Autonomous and Connected Transport scenarios evaluation based on simulation analysis

WG5: Thematic Report

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Acronyms

Table 1: WG5 Thematic Report list of acronyms used

Acronym	Full term
SAV	shared automated vehicle
ACT	automated connected transport
CAV	connected automated vehicle
PT	public transit
VMT	vehicle-miles travelled
VKT	vehicle-kilometers travelled
TT	travel time
P&R	park and ride
AMoD	automated mobility on demand
aRS	automated ridesharing service
PAV	partially automated vehicle: only longitudinal control of the vehicle is handed over to the system and the lateral movement, specifically lane changing, is controlled by the driver.
HAV	highly automated vehicle: both longitudinal and lateral movements controlled by the system.
ABM / ABS	Agent Based Modelling/ Agent Based Simulation

Chapter 1:
Introduction

Automated and connected transport (ACT) is based on a combination of emerging technologies, which are expected to have a disruptive impact on people's lives in the coming years by greatly widening accessibility for example or by modifying the business case for a lot of transport services. One of the most important elements of ACT is indeed Automated Vehicle (AV) technology, on which this report focuses. Through the report, AV is used as an encompassing term including different SAE levels of automation. Connected vehicles are equally important, but this report assumes that all AVs will have a minimum level of connectivity, hence will be automated and connected vehicles by default. For more details see Alonso Raposo et al. (2019). AV technology is developed at an unprecedented pace, which has not been significantly affected, not even by the COVID-19 pandemic, led by the traditional automotive industry and the Information Technology (IT) sector. Moreover, ubiquitous communication allows people (and vehicles) to be connected as never before, with ever growing streams of (big) data exchanges around the world via smartphones, computers, vehicles, and a plethora of innovative "smart" devices.

Early reports projected immense potential benefits by the widespread deployment of AVs, on both economic terms, generating a huge reduction of transport costs, and safety terms, via a drastic reduction of road injuries. However, the resulting figures are largely affected by the AV development scenarios that are considered in the analyses, which, due to the huge uncertainty in AV deployment, are very broad in nature.

The aim of the WISE-ACT Working Group 5 (WG5) is to shed light on the methods and results that have appeared in the AV domain, investigating simulation experiments and analyses, while building on those to develop and assess new scenarios. This is done for example by employing or developing novel simulation methods and tools, tailored to address the ever-growing complexity of future transport systems. A special emphasis is also on the criteria and indicators that are used to evaluate the results and that are of pivotal importance for well-informed decision-making. This approach was favoured against others such as field test analyses due to the relatively low number of prototype vehicles currently on public roads and on the secrecy that automakers legitimately keep on the capabilities of said prototypes. Simulation studies, on the other hand, have extensively studied, the state of the art currently including a wide range of modelling tools. In particular, the key tasks of WISE-ACT WG5 have been identified in the WISE-ACT MoU (Memorandum of Understanding) as:

- T12: develop and evaluate a number of scenarios of AVs deployment throughout Europe.
- T13: compare the results of simulation analyses across different localities.
- T14: develop a set of criteria and indicators which can inform policy makers about deployment of AV in a certain locality.

This thematic report is structured as follows. First, we briefly present, in Section 2, the methods used to develop the report. We then proceed by looking at the main issues on scenario development and evaluation in Section 3. Section 4 presents the models and tools that are used for simulating the scenarios while Section 5 discusses the criteria and indicators that may be obtained as final output of the simulations or further analyses. Finally, Section 6 concludes the report, highlighting the main findings and suggesting future directions.

Chapter 2: Method

This thematic report aims at discussing the main findings and developments resulting from the activities of WISE-ACT WG5 members, as well as other efforts in the same area by experts worldwide. Instead of aiming at a comprehensive review of existing literature, we aim at providing an informed overview, trying to embrace the diversity of studies related to simulations and analyses of future AV scenarios. The following table 2 provides a brief overview of the literature published on AV deployment and the respective AV deployment scenarios already tested by researchers. The table is indeed a snapshot of the different kinds of scenarios currently analysed in literature and is not meant to report the whole literature considered in this report. The wider literature is instead summarized in Table A in the Appendix, where we identified a set of studies, published in peer-reviewed journals, conference proceedings, or other publicly available dissemination channels, which have been published within the timeframe of WISE-ACT (2017-2022), linked with the WG5 objectives.

Based on the identified studies, we then proceed by analysing the various aspects that have been considered, considering three dimensions, roughly following the key tasks of WG5. Firstly, we start by looking at all knowledge that is produced before any simulation is implemented, by outlining which are the aims and goals of different studies investigating scenarios which have been defined, and what assumptions and factors were considered for such choices (Section 3 – MoU T12). Secondly, we focus on the simulation models and tools that have been used to investigate the developed scenarios, looking at the methodological differences and at their qualitative and quantitative impact on results, which is a prerequisite for balanced comparisons among findings (Section 4 – MoU T13). Thirdly, we investigate criteria and indicators, which can be produced as results of simulations or other analyses, discussing how they may reflect the performance of future ACT systems and what are the implications on policy making.

City locations

Table 2: Snapshot of the main kinds of scenario currently designed and assessed in literature

Source	City / Locality	AV deployment scenarios	Main findings	
Hartmann et al. (2017)	German freeway	Ex-ante impact assessment of automated vehicles on capacity of freeways using **microscopic traffic flow simulation**.	Technologies that allow shorter headways between vehicles have the potential to increase the capacity of the freeway network by up to 30% and reduce traffic delays significantly. However, small market penetration rates of automated vehicles do not lead to discernible capacity benefits.	**Link**
Bösch et al. (2018)	Zug region, CH	**Differing business models**: 1. monopoly service of automated taxis; 2. monopoly service of AVs for ride-sharing; 3. six different providers with different services; 4. no-AV base case.	Taxi service profitability is based on fleet size and price. Automated taxis gain substantially from slow modes. AV services increase VKT but could reduce travel time.	**Link**
Miller et al. (2019)	Ljubljana (Slovenia) & Seattle (WA, USA)	**Cultural differences in takeover response** (L3 driving)	The results of a study performed in driving simulators at two different locations show significant differences in responses to unexpected take-over requests (TOR) in Level3 driving. All participants in Slovenia responded to the TOR while only 74% of the USA participants responded to the TOR. Slovenian participants also responded significantly faster compared to the USA.	**Link**
Gueriau and Dusparic(2020)	Ireland	Testing surroundings of urban, suburban or highway. **Testing 3 traffic loads**. A range of penetration rates and levels	Near-maximum efficiency improvements in congestion are observed at relatively low CAV penetration rates but reveals further insights that the exact penetration ranges between 20% and 40% depending on the network type and traffic conditions. Safety results show a 30% increase of conflicts at lower penetration rates, but 50-80% reduction at higher ones, with consistent improvement for increased penetration. Congestion has a higher impact on conflicts than penetration rates, highlighting the importance of unified evaluation of efficiency and safety.	**Link**
Emberger and Pfaffenbichler(2020)	Austria	**Sensitivity analysis** concerning the demand effects of road capacity, perception of in-vehicle time. remote parking, new user groups for private car, car and ride sharing and public transport	Clear indications that AVs, especially if private cars prevail, will have a significant impact on veh-kms travelled. According to these findings, veh-kms travelled by 2050 might increase by up to a third compared to a no automation scenario. Automation will likely have a negative impact on the use of active and public modes of transport. Car dependency and, without significant changes in powertrains, the related energy and resource consumption will go up – which is in contradiction to all the political goals towards sustainability and climate protection as laid out in the Paris Agreement. On the other hand, automation as part of public transport, e.g. as automated shuttles for the first and last mile, has the potential to significantly reduce car dependency, veh-kms travelled and associated negative environmental impacts.	**Link**
Lu et al. (2021)	Munich, DE	**Different driving "styles"** for AV vehicles, calibrated based on existing data	Exploration of the influence of automated vehicles with different driving styles on the network efficiency. K-means algorithm is applied to categorize the car-following maneuver trajectories first, followed with the calibration of car-following models via FDSA. The calibrated car-following models are used to represent the automated vehicles with different driving styles. Different deployment scenarios are designed and simulated on the network of Munich city center. When vehicles are assembled with the same driving style, it presents those aggressive vehicles lead to higher speeds and shorter travel times in general	**Link**

Nahmias-Biran et al. (2020)	Singapore	**Shared AMoD strategies:** 1. availability of AMoD service in the central business district (CBD), and 2.a full operation of AMoD city-wide in the absence of other on-demand services.	City-wide deployment of AMoD results in greater accessibility and network performance. Moreover, the accessibility of low-income individuals is improved relative to that of mid– and high-income individuals. the accessibility of low-income individuals is improved relative to that of mid– and high-income individuals.	**Link**
Papantoniou et al. (2021)	AttikiOdos Motorway, Athens, GR	**Different proportion of automated and human driven vehicles** (0%, 25%, 50%, 75% and 100% of AVs) while NOx and CO emissions are investigated in each scenario	Results indicate that Autonomous Vehicles have the potential to increase the emissions on the motorway. Additionally, the specific increase of emissions is estimated in all different scenarios of autonomous vehicles' percentages in the mixed traffic scenarios.	**Link**
Petrov et al. (2020)	Zilina & Bratislava/Slovakia	Emergency **vehicle prioritization in CAV environment** – A feasibility study of a V2V communication-based system for formation of an emergency lane free of obstacles applicable to AVs.	During the transition period with mixed traffic (various levels of automation but 100% connected), the proposed EV warning system can increase the reaction time available for the human driver significantly – the maximum available reaction time reached 320 s. However, high values of available reaction time open a new set of issues that must be addressed as there is no point for the driver to take any action for several minutes. On the contrary, such an action could disrupt traffic fluency and cause other unexpected effects. Therefore, especially when the available reaction time is large, the EV should update the vehicles with information about the estimated time when it is supposed to reach the informed vehicle.	**Link**
Agriesti et al. (2021)	Italy, Trento	**Highway Chauffeur (L3 driving)**. The analysis of this system is carried out on a roadwork scenario to assess the positive impacts arising from a joint implementation of the automated system and the C-ITS Use Case signaling the closure of a lane.	The results showed how triggering the take-over maneuver in advance fosters the bottleneck efficiency (the same speed values reached between 80 and 100% Market Penetration for around 700 m range of the C-ITS message are reached at 50% Market Penetration with a 1500 m range). Besides, an in-creased speed up to 30 km/h at the bottleneck is recorded, depending on the market penetration and the message range. Finally, the delay upstream the roadworks entrance is reduced by 6% and arises at around 700 m, without the need to deploy the message up to 1500 m.	**Link**

As it can be noticed from Table 2, the studies concerning AV already cover a large range of scenarios spanning from example from urban (e.g. Nahmias-Biran et al. (2020)) and extra-urban settings (e.g. Hartmann et al. (2017) or Agriesti et al. (2021)). The focus itself greatly varies and different scales may be adopted for various scenarios, for example Gueriau and Dusparic(2020), Lu et al. (2020), and Hartmann et al. (2017) focus on microscopic simulation and investigates the impact of operational parameters while others cover wider areas and may tackle issues of fleet management, demand estimation and business cases (Nahmias-Biran et al. (2020), Bösch et al. (2018)). Great focus is also dedicated to the estimation of environmental impacts Papantoniou et al. (2021). Part of literature covers even wider areas while designing the scenarios and investigates cultural differences and propensities towards AV(Emberger and Pfaffenbichler, 2020). Rashidi et al. (2020) have compared the results from existing literature on the value of travel time (VoTT) in conjunction with AV. Their identification based on current evidence suggests a strong possibility that AV use will increase the VoTT in the future. The core identifications by Harb et al. (2021) suggests that preferences of an average user when offered a choice between a shared and an owned AV vary between 19% to 63%, also linked to the unwillingness of adaptations (of AV technology). Equally important according to the same authors are the AV scenario and broader context, in conjunction with the Vehicle Kilometres Travelled (VKT), although there is a large variation (1% to 90%) observed in the literature. Finally, many studies have already started drafting scenarios to assess jointed impacts of AV with other Intelligent Transport Systems (e.g. Agriesti et al. (2021), Petrov et al. (2020)). Overall, this great diversity in the scenarios considered is due to the wide range of estimations that are related to AV. Indeed, the assessed impacts vary from traffic efficiency ones such as capacity improvement, to environmental ones, or socio-economic ones such as perception of in-vehicle time or cultural propension to allow take-overs. This, in turn, calls for a wide range of scenarios, boundary conditions and operational parameters to be tested in different geographical contexts. In the context of this report, we define a scenario as the combination of input variables and system assumptions for a simulation, the wider analysis of the relevant scenarios in literature is going to be provided in Section 3. The need for said analysis focused on scenario comparisons highlighted in contemporary publications such as Milakis and van Wee (2020), Thomopoulos et al. (2021), Etzioni et al. (2020) or Polydoropoulou et al. (2021).

Indeed, the high number of AV applications compared to the considerably lower number of field tests completed by 2021 (see WISE-ACT WG4 Thematic Report), make the task of comparing results challenging due to the low replicability of simulation studies or the low transferability issue posed by regional differences. This report tries to tackle this by providing a first comparison of both the scenarios and the results.

Chapter 3:
Scenario development

This section builds on efforts done within WISE-ACT WG5 as well as adopt a wider perspective from global activities/ literature in relation to T12 "Develop and evaluate a number of scenarios of AVs deployment throughout Europe".

For the thorough validation of the impacts of the ACT, WISE-ACT set out to develop and evaluate a number of scenarios of AV deployment throughout Europe. In this context, there were multiple efforts by the WISE-ACT members both in united efforts as well as independent research projects by the members. The wider impacts of AV have been at the center of discussion for numerous researchers in recent years. It is of value to those shaping our society to have the capability to address those directly and indirectly affected by the deployment of AVs. While there has been discussion over both positive and negative impacts of AVs on highway capacity, driving behaviour, public transport services, value of travel time, private parking infrastructure and accessibility, it has been also reported that there is a risk of negative environmental impacts e.g. by increased total VMT (or VKT) and consequences on travel time (Etzioni et al., 2020). However, these different consequences are not all realised at once, but some may be tradeoffs of others. The different analyses of varying scenarios show that the eventual results of a simulation are highly dependent on the scenario which is realised at deployment. For example, Narayanan et al. (2020), and many others, point out the difference in deploying SAVs in comparison to privately used AVs. SAVs can reduce the traffic load considerably, but "improved traffic conditions again would result in increased traffic levels." A highly car ownership-oriented transportation system will lead to an increase in vehicle-kilometers travelled as AVs are deployed, ceteris paribus. The different ways that the deployment takes place thus impacts, for example, how the VKT, environmental emissions and expected network delay develop.

Jing et al. (2020), thoroughly reviewed 44 scientific publications to identify and explore the different scenarios developed for AV under different ABS frameworks. They paid careful attention to identifying the significant variables considered in the sensitivity analysis and different scenarios that would affect the simulation's performance, and to some extent suggested the model's progress. These are essential for gaining a better understanding of the ABS and to compare the various studies on model and system efficiency. According to them, the key application of ABS frameworks is to measure the large-scale effects of AVs and other motivations include system understanding and monitoring, as well as development of strategic decision support systems. On the other hand, ABS is seldom used for hypothesis testing for AV(Jing et al., 2020).

Hartmann et al. (2017)develop microscopic simulation exploring the car-following mechanisms of an AV platoon on German highways. The choice of model type is relevant for answering the question of traffic flow increase due to utilisation of vehicle connectivity. The results are universal regardless of other factors such as ownership rate or vehicle occupancy rate. Meyer et al. (2019)have pointed out that a possibility involves the increase in traffic due to the deployment of automated vehicles as it may induce increased travel. These scenarios were defined and calculated using the macroscopic VISUM. The predictions of the review by Narayanan et al. (2020) regarding restricted benefits of automated vehicles may thus turn out to be true. Bösch et al. (2018) also came to the conclusion that an increase in fleet operators makes the system increasingly inefficient using MATSim – they did not consider the possibility of single owner private ownership, only SAV fleet policy schemes. Ortega et al. (2020) hypothesized about the possibility of using Park & Ride schemes and grouping trips into a central business district using MATSim. This would increase travel time due to added waiting time and the increased cost of not going the direct route. There are therefore different scenarios based on the different questions raised and the different requirements of the modelling approaches.

To understand the different levers and knobs available to policymakers, the following findings are drawn together to explore the different researchers' hypotheses, to then compare the simulations and eventually prepare indicators and evaluation methods for when decision-makers intend to deploy automated vehicles in any particular locality. Based on the above-mentioned studies and those in table 2 it can be summarised that the following attributes were used as simulation inputs and are therefore seen by the research community as relevant for the settings of deployment:

Figure 1:Components of SAV modelling,
Source: Narayanan et al. (2020)

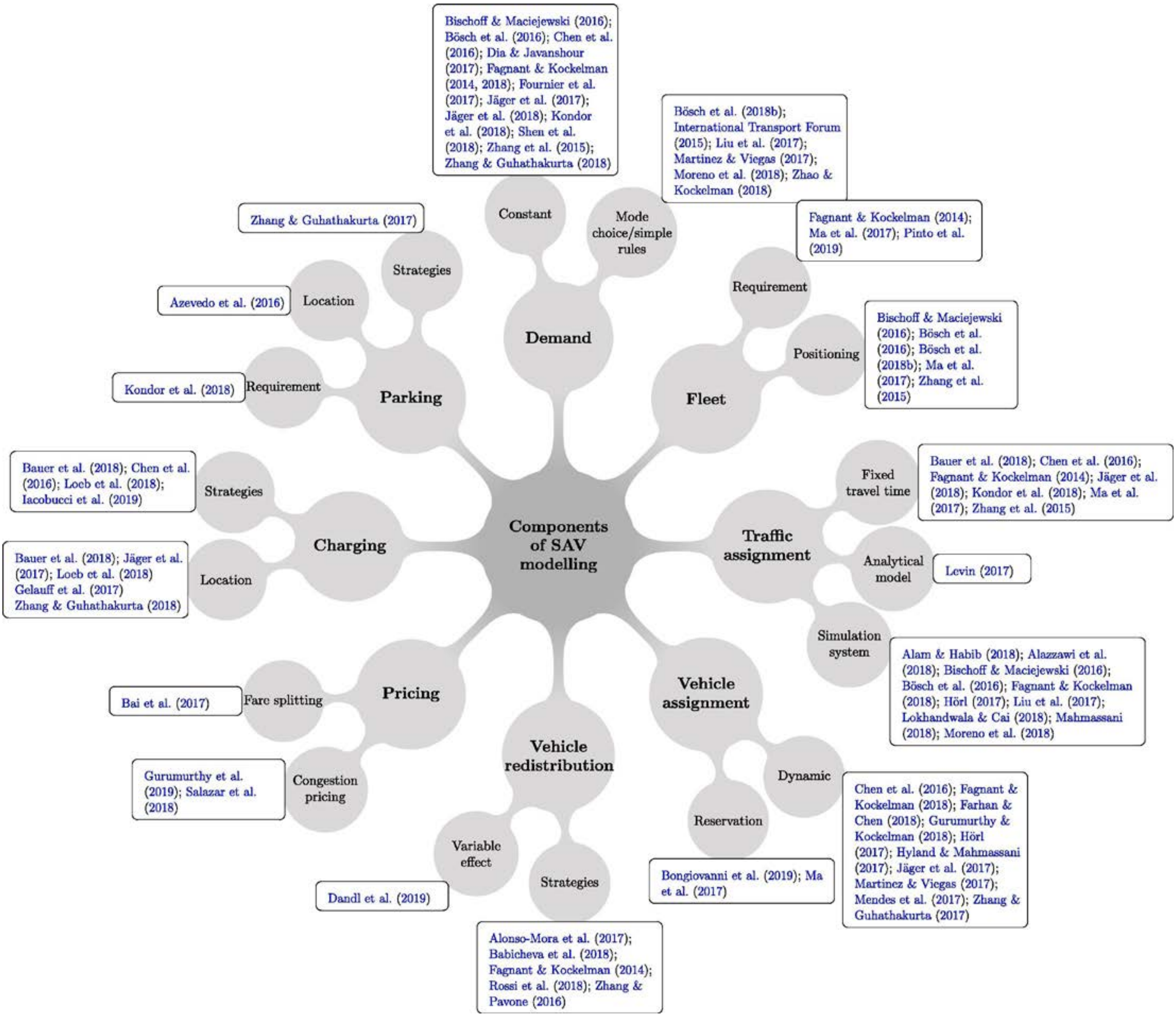

Table 3: Attributes were used as simulation inputs

Attribute category	Scenario attributes	Source examples
Environment	Urban / Rural / Highway (Predictability of road-space)	Hartmann et al. (2017); Gueriau and Dusparic(2020)
Business case	Competition / Centralisation of MoD services	Bösch et al. (2018); Nahmias-Biran et al. (2019); Gueriau and Dusparic(2020)
	Fleet size	Bösch et al. (2018); Alam& Habib (2018)
	Last mile vs door-to-door service	Chee et al. (2020)
Traffic dynamics	Deployment rate / mixture of automated vs non-automated vehicles	Mattas et al. (2018); Gueriau and Dusparic(2020)
	Presence of traffic management	Perraki et al. (2018); Agriesti et al. (2021); Petrov et al. (2020)
	Takeover preferences	Miller et al. (2019)
Parking	Organisation	Ortega et al. (2020)
	Infrastructure	Elvarsson et al. (2021)
In-vehicle experiences	Feeling of Safety	Kyriakidis et al. (2020)
	Price of trip	Liu et al. (2017)
	Value of travel time	Etzioni et al. (2020)
Travel behaviour	Long distance travel	Hamadneh and Esztergár-kiss (2021)
	Vehicle ownership	Emberger and Pfaffenbichler(2020)

Table 4: Four scenarios with extremely different outputs

1 Full centralised automation and connectivity Requires high investment in infrastructure. Prior to this, technological advancement is a prerequisite. The law has fully considered the exchange of data and communication. The automated vehicles are to drive relying on a central transmitter. Their sensors will have a secondary function. Increasingly separation of modes in urban areas.	**2 Overnight technological shift** Vehicles will have to operate with the infrastructure in place. Technology will be expensive, so TNCs will offer AV services leading to increased traffic in cities.
3 Centralised last-mile system There will be a centralised AV system set up, focusing mainly on serving the already-in-place mass transit system. AVs pick-up and drop-off mass transit users requiring to be driven the first/last mile.	**4 Highway automation, but urban exile** Automated vehicles will be in full capacity on highways where they can be driven without interruption of less predictable traffic participants. Non-automated vehicles will be transitioned from highways. Automated vehicles will be transitioned out of cities, where urban residents will be in the focal point.

Similarly, Narayanan et al. (2020) also summarized their findings in their own chart (see Figure 1)

Miskolczi et al. (2021) have also reviewed different scenarios published and categorised the scenarios of the reviewed papers into four groups: (1) the "grumpy old transport", (2) those suggesting the change will come "At an easy pace", (3) the sharing preference "mine is yours" and the (4) optimistic "tech-eager mobility". They furthermore predict that based on the scenarios published over years optimism within the scenarios is not increasing, thus they find that "the transition towards higher automation and shared mobility will be rather slow". Ultimately, the following four scenarios can be considered as four extreme scenarios to show fundamentally different outcomes:

3.4 Future outlook for scenario development

While laying the foundations for the following sections in this WG5 Thematic Report, a shortcoming worthy of mentioning is finding that automated vehicle mode acceptance has not yet been surveyed thoroughly in real-life scenarios. Guo et al. (2020) provide results of a survey on passengers of an automated shuttle bus expressing their reasons for choosing the shuttle as a mode. This experiment was performed on a shuttle bus already in operation in Stockholm, Sweden. The Digibus project in Salzburg, Austria has furthermore been testing the use of automated shuttles as a last-mile service in rural areas (www.digibus.at). In the future researchers and practitioners will be able to use this knowledge comparing prototypes and pilot projects with different scenarios and the simulation results to validate them.

Furthermore, Makridis et al., (2021) have reported the availability of an open access database on empirical data based on adaptive cruise control reported data. This could allow the generation of traffic behaviour scenarios based on real empirical data. Added experience in the field allows for the generation of scenarios that are more based on empirical evidence and are less arbitrary. As pilot projects become increasingly prevalent, also demonstrated through the WISE-ACT Trials Database, they can be used as starting points for the scenarios, at least to illustrate the state-of-practice. These testbeds for AV projects would enable the surveying of actual users. These would be beneficial as observed revealed preferences generally illustrate different results to stated preferences (Wardman, 1988). A relevant database using simulation parameters used in the UK (i.e., MUSICC) has been showcased through a WISE-ACT webinar, demonstrating the potential value of such initiatives.[1]

The broad range of the scenarios found in Table 4 can be explained by the various research questions that are posed. There are various unsolved questions relating to AVs. As these questions are posed, they take different assumptions into account to explore the effects of the isolated questions posed. Therefore, the definition of each scenario may differ largely depending on the questions posed, particularly as the tools used for the simulations of the scenarios also differ. The difference in tools is discussed further in the following section.

1. Webinar on MUSICC in full length is accessible here: https://www.youtube.com/watch?v=tQs9RlsCsfU

Chapter 4:
Simulation model and tools for analyses

This section builds on efforts done within WISE-ACT WG5 and adopts a broader perspective based on worldwide activities and literature linked with T13.

Besides, to make the findings as relevant as possible, a wider range of sources has been adopted, scientific literature or parallel projects have been analyzed. WISE-ACT, and its members, has closely followed the development and evaluation of AV scenarios throughout Europe and further. For instance, Gora et al. (2020), a MC member of WISE-ACT, reviewed microsimulation models for the AV and compared the existing finding for different scenarios and simulation tools used in AV studies. Due to the heterogeneities in scenarios, the algorithm behind the simulation tools wasn't easy to compare and draw proper conclusions. Nevertheless, they have suggested developing an open-access repository to collect real-world data as a helpful resource to develop simulation and calibrate models in the future.

In Section 3, the development of AV scenarios is discussed with a broader perspective. The objective of this section is to provide insights regarding microscopic and agent-based simulation models for AVs. To do so, we purposefully focus on the comparison of the results of simulation analysis in terms of different characteristics such as simulation software used, parameters settings, car-following and lane-changing models used, methods and data, vehicle composition (conventional vehicle, HV rate, AV rate), and study area (urban or rural area), highways or streets, with or without interaction with signalized and non-signalized intersection).

After the following table summarizing our findings from the literature review, a broader analysis concerning the applicability of different tools to different research questions, the uncertainties about future AV implementations and how to model accordingly are provided.

Table 5: Simulation scenarios related to AV studies.

Software	Source	Year	Model's parameters settings	Focus	Vehicle composition	Study Area	Highlights
Sim Mobility	Nahmias-Biran et al.	2020, 2019	N.A.	SAV for AMoD	1. 5000, 7500 SAV 2. 25000, 30000, 36000, 40000, 45000 SAV	Urban area: Singapore	1. When only AMoD operated in the CBD, a large increase in PT mode share from 40% in the Base Case to 56% are observed resulted by a dramatic reduction in Car usage from more than 19% in Base Case to 6.4% as well as significant reduction in Walk and Private Bus mode share, which were cut by half as compared to Base Case. Besides, a reduction in MoD demand observed from 11.7% in base case to 7% due to the CBD restriction and the competing AMoD services and its attractive travel fares. When AMoD modes replaced the traditional and Uber-like services city-wide, AMoD consists of 12.7% of the demand, while all other mode shares are similar to those in the Base Case. 2. When demand for AMoD is over four times greater than that of traditional MoD, only about twice as many fleets are required to satisfy the increased demand levels. In the "traditional MoD only" case, there are 20,000 taxis available during the morning peak. For the "AMoD only" case, we employed simulation tests to obtain the user-optimal fleet size of 45,000 for the same period, servicing 0.2 million trips (over 5 times those of traditional MoD).
Sim Mobility	Basu et al.	2018	Fleet size is selected to match or be slightly higher than the demand for the remainder of the day but will only match about 10–15% of the demand during peak periods.	SAV for AMoD	Dynamic fleet sizing strategy based on daily demand	Urban area: Virtual city	The average vehicle occupancy to decrease from 1.80 to 1.47 with AMoD scenario. The proportion of shared trips also decreases by around 30%, thereby indicating that AMoD adjusts to incorporate more ride-sharing as demand increases. For the With AMoD scenario, around 60% of total VKT is spent while traveling with a passenger, 35% while going for pick-up or parking, and 5% for empty vehicle cruising. The same observations for the Without Mass Transit scenario are 55%, 40%, and 5%, respectively.

Software	Source	Year	Model's parameters settings	Focus	Vehicle composition	Study Area	Highlights
AIMSUN	Mattas et al.	2018	AVs Car-following model: modified Gipps for manually driven vehicles: Max acc. 4 m/s2; Max deceleration -6 m/s2, Reaction time 0.8s. AVs without V2V and V2I connectivity capability: first order model representing ACC vehicle longitudinal behaviour proposed in (Shladover et al., 2012). For the lateral movement, default AIMSUN model. AVs are forced to obey the speed limits, in contrast to manually driven vehicles that have an acceptance factor allowing them to accede to the speed limit: Max acc. 2 m/s2, Max deceleration -3 m/s2, Reaction time 0.3 s. CAVs' car-following behaviour is similar to CACC vehicles while cruising described by (Talebpour and Mahmassani, 2016). CAV will behave as an AV when it is not able to exchange information with its neighbouring vehicles. CAVs are also forced to obey the speed limits, in the same way as AVs. Lane changing: default AIMSUN algorithm, using the CAVs particular car following deceleration model: Max. Acc 2 m/s2, Max deceleration -3 m/s2, Reaction time 0.3 s.	CAVs	– Penet. rate of AVs: 0%, 20%, 40%, 60%, 80%, 100% – Penet. rate of CAVs: 0%, 20%, 40%, 60%, 80%, 100%	Ring road: Antwerp (Belgium) 119 km of roads, 27 centroids (origin/destination points), 117 intersections without traffic lights	CAVresults: For the largest set time gap, the speed improves over the case of only human-driven vehicles only after the share of CAVs reaches 60%. In contrast, for the shorter set time gap, the introduction of CAVs in the network is always beneficial to travel speeds, even with the lowest penetration rate of 20%. AV results: With short set time gaps and low AV penetration rates, the negative impacts are relatively small. For a 20% penetration rate, the harmonic speed even slightly increases over the base scenario. However, as the penetration rate of AVs increases, the impact on speed becomes negative and more pronounced. In all cases, the speed is lowest with the 100% AVs penetration rate. Furthermore, the time period in which speeds are negatively affected is also longer when the share of AVs is larger. With no AVs, the speed is restored to free flow conditions 30 min after the peak demand period ends. But, with 100% AVs, this takes about 50 min. Similarly, the drop in the speed at the beginning of the peak demand period is steeper with the higher AVs penetration rates. Emissions results: At the lower level of traffic demand, the most emissions per kilometre measured in the case that all vehicles are human-driven. With the higher demand levels, the introduction of AVs in the vehicle mix, especially at high penetration rates, increases emissions. In contrast, CAVs seem to decrease emissions. These findings can be explained by the average speed on the network (time gap 1.6 s).
VISSIM	Hartmann et al.	2017	Desired time gap: if CAV is following another CAV: 0.9s and if CAV is followinga non-CAV vehicle: 1.8s. In order to investigate the potential impact of AVs on freeway capacity, an extreme headway setting for CAV simulated: 0.5 s.	CV PAV CAV HAV	2030: CV 74%, PAV 11%, HAV 9%, CAV 6%. 2040: CV 32%, PAV 28%, HAV 22%, CAV 18%. 2050: CV 12%, PAV 35%, HAV 27%, CAV 26%.	Freeways: Germany including basic, merge, diverge, and weaving segments	The conservative driving behaviour of automated vehicles, as foreseen by the current legislation, has a negative impact on the capacity of freeways. On the contrary, automated technologies that allow shorter headways between the vehicles, have the potential to increase the capacity of the freeway network by 30 % and reduce traffic delays significantly. Total delay (+32% to – 63%); travel time (+4% to -7%); capacity (down up to 7%, maximum increase of 30%)
VISSIM	Alam and Habib	2018	Wiedemann 74 car-following model is calibrated (i) average standstill distance (ax_average) =1, (ii) additive part of safety distance (bx_add)= 0.6, and (iii) multiplicative part of safety distance (bx_mult)= 0.7 used in Cobb Parkway model calibration.	SAV	15% and 20% trips by SAV	Urban area: Halifax (Canada)	Fleet size of 900 SAVs serves 20% of the total morning commute trip requests. The share of the total trip requests served ranges from 15% – 68% in the morning rush hours causes a 25% – 47% reduction of HVs. With the increase in fleet size, the number of per SAV trips decreases, alternatively, causes less utilization of SAVs. Scenario (85-15% --> 3 h): %change in avg. speed = 9.64,-12.1,-25.3; %change in total travel time = -4.7,15.4,33.4; %change in total network VKT = 1.73 ; Scenario (80-20% 3 h): %change in avg. speed = 7.5,-2.4,-15.2; %change in total travel time = -3.0,8.5,18.7; %change in total network VKT = 3.63.;

Software	Source	Year	Model's parameters settings	Focus	Vehicle composition	Study Area	Highlights
VISSIM	Dinar	2020	VISSIM car following/lane changing models for traditional traffic. CAVs Car-following/lane changing models with following parameters: NumInteractObj = 2; NumInteractVeh = 99; W99cc0 = 1.5; W99cc1Distr=0.9; IncrsAccel = 1; Platooning = 7. Three driving behaviour with some oscillations of the above: cautious, normal and aggressive.	CV, AV, CAV	15 combinations of CV, AVs and CAVs	Inner city: Munich	Emissions: optimum penetration levels are seen at the penetration of 60%, 50% and 70% for the peak hour demand, 20% below peak hour demand and 20% above peak hour demand, respectively. Average travel time and delay time of the study corridor decreased, while speed and connectivity, among C/AVs sharply increased, for high penetration rates of C/AV, up to the optimum penetration.
SUMO	Lu et al.	2021	Car-following model: IDM and default ACC model. Minimum gap when standing (Cautious driver 2.66, Normal driver 2.92, Aggressive driver 1.25). Maximum desired acc. following car =2 for all drivers. Absolute of the maximum desired dec. following car (Cautious= 7.3, Normal= 8.01, Aggressive= 8.6). Safe time headway (Cautious= 1.69, Normal= 1.13, Aggressive= 0.5). Acc. component for all drivers= 4.	AV	AV C (cautious driver), N (normal driver), and A (aggressive driver);	Inner city: Munich	CN can form the most stable network state and facilitate the 'delivery' efficiency of the network. Surprisingly, it is found that the worst mean speed and travel time are obtained at r(ratio between behaviours) = 0.5 for all combinations. Furthermore, in the experiments with all three driving styles, C is least sensitive to the ratio, while A is the most sensitive.
SUMO	Guériau et al.	2020	Shared Autonomous MOD (SAMOD) vehicles Currently proposed AV car-following models are not validated in urban scenarios, so, in this work, both AVs and private vehicles are ruled by SUMO's default car-following Krauss model.	SAV	Scenario 1 (base): no SAVs, 2,000 private vehicles. Scenarios 2 and 3: 5-10% SAVs. Scenario 4 (pessimistic case): SAVs do not replace any private vehicles but are added to the existing private vehicles from scenario 1 (10% more SAVs are added).	Urban area: New York city (Manhattan)	The detour time for the RS-enabled configuration has now almost doubled (e.g., from 6.31 to 11.48 min when picking up additional passengers in neighboring zones is allowed), as vehicles travel the same distance but with a lower average speed. Travel time: The lowest travel time of 1.807 min is observed in scenario 3 (with 1,987 vehicles), followed by scenario 1 (1,991 vehicles, 1.81 min), scenario 2 (2,005 vehicles, 1.812 min), and, finally, scenario 4 (2,156 vehicles, 1.817 min). Scenario 3, with 10% SAVs, has a shorter travel time than the baseline scenario that has no SAVs, while scenario 2, with 5% SAVs, has a longer travel time than the baseline.

Software	Source	Year	Model's parameters settings	Focus	Vehicle composition	Study Area	Highlights
SUMO	(Guériau and Dusparic	2020	– Default car-following model of SUMO, – CAVs level 2 and their acceleration relies on an implementation of CACC. – Car-following model: Intelligent Driver Model (IDM) for CAVs level 4 as it better mimics the behaviour of an automated system and is more conservative since designed to be collision-free.	CAV	Level 2 and level 4 cars and heavy goods vehicles, with penetration rates of level 2 vehicles in 0-50% range, and level 4 in 0-20% range. CAVs penetration have been evaluated for 2.5%, 7%, 20%, 40%, and 70%.	Irish highways	Near-maximum efficiency improvements are observed at relatively low penetration rates but reveals further insights that the exact penetration ranges between 20% and 40% depending on the network type and traffic conditions. Dublin city center (safety): With the first introduction of CAVs, a slight increase of conflicts occurs (scenario B with results in 8 additional conflicts). From that point on, first a slight reduction in conflicts is observed (at 7% to 20% penetration rates, scenarios C and D) and then their drastic reduction (40% to 70%, scenarios E and F). The best improvement is observed with higher number of CAVs (70%, scenario F) and enables a 58% reduction of the number of conflicts compared to the baseline scenario A. (Traffic efficiency) Firstly, low penetration rates of CAVs create more congestion (scenarios B and C) resulting in higher average travel rates. This effect is reversed by the gradual deployment of level 4 technologies, and a positive impact on traffic flow can be observed from 20% of CAVs (scenarios D to F). Motorway scenario (safety): The introduction of level 2 automation will generate more conflicting situations (2.5% to 7% penetration rates, scenarios B and C). Further deployment of level 4 automation (20% and up, scenarios D to F) is shown to reduce the number of detected conflicts, confirming the positive impact of HAVs on safety.
MATSim	Liu et al.	2017	5.6 to 7.7 HVs per SAV, assuming that the average SAV serves 17–20 person-trips per day; empty vehicle miles traveled: 7.8 to 14.2.	SAV	Optimal fleet size around 30% of agents requesting SAVs (served SAV requests > 95%)	Urban area: Austin Texas	SAVs were simulated to serve the MATSim DUE travel demand under four different fare rates, $0.50 to $1.25 per mile, resulting in four levels of demand for SAVs 43.3% to 7.0%. The average service time (i.e., trip duration, not wait time) is 15.7 min if the fare rate is $0.5 per mile, but it is only 8.3 min when the fare is $1.25 per mile.
MATSim	Bösch et al.	2018	Average waiting time not more than 10 min, AVs' passenger pick up time of 120 s and a drop-off time of 60 s.	AV	Dynamic fleet size based on the average waiting time.	Urban area: Budapest	AV (1 AV replacing 4 vehicles; Avg. Waiting Time = 3.7 min; ratio of empty to occupied driving times = 26.5%); AV+P&R (1 AV replacing 2.4 vehicles; ratio of empty to occupied driving times = 19.6%).
MATSim	Ortega et al.	2020	N.A.	AV	AV for aRS Four scenarios: 6000 aTaxis, 4000 aRS, both aRS and aTaxi, no AV-based services.	Zug region Switzerland	Monopoly aTaxi services have the potential to reduce TT. However, this improvement comes at a great cost: a 4.1% reduction in TT for a 16.0% increase in VKT (averaged across all combinations without outliers). With aTaxis, the expected pick-up and drive time were 2.6 min and 2.4 min, whereas for aRS these were 12.4 min and 10.9 min, despite similar served average Manhattan trip distances (aTaxi: 1.28 km, aRS: 1.32 km). Furthermore, although positive effects of SAV fleets can be expected, for example, 12.4% of mode share switching from private cars to aTaxis, which would result in a substantial fleet size reduction (10), they might also come at great cost: in additional VKT, and an increased risk of congestion, as suggested by the presence of outliers. The additional VKT originate from empty rides, but also from substantial mode share changes from the VKT-neutral modes aPT and SM to aTaxis (16.1 percentage points from SM and 4.3 from aPT).

Software	Source	Year	Model's parameters settings	Focus	Vehicle composition	Study Area	Highlights
MATSim	Hamadneh and Esztergár-Kiss	2021	AVs' acceptable waiting: time for a traveller is around 10 minutes equivalent to an average parking time for car users, and walking time for public transport users, Marginal utility of performing activity = -6, Marginal utility of money = 0.0018, Monetary distance rate per meter = -0.4 per car, -0.038 PT, -0.004 bike, -0 walking, Marginal utility of travelling for all modes = -2.5 per car, -0.5 PT, -0.3 bike, -0.1 walking, Constant = -0.2 car, 3.92 PT, 2.64 walking, -17.81 bike. The groups are (a) long-trip travellers (b) public transport riders, and (c) travellers with specified characteristics.	AV	Initially, a random AV fleet size is generated on the road network based on the 95th percentile waiting time of travellers, and this process is repeated several times until an optimal fleet size is determined based on the demand with the plausible waiting time. The daily activity plans used to study the possibility of increasing the utility of travellers through minimizing the TT by using Avs.	Urban area: Budapest	Reduction in the trip time: 13% to 42% for group (a), 33% for group (b), and 16% to 28% for group (c) compared with the original trip times. It is worth mentioning that the simulation of the entire sample size (8,500) showed that the average trip time for all travellers was 33.4 minutes and the average trip distance was 3.9 km. Long trips(In this section, three scenarios are studied, as follows: (1) travellers who travel more than 40 min-utes regardless of what mode of transport is used, (2) travellers who travel more than 40 minutes with a motorized mode of transport, and (3) travellers who travel more than 10 km): Fleet size 120, AVG trip time 14.5, AVG waiting time = 4.7, empty driven time = 88.4, occupied time = 286.9, pick up time = 38, drop off time = 19. Fleet size 70, AVG trip time 20.4, AVG waiting time = 4.3, empty driven time = 25.6, occupied time = 117.8, pick up time = 11.9, drop off time = 5.9. Fleet size 300, AVG trip time 15.4, AVG waiting time = 3.5, empty driven time = 151.9, occupied time = 762.6, pick up time = 87.2, drop off time = 43.6. Travellers who use public transport: Fleet size 425, AVG trip time 13.2, AVG waiting time = 3.6, empty driven time = 354.6, occupied time = 454.8, pick up time = 195, drop off time = 97.5
BusMezzo: combination of multi-agent PT simulation and heuristic optimization	Hatzenbühler et al.	2021, 2020	Transition from existing PT systems towards line-based PT systems operated partially or exclusively by Autonomos Bus (AB) evaluated (i) using AB specific operator cost formulations, (ii) integrating infrastructure costs required for AB operations, (iii) utilizing a dynamic, stochastic and schedule-based passenger assignment model for the simulation of PT networks, (iv) by formulating a multi-objective optimization problem allowing to investigate the stakeholder specific impacts of AB.	SAV	Not available	Urban area: 1. Kista, Sweden 2. Barkarby, Sweden	1. The deployment of AB leads to an increase in service frequency and a marginal reduction in vehicle capacity. Furthermore, it could be seen that the deployment of AB increases the passenger load on AB lines and that passengers can shift from other PT modes towards the AB services. 2. The differences in user-focused and operator-focused network design are analyzed and the impact of AB on these is quantified. a full-sized, line-based PT network is designed to exclusively operate AB. Results indicated that the autonomous technology reduces the number of served bus stops and reduces the total PT network size. Additionally, average passenger waiting time can be reduced when deploying AB on user-focused PT networks, which in turn leads to a further reduction of user cost.

4.2. Limitations and directions for future developments

Since there are no universal methods and tools used to simulate ACT scenarios, it is not trivial to compare different works and draw proper conclusions regarding the outcomes. One key reason is the lack of empirical AV data that could be used for an accurate calibration and validation of models. Although different commercial (AIMSUN and VISSIM) and non-commercial software (SUMO, MATSim) are constantly improving their capabilities to simulate AVs, uncertainty over the operational characteristics of the future does not allow to identify which models may eventually become most accurate and useful. This is part of an ongoing debate among academics and practitioners regarding Operational Domain Design; ODD (Berman, 2019). In addition, it may turn out that the development of microscopic simulation models of AVs may also lead to the development of better control algorithms of AVs in real traffic.

It should be highlighted how the different tools described in this section may not be perfectly comparable in how they model AVs. Agent-based models like MATSim or SimMobility focus on a disaggregated demand, usually exploited to define the size of an automated fleet or to design a service which is economically viable and competitive against other modes. The supply side of these models is very simplified and rarely goes beyond a mesoscopic model, which does not allow to include driving features characterising AVs. This is a necessity due to the computational burden involved in the case studies simulated through agent-based models, i.e., large-scale urban areas. Alternatively, tools that are built on microscopic traffic simulators, such as Aimsun, SUMO, or VISSIM, providing a detailed simulation of the supply side, via accurate car-following and lane changing models at microscopic level (i.e., focused on behaviour of individual vehicles); however, often the demand is defined in an aggregated manner (through O/D matrices). This, in turn, is reflected on the research questions that are usually answered through these tools, e.g., the impact assessment of a car-following model or of a strongly reduced headway; indeed, the considered case studies are usually more limited in space and time, examples would be a stretch of highway or a crossing during peak hours. In the end, it is very important that the right tool is chosen depending on the research question or the task at hand and the aim of this section is to provide evaluators, stakeholders, and professionals with the knowledge to make the correct choice, rather than identifying the best modelling tool among the possible ones. At the present stage, no existing tool outperforms the others in all the possible modelling tasks.

To tackle the aforementioned challenges, WISE-ACT WG5 recommends:

1. building an open repository of real-world data (e.g., trajectories) for AVs, based on existing data from experiments and pilots.

2. establishing standards for building, calibrating, and validating traffic models of CAV using real-world data.

3. building scenarios (e.g., standard road networks) to conduct experiments for CAVs.

4. developing a generic, open, software-agnostic benchmarking platform for the evaluation of alternative modelling approaches, and conducting further meta research to build a database of models and research works with information about; assumptions, inputs, outcomes, scope of applicability, in order to ensure comparability and reproducibility of results.

The above is not trivial, given the high complexity of the task and the large heterogeneity of assumptions, case studies, tools, boundary conditions, to name a few. Tools can be clustered depending on the degree of precision and the research questions tackled, further classifications would be based on the geographical realities, considered traffic conditions, relevant scenarios, and the kind of automation that is simulated (AVs, rather than CAVs or SAVs). Only after this activity has been carried out can a benchmarking platform be realized. This WG5 Thematic Report is a first step in that direction.

To base future models on real-world data may be desirable but may prove challenging given the relatively low number of public trials and their limitations. Many of the AV prototypes on public roads use very cautious driving styles, in Europe they are limited to collective transport services. This differs from the US where private cars are also used widely across AV trials, but the norm is still for AVs to drive in a more cautious and sage mode. One possible solution would be to strengthen ties and collaborations between the institutions carrying out modelling works (academia) and companies currently developing prototypes (OEMs). Data sharing between such diverse stakeholders, across countries/continents, is a challenge highlighted in WISE-ACT Data country reports[2] and WG1 Thematic Report. This would not solve the issue of real-world data but would allow the models to replicate the planned behaviour of future CAVs, highlighting criticalities before any tests. These would validate assumptions and results from modelling, being based on the same behaviour, if not the same control algorithms.

2 https://wise-act.eu/reports-publications/

Chapter 5

Criteria and indicators for ACT deployment

This section builds on efforts done within WISE-ACT WG5 and adopts a broader perspective based on worldwide activities and literature linked with T14 "Develop a set of criteria and indicators which can inform policy makers about deployment of ACT in a certain locality". Sections 3 and 4 have reviewed contemporary studies (Task-12) and compared the results to draw knowledge gained (Task-13). The scope of this section extends task-12 and task-13, identifying indicators and criteria that might be helpful for different stakeholders, especially relevant for policymakers to define future ACT projects, sections of scenarios, associated tools, data, and models.

Indicators are such an essential element of assessments that some researchers and practitioners frequently confuse evaluation with indicators. There is no question that indicators are crucial foundations of assessment; however, it is important to remember that they should not be utilised automatically and require a specific interpretation. An indicator's output should be quantifiable, which means it should be stated as a value with a relative unit of measure, which makes a direct and obvious relationship between the indicator and a policy objective, goal, or target. Developing standardised indicators usually results from a long process of collective discussion with the various stakeholders involved in the development activities. However, the AV scenario-based simulation studies are not advanced enough to set a well-accepted standard indicator list. In this thematic report, the following are some of the most utilised indicators that we have identified from the studies considered in section 4.1 (Table 5).

In the evaluation and assessment literature, indicators are often categorised and re-grouped in various ways; nevertheless, the most valuable distinction for an ACT simulation scenario-based project that we could develop based on the handful of indicators listed in Table 6 as follows:

Table 6: Indicator list and their unit of measurement.

Indicator	Unit of measure
Dead kilometre travel	Kilometre
Delay	Minutes
Fleet size	Number of vehicles
Modal share	Percentage
Peak hour demand	Trip/h
Penetration rates	Percentage
Road capacity	Vehicle/KM
Service area	Square kilometre
Total distance travelled	Kilometre
Travel cost	€/km
Travel time	Minutes
Vehicle capacity	Person/vehicle
Vehicle recharge/refuelling duration	Minutes
Value of travel time saving	€/h
Vehicle relocation time	Minutes
Vehicle replacement rate	Conventional Vehicles/AV
Vehicle range	Kilometre/full charge
Waiting time	Minutes

Table 5: Indicator type, goals and measurement directions.

Type of indicators	Policy goal/objective/target	Indicators	Direction
Input/Resource indicators	– Measure input variable and simulation settings parameters – Minimise input – Minimise cost	Fleet size	Increase/decrease
		Modal share	Increase/decrease
		Peak hour demand	Decrease
		Penetration rates	Increase
		Service area	Increase
		Travel cost	Decrease
		Travel time	Decrease
		Vehicle capacity	Increase
		Vehicle recharge duration	Decrease
		Vehicle range	Increase
		Vehicle relocation time	Decrease
Output/Result indicators	– Measure the immediate (dis-) advantage of the project – Optimise the output – Maximise the utility	Dead kilometre travel	Decrease
		Delay	Decrease
		Total distance travelled	Increase/decrease
		Value of travel time saving	Increase/decrease
		Waiting time	Decrease
Impact Indicators	– Measures the indirect medium to long-term consequences. – Maximise and ensure societal sustainability – Long-term mobility decisions – Residential attractiveness – Improve transport equity and accessibility	Road capacity	Increase
		Vehicle replacement rate	Increase

To avoid the critiques on how the **valuation of travel time** and to ensure the social benefit appraisals of future ACT projects, Rashidi et al. (2020) suggested for correcting the marginal utility of income or inflation of VoTT to obtain consistent social value/gain/benefits/welfare estimates. Otherwise, depending on the users whose VoTTs are more impacted by the policy, it is highly likely that the overall benefits of a policy are over/underestimated. In the case of AVs, which are intended to enhance the accessibility and mobility of people with the option of shared mobility in urban areas, less benefit from this technology can be expected from sparse sections of the network.

Technological advances will not necessarily generate a positive societal impact if it does not properly reflect on the policy level, a laissez–faire **governance approach** (absence of government intervention) could prolong ACT deployments and reflect less sustainable societal benefits. Both private and public stakeholders need to cooperate with each other for the development and implementation of ACT technologies in the future, which should be compatible with the existing long-term objectives of local or regional authorities. To enhance the ACT as a sustainable mobility option for the future, a time relevant intervention in existing and future land use policy and regulations is suggested, together with push and pull measures as well as increased incentives for shared ACTs (Narayanan et al., 2020a). 2020a).

Harb et al.(2021) in the concluding remark of their comprehensive work listed the methodical benefits and limitations to address how ACT could impact our travel-related behaviour. Controlled testbeds, driving simulators, and virtual reality are useful for ACT safety studies, but do have limitations to answer the ACT influence on **travel behaviour changes**. On the other hand, agent-based and travel-demand models are an effective tool to study the impact of policy decisions and changes in travel-related behaviours on the transport system, also but do not inform much how automation will change travel behaviour. Finally, field experiments together with surveys (mixed approach) might help us to explore changes in travel-related behaviours; however, has very limited empirical evidence. There is also limited convergence on what is intended by adoption of **ACT service models** (car as a service vs. car as a property) are considered to need further research.

After a comprehensive analysis of existing literatures on ABS in combination with ACTs, Jing et al. (2020) have identified a list of variables that are considered until now by different literatures. The variables all of which were collected indicate that they differ among the scholarly works; however, the variables that were not included by them do not imply that they are not needed. According to them the *fleet size, demand, strategy, ridesharing, pricing schemes, station configurations, travel mode, vehicle power, service area, refuel/recharge time, maximum waiting time, and vehicle relocation time/cruise time* are the critical variables that considered in the sensitivity analysis and different scenarios of the ABS that would affect the system performance (Jing et al., 2020).

The performance of future ACTs, which often provide services to customers with a vehicle fleet, would be highly influenced by fleet size. While the conventional vehicles were replaced by ACTs, the fleet size was the first and foremost important for researchers to be considered as the significant variable in the agent-based ACT simulations. Nevertheless, the fleet size and vehicle replacement rate are one of the major outputs of the simulation studies (Jing et al., 2020). According to Marczuk et al. (2015), the total fleet size highly depends on the operating area, average demand, quality of service (average waiting time, service and reject rate), routing strategy, relocation strategy, and facility configuration. Along with those eight significant variables identified by Jing et al. (2020), that eventually will influence the fleet size or replacement rate are (1) network/service area, (2) average demand, (3) average speed, (4) average waiting time, (5) service and reject rate, (6) ridesharing, (7) vehicle relocation policy, and (8) facility configuration are highly suggested to take into consideration for future ACT simulation projects. It's difficult to come up with a single precise or concrete number that represents the replacement rate of a traditional vehicle by an ACT vehicle because of the variation of simulation scenarios, network conditions, service provided, and related assumptions made by the researchers. Therefore, the WISE-ACT WG5 suggestion (Section 4.2) of creating a relevant Open Database is an important recommendation for the way ahead as it would act as a valuable resource not only for researchers, but also for practitioners and policy makers e.g., city authorities.

Another important thing to remember is demand, which is divided into two categories: trip demand and ACTs market penetration rate. Several assumptions/considerations have been made by the researchers such as sensitivity analysis on the average daily trip demand rate, different trip generation rates differing by region: downtown, urban, suburban, and extra-urban areas; and tested different combinations of services together with different ACT penetration rates ranging up to 100%. When investigating the ACTs system's efficiency, it's important and highly suggested to consider several strategies into considerations: scheduling strategies, assignment strategies, implementation strategies, process strategies, hailing strategies, congestion charge/tolling strategies, and vehicle relocation strategies (Jing et al., 2020).

Ridesharing is another variable that the researchers have taken into account when designing ACT scenarios in order to reduce the size of the ACT fleet. However, when designing such scenarios, it's also necessary to consider the users' willingness to share rides with others will eventually drop the vehicle capacity. Trip purpose i.e. commuting or leisure (Thomopoulos et al., 2021), passenger gender (Polydoropoulou et al., 2021) and other socio-economic passenger features e.g. age (Kyriakidis et al., 2020)are further variables to consider. If private vehicles are replaced by electric ACTs or pooled electric ACTs, the allocation/availability of charging facilities (private versus public), charging duration (regular slow versus fast charging), vehicle range, and charging pricing strategy will all have a substantial effect on the level of substitution (Kyriakidis et al., 2020).

The preferences of passengers, the variability of travel demand, and the travel modes, such as users' willingness to travel alone or with fellow travelers, as well as the travel modes choice and vehicle type, should all be taken into account while defining the scenarios for ACTs. Finally, to achieve more case studies confirmation and concrete outcomes, it is highly recommended to develop more scenarios in various countries and regions to be tested through different simulation platforms (Jing et al., 2020).

Chapter 6
Conclusion

This report offers a summary of existing research related to the development, simulation, and assessment of future AV systems. It is obvious that the complexity of future mobility systems, as well as the uncertainty in technological developments does not make it easy to "predict" what is going to happen on roads worldwide. Still, numerous efforts have been done trying to identify possible AV impacts, via assessing simulation scenarios, often based on small-scale real-world experiments. However, such efforts have been characterised by a limited scope, where different impacts have been assessed in separated research works. This is also due to a lack of harmonisation in modelling and simulation methods and tools; in fact, existing tools characterised by a strength (e.g., accurate representation of travel demand), lack in another (e.g., modelling AVs driving behaviour). Finally, the choice of scenario and tool is directly linked to the criteria and indicators that can be produced, as well as their accuracy and granularity.WISE-ACT has contributed to bridging such gaps by facilitating cross-border collaboration and knowledge exchange. Certainly, there is much more to be achieved in this field and international collaboration among experts and practitioners is key.

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For further information visit the WISE-ACT COST Action website at www.wise-act.eu
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Appendix

Table A: Studies related to WISE-ACT WG5 and the respective deployment scenarios

Source	City / Locality	AV deployment scenarios	Main findings	
Hartmann et al. (2017)	German freeway	Ex-ante impact assessment of automated vehicles on capacity of freeways using microscopic traffic flow simulation.	Technologies that allow shorter headways between vehicles have the potential to increase the capacity of the freeway network by up to 30% and reduce traffic delays significantly. However, small market penetration rates of automated vehicles do not lead to discernible capacity benefits.	**Link**
Liu et al. (2017)	Austin, TX	SAV mode requests simulated in MATSim through a stochastic process with differing pricesfor four possible fare levels: $0.50, $0.75, $1, and $1.25 per trip-mile.	Different fare levels of $0.50, $0.75, $1, and $1.25 per trip-mileThese fares resulted in mode splits of 50.9, 12.9, 10.5, and 9.2% of the region's person-trips, respectively.	**Link**
Bösch et al. (2018)	Zug region, CH	Differing business models: 1. monopoly service of automated taxis; 2. monopoly service of AVs for ridesharing; 3. six different providers with different services; 4. no-AV base case.	Taxi service profitability is based on fleet size and price. Automated taxis gain substantially from slow modes. AV services increase VKT but could reduce travel time.	**Link**
Mattas et al. (2018)	Antwerp ringroad, BE	Various traffic mixtures of manually driven vehicles, AVs and CAVs, different desired time headways settings and traffic demand levels.	Depending on the demand, AVs introduction can have negative effects on traffic flow, while CAVs may benefit the network performance, depending on their market penetration.	**Link**
Perraki et al. (2018)	Motorway A20, NL	Testing AIMSUN microsimulations with CAVs and various scenarios with/without traffic management using AIMSUN microsimulations.	CAVs may deteriorate traffic conditions if they are not managed properly. In particular for mixed traffic, using appropriate traffic management allows to avoid deteriorating traffic conditions.	**Link**
Miller et al, 2019	Ljubljana (Slovenia) & Seattle (WA, USA)	Cultural differences in takeover response (L3 driving)	The results of a study performed in driving simulators at two different locations show significant differences in responses to unexpected take-over requests (TOR) in Level3 driving. All participants in Slovenia responded to the TOR while only 74% of the USA participants responded to the TOR. Slovenian participants also responded significantly faster compared to the USA.	**Link**
Nahmias-Biran et al. (2019)	Singapore	Comparing tfhe fully decentralized traditional MoD with the future AMoD services	AMoD results in a more efficient service even with increased demand. Parking strategies and fleet sizes will also have an effect on user satisfaction and network performance.	**Link**
(Cugurullo et al, 2020)	Ireland	In-depth survey conducted in Dublin (1,233 respondents)	Empirical evidence of (a) the public interest in autonomous cars and the intention to use them once available, (b) the fears and concerns that individuals have regarding autonomous vehicles and (c) how people intend to employ this new form of transport.	**Link**
(Gueriau and Dusparic, 2020)	Ireland	Testing surroundings of3 scenarios – urban, suburban or, highway. Testing 3 traffic loads. A range of penetration rates and levels	Near-maximum efficiency improvements in congestion are observed at relatively low CAV penetration rates, but reveals further insights that the exact penetration ranges between 20% and 40% depending on the network type and traffic conditions. Safety results show a 30% increase of conflicts at lower penetration rates, but 50-80% reduction at higher ones, with consistent improvement for increased penetration. Congestion has a higher impact on conflicts than penetration rates, highlighting the importance of unified evaluation of efficiency and safety.	**Link**

(Gueriau et al, 2020)	Manhattan	Testing Evaluation of shared AMoD in the presence of congestion in a microscopic simulation	The impact of congestion is clear when looking at absolute performance of both baseline and SAMoD; up to 10% of the requests are not served and detour time for ride-sharing is doubled in the presence of congestion. Implications of this result are twofold. Contrary to the standard in the current literature, this paper shows that the evaluation of SAV approaches needs to take congestion into account to accurately estimate level of service. In addition, results highlight the need for SAV assignment and rebalancing algorithms to be congestion-aware	**Link**
Alam& Habib (2020)	Halifax, Canada	Fleet size available to meet demand. VISSIM microsimulation with SAVs replacing traditional vehicles.	Fleet size of 900 SAVs serves 20% of the total morning commute trip requests. 3600 SAVs serve about 68% of the morning commute.	**Link**
Basu et al. (2020)	Singapore	1. AMoD in lieu of mass transit modes such as Bus and MRT, 2. The inclusion of AMoD along with availability of all modes from the base case scenario.	Results show that mass transit is irreplaceable, despite the high efficiency of AMoD, in order to avoid congestion and maintain a sustainable urban transportation system with acceptable levels of service.	**Link**
Chee et al (2020)	Stockholm, SE	Estimation of willingness to use and willingness to pay for different service deployment of automated vehicle: 1) door-to-door on-demand personalised AV service (PAV), 2) demand responsive shared AV (SAV) service, and 3) operating the service as for first-/last-mile service as on regular public transport service with fix route	Results show people hold different expectations towards each type of AV service. These expectations act as the minimum requirements for people to pay for the AV services. In details, the respondents are willing to pay more for PAV service if the service is safe, provides good ride comfort and has competitive price in comparison to the price travelling by metro and train given the same distance. Other than service quality attribute perceptions, income level, existing travel modes for daily trips, familiarity with automated driving technology and AB ride experience are important factors affecting WTP for the AV services. This model can be applied to understand the expectations of potential users towards a new AV service, and to identify the user groups which are willing to pay the service.	**Link**
Cugurullo (2020)	Abu Dhabi	Analysis of the built environment needed by AVs	The analysis shows that, outside confined urban spaces, AVs face and cause substantial challenges in terms of urban design, urban planning and ethics.	**Link**
Dinar (2020)	Urban corridors in downtown Munich, DE	Sensitivity analysis on the driving behaviours of autonomous vehicles (AVs) as well as an impact study of CAVs in a mixed traffic region for the three most frequently seen driving modules. Examining different parameters including traffic (travel time, speed and delay time), environmental (CO_2 and NOx) and road safety	The results indicate that the impact of C/AVs is generally positive up to a limit, which is directly connected with the number of interacting vehicles. CAVs are better performers in traffic than AVs. However, both CAVs and AVs have higher traffic performance and fewer road accidents in lower traffic demand cases, although the emission outputs are the same. Three parameters were found to be the most influential for AVs: the number of interacting vehicles, look back distance and minimum clearance (front/rear).	**Link**
Emberger, Pfaffenbichler (2020)	Austria	Sensitivity analysis concerning the demand effects of road capacity, perception of in-vehicle time. remote parking, new user groups for private car, car and ride sharing and public transport	Clear indications that AVs, especially if private cars prevail, will have a significant impact on veh-kms travelled. According to these findings, veh-kms travelled by 2050 might increase by up to a third compared to a no automation scenario. Automation will likely have a negative impact on the use of active and public modes of transport. Car dependency and, without significant changes in powertrains, the related energy and resource consumption will go up – which is in contradiction to all the political goals towards sustainability and climate protection as laid out in the Paris Agreement. On the other hand automation as part of public transport, e.g. as automated shuttles for the first and last mile, has the potential to significantly reduce car dependency, veh-kms travelled and associated negative environmental impacts.	**Link**
Guo et al. (2020)	Stockholm, SE	Analysis of user survey	Findings indicate that (1) The presence of onboard operators has a positive impact on perceived safety, (2) People who have not taken automated buses before have a more negative perception of driving speed of the bus service than people who have taken the buses before, (3) Attitudinal factors, such as public perceptions of safety, driving speed, reliability, and convenience, have a significant influence on the acceptance of the new bus system, (4) Automated buses are expected to attract a high share of regular public transportation mode users and the younger generations in the future, (5) Social-demographic characteristics such as gender and income, had no significant impacts on the adoption of the new technology.	**Link**

H. Lengyel, T. Tettamanti and Z. Szalay; 2020	Budapest, HU	The first critical situation was: the speed assist system (based on speed limit traffic sign recognition) conflicts with the traffic infrastructure. The second critical situation was: the ACC (Adaptive Cruise Control) and LKA (Lane Keeping Assist) conflicts with the traffic infrastructure.	Based on the analyzed simulations, it is concluded that autonomous vehicles do not necessarily have to be designed for existing infrastructure. Nevertheless, the infrastructure also needs significant change, which could mean building new signs, other types of lanes, or possibly overhauling.	**Link**
Hamadneh and Esztergár-kiss (2020)	Budapest, HU	A total of seven scenarios were derived from the collected data and simulated twice to include the existing transport modes and the presence of AVs	The results have shown a reduction in the trip time: 13% to 42% for group (a)long-trip travellers , 33% for group (b) PT riders, and 16% to 28% for group (c) travelers with special characteristics; compared with the original trip times..	**Link**
Lu et al. (2020)	Munich, DE	Different driving "styles" for AV vehicles, calibrated based on existing data	Exploration of the influence of automated vehicles with different driving styles on the network efficiency. K-means algorithm is applied to categorize the car-following maneuver trajectories first, followed with the calibration of car-following models via FDSA. The calibrated car-following models are used to represent the automated vehicles with different driving styles. Different deployment scenarios are designed and simulated on the network of Munich city center. When vehicles are assembled with the same driving style, it presents that aggressive vehicles lead to higher speeds and shorter travel times in general	**Link**
Lu et al. (2020)	Budapest, HU	1) 8×8 urban grid network with 60 nodes and 36 intersections 2) Real-world network (in Budapest) with 30 road links only forming an intrinsically homogeneous sub-network	The AVs penetration has a positive impact on improving the road network capacity in a quasi-linear way. Maximum traffic flows in case of 100% AVs penetration are 16-23% larger than that of all conventional vehicle scenario. The benefit is not obvious when there is not enough driverless cars on the road as the autonomous vehicles must adapt itself to the conventional vehicles obviously. When self-driving cars start dominating the roads, a plateau occurs around the maximum flow. With the adoption of 100% autonomous vehicle, the road network becomes more stable and can avoid getting congested easily to some extent.	**Link**
Nahmias-Biran et al. (2020)	Singapore	Shared AMoD strategies: 1.availability of AMoD service in the central business district (CBD), and 2.a full operation of AMoD city-wide in the absence of other on-demand services.	City-wide deployment of AMoD results in greater accessibility and network performance. Moreover, the accessibility of low-income individuals is improved relative to that of mid– and high-income individuals. the accessibility of low-income individuals is improved relative to that of mid– and high-income individuals.	**Link**
Narayanan et al. (2020a)	global / review article	Shared autonomous vehicle services	A systematic review of the literature on shared autonomous services, focusing on their impacts. The review is organized on a number of categories, i.e. impacts on the economy, the environment, governance, travel behaviour, traffic and safety, transport supply and land use. A policy and operational framework for effective shared autonomous services is proposed.	**Link**
Narayanan et al. (2020b)	global / review article	Impact of AVs on traffic flow	19 factors that influence traffic flow efficiency implications of autonomous vehicles are identified and grouped into four categories, namely (i) vehicle characteristics, (ii) travel behaviour, (iii) network characteristics, and (iv) policies. The chapter ends with a discussion on policy recommendations in tune with the factors identified. The discussion shows that the policy makers should enact laws to ensure connectivity between AVs to experience significant benefits, integrate CAVs with public transport to avoid mode shifts, incentivize ridesharing to reduce network load, develop suitable parking management policies to avoid empty relocations and introduce congestion pricing to curb induced demand.	**Link**
Ortega et al. (2020)	Budapest, HU	Comparison for forcing private car users to use park-and-ride (P&R) facilities as a way of decreasing traffic in city centers. 1. Existing condition. 2. with automated vehicles. 3. Park & ride with existing conditions. 4. P&R with AV	The result showed that using the P&R system increased overall travel time, compared with using a private car. The results also demonstrated that using AVs as a replacement for conventional cars reduced travel time.	**Link**

Papantoniou et al. (2020)	AttikiOdos Motorway, Athens, GR	Different percentages of automated and human driven vehicles (0%, 25%, 50%, 75% and 100% of AVs) while NOx and CO emissions are investigated in each scenario	Results indicate that Autonomous Vehicles have the potential to increase the emissions on the motorway. Additionally, the specific increase of emissions is estimated in all different scenarios of autonomous vehicles' percentages in the mixed traffic scenarios.	**Link**
Petrov et al. (2020)	Zilina & Bratislava/ Slovakia	Emergency vehicle prioritization in CAV environment – A feasibility study of a V2V communication-based system for formation of an emergency lane free of obstacles applicable to AVs.	During the transition period with mixed traffic (various levels of automation but 100% connected), the proposed EV warning system can increase the reaction time available for the human driver significantly – the maximum available reaction time reached 320 s. However, high values of available reaction time open a new set of issues that have to be addressed as there is no point for the driver to take any action for several minutes. On the contrary, such an action could disrupt traffic fluency and cause other unexpected effects. Therefore, especially when the available reaction time is large, the EV should update the vehicles with information about the estimated time when it is supposed to reach the informed vehicle.	**Link**
Qurashi et al. (2020)	Munich, DE	Estimation of fuel consumption and environmental impacts of shared autonomous vehicle services	Development of a simulation platform, execution of a number of scenarios, estimation of fuel consumption and environmental footprint of different penetrations and system configurations (e.g. number of vehicles) of shared autonomous vehicle services.	**Link**
(Acheampong et al, 2021)	Dublin, Ireland	Survey of attitudes and adoption modes for AVs (private, shared, public transport etc)	The paper examines the latent behavioural and socio-demographic factors that will drive the adoption of and preferences for different use options of autonomous vehicles, utilizing survey data from 1200 residents of Dublin, Republic of Ireland	**Link**
Agriesti SAM, Ponti M, Marchionni G, Gandini P (2021)	Italy, Trento	Highway Chauffeur (L3 driving). The analysis of this system is carried out on a roadwork scenario to assess the positive impacts arising from a joint implementation of the automated system and the C-ITS Use Case signaling the closure of a lane.	The results showed how triggering the take-over maneuver in ad-vance fosters the bottleneck efficiency (the same speed values reached between 80 and 100% Market Penetration for around 700 m range of the C-ITS message are reached at 50% Market Penetration with a 1500 m range). Besides, an in-creased speed up to 30 km/h at the bottleneck is recorded, depending on the mar-ket penetration and the message range. Finally, the delay upstream the roadworks entrance is reduced by 6% and arises at around 700 m, without the need to deploy the message up to 1500 m.	**Link**

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