D4.7 Guidelines: How to become an automation-ready road authority?

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Table of contents

1 Introduction 4
2 Current state of automation-readiness" in European cities 6
2.1 Expectations 6
2.2 Challenges 8
2.3 Strategy and approach 9
2.4 Participation and cooperation 10
2.5 Planning measures towards automation-readiness 12
3 Automation-ready Transport Modelling 13
3.1 Methodology 13
3.2 Automation-ready microscopic traffic modelling tools 14
3.3 Automation-ready macroscopic travel demand modelling 16
4 Automation-ready Road Infrastructure 18
4.1 Impact assessment methodology 18
5 Automation-ready Road Authorities 19
5.1 CoEXist use case implementation 20
5.2 Automation-ready framework 37
5.3 Automation-ready Fora: local cooperative planning and policy discussions 38
5.4 Automation-ready Action Plans 41
6 Lessons learnt and recommendations 41
7 Glossary 43
8 Partners 44

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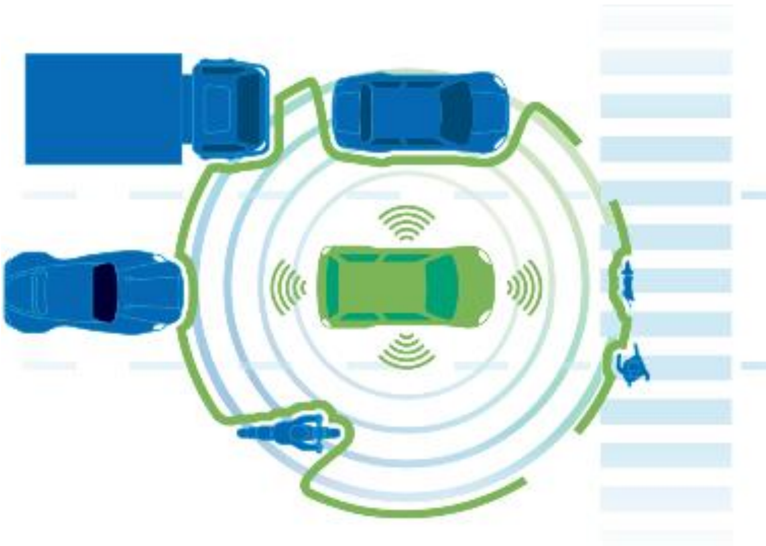
1 Introduction

CoEXist understands that automation-ready transport and infrastructure planning in cities are a key precondition for fulfilling the promises of connected and automated vehicles (CAVs). To ensure a positive roll out of CAVs and its alignment with local policy goals, authorities will have to play a key role and should take the lead with proactive planning approaces. This begins with planning, as early as possible, how the introduction of CAVs should unfold, to minimise the potential negative impacts and more importantly make the most of the opportunity to influence the paradigm shift into a more sustainable urban mobility vision.



The promises of Cooperative Connected and Automated Mobility (CCAM) to improve traffic and space efficiency, enhance safety and improve mobility for all, will only be fulfilled when local authorities have the capability to shape the deployment of CAVs to their needs. Without it, CCAM could certainly worsen the urban mobility problems that local authorities are currently facing.

There is a clear need for considering CAVs in local policy discussions and planning processes (e.g. SUMP), but its purpose should not be misunderstood as endorsing the disruptive technologies surrounding CCAM and their impacts, but rather empowering the local authorities to critically review the anticipated technological changes and shape the future according to their expectations.

This is defined in the CoEXist project as ‘automation-readiness’, i.e. the capability of making structured and informed decisions about the comprehensive deployment of CAVs in a mixed road environment, and it requires:

- A clear awareness of the technology underpinning CAVs, the different functional uses and business models for CCAM and a high-level understanding of the impacts different deployment scenarios can have on traffic, quality of life and stakeholders involved in local transport planning.
- The institutional capacity to plan for a future with CCAM by using tools that accurately represent CAV behaviour in order to identify the impacts of different deployment scenarios.
- A strategic approach in planning a wide range of measures that will ensure a deployment of CCAM, which supports higher level mobility goals, which can be achieved by following the SUMP concept and its principles.

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CoEXist has addressed three key steps in transport and infrastructure planning:

Automation-Ready Transport Modelling

Validated extension of existing microscopic traffic flow simulation and macroscopic transport modelling tools to include different types of CAVs (passenger cars/light-freight vehicles with different automation levels).

Automation-Ready Road Infrastructure

Develop tools to assess the impact of automated vehicles on traffic efficiency, space demand and safety, and provide guidance on infrastructure development, to suit both conventional and automated vehicles.

Automation-Ready Road Authorities

Elaboration of eight use cases in four local authorities (Gothenburg, Helmond, Milton Keynes and Stuttgart), used to evaluate – with the CoEXist tools – the impacts of automated vehicles on traffic efficiency, road space requirements and safety, to guide local policy discussion and identify strategies to improve automation-readiness.

This document aims to provide guidance and best practice examples to road authorities in Europe and beyond on how to become automation-ready. To do so, it presents a comprehensive overview of CoEXist's research and key results.

Chapter 2 describes the current state of automation-readiness in European cities, evidencing the need for guidance and knowledge exchange regarding CCAM. It presents the results of CoEXist's stakeholder consultation activities and reflects on the main aspects to be considered.

Then, Chapters 3 and 4 present the developed automation-ready modelling tools and road infrastructure impact assessment methodology, respectively, setting a technical framework to investigate CCAM scenarios and evaluate expected effects on urban mobility.

Furthermore, Chapter 5 focuses on the demonstration of CoEXist's tools in partner road authorities. Results and conclusions from each of the eight strategically selected use cases are presented and analysed. Also, the automation-ready planning framework is introduced, as well as its application in CoEXist cities for the development of concrete Action Plans, outlining key measures, the followed strategies and lessons learnt.

In this way, this report delivers concrete guidance, tools and methodologies to enable cooperative action and informed decision-making about the deployment of Cooperative Connected and Automated Mobility (CCAM), supporting road authorities in their way towards automation-readiness.

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2 Current state of automation-readiness” in European cities

In the light of providing guidance on **how to become an automation-ready road authority**, it has been an essential step to assess the current state of automation readiness among European cities. Therefore, far-reaching consultation took place, including an Online Automation-ready Survey with over 65 respondents from 21 different countries and a diverse background:

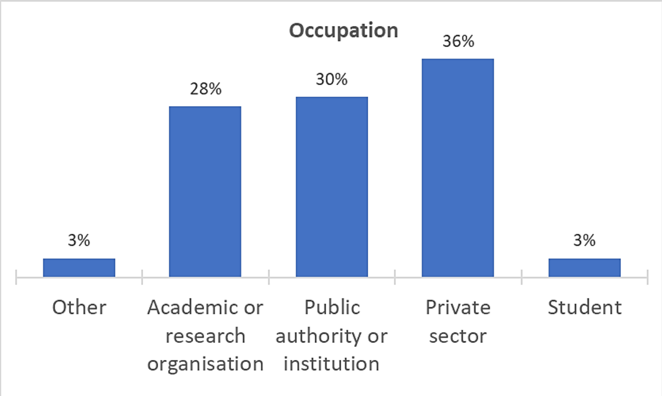

Figure 1: Occupation of Respondents to CoEXist's Online Automation-ready Survey

The consultation also included interviews with experts from Gothenburg, Helmond and Milton Keynes as well as experts not directly involved in the CoEXist project – namely Leipziger Verkehrsbetriebe, Deutsches Zentrum für Luft- und Raumfahrt, and the city of Bremen.

Moreover, the broad number of participants to CoEXist’s dissemination events, both in conferences (e.g., CIVITAS, SUMP and POLIS conferences) and online (e.g., webinars and the project’s virtual final conference) were polled and consulted, thus contributing to the findings on automation readiness.

The results are divided into **expectations**, **challenges**, **strategy and approach**, **participation and cooperation**, as well as **planning measures towards automation-readiness**. In general, these outcomes evidenced the high-level of uncertainty of the field and the need for guidance, capacity development and enhanced knowledge exchange.

2.1 Expectations

In order to specify the timeframe for all expectations on AV, one first question at several events was when participants expected fully automated vehicles to be commercially available. The consolidated and generalized results show that - despite the high level of expertise – the expectations vary considerably.

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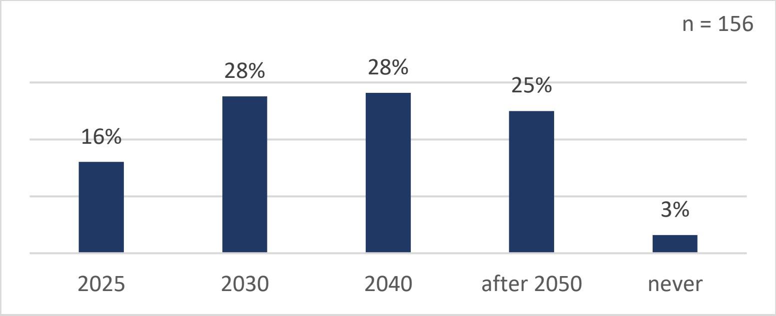
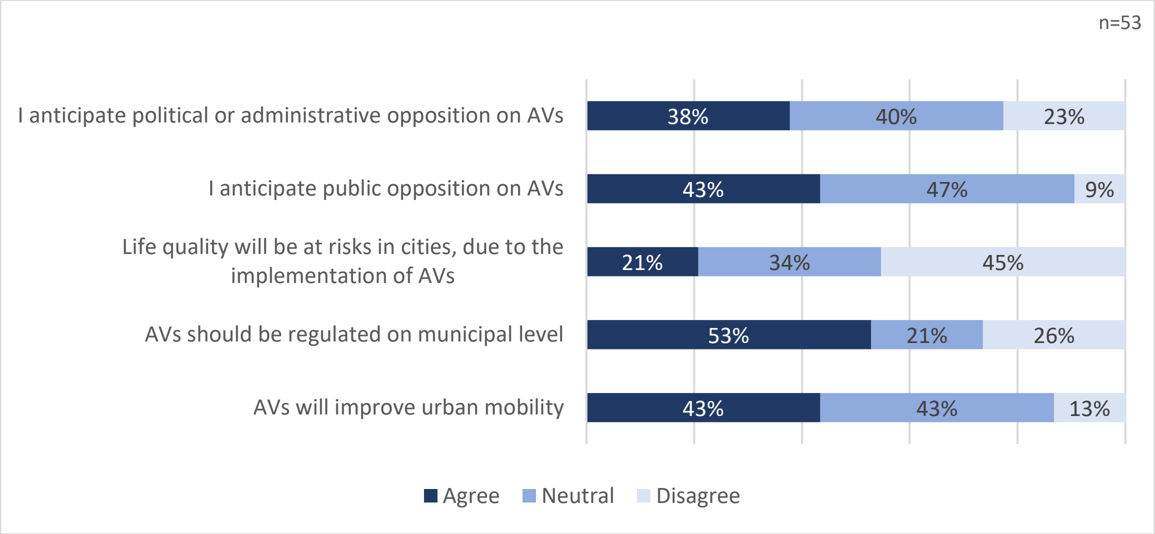
Question: When do you expect fully automated vehicles to be commercially available?



Stakeholders in general anticipate some opposition at political and public levels, and there is cautious consensus on expected improvements of urban mobility as a whole.

Question: Please indicate the extent to which you agree to the following statements.



In a more precise question where respondents were asked to evaluate certain potential impacts of AVs, it is pointed out that an increase in total vehicle kilometers travelled (vkm) is imminent, but accident rates are projected to decrease. Especially, no consensus was reached on expected effects of CCAM on congestion and personal transportation costs.

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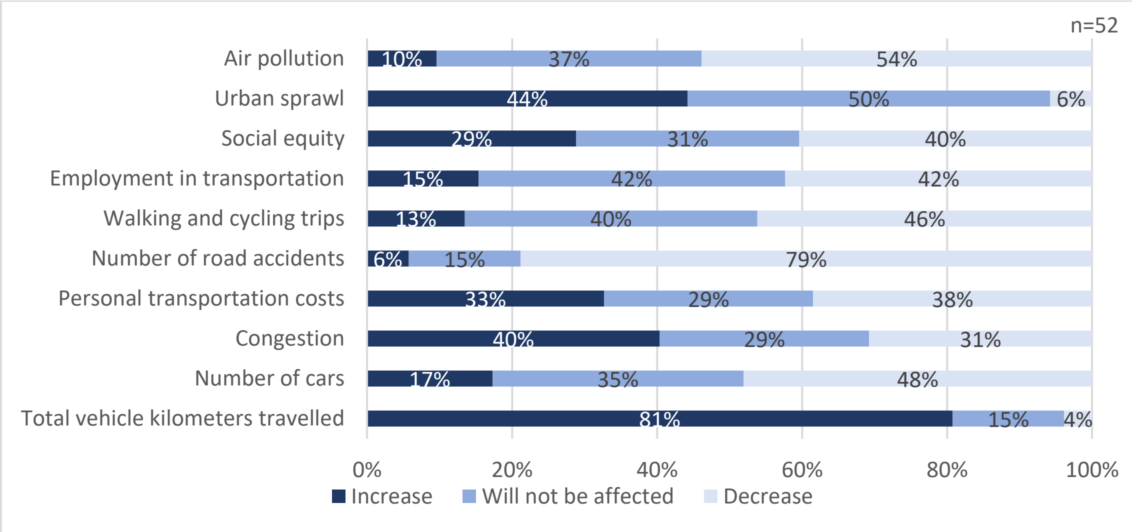
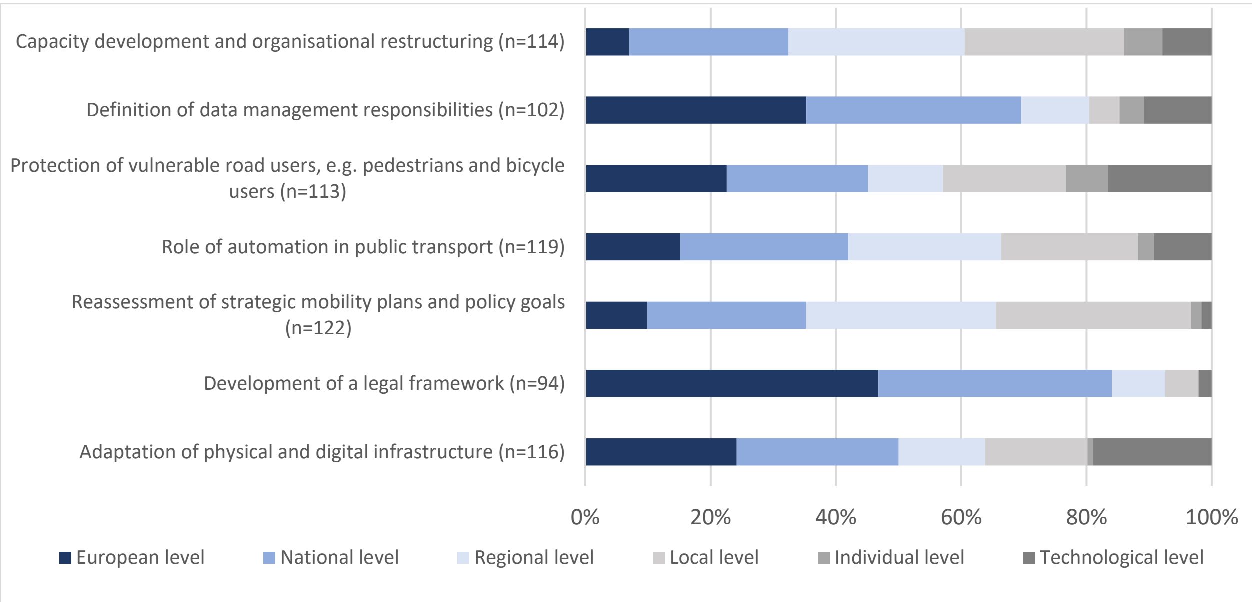
Question: How do you think AVs are likely to change the following aspects of urban mobility in your city/ region?



2.2 Challenges

Apart from potential impacts of the deployment of CAVs, barriers to the successful implementation of automated driving were examined by asking at which level certain challenges should be addressed. This poll question shows that European-level involvement is requested to define data management responsibilities and help develop a legal framework, which is also seen as a responsibility of national governments. Moreover, a majority of experts sees local-level authorities as the party responsible for the reassessment of strategic mobility plans and policy goals.

Question: At which level should these automation-related challenges be addressed?



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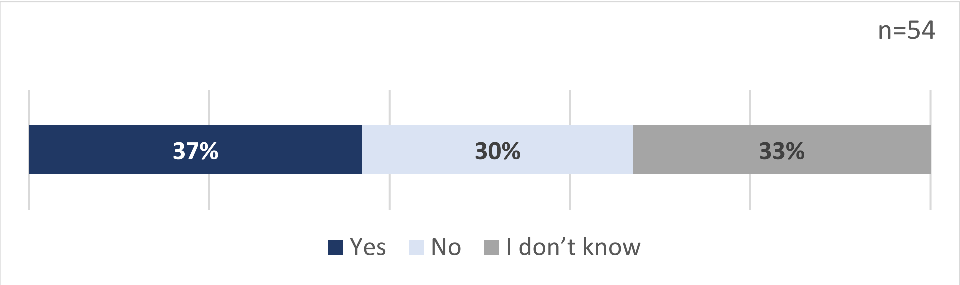
Apart from the concrete challenges that respondents were asked to assess, there are underlying obstacles that surface when analysing the interviews conducted with three of the CoEXist cities and the above-mentioned group of experts. Examples for such obstacles are the useful deployment of capabilities in road authorities, today's road infrastructure issues that need to be resolved before thinking about CAV-specific infrastructural adjustments, and general unpredictability. Furthermore, it is criticized that many cities follow future scenarios that might not turn out to be realistic and should instead focus on measuring probable impacts.

2.3 Strategy and approach

Strategies to resolve certain obstacles on the road to becoming automation ready are diverse. One approach named by a CoEXist partner city, for example, is based on frequent and iterative investigation and evaluation of the technology's capabilities in order to understand where and how it could be applied. Another approach focuses on finding solutions for today's transport issues that are feasible with market-ready ITS solutions, or in other words: capturing "quick-wins". One last CoEXist city approach prioritizes digitalisation, communication and stakeholder involvement as key strategic pillars. From the expert interviews, one can conclude that developing a vision and clear goal-setting should be at the basis of any strategy developed in the light of becoming automation ready. Key objectives defined are to gain an understanding of the future role of automation and to start solving current issues with new technologies as they arise. It is asserted by the experts that cities need to prioritize the available modes of transport in their strategies and redefine the role of passenger cars, which likely become more attractive for individual users as automated driving technologies gain traction. A central element of all strategic considerations among the cities is the fundamental uncertainty on impacts, capabilities and availability of CAVs. Some of the cities consulted tackle this problem by proactive technology monitoring and a "learning-by-doing" approach in the implementation of new solutions, others choose not to define concrete plans or measures and to "wait-and-see". Due to this early stage in the innovation cycle of said technologies, the experts recommend to monitor, but advise not to invest into infrastructure too early, as uncertainty prevails.

One key survey question on this matter quantifies the spread of concrete plans concerning connected automated driving among the experts' cities. Less than 40% of the experts surveyed can say that their city or organization has concrete planning documents on preparing for the deployment of CAVs.

Question: Are there any planning documents which address connected and automated driving (CAD) in your city or region of residence?



Another central component of the assessment of strategies and approaches of the cities consulted is a self-assessment on automation readiness. As shown, a vast majority of the surveyees indicate that their

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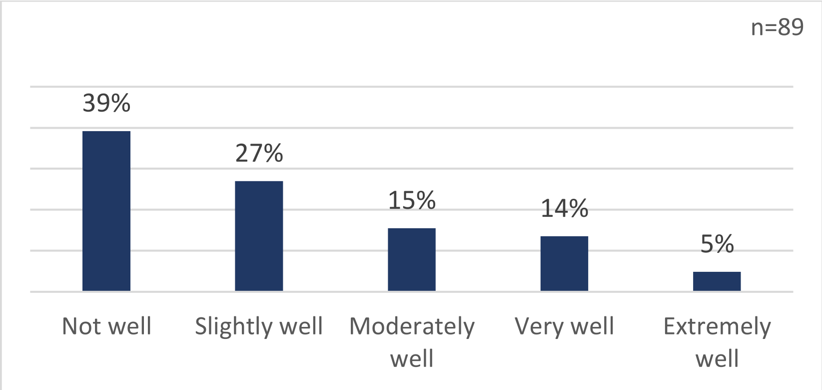
city or organisation has made little progress in preparing for the deployment of connected and automated vehicles while only around 20% fifth feel “very well” or “extremely well” prepared.

Question: How well prepared would you say your city or organisation is for the introduction of CAV?

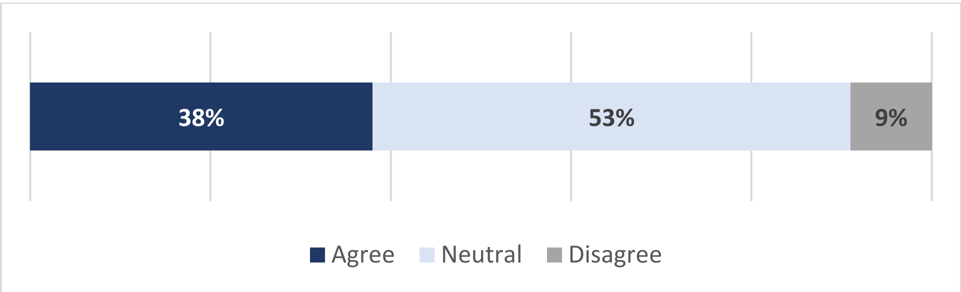


Cities that identify as rather well-prepared follow aforementioned proactive approaches like “learning-by-doing”, or “trial-and-error”. It is however important to mention that the mass introduction of CAVs is years ahead, which means that no city is fully prepared for this as of now. Time will have to show whether automation will ever be city-ready, as one expert pointed out.

2.4 Participation and cooperation

Public opposition or scepticism is also regarded as barrier to the deployment of connected and automated driving technologies, as shown below.

Question: Do you anticipate public opposition to the deployment of CCAM?



With a team of partners, Missions Publiques ran the first of two phases of an international and local citizens' dialogue processes in 2018 and 2019, where cities from Europe, North America, and Asia hosted deliberations focused on scenario building, trust, and policy. Automated mobility was one of the key topics of interest. As part of the international consortium of the citizen’s debate on driverless mobility, the City of Aachen joined up with RWTH Aachen University to host a debate with 100 of its citizens. Similarly, automated mobility was the topic of a citizen’s dialogue in five Austrian cities, led by AustriaTech. Almost 170 people attended the events in Vienna, Linz, Graz, Pörtschach and Salzburg to discuss the potential of this new technology.(For more information, visit http://themobilitydebate.net/).

Representatives from AustriaTech and the City of Aachen, participated in the CoEXist coordinated session at the CIVITAS Forum 2019. The data presented shows that citizens are in fact not entirely against testing

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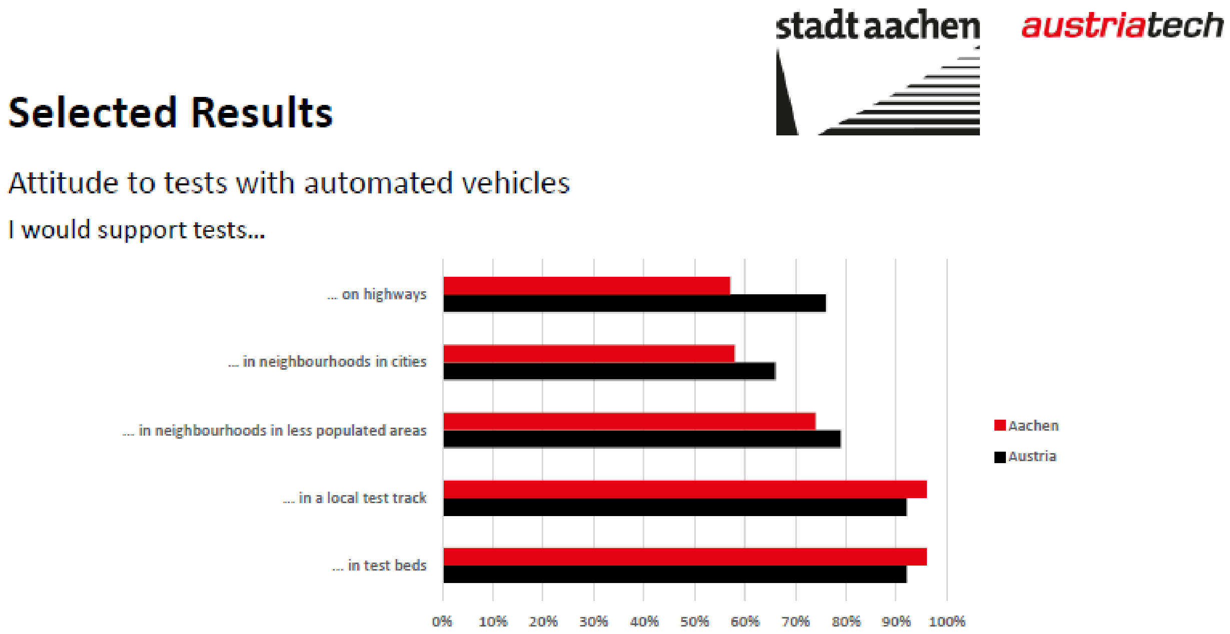
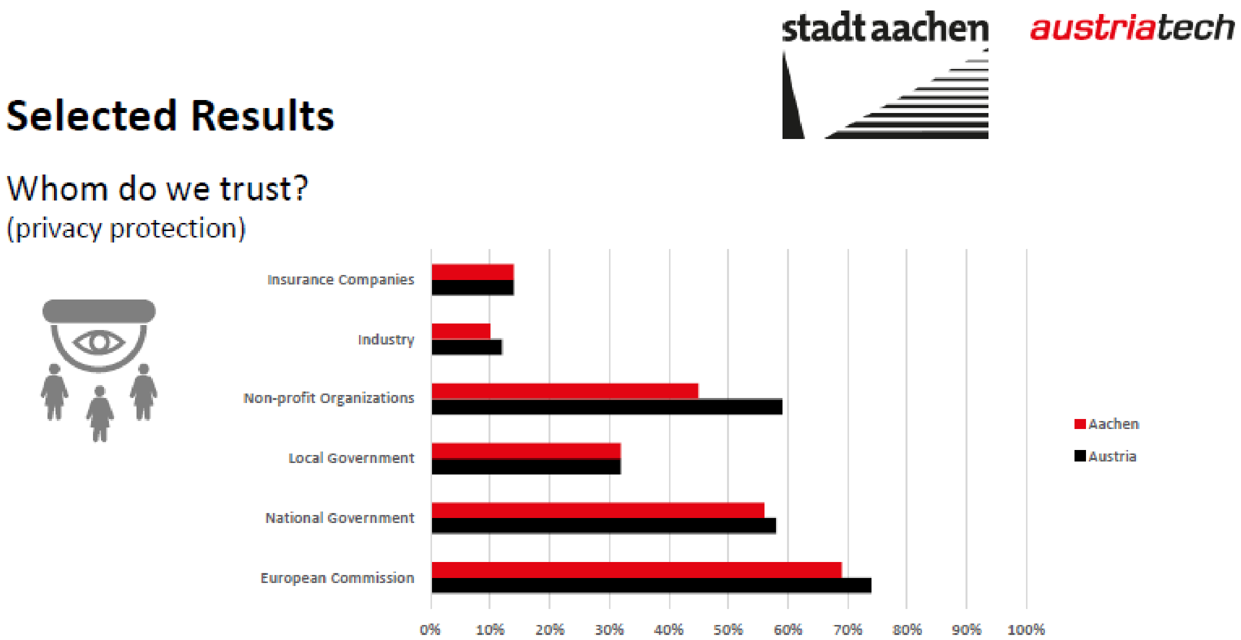
on public roads, as more than half of the surveyees in both Germany and Austria would support tests with automated vehicles on both highways and urban roads. The acceptance of such tests on specific test tracks is close to 100%. In terms of data security, citizens in both debates are cautious of private sector companies, while granting trust to the European Commission and national Governments.



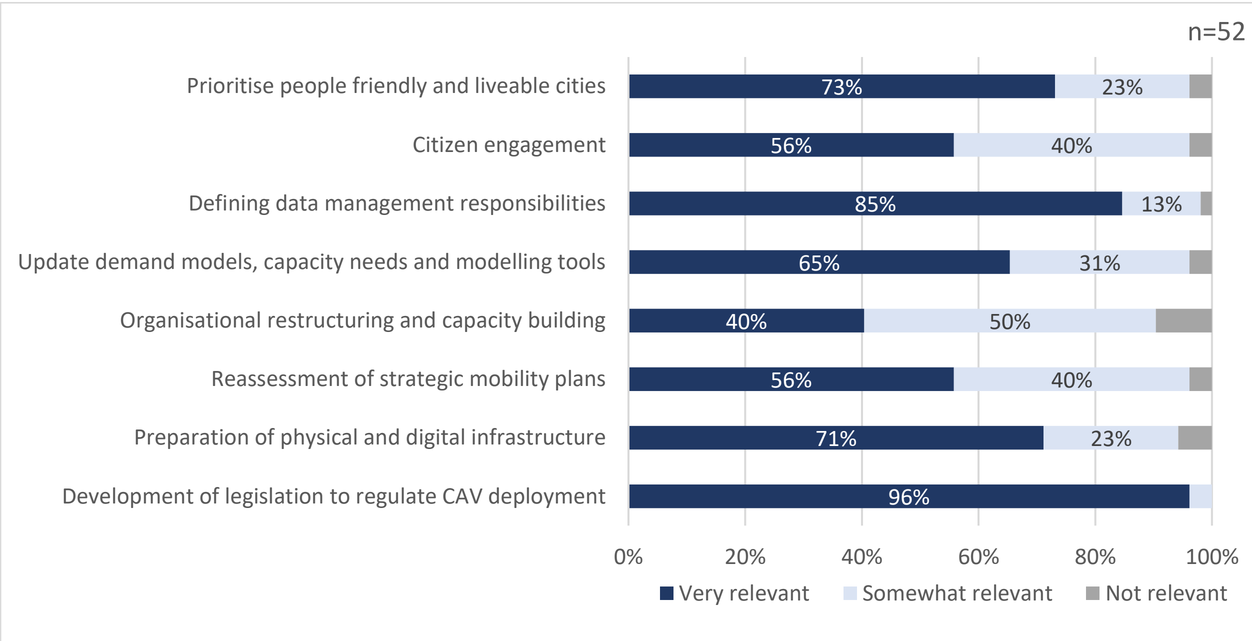


While the round of interviews held with experts confirms the general emphasis on civil engagement as key element of a successful strategy, it also points out the difficulty of leading discussions with city councils, citizens and manufacturers in this early stage of technological development.

2.5 Planning measures towards automation-readiness

The way cities prioritize different measures provides an insight into the current state of automation-ready planning activities. Therefore, one survey question asks surveyees to evaluate measures' relevance. The results show that legislation is an absolutely critical point and should therefore be addressed with high priority. Similarly, important, according to the experts, is data management and assigning responsibilities for data management. Furthermore, keeping the focus on liveability of cities is a priority and the preparation of physical and digital infrastructure are key steps in becoming automation-ready. Regarding infrastructural adjustments, experts advise caution due to uncertainty of future technological requirements on infrastructure but anticipate the clear need for changes like exemplarily the segregation of car and bike/ pedestrian traffic.

Question: How do you assess the relevance of these measures and policies to prepare for the arrival of CAVs?



To expand the results regarding prioritization of measures, two open questions aim at capturing any other measures that the attendees of the CoEXist Final Conference consider relevant. When asked about ways to enable benefits of connected and automated driving and general measures to become automation ready, the experts most frequently name activities in the field of impact assessment, acquisition and exchange of field data, and the development of policy and political emphasis. This conclusion was made by categorizing a total of 76 qualitative answers into technology, capacity building, goal-setting, impact assessment, cooperation, field data, policy, regulatory, and funding-related activities recommended by the respondents.

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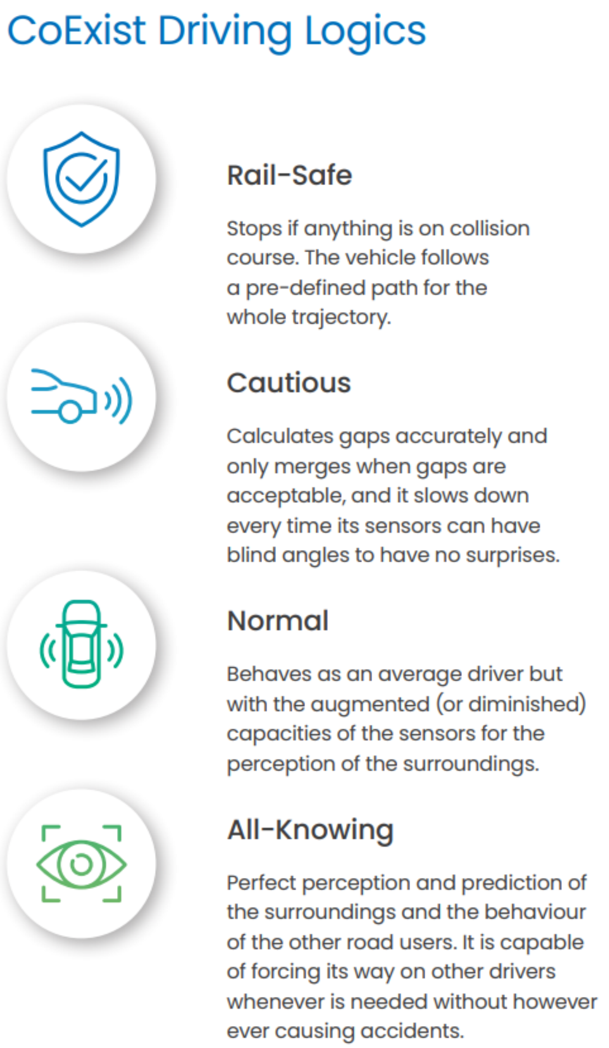
3 Automation-ready Transport Modelling

Many transport planning decisions affecting urban mobility and road infrastructure are based on the results of traffic flow and transport demand modelling. For this purpose, the availability of adapted simulation software is necessary, including new features and functionalities to allow for more accurate modelling of CAVs.



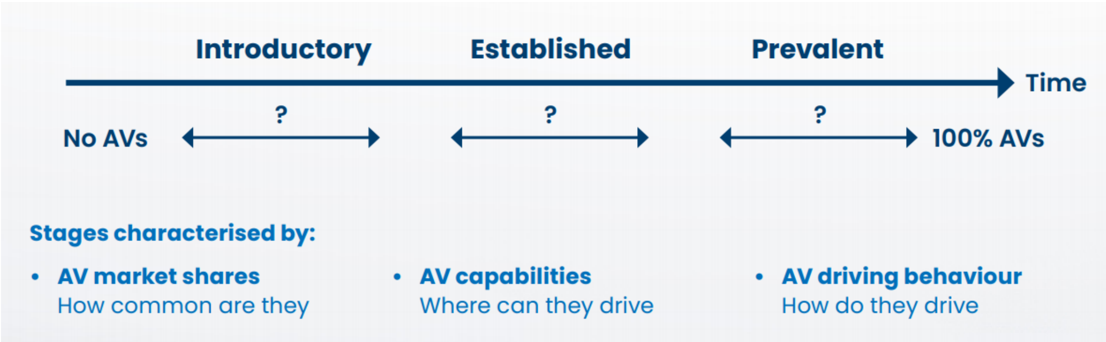
3.1 Methodology

Since there are many uncertainties about how future CAVs will behave, CoEXist general modelling approach aims at describing a range of possible behaviours of these vehicles.

The behaviours of the automated vehicles are specified by driving logics which are functionally defined, that is, in terms of how and where they can operate safely, disregarding which technologies make this possible.

As CAVs will likely behave differently in different environments, the driving logics are combined to AV-classes (basic, intermediate or advanced) by determining which driving logic each vehicle should follow, in different road environments.

A goal of the traffic modelling in the CoEXist project is to assess how the impact of automated vehicles on traffic efficiency, space demand and safety, evolves during the whole period of coexistence of conventional vehicles and CAVs, from the first introduction of small number of automated vehicles until when only a few conventional vehicles remain. To enable such assessment the transition period is divided into three stages: introductory, established and prevalent.



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In this way, the impact of automated vehicles is assessed for each stage with a range of assumptions for the considered variables, to address the uncertainty of the predicted impact. To limit the number of possible combinations, a correlation is assumed between them, considering the vehicles capabilities for each AV-class and the context for each road environment, to determine the applicable driving logics (see an example of the considered mixes in Table 1). Furthermore, the considered uncertainty parameters include the penetration rates of the various AV classes, traffic volumes and traveller behaviour adaptation (e.g., changes in travel time perception or pedestrian interaction with other road users).

Table 1: Example relation between AV-class, driving logics and road environment

Road type	Basic	Intermediate	Advanced
Motorway	Cautious	Normal	All-knowing
Arterial	Cautious	Cautious / Normal	All-knowing
Urban street	Manual	Cautious	Normal
Shared space	Manual	Rail-safe / Human	Cautious

3.2 Automation-ready microscopic traffic modelling tools

Within the H2020 CoEXist project, significant progress has been made on the macro- and microscopic simulation capabilities to model CAVs and their interactions with conventional vehicles and other road users.

Figure 2: PTV Vissim Simulation Environment - AV Shuttle Pods example ©PTV Group

The microscopic traffic flow simulator PTV Vissim was further developed to enable the simulation of CAV-behaviour, considering the differences in car-following distances, simple communication aspects (V2V and V2I) and acceleration behaviour, among other aspects.

Empirical data collected from real AV's on DICTM test track in Helmond (NL) and co-simulations integrating CAV driving logics (VEDECOM), vehicle dynamics (PreScan) and traffic simulator (PTV Vissim), were used to derive, calibrate and validate behavioural parameters of CAVs.

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What is possible in PTV Vissim?

Automated vehicles can have different automation levels, 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.

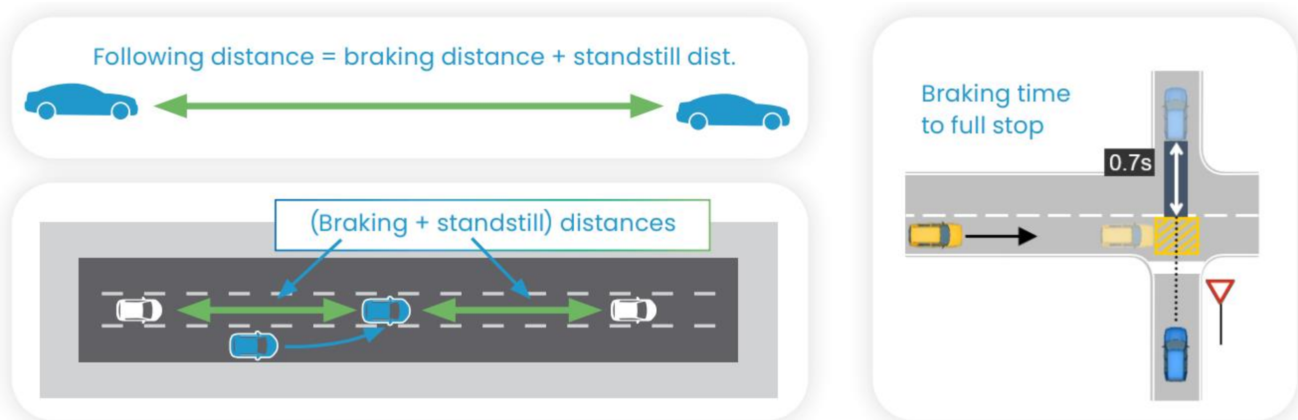

Figure 3: Examples of considered aspects for simulation of CAV-behaviour ©PTV Group

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 the software., allowing direct testing of algorithms, and giving the ability to visualize and compare the interactions 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. Saying, for instance, automation level 4 is insufficient for microscopic simulation because it requires knowledge or assumptions about the specific 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.).

Platooning**:** Platoons - groups of connected vehicles traveling closely together - are increasingly becoming a factor in traffic planning. Thus, a new feature was developed allowing you to model the effects of platooning on overall traffic.

For more informatio, see *D2.11 Guide for the simulation of AVs with microscopic modelling tool - Final Version*

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3.3 Automation-ready macroscopic travel demand modelling

CAV will influence not only traffic flow but also travel demand. If cars become more comfortable and use the road space more efficiently, car travel demand is likely to increase. Travel demand models replicating interactions between transport supply and travel demand permit estimations how CAV may influence demand.

Starting point are the results of the validated CAV-ready microscopic traffic flow model. They are used to create assumptions for the supply-side of macroscopic travel demand models. Volume-Delay functions are adapted to replicate the impacts of CAV on capacity, which depend on vehicle class, on road type and on the share of CAV. In addition, existing travel demand models can be extended to include changes in the perception of car travel time, as drivers may use some of this time for non-driving activities.

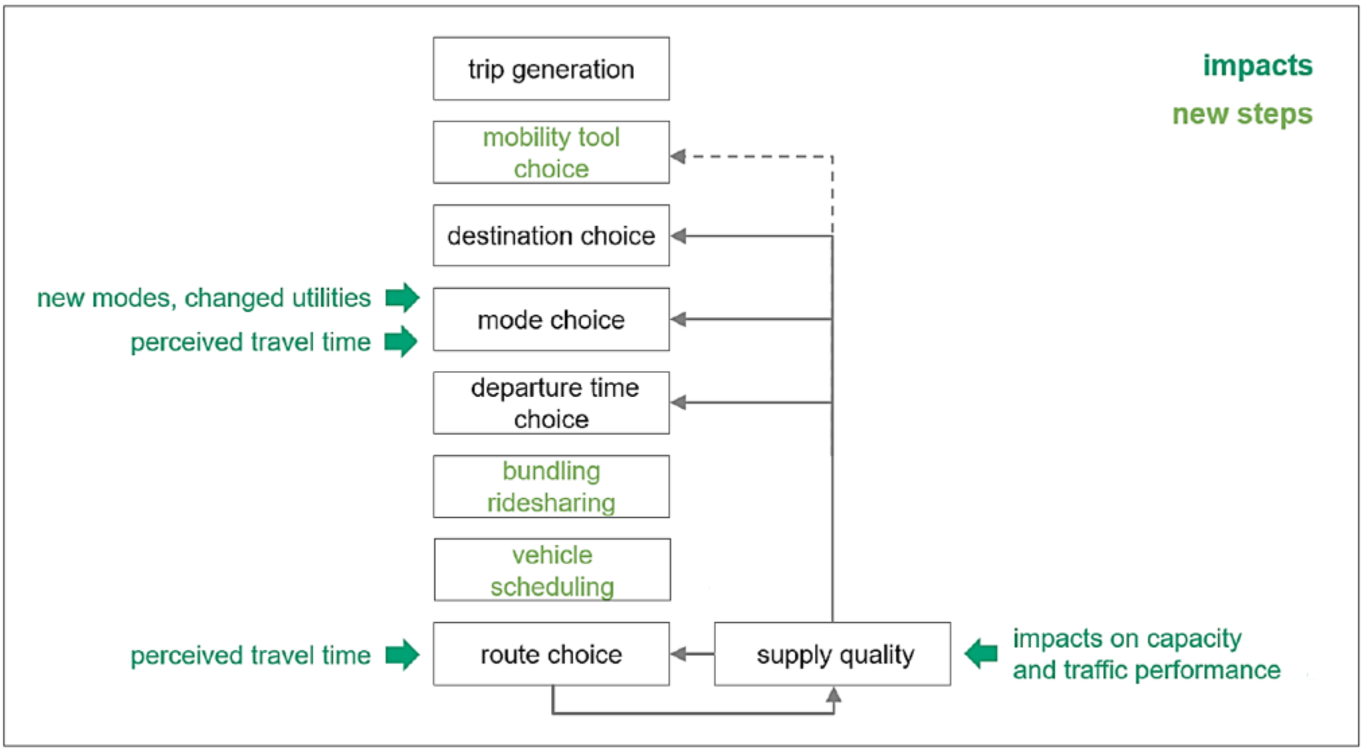

Figure 4: Modelling CAVs with macroscopic travel demand models (©University of Stuttgart)

CoEXist's macroscopic modelling tools provide extensions to PTV Visum by adding functionalities to the software in form of Visum compatible scripts, Visum procedure files and Visum Add-Ins. The tools can be integrated into the software to replicate the impacts of CAVs on capacity and demand. They allow the model developer or model user to test various assumptions, extending the capabilities of Visum to enable the consideration of CAVs in travel demand simulations.

Traditional travel demand models apply the four-step algorithm, where trip generation, destination choice, mode choice and route choice are covered to replicate people's behaviour and their movement. Departure time choice may also be considered as a step. Integrating automated vehicles or new mobility services into these models requires additional steps in the procedure, to account for the impacts of AV on supply and demand.

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Volume-Delay Functions: Traffic assignment methods apply volume-delay functions to describe the relationship between traffic flow, capacity and travel time on each network element. In order to replicate impacts of CAV on capacity, CoEXist's uses the concept of passenger car units (PCU) where capacity and vehicle volumes are converted into passenger car equivalents. Specific PCU values are assigned to CAV depending on the driving logic and road type. The procedure accounts for non-linear effects of different CAV-shares on travel time.

Figure 5: Example of different PCU values per type of vehicle **(©University of Stuttgart)**

Perception of travel time: Vehicles that can drive automated on certain road types or network sections permit drivers to use part of the journey for non-driving tasks. As a result, the in-vehicle time is perceived in a different way, affecting the attractiveness of private cars.

Ridematching: An algorithm is provided which enables pooling trips of suppliers (today typically drivers of conventional vehicles, in the future mobility-as-a-service providers) and demanders (travellers).

Vehicle scheduling: The model extension computes schedules for fleets of MaaS vehicles while minimizing the fleet size and determining the required empty runs between drop-off and pick-up locations. As result, the model extension provides the required fleet size and the number of empty vehicle trips for a predicted or given demand. Such algorithms already exist for integer demand. However, the developed method is also able to handle non-integer demand, which makes it applicable for macroscopic travel demand models.

For more information, please see *D2.7 AV-ready macroscopic modelling tool*, *D2.8 Guide for the simulation of AVs with macroscopic modelling tool*, and *D2.9 Built-in functionality for the AV-ready macroscopic modelling tool available*.

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4 Automation-ready Road Infrastructure

4.1 Impact assessment methodology

Automation-ready planning in a mixed road environment, also requires a high-level understanding on the uncertainties and variations of the impacts of CAVs on traffic efficiency, space demand and safety. And consequently, its implications to stakeholders involved in local transport planning. Thus, it is essential to enhance institutional capability to plan for a future with CAVs, by using tools that accurately represent CAV behaviour and identify the impacts of different deployment scenarios.

In addition to accurate and robust modelling tools, it is necessary to define relevant indicators to be measured and to develop tools and methods to process modelling results and determine the impacts of CAV deployment on urban mobility and road infrastructure. CoEXist has focused on evaluating the effects of CAVs on: traffic performance, space efficiency and safety.

Table 2: CoEXist Road Infrastructure Impact Assessment Metrics

CoEXist Road Infrastructure Impact Assessment Metrics		
Traffic Performance	**Space efficiency**	**Safety**
• Served Demand Ratio (SDR) • Average travel time (ATT) • Average individual travel time per distance (AITTD) • Average delay (AD) • Vehicle kilometres travelled (VKT) • Person kilometres travelled (PKT) • Vehicle Hours Travelled (VHT) • Person hours travelled (PHT)	• Average Space claim (ASC) • Average space time footprint (STF) • Space time utilisation (STU)	<u>Qualitative safety assessment approach:</u> Identification of conflict situations incorporating boundary conditions (such as road environment, road characteristics, type of accident, etc.) which are potentially addressed by each driving function, to qualitatively assess the impacts of automated functionalities on road safety. <u>Quantitative safety assessment:</u> through combined simulation and road safety inspections.

For a full definition of the metrics and their calculation methods, please see *D3.2 Definitions of performance metrics and qualitative indicators* at www.h2020-coexist.eu/resources

CoEXist's automation-ready road infrastructure assessment tool consists of a set of scripts and spreadsheet-based tool's for the calculation of the above specified metrics and the use case specific impacts on traffic performance and space efficiency based on the micro- and macroscopic simulation outputs, as well as a qualitative estimation of traffic safety effects of different AV-functions for a specific use-case.

For a detailed explanation of the tool's functionalities and guidance for its usage, please see *D3.3 AV-ready hybrid road infrastructure assessment tool*. The scripts and the spreadsheet-based tools are also available for download at www.h2020-coexist.eu

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5 Automation-ready Road Authorities

The overall outcome of the project is to support local authorities on their road towards automation-readiness. Yet the concept of “automation-readiness” should not be misunderstood as an endorsement of the disruptive technologies surrounding CAVs and their impacts, but rather an empowerment of local authorities to critically review the anticipated technological changes and shape the future according to their expectations. Hence, the concept of “automation-readiness” is defined as:

The capability of making structured and informed decisions about the comprehensive deployment of CAVs in a mixed road environment. This capability requires:

- A clear awareness of the technology underpinning CAVs, the different functional uses and business models for CAVs and a high-level understanding of the impacts different deployment scenarios can have on traffic, quality of life and stakeholders involved in local transport planning.
- The institutional capacity to plan for a future with CAVs by using tools that accurately represent CAV behaviour in order to identify the impacts of different CAV deployment scenarios.
- A strategic approach in setting up a wide range of measures that will ensure a deployment of CAVs, which supports higher level mobility goals.

5.1 CoEXist use case implementation

The automation-ready tools developed within the CoEXist project have been used to evaluate the traffic impact of automation for eight strategically selected use cases in four different cities.

The following sections present a general description of the implemented use cases and a brief analysis of the main results.

Gothenburg, Sweden

- Shared spaces
- Accessibility during long-term construction works

Helmond, the Netherlands

- Signalised intersection including pedestrians and cyclists
- Transition from interurban highway to arterial

Milton Keynes, United-Kingdom

- Waiting and drop-off areas for passengers
- Priority Junction Operation (roundabouts)

Stuttgart, Germany

- Impacts of CAVs on travel time and mode choice on a network level
- Impact of driverless car- and ridesharing services

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5.1.1 Use case 1: Shared space (Gothenburg, SE)

Can CAVs get through a lively shared space, packed with pedestrians?

A shared space in the city centre of Gothenburg is modelled with a microsimulation model in Vissim, with the Viswalk addition to better represent the motion of the pedestrians. The evaluated scenario is the introduction of an automated last mile service passing through the shared space to assess how advanced automation technology is required for such a service to be feasible from a traffic performance perspective.

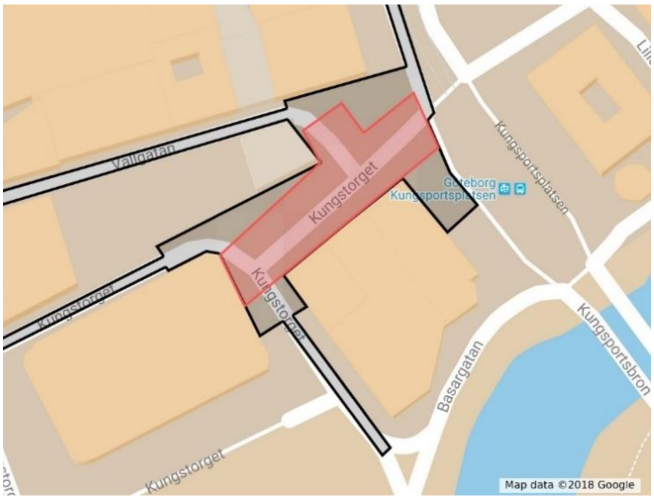

Figure 6: Use case 1 deployment area (©VTI)

Figure 7: Use case 1 illustration (City of Gothenburg)

The deployment area is characterised by high flows of pedestrians and public transport (PT), and lower capacity for car traffic expected through CAV introduction, due to possible difficulties concerning the interaction between the vehicles and pedestrians. The addition of zebra crossings for the channelization of pedestrian flow was considered as measure to be tested.

Vehicle travel time increases through the shared space area.
The simulations indicate a negative impact on traffic performance for all three stages. However, since this is partly due to full speed limit compliance of CAVs this may be positive for safety. Delay for cars and minibuses increases substantially when automated vehicles are introduced since the first CAVs are very cautious when interacting with pedestrians. When the CAVs get more advanced their negative impact on traffic performance is reduced. Twice the average walking speed is often seen as a minimum for a last mile service to be attractive. The simulations indicate that the minibuses will have an average speed lower than this threshold through the shared space due to delays resulting from interactions with pedestrians. However, minibus trips will not only go through shared space areas which will result in an average trip speed above twice the walking speed.

Traffic performance for pedestrians is unaffected by the introduction of automated vehicles
Both automated and conventional vehicles give way to pedestrians and the additional safety distance kept by automated vehicles does not affect the pedestrian traffic; the pedestrians were already mostly unaffected by the vehicle traffic since they always claim their right of way.

Channelizing pedestrian flows leads to breakdown of vehicle traffic
The investigated measure to channelize pedestrian flows using pedestrian crossings fails dramatically. Long queues of vehicles are formed behind automated vehicles waiting at the pedestrian crossings unable to get past the continuous flow of pedestrians formed by the channelization; vehicle traffic breaks down completely.

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Potential safety effects

The analysis indicates a positive impact on the safety both for pedestrians and vehicles (excluding potential technology failures). A large part of the risk reduction is due to that AVs are assumed to make less (or no) "driving errors", compared to human drivers. Furthermore, automated vehicles can be expected to be more effective in reacting to unforeseen situations (e.g. a pedestrian that suddenly cross the road), due to their improved reaction times. However, there might be an increased risk of rear-end collisions due to preceding cautious automated vehicles driving at a very slow speed, and a high possibility of sudden braking. In consequence, the following car could be led to keep smaller distances with the vehicles in front and, therefore, jeopardise safety.

Design recommendations

The findings described above suggest that the current design works well from a pedestrian perspective but not so well from a vehicle traffic performance perspective when automated vehicles are introduced. Channelization do not solve the problem. Rather, the results indicate that it may be beneficial for vehicle traffic performance to spread out pedestrian flows crossing the road over a larger area rather than channelizing the flows to pedestrian crossings. The current design also works quite well from a safety point of view, but some minor changes are suggested as increased visibility of some signs and removal of some obstacles, which to a large extent also could increase safety in the current situation. But there are also recommendations that focuses mainly on automated vehicles as increasing the space between the vehicle carriageway and the no traffic area which can help automated vehicles to better identify pedestrians that are going to make some risky movement (e.g. crossing the street) and, if the space is clearly highlighted (e.g. by the use of different pavement heights, textures or colours), pedestrians will probably be more careful while crossing the road and give more possibilities to the vehicles to move on and don't stop.

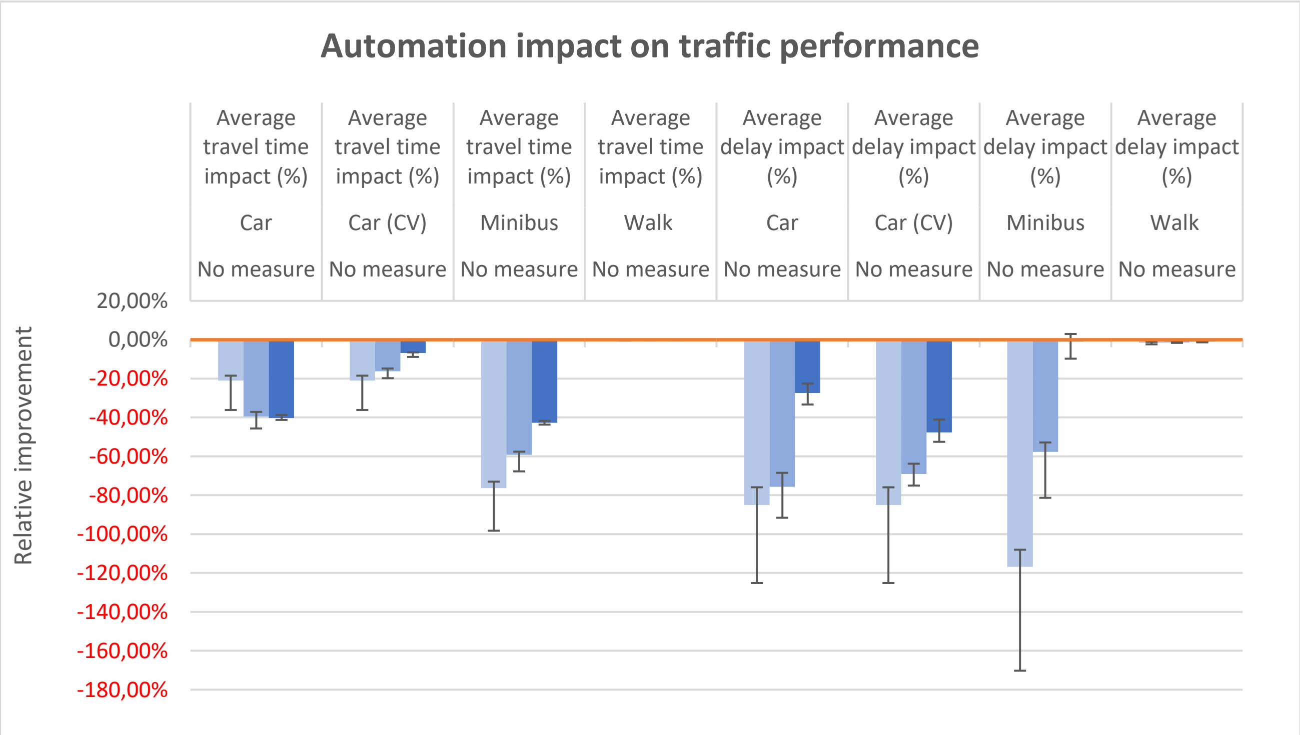

Figure 8: Automation impact on traffic performance in use case 1 (VTI)

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5.1.2 Use case 2: Accessibility during long-term construction works (Gothenburg, SE)

How does the introduction of AVs cope with constant changes of traffic flows during construction works?

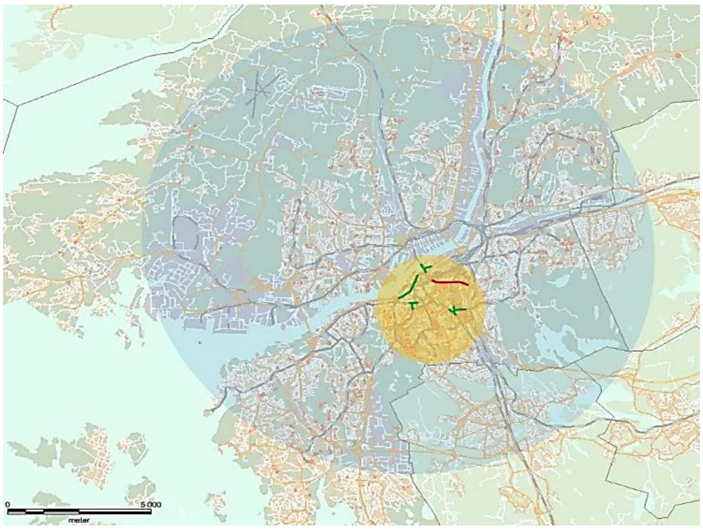

Figure 9: Modelled area in Greater Gothenburg

A macroscopic Visum model for Greater Gothenburg has been used to investigate how accessibility during long-term road construction works is affected by the introduction of CAVs.

Long-term construction is a common issue in cities and puts a lot of stress on the traffic system. It is therefore important to ensure that the introduction of AVs does not imply further negative effects and investigate which measures can improve traffic during extended construction periods.

Figure 10: Use case 2 model illustration (VTI)

Depending on the CAV penetration rate, bidirectional traffic and other capacity supporting measures in tunnels could be possible. In this sense, two measures have been tested: (1) a two-way AV-only tunnel tube for the Göta Tunnel; and (2) reserved bus and AV lane on the major motorway network.

Transition from negative to positive impacts of AVs during the Established stage

The modelling results show a minor increase in car travel times and slightly larger increase in car delays during the Introductory stage. This negative impact on traffic performance switches to positive (decrease in car travel time and delay) in the Established stage. In the Prevalent stage, a rather substantial positive impact on car travel times and delays are observed. At the meanwhile, large variations in travel time and delay are estimated in the Established stage which can be attributed to transition from mainly cautious to more advanced AVs and with a large uncertainty regarding the mixture of AV types. Important to note is that the model results do not include increases in travel time due to increased speed compliance of CAVs which is considered in some of the microscopic use cases, but this is probably of minor importance since the network in general is highly congested.

Positive impact in Established and Prevalent stages from redesigning from a one-way three lane tunnel tube into a two-way AV-only tunnel tube (measure 1)

Long-term constructions imply closing of a tunnel tube in one direction. A redesign as shown by the figures leads to a marginal increase in car travel times and delays in the Introductory stage but a

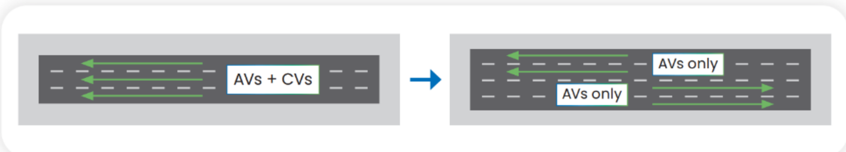

Figure 11: Measure 1 - Two-way AV-only tunnel tube

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slight decrease in travel time and delay in the Established stage and somewhat larger effects in the Prevalent stage. CVs have a shorter travel time and delays compared to the case without this measure. in the Established and Prevalent stages. This is due to route shift of AVs from alternative routes to the tunnel, which free capacity on alternative routes.

No positive impacts in any of the three stages from reserving a bus and AV lane on the motorway network (measure 2)

This measure leads to a marginal increase in car travel times and delays in the Introductory stage but no increase or decrease in the Established and Prevalent stages. Travel times on bus lanes decrease in Introductory stage but increase in Established and Prevalent stages and gains of reserving a lane for buses and AVs disappear.

Potential safety effects

The macroscopic transport model used in this use case does not provide data or sufficient information for assessing impacts of AVs on safety, but it is possible to analyse effects on vehicle kilometres. An increase in kilometers driven imply more accidents if the accident probability per vehicle kilometers stay the same. The vehicle kilometers on motorways seems to decrease in the Introductory stage and increase in the Established and Prevalent stages, while total vehicle kilometers on urban streets exhibit an opposite trend. This indicates potentially an increased risk (if assuming no change in risk per km of the AV introduction) on motorways in the Established and Prevalent stages due to higher volumes.

Design recommendations

The findings described above suggest that a slight increase in delays and congestion levels on the urban core networks in the Introductory stage, especially on motorways. In the Established and Prevalent stages, delays and congestion levels have a moderate decrease. Reserving a bottleneck link (in this case a tunnel) that increases the capacity for AVs has in general a positive impact on traffic performance in the Established and Prevalent stages when AV share is high. However, only reserving a lane on the major motorway network that does not increase overall capacity but just redistributes capacity to AVs does not lead to any positive impacts on traffic performance. In the Introductory stage, buses gain from a shorter travel times and delays while cars lose from such a measure. In the Established and Prevalent stages, there is no gain or loss for either buses or cars

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5.1.3 Use case 3: Signalised intersection including pedestrians and cyclists (Helmond, NL)

Is the performance of the intersection getting better because of a more efficient flow thanks to CAVs?

A microscopic Vissim model is utilized to investigate the impacts of introducing automated vehicles to the traffic at the transition from highway to arterial road with signalised intersections.

Use case 3 focuses on evaluating the impact of CAV deployment, on the performance of a signalised intersection.

Figure 12: Signalised intersection in Helmond

Key factors:

- Advanced signal control strategy is represented in Vissim through a connection to an external traffic signal simulator.
- All modes present in the intersection are modelled, assessing the effects on pedestrian and cyclists due to reallocation of traffic signal times.
- The city's strategy 'Mobility Vision 2016-2025' aims to provide a sustainable and safe traffic system, promoting bicycle and smart mobility.

Increased travel time, especially for CAVs
Due to the full speed limit compliance of the automated vehicles, these experience significantly increased travel times. The speed compliant CAVs also reduce the possibility of speeding for the conventional vehicles, increasing their average travel time. This effect increases with the penetration rate of CAVs but is partly counteracted by decreased delay at the intersection as the CAVs get more advanced.

The advanced adaptive traffic signal control adapts to the partly automated traffic, redistributing green time between motorized traffic and active modes
The saturation flow is lowered by the presence of cautious AVs and increased by the presence of advanced AVs since the former claim more safety margins and the later less. The advanced traffic signal control algorithm reacts to the changes in saturation flow (or some effect of them), by redistributing green time from and to the active modes, respectively. That is, in the introductory stage the green time share is increased for vehicles and reduced for bicycles and pedestrians to keep the vehicle flow up, while it is opposite in the Prevalent stage. This adaption leads to increased delay and travel time for active modes in the Introductory stage, while decreased delay and travel time in the Prevalent stage.

Potential safety effects
The analysis indicates a potential reduction of road traffic crash risk and that the benefits increase with increased penetration rate of automated vehicles. A large part of the risk reduction is due to that AVs are

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assumed to make less (or no) “driving errors”, compared to human drivers. Most of the remaining risk is due to situations where the automated vehicle could be involved in a crash due to a traffic condition caused by a conventional vehicle. The more conservative driving logics may lead to more frequent sudden brakes which might cause problems from a human driver perspective.

Figure 13: Use case 3 model illustration (Helmond)

Design recommendations

When advanced adaptive traffic signal control algorithms are used, care should be taken to ensure that the introduction of automated vehicles does not lead to an unwanted redistribution of green time from active modes, especially in the Introductory stage. However, since this type of intersection is very structured with time separation of all conflicts, the negative impact in the Introductory stage is rather small, so for this stage this type of intersection is preferable.

From a safety perspective it is of interest to find ways to give more time to the AVs to react and understand what happens, e.g. by wider, raised or rumbled lane markings or coloured and raised strips at waiting areas in the intersection.

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5.1.4 Use case 4: Transition from interurban highway to arterial (Helmond, NL)

Can CAV deployment improve traffic conditions in transitions from highway to arterial roads?

In complement to use case 3, this use case focuses on investigating highway traffic conditions and the impacts of introducing automated vehicles to the traffic at the transition from highway to arterial road.

Figure 14: Use case 4 site

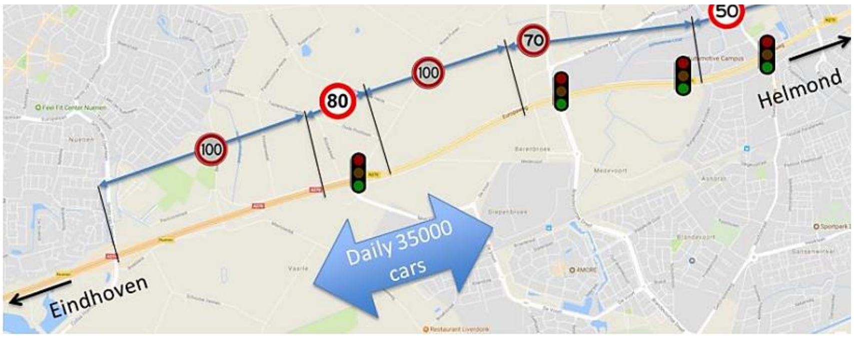

Figure 15: Varying speed limits illustration – use case 4 (Helmond)

The use case site is the road between Eindhoven and Helmond, which changes from an interurban motorway to an urban road, with each having very different speed limits and traffic conditions.

Helmond is very active in researching and evaluating all kinds of projects in the field of CCAM. The city is currently also strongly committed to rolling out Intelligent Speed Adaptation (ISA), considering that CAVs (with ISA applications), could contribute to reducing speeding violations and achieving a more homogeneous speed, that results in more reliable travel times and fewer delays for total traffic.

Cooperation among CAVs as part of a convoy (platoon), constitutes a promising functionality for the optimisation of traffic conditions in these types of roads. To evaluate such impacts, Helmond has tested measures including: (1) enabling the formation of CAV-platoons of up to 8 vehicles; and (2), then, limiting platooning to the right lane only.

CAV speed compliance leads to increased travel time both for CAVs and CVs

The full speed compliance of automated vehicles reduces speeding among the conventional vehicles and leads to longer travel times for all vehicles except for very high penetration rates of advanced CAVs.

Large discrepancy in delay between automated and conventional vehicles

Since the desired speed of CAVs is close to the speed limit they are hardly delayed at all (except at intersections) while many of the conventional vehicles have desired speeds significantly above the speed limit and are thus delayed significantly by slow-moving CAVs.

Platooning leads to a slight improvement overall for motorized traffic and significant improvement for active modes

Allowing CAVs to form ad-hoc platoons, either in any lane or only in the rightmost lane, slightly improves travel time and delay for motorized traffic. Platooning leads to increased saturation flow at intersections and thereby less need for green time, which enables redistribution of green times to the active modes who

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receives the benefits of the increased intersection capacity. The difference between allowing platooning in any lane or only in the rightmost is small.

Potential safety effects

The analysis indicates a potential reduction of road traffic crash risk and that the benefits increase with increased penetration rate of automated vehicles. A large part of the risk reduction is due to that AVs are assumed to make less (or no) “driving errors”, compared to human drivers. Most of the remaining risk is due to situations where the automated vehicle could be involved in a crash due to a traffic condition caused by a conventional vehicle. The risk reduction increase with increasing penetration rate of AVs but the change is not that large since higher penetration rates also imply more “aggressive” AVs using the All-knowing driving logic which aggressiveness might lead to unexpected behaviour compared to the two more conservative driving logics, so new crashes could occur.

Design recommendations

Facilitating platoon formation at intersections can be a way of improving the conditions for active modes without reducing the throughput of motorized traffic. The recommendations from a safety point of view consist to a large degree of measures that also improve safety for the current situation with conventional vehicles, e.g. installation of safety barriers and barrier terminals, replace street lamps by breakable poles, removing obstacles, reducing speed limits, etc. This is natural since most of the residual risk is due to the traffic situations caused by conventional vehicles which will be present in the future scenarios

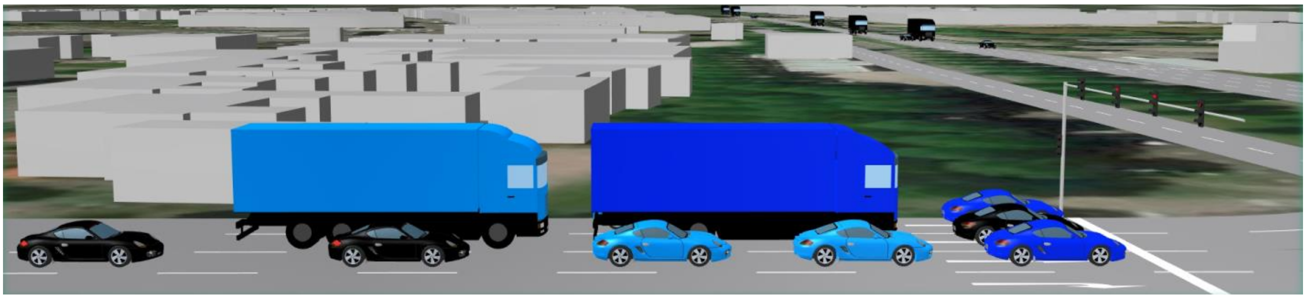

Figure 16: CAV Platooning ©PTV Group

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5.1.5 Use case 5: Waiting and drop-off areas for passengers (Milton Keynes, UK)

What would be the city-wide traffic consequences for Milton Keynes if CAV's become commonplace and the city-centre is re-defined as a car-free space?

The objective of this study was to explore the impact of widespread CAV take-up combined with a plan to re-define the city-centre as a car-free zone. The objective was to assess traffic flows on the streets surrounding a car free city-centre. The simulation included passenger pick-up and drop-off points which were placed at multiple points around the perimeter of the car free zone. CAV's obey logical and precise rules of movement and do not respond in a manner which reflects the conventional behaviour of a human driver. Traditional macroscopic modelling techniques could not therefore be used for this study.

For this reason, an extensive VISSIM microsimulation model was built and exercised. Current roads and traffic flows were simulated first to provide a 'reference scenario'. In this model, the city centre was open to all vehicles and the vehicles were given normal non-CAV behaviours. In subsequent models, different pick-up/drop-off configurations were examined alongside different levels of CAV penetration.

This use case evaluated the relative merits of three different approaches to providing pick-up/drop-off facilities for the users of CAV's, and analysed how the city of Milton Keynes could be best prepared to tackle the widespread future uptake of autonomous vehicles

Figure 17: Use case 5 – area of interest (Milton Keynes)

Introduction of CAVs first significantly worsen and then significantly improve traffic performance

On the one hand, the cautious AVs in the Introductory stage cause significant delay, likely at the many roundabouts of the city. On the other hand, in the Prevalent stage advanced AVs significantly improve the traffic performance and decrease travel time even though they comply fully to the speed limits.

Introduction of pickup and drop-off areas reduce in-car travel time significantly
The introduction of high capacity pickup and drop-off areas at the perimeter of the city centre significantly reduces in-car travel time. However, part of the reduced travel time is replaced by travel between the origin/destination in the city centre and pickup and drop-of areas, which is not included in the model.

Car parks at the city perimeter increase in-car travel time due to their limited inflow capacity
If the pickup and drop-off areas are replaced by car parks the result is instead an increase in travel time and delay due to queue formation from the car park entrances. However, if it is possible to add a third lane on the links towards the car parks there are even larger positive effects than from the pickup and drop-off areas.

Potential safety effects
The analysis indicates that introduction of AVs would impact the city safety positively. As expected, due to better lane control, better surrounding awareness, etc. there would be less accidents on both arterials and urban streets. In addition, restricting the access to the city centre will remove human error accidents in this

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area. As there is grade separation between motorized vehicles and active modes within Milton Keynes a lot of accidents with pedestrians and accidents with parked vehicles are already avoided regardless of AVs and the main gain would be related to single vehicle crashes or vehicle collisions.

Design recommendations

Vehicle intercept locations at the city centre perimeter can lead to significant traffic performance improvement, provided that their capacity is sufficient to handle the incoming traffic and that there exists a well-functioning transit system within the city centre.

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5.1.6 Use case 6: Priority Junction (roundabouts) Operation (Milton Keynes, UK)

What is the effect on traffic flows at un-signalised intersections (roundabouts) at various different stages of CAV take-up?

The focus of this use case was to assess traffic performance at the major arterial road intersections in suburban Milton Keynes. Most of these intersections are unsignalized roundabouts.

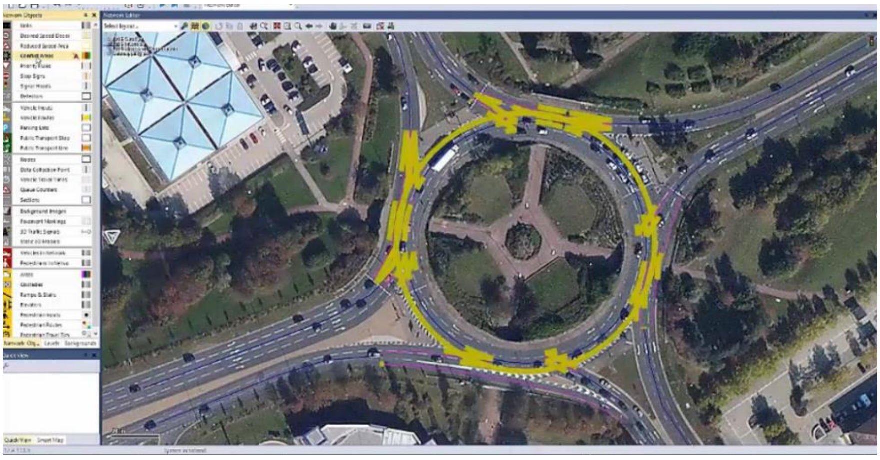

Figure 18: Use case 6 model development process (University of Cambridge)

How vehicles behave at roundabouts is therefore critical to the creation of the general traffic conditions in the city. This makes it an ideal testing ground for how autonomous vehicles might interact within intersection spaces and to evaluate what sort of interventions (measures) might be needed to facilitate the arrival of CAVs

An initial 'reference' case was simulated in which only conventional vehicles were included in the model. Thereafter, a small number of specific interventions were examined and the results were compared to the reference case.

The interventions (measures) which were examined included: (1) the introduction of V2V communication between vehicles when merging at intersections; (2) introduction of an additional (third) lane in the approach to each intersection

Large increase in travel time and delay for the Introductory stage

The cautious CAVs in the Introductory stage have trouble entering roundabouts due to their large required gaps, leading to queue build-up behind them and large delays for both automated and conventional vehicles. For a future demand of 120% of todays the system seems to be close to breakdown in the Introductory stage with very large delays. However, the traffic condition improves as soon as the Basic AVs are replaced by Intermediate AVs and there are large improvements as most of the traffic is advanced AVs.

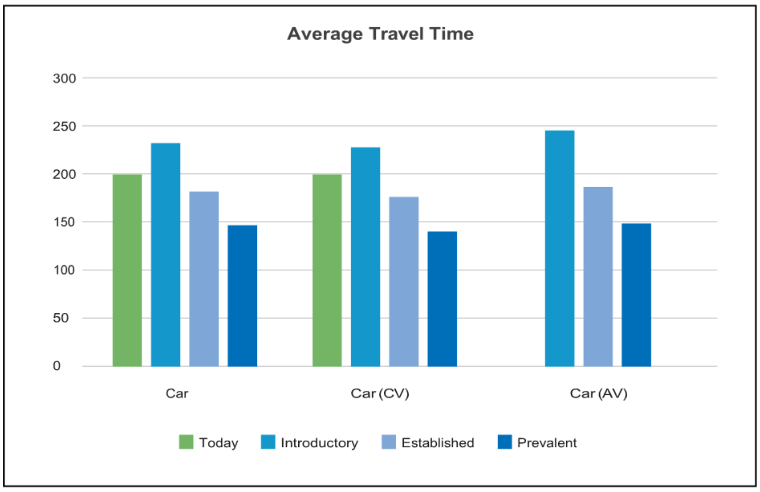

Figure 19: Average travel time

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Adding traffic control based on V2V communication at roundabouts amplify the effects
Implementing a specific V2V based control system for CAVs at roundabouts increases the effects; the traffic conditions deteriorate even more in the introductory stage with several hundred percent increase in delay, and the benefits in the Established and Prevalent stages are also amplified.

Adding a third lane would dramatically improve traffic performance if possible
If CAVs are able to drive much more precise than human drivers, it could be possible to reduce the lane width to two thirds of the present width and thus include three lanes in each direction. The simulations indicate that this would dramatically increase traffic performance, but it would require a fully automated vehicle fleet.

Potential safety effects
The analysis indicates that introduction of AVs would impact the safety positively. As expected, due to better lane control and better surrounding awareness there would be less accidents. As there is grade separation between motorized vehicles and active modes along the arterial and in the roundabouts a lot of accident with pedestrians and accidents with parked vehicles are already avoided regardless of AVs.

Design recommendations
The evaluated V2V-based control system should not be implemented until the CAVs present in the system is sufficiently advanced, corresponding to the Established stage used in the evaluation. The city should continue to investigate further solutions to improve the capacity at roundabouts for cautious CAVs to be prepared if the CAV development and deployment result in a scenario similar to the introductory stage investigated in CoEXist.

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5.1.7 Use case 7: Impacts of CAV on travel time and mode choice on a network level (Stuttgart, DE)

What changes can be expected on motorways, on urban arterials and on urban roads with mixed traffic? What impacts can be expected on road capacity, congestion levels and travel times?

Use case 7 looks at the effects of automated vehicles on travel time, mode choice and route choice, resulting from changes in traffic performance and changes in comfort of car usage. An extended version of the existing travel demand model of the Stuttgart Region is used to examine the impacts of highly, but not fully automated vehicles.

The use case examines the effects of the following variables on travel demand:

- CAV stage: The stages introductory, established and prevalent vary the characteristics of CAV. In the introductory stage, the driving logic of CAV leads to careful driving which reduces road capacity. In the established stage CAV outperform conventional vehicles on motorways and arterial roads, where cars and non-motorized modes are separated. The prevalent stage assumes that CAV can even operate efficiently on urban streets.
- CAV-Share: The share varies between 0% and 100%
- Network: Two cases are distinguished. The case "motorway" assumes that CAV can operate automated only on motorways or on roads with a similar characteristic. The case "main road" additionally includes main roads as CAV-ready roads.
- Perception of travel time: Drivers of CAV may use some of the in-vehicle time for non-driving tasks. This can reduce the perception of the actual travel time. Perception factors of +/-0%, -15% and -30% of CAV travel time are considered, to account for changes in travel time perception.
- Combination of variables are used to examine 60 scenarios. Running the travel demand calculation each scenario produces values for a set of indicators: number of trips by mode; total distance travelled by mode; and total time spent by mode.

Cautious CAVs lead to lower traffic performance/capacity while more advanced AVs improve traffic performance

The modelling results show a modal shift from car modes (car driver and passenger) to other modes in the Introductory stage with cautious CAVs (which decrease road capacity). In the Established and Prevalent stages, more advanced CAVs that imply increased road capacity lead to a modal shift from other modes to car modes.

Travel time assumed to be perceived as a shorter period amplifies the modal shift towards car transport to an even greater extent than traffic performance/capacity impacts

On the one hand, an introduction of CAVs means that travel time can be perceived as a shorter period due to the possibility to do other things than driving. On the other hand, an introduction of CAVs leads to a decrease/increase in road capacity. The impact from travel time perception amplifies the modal shift towards car to an even greater extent than road capacity impacts.

Advanced CAVs also lead to a different destination choice

The possibility to do other things than driving makes traveling by car more comfortable, which consequently will cause people to conduct longer trips on average and therefore total distance travelled and total time spent increases for car traffic.

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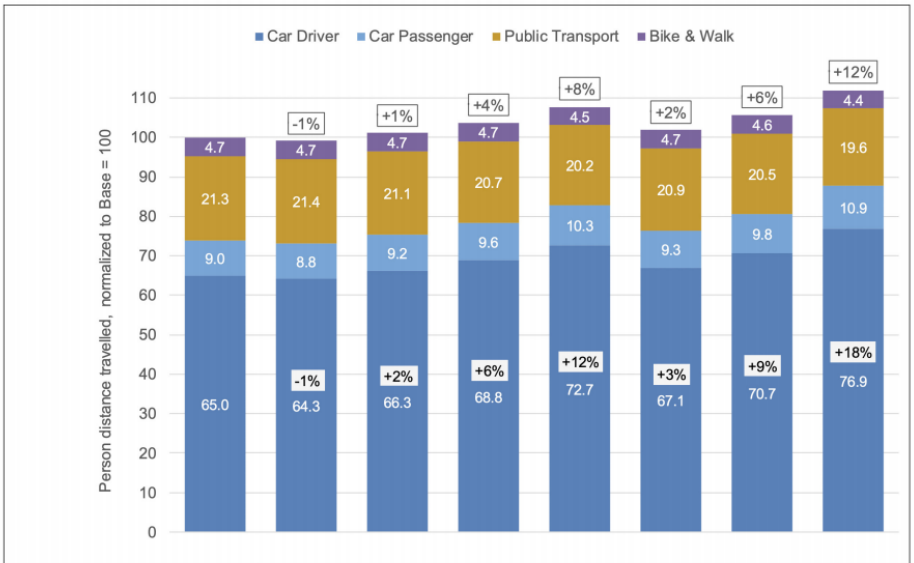
More roads included in the operational design domain (ODD) of CAV amplify the impacts
If CAVs' can and are allowed to operate in automated driving mode on all main roads compared to if they only can and are allowed to operate in automated mode on motorways amplifies the impacts on traffic performance. A bigger magnitude of a decrease in traffic performance metrics can be found in the Introductory stage with cautious CAVs while that of an increase are found in the Established and Prevalent stages with more advanced CAVs.

Potential safety effects
The macroscopic travel demand model used in this use case does not provide data or sufficient information for assessing impacts of AVs on safety, but it is possible to analyse effects on vehicle kilometres. An increase in kilometers driven imply more accidents if the accident probability per vehicle kilometers stay the same. The more advanced AVs imply an increase in the vehicle kilometers travelled by car and the effect is enlarged if the travel time perception decrease. Hence, there might be a risk of decreased safety (if assuming no change in risk per km of the AV introduction) due to more car kilometers when AVs are introduced.

Design recommendations
Until fully automated vehicles and related services are available, there will be a long period with highly automated vehicles. This use case shows a probable development in cities and regions. The findings described above suggest a general trend of decreased traffic performance/capacity with cautious CAVs while more advanced CAVs which may only be available at a later stage lead to increased traffic performance/capacity. Perception of travel time plays a very important role as it represents benefits in travel comfort for car trips and the related impact on mode choice and destination choice is larger than traffic performance/capacity impacts.



Stage	Base	Intro	Established			Prevalent		
CAV-share	0%	40%	60%			80%		
Network: Motorway	☒	☒	☒	☒	☒	☒	☒	☒
Main roads	☐	☐	☐	☐	☒	☐	☐	☒
Perception	+/-0%	+/-0%	+/-0%	-30%	-30%	+/-0%	-30%	-30%

Figure 20: Use case 7 – Overview of results for Person distanced travelled (University of Stuttgart)

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5.1.8 Use case 8: Impact of driverless car- and ridesharing services (Stuttgart, DE)

What impact will the introduction of car- or ridesharing services have on modal split and traffic volumes?

The aim of use case 8 is to examine the impacts of automated car- and ridesharing services on demand. The basic assumption is to have 100% CAV capable of operating completely automated (and therefore driverless) within the Stuttgart Region.

Case	Public Transport			Car Transport		
	Bus	Rail	Ridesharing RS+	No-Sharing NS	Carsharing CS	Ridesharing RS-
0	Yes	Yes	No	Yes	No	No
1	Yes	Yes	No	Yes	No	Yes
2	Yes	Yes	No	Yes	Yes	No
3	Yes	Yes	Yes	Yes	No	No
4	No	Yes	Yes	Yes	No	No
5	No	Yes	Yes	Yes	Yes	No

The examined scenarios vary the characteristics of the supply and assumptions on the behaviour:

- Supply characteristics: Case 0 corresponds to the baseline scenario. Cases 1-3 each cover one additional mode with sharing vehicles on top of the traditional modes available in the base case. Case 4 investigates the impact of on-demand services integrated into public transport under the assumption of omitting bus service completely. Carsharing as a competitive mode added to the case 4 is covered by case 5.
- Prices: Prices for shared vehicles (CS, RS-) consist of a fixed booking price and a distance-based price. Integrated ridesharing (RS+) is included in the public transport ticket.
- Car ownership: Car ownership is an input variable to the model. In some scenarios, car ownership is reduced assuming that persons are willing to share vehicles or rides.

Mode	Properties
Bus	Buses operate as in the baseline scenario, no specific assumptions on automation.
Rail	Light and heavy rail operate as in the baseline scenario, no specific assumptions on automation.
RS+	Ridesharing integrated into public transport. This can come in the form of a last mile service or as direct service in areas with low demand (bus on demand). The system operates with one vehicle size (6 seats). Passengers must transfer to bus/rail, if this provides a reasonable service. Travel time depends on road saturation.
NS	No sharing, cars are privately owned. No specific assumptions on automation. Travel time depends on road saturation.
CS	Carsharing, travel time depends on road saturation. This supply is equivalent to a personal on demand service.
RS-	Ridesharing not integrated in public transport. Travellers always travel without transfers. The system operates with one vehicle size (6 seats). Travel time depends on road saturation.

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All considered mobility services lead to modal shifts to this new service

In all scenarios tested, driverless carsharing, direct ridesharing services and ridesharing not integrated in public transport have a non-neglectable share, suggesting that all considered mobility services lead to modal shifts. This also leads to increase of vehicle mileage in the study area and its impact is larger in the city compared to the region. The direct ridesharing services of public transport get large modal shares compared to driverless carsharing and ridesharing not integrated in public transport.

Substantial substitution rates between the considered services and privately owned vehicles

For the same number of trips, driverless carsharing service needs roughly twice as many vehicles as driverless ridesharing service. If bus services are removed completely the public transport integrated ridesharing service can replace the bus service (with direct trips and feeder service to rail transport), but vehicle mileage will increase, especially in the city. One ridesharing vehicle is able to replace approximately seven privately owned vehicles.

The considered variation in mobility service prices only had small effects

The price reduction for direct ridesharing services by 20% leads to only neglectable increase in modal shift and trip distance in the city (less than 1%). However, only a limited set of price variations is tested.

Design recommendations

There is a big difference in terms of the results if the mobility service is integrated into public transport or not. If the driverless ridesharing service is integrated into public transport, the public transport operator decides on which trips are suitable or allowed for direct service (door-to-door) and which trips will only be supplemented by a feeder service (with CAV) to line-based public transport. In this use case, direct ridesharing service is included in the public transport ticket while costs for direct ridesharing service correspond to average public transport costs depending on trip distance. However, the cost is assumed lower than costs for ridesharing not integrated into public transport or carsharing. The results heavily rely on assumptions and are consequently very speculative. The decisive assumptions mainly concern the characteristics of the automated mobility services and how travellers with or without car availability perceive and evaluate these services.

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5.2 Automation-ready framework

In order to provide guidance and empower local authorities to make critical and reasonable decisions about the introduction of CAVs into their road networks, CoEXist has developed an automation-ready planning framework. It includes elements of strategic urban mobility planning (SUMP) for CAVs and a guide for urban transport planners with concrete actions to be followed. Furthermore, it brings together methodologies and tools developed within the project, as well as lessons learned from their implementation.

The automation-ready framework is organised in three phases, which represent strategic focus areas for urban mobility planning processes. Still, the different stages do not correspond to a time period as different cities may be in a different phase depending on local circumstances. They can be overlapping, parallel and interlinked. The automation-ready framework aims to reduce uncertainty as cities go through each of the phases.

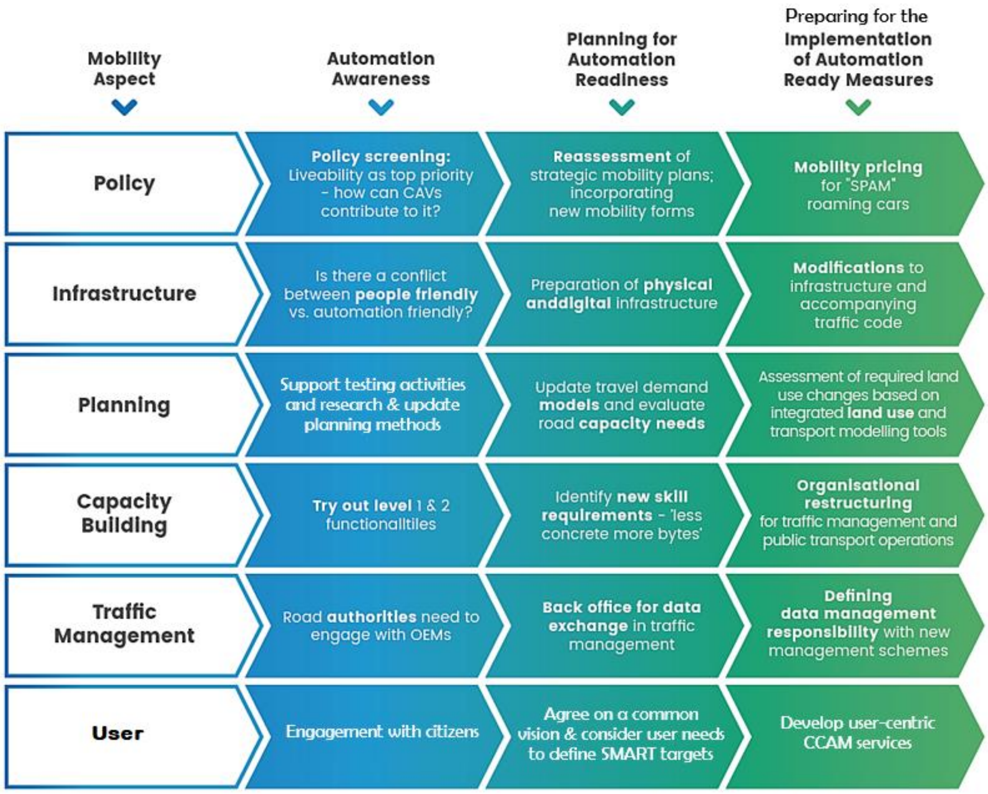

Figure 21: Overview of the phases towards automation-readiness (Rupprecht Consult)

For each phase, a set of measures are recommended to facilitate the reduction of uncertainties and to ensure a smooth transition into the sustainable deployment of CAVs in cities. Also, the technological scope of the framework aims to provide recommendations that are applicable to different European cities, which will experience a wide range of CAV deployment due to unique local circumstances with regard to the mode share between privately, shared or collective CAVs. The figure presents an overview of the proposed phases towards automation-readiness and some examples of the types of measures considered for each aspect of urban mobility.

Reduce uncertainties through:

- Guidance on technology, analysis methods, impacts and measures
- Clear-headed and informed decisions about automation
- Automation FAQ for cities

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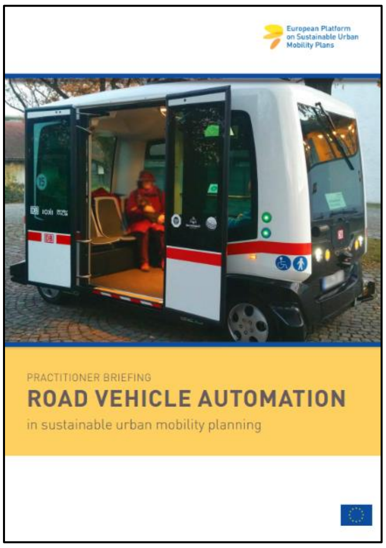

Road Vehicle Automation in Sustainable Urban Mobility Planning (Practitioner Briefing):

As part of the SUMP EU Guidelines update process, CoEXist has lead the development of a Practitioner Briefing on planning for road vehicle automation, which provided an initial basis of support for authorities to undertake the challenge of addressing CCAM in SUMP processes.

The document provides guidance on key tasks and factors to be considered within the SUMP methodology, mapping for the main uncertainties and discussion guiding principles on how to mitigate them. Furthermore, it delivers recommendations on how the eight SUMP principles can be applied in the context of CCAM, and shares useful tools and good practice examples.

5.3 Automation-ready Fora: local cooperative planning and policy discussions

A broad participatory approach is key to ensure that CCAM is being deployed to the benefit of all and not the few. Not one single actor is able to find the answers to all these complex issues. An effective working structure needs to be established, ensuring the active participation of citizens and key stakeholders, whilst steering institutional cooperation and coordination at different government levels.

Consequently, CoEXist's cities have hosted 'Automation-ready Fora' to engage with local stakeholders, citizens and institutions, based on the 'Automation-ready framework'. Aiming to facilitate a more informed discussion about the city's vision for automated mobility, each CoEXist city has strategically chosen the scope and target audience of its forum to adjust to its local activities and priorities:

5.3.1 Gothenburg

The main objective of the forum was to raise awareness of CAVs amongst stakeholders such as national, regional and local authorities as well as other urban mobility stakeholders;

Figure 22: Automation-ready Forum in Gothenburg

A full seminar day on the topic of societal development and automated transports was jointly organised by CoExist and Drive Sweden. Drive Sweden is a cross-functional collaboration and innovation platform that drives the development of efficient, connected and automated transport systems that are sustainable, safe and accessible for all. One of the core questions raised at the seminar was: how can cities plan for a future where CAVs constitute a natural and integrated part of the urban transport system? Objective was to receive key input and feedback to evaluate the perspectives of stakeholders on the strategy/measures towards the deployment of CAVs.

Figure 23: Automation-ready Forum in Helmond

5.3.2 Helmond

The leading role in dynamic traffic management and its active approach as a Living lab for ITS pilots and showcases, has given Helmond the name "City of Smart Mobility". The city believes in the principle of learning by doing and is convinced that innovative developments can be taken one step further by actually testing them together with the business community and educational institutions. Helmond participates in several national and European projects that are wholly or partly related to self-driving vehicles and CCAM, with a clear focus on cooperative traffic systems and connected vehicles.

Within CoEXist, Helmond organised an Automation-ready Forum aiming to engage with all internal stakeholders of the municipality of Helmond, from policymakers to implementers, and evaluate the challenges and opportunities of CCAM, and setting objectives and measures for the future.

Representatives from the various research projects related to CCAM Helmond is involved in (including MAVEN, Autopilot, CoEXist, Fabulos and ISA) came together in an effort to create a common understanding and holistic coordination of efforts in this field. The workshop resulted on a joint assessment of the city's automation-readiness and the identification of strategic measures going forward.

5.3.3 Stuttgart

Figure 24: Automation-ready Forum in Stuttgart

Planning for CCAM concerns many different aspects of a municipality. Due to the multitude of different questions that have to be asked and answered in connection with this new form of mobility and the (new) tasks that have to be mastered, it is essential that the different organisational units concerned with their different responsibilities, work hand in hand.

In order to ensure the most constructive and effective cooperation between different authorities and responsibilities, the City of Stuttgart has long established a dedicated working group, called the "AG Mobilität" (Mobility Working Group), which aims for a holistic and competent design of mobility, and its contribution to a sustainable urban development strategy.
During CoEXist, the organisational units in Stuttgart have extended their level of expertise concerning automated driving. Therefore, the framework of the Automation-ready Forum was used to reflect the working methods of this expert group, critically assessing the city's automation-readiness. The main aim of the Automation-ready Forum was to create a uniform, knowledge-based understanding of the chances, possibilities and risks of CCAM deployment. This included defining, and raising awareness on, the roles and responsibilities of every affected internal organisational unit.

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The Automation-ready Forum confirmed that the complexity of achieving automation-readiness, and how various competences and responsibilities in a municipal administration need to be addressed. Therefore, the activities of the specific units have to be linked and coordinated. A continuous exchange of expertise and activities has to be established. In addition, human and financial resources must be provided to guarantee a continuous work – concerning strategic, planning, administrative and technical aspects.

5.3.4 Milton Keynes

Figure 25: Milton Keynes - Youth Parliament

Reflecting on the excellent work produced by the UK Autodrive project, and recognising the potential shortcomings helped define the approach, Milton Keynes took to engaging with stakeholder for the CoExist programme. The city identified opportunity to further inform citizens, providing targeted information and clearer explanations on the potential benefits and risks from this innovative technology. A series of workshops were designed to target specific groups who would be critical to the development of future CCAM initiatives, especially for the transition phase. This meant working with: younger people – those approaching adulthood and to using independently, transport systems; and older and disabled group - with specific transport and mobility needs.

Three events were undertaken, using different formats designed to maximise meaningful engagement and interaction with the very different target audiences.

- Elderly and disabled citizens participated in a storytelling workshop aimed to develop their response to the information provided and demonstrations, where they had the opportunity to ride an AV (POD operating in Milton Keynes). The workshop focused on developing a narrative based on a ‘quest’ which sought to unpick people’s feelings, before, during and after their trial journey, guided by a professional facilitator to engage the topic in a non-technical way.
- Aiming to evaluate the changes in perspectives, school students and the MK Youth Parliament were surveyed both at the beginning of the event and after hearing from the potential benefits and challenges of CCAM and participating in a facilitated discussion.

Through these workshops, the city could confirm the importance of understanding the needs and views of all local stakeholders, to facilitate informed decision making about the introduction of such a disruptive technology, which may indeed have short term negative impact during the transition phase. Besides, it showed how bespoke methods can be adopted to engage with key stakeholder groups, and the meaningful outputs that can be achieved by using effective communication techniques:

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5.4 Automation-ready Action Plans

The ambition of CoEXist is that the research results and analysis achieved throughout the project, including the practical application of CoEXist tools on the selected use cases, should influence the transport and infrastructure planning in road authorities and steer their progress towards automation-readiness. In this way, the project aims to strengthen the capacities of local authorities, partners and cities in general benefiting from the project's results, to make informed decisions about the deployment of CCAM.

Therefore, each CoEXist road authority has developed a concrete 'Automation-ready Action Plan', providing detailed guidance on their specific processes and steps that should be taken to conduct automation-ready transport and infrastructure planning.

These Automation-ready Action Plans[1] include an analysis of the local legal framework and policy context for each city, as well as a description of the strategy definition, vision and objectives for CCAM deployment, considering the risks identified and expected impacts. Besides, each city has reflected on the results from their automation-ready forum and use case impact assessment. Building upon this basis, CoEXist road authorities have performed a self-assessment of their current level of automation-readiness, analysing their progress and challenges for each aspect of mobility and for each phase of the automation-ready framework, and defined a set of measures and activities going forward.

In this way, the action plans provide a comprehensive overview of each city's paths towards automation-readiness, including previous experiences and successful approaches, and future strategies based on CoEXist's results and lessons learnt.

The main strategies highlighted by CoEXist cities towards automation-readiness, and lessons learnt from the project research, are presented in the next section.

6 Lessons learnt and recommendations

CoEXist has delivered tools for a structured approach of assessing future scenarios and handling uncertainties, including automation-ready modelling tools for both microscopic traffic flow simulation and macroscopic travel demand modelling, in addition to a comprehensive modelling approach and impact assessment tools and methodologies, and an automation-ready planning framework.

The new features implemented in traffic modelling tool to allow simulation of automated vehicles, modellers should be aware of the assumptions and system parameters to be defined, such as how the vehicles should or will behave. To guide the definition of these behavioural parameters, CoEXist has developed a set of Driving Logics. Still much research is ongoing, and there are no fixed rules or standards and high uncertainties remain.

Although the tools developed enable the assessment of innovative infrastructure measures, use case implementation showed mobility improvements mainly for high automation and penetration levels, and open-questions remain on when and how urban road infrastructure and road design should change to facilitate the transition phase towards CCAM.

[1] D4.6 AV-Ready Action Plan for each road authority. www.h2020-coexist.eu/resources

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Inserting CAVs in traffic does not necessarily improve efficiency. Depends on penetration rate, driving logic and spatial conditions. Higher penetration rates, combined with more advanced CAVs, will start to generate some gains.

Yet, the potential deterioration of urban mobility at the initial stages of CAV deployment, encountered in some use case simulation results, accentuates the need for cities to actively plan for the transition phase, closely regulating where and how CCAM is deployed, the types of services and behaviour implemented.

To do so, it is important to define a clear vision for CCAM, materialised in realistic and measurable targets, that will enable effective expectation management, challenging the positive hype around CAVs- in particular for the transition phase.

Cities should also be aware of the various opportunities, and challenges that arise from CCAM deployment. For instance, considering its potential role in transforming travel behaviour, and facilitating modal shift towards integrated Public Transport with, for example, automated (shared) fleets. A structured & well-informed decision-making process, through holistic frameworks, is required to ensure sustainable and affordable services that align with local policy goals and respond to user needs.

How can local authorities shape CAV deployment in alignment with their policy goals?

- Authorities should look at planning for Cooperative Connected and Automated Mobility (CCAM) as an element of a more **fundamental change process: proactive action** to get ready for the challenges of conducting planning processes towards CAV deployment.
- Planning for CCAM should be **based on analyses of all modes** and supported by all **stakeholders** (and not on an SAE perspective).
- Transport and infrastructure planning through adequate tools: **automation-ready modelling functionalities** & **impact assessment** framework, with strategically defined **Key Performance Indicators** in relation to **local policy goals**.
- In addition to (old) risks, **new opportunities** for sustainable urban development arise, which can potentially spur **flexibility** and create **room for experiments.**

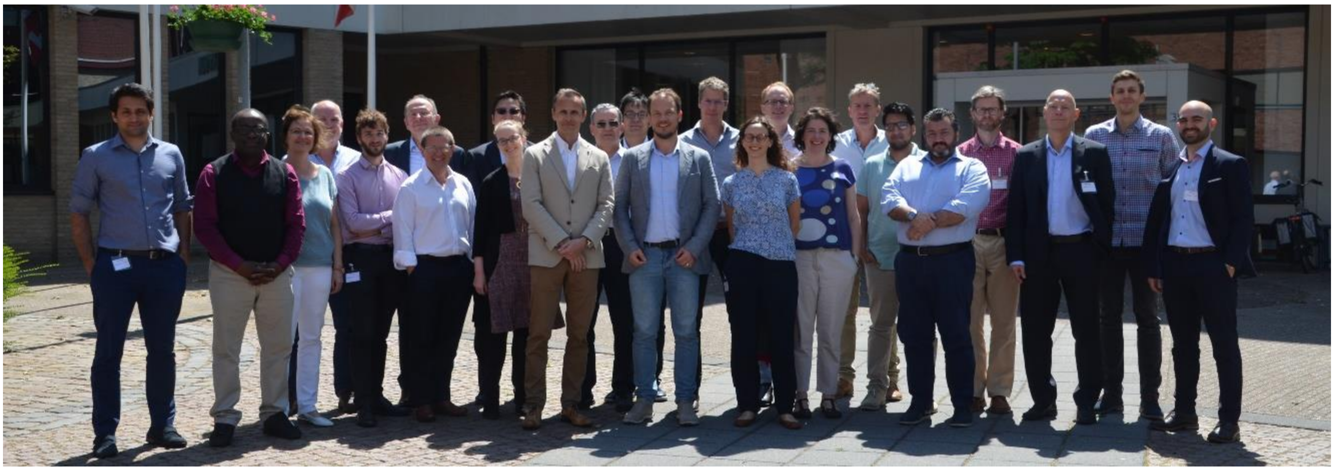

Figure 26: CoEXist Consortium Meeting in Helmond

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7 Glossary

Automation-readiness:

capability of making structured and informed decisions about the deployment of Cooperative Connected and Automated Mobility.

CCAM:

Cooperative, Connected and Automated Driving

CAV:

Connected Automated Vehicle

AV:

Automated Vehicle

Levels of Automation:

Degree of automation of a driving system, in accordance to the scope of its functionalities.

SAE levels of driving automation:

Classification of driving automation levels, as defined by SAE International:
https://saemobilus.sae.org/content/J3016_201806

Operational Design Domain:

specific set of conditions under which an automated driving system is designed to operate properly. It can include environmental conditions such as weather and visibility due to daytime/night time, geographical conditions, roadway types, traffic laws and regulations, and speed range, among others

SUMP:

Sustainable Urban Mobility Plan/Planning.

C-ITS:

Cooperative Intelligent Transport Systems

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8 Partners

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