately: the level of CAV introduction (including the capabilities of vehicles, their driving functions and driving logics), travel demands and assumptions concerning the travel behaviour adaptions of human drivers.

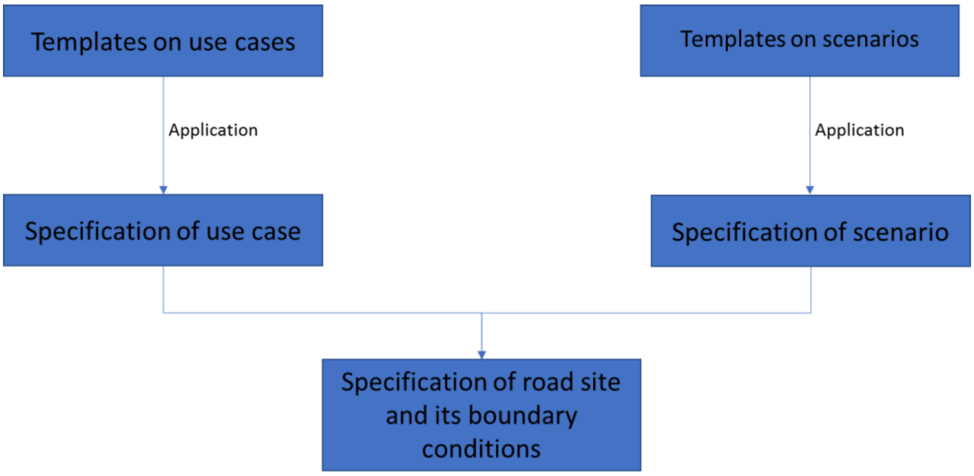

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Figure 1: Specification of road site to be analysed by use case and scenario templates

The use case and scenario description includes important information on the driving functions, conflict situation and penetration rate for applying the impact assessment.

The impact assessment and the respective tools developed within CoEXist will focus on the impacts of the introduction of CAVs on road safety, traffic performance and space efficiency. The respective project work is still in progress. As the authors of the present paper are mainly responsible for the part dealing with road safety, the following explanations focus on the safety aspects.

On the whole, partners of CoEXist are trying to develop methodologies which would allow a quantitative impact assessment as quantitative results from traffic

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models and simulations are available. Referring to road safety, it turned out, that a quantitative assessment will not be possible for the following reasons:

The state of the art approach for quantifying safety impacts based on results of microscopic simulation is the so called surrogate safety assessment model (SSAM). It automatically identifies safety conflicts based on trajectory data of the simulation and calculates several indicators, so called surrogate safety measures, for each of the conflicts. Based on thresholds for surrogate safety measures or correlations between surrogate safety measures and accident indicators, it is then possible to quantify the accident situation for the analysed road site. As neither these thresholds nor the relations between surrogate safety measures and accident indicators are valid for CAVs, SSAM cannot be applied directly for the impact assessment developed in CoEXist.

Therefore, other approaches which are not based on results of microscopic simulation have been considered. The partners concluded that the data-based impact assessment of driving functions [RO18] which has mainly been worked out by the IKA institute of RWTH Aachen might be an appropriate basis for working out the safety related impact assessment within CoEXist. This IKA-approach focuses on the analysis of driving functions. Scenarios which are potentially affected by the respective driving function are identified. Afterwards the impact of the respective driving function on accidents (severity and number of accidents) of the respective scenarios are analysed by accident simulations. Finally, the impacts of each driving function are extrapolated on national level. This approach has recently been applied to Germany to assess the impacts of driving functions on German roads. The results of these studies will be published soon, hence not available for CoEXist.

Since assessing safety impacts quantitively is problematic, the project partners of CoEXist have been working on a qualitative assessment instead, following the general ideas of the IKA-approach but not going that much into detail (see Figure 2): Just like the IKA-approach [RO18], CoEXist also focusses on the driving functions and their impacts. Conflict situations incorporating boundary conditions such as road environment, road characteristics, type of accident, etc. which are potentially addressed by the driving functions are identified and a qualitative assessment of the impacts of each driving function on road safety has been carried out. The qualitative assessment is based on a scale classifying the impacts into two levels: safety improvement or no significant impact.

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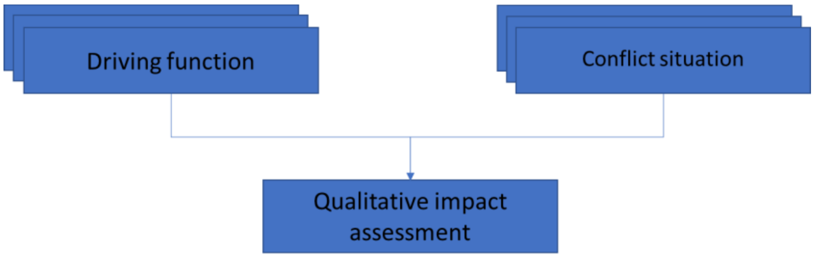

Figure 2 Qualitative impact assessment for driving functions

This qualitative assessment focusses on the CAV and the question whether the driving function helps to avoid errors that lead to accidents. Just like the IKA-approach it is assumed that driving functions would not lead to a significant increase in accidents caused by the CAVs [RO17]. Therefore, the above-mentioned scale does not comprise a level for deterioration of road safety.

The qualitative assessment described so far does not consider potential positive or negative safety impacts on the surrounding conventional vehicles which are not equipped with the respective driving function. To consider these effects which – especially in case of low penetration rates of CAV – might be the determining factor for the safety impacts of a driving function an overall function has been developed representing those effects.

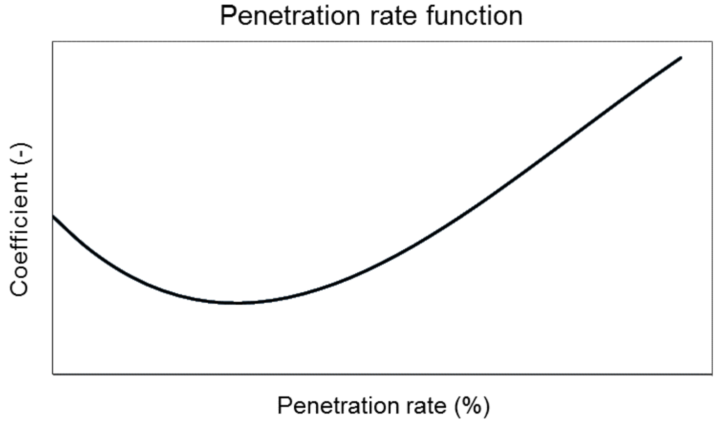

Figure 3: Function of the penetration rate

Although the function describing the impacts of the penetration rate is not defined in detail (see Figure 3) it covers the following aspects: The introduction of CAVs with low penetration rates would lead to higher uncertainty and a deterioration of human drivers' road safety because of unexpected behaviours of the CAVs. This assumption might become plausible if one thinks about CAVs following the all-knowing or rail safe driving logic: Their driving behaviour will differ widely from the one of conventional vehicles. Furthermore, it is assumed that human drivers would learn to adapt their own behaviour with increasing penetration rates to cope with the behaviour and driving manoeuvres of CAVs.

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Therefore, it is assumed that road safety for conventional vehicles increases with increasing CAVs penetration rate. It is clear that the assumption here is strong and relies on the current vision one can have. Ways to validate this assumption are currently under discussion which means that modification could still take place. Furthermore, this function might be refined according to new knowledge gained over time.

By combining the evaluation of the driving functions and the penetration rate function for relevant conflict situations, a qualitative impact assessment is generated, giving an indication of the change in road safety one could expect.

5. THE USE CASES

The tools developed during the project will be applied in four road authorities within the next two years. Each of them in two scenarios that are particularly relevant for them. An overview is shown in Table 2 below:

Table 2. Overview of the CoEXist use cases (adapted from [GY18])

City	Use Case	Modelling approach[8]
Gothenburg, Sweden	1) *Shared space*: The effect of an automated last mile service on the traffic will be studied in areas with conventional traffic regulations but dominated by large volume of pedestrians, i.e. shared space.	Micro
	2) *Accessibility during long-term construction works*: Estimation of the effect of different measures that could be taken during long-term construction work such as allowing CAVs to cross the area on narrow temporary lanes while conventional cars would be diverted, bidirectional CAV traffic in tunnel, etc.	Macro
Helmond, The Netherlands	3) *Signalised intersection including pedestrians and cyclists:* Exploration of how traffic optimisation in mix CAV and CV traffic can be redistributed to pedestrians and cyclists in terms of space and time.	Micro
	4) *Transition from interurban highway to arterial*: In this use case the focus will be on speeding problems on interurban highway to arterial junction. In particular the influence of CAV equipped with intelligent speed adaptation on the traffic.	Micro

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Milton Keynes, United Kingdom	5) *Waiting and drop-off areas for passengers:* Evaluation of the impact of waiting and drop-off areas for CAVs at the edge of the city centre and restricted vehicle access to the city centre.	Micro
	6) *Impact of AV deliveries and freights movements:* Extension of use case 5 focusing on freight deliveries and pick-ups instead of passenger drop off or pick-up.	Micro
Stuttgart, Germany	7) *Impacts of CAV on travel time and mode choice on a network level*: Investigation of how the motorway capacity increase expected with the introduction of CAV will impact travel time and mode choice on a network level.	Macro
	8) *Impact of driverless car- and ridesharing services*: Examination of the potentials of CAVs for car- and ride-sharing services and their impact on public transport and urban traffic flow.	Macro

6. CONCLUSION

Within the H2020 CoEXist project significant progress has been made on microscopic simulation software and their capability for simulating CAVs and their interactions with conventional cars during the transition period in which both vehicles types will share the same infrastructure. As today there are still some knowledge gaps about which driving functions and driving behaviours future CAVs will have. PTV Vissim 11 allows to simulate their full range.

Furthermore, first steps towards safety impact assessments for CAVs have been made which allows considering specific local conditions. The impact assessment will be worked out in details within the next months.

In parallel, the transition phase will be also studied with the macroscopic modelling tool PTV Visum which will be further developed as well.

These tools will finally be applied to the above-mentioned use cases for deriving general recommendations for getting road infrastructure AV-ready.

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NOTES

1. https://www.h2020-coexist.eu/
2. For more details, please refer to the documents and other publications published as part of the CoEXist project and available on https://www.h2020-coexist.eu/.
3. Software commercialised by TASS International.
4. For more details, please refer to deliverable 2.6 of the CoEXist project, available on https://www.h2020-coexist.eu/.
5. For more information, links to a webinar and documentation are available on https://www.h2020-coexist.eu/. A “what’s new document” can also be found on https://www.ptvgroup.com/fileadmin/user_upload/Products/PTV_Vissim/Documents/PDF/PTV-Vissim_What-is-new-in-Vissim-11_EN.pdf.
6. For more information, please refer to Appendix 1 and 2 of CoEXist deliverable D2.2 available on https://www.h2020-coexist.eu/
7. For more information please refer to deliverable 2.3 *Default behavioural parameter sets* that can be downloaded on CoEXist website https://www.h2020-coexist.eu/.
8. As already stated at the beginning of the article, macroscopic modelling tools (PTV Visum) are also being enhanced within CoEXist. However, this paper focuses on the microscopic part only.

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