Autonomous and Connected Transport as Part of an Inclusive Transport System

WG2: Social Challenges

WISE-ACT
COST ACTION CA16222

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The WISE-ACT COST Action CA16222 is an international network of 200 experts in 42 countries which started in 2017 to explore the Wider Impacts and Scenario Evaluation of Autonomous and Connected Transport. WISE-ACT activities have been supported by the COST Association.

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This publication is based upon work from COST Action WISE-ACT, CA16222 supported by COST (European Cooperation in Science and Technology).

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COST is supported by the Horizon 2020 Framework Programme of the European Union

April 2021

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Citation

Recommended report citation: Martens, K., Beyazit, E., Henenson, E., Thomopoulos, N., Milakis, D., Mladenovic, M., Pudane, B., van Wee, B., Di Ciommo, F., Curl, A., Cugurullo, F., Dimitrova, E., Negulescu, M. (2021) WG2 Thematic Report: Autonomous and Connected Transport as part of an Inclusive Transport System, COST Action CA16222 WISE-ACT.

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Preface

This report has been written within the framework of COST Action CA16222: Wider Impact and Scenario Evaluation of Autonomous and Connected Transport (WISE-ACT), which has been co-funded by the European Commission H2020 program. The 'action' encompassed five working groups, each addressing different issues and themes related to autonomous and connected transport. This thematic report describes the main concepts and recommendationsof Working Group (WG) #2, which was tasked with examining the potential social challenges of autonomous and connected transport (ACT).

WG#2 addressed a number of key social challenges, namely accessibility, equity, personal security and privacy. More specifically, the working group aimed at addressing three topics (or 'Tasks' according to the WISE-ACT COST Action Memorandum of Understanding-MoU):

- Understand the value of travel time under an ACT scenario (**Task 4**)

- Evaluate the privacy and security concerns emerging from the deployment of ACT (**Task 5**)

- Categorize the anticipated equity impacts and propose suitable principles and criteria for an inclusive and fair transport system of the future (**Task 6**)

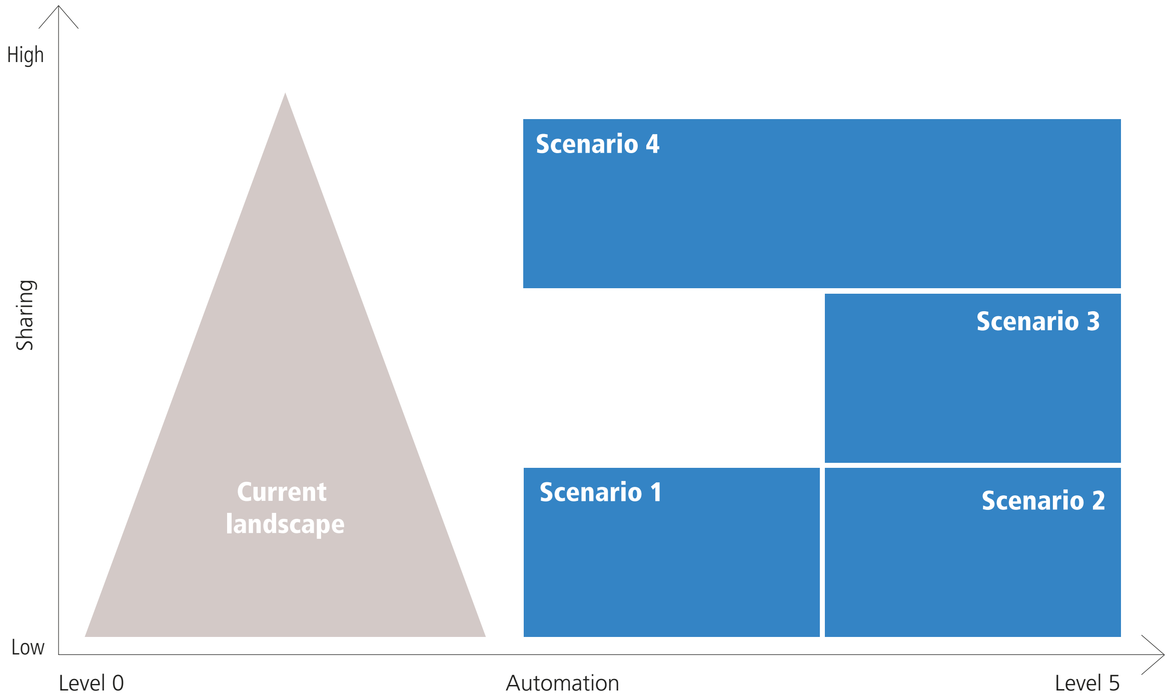
This report covers these three tasks, while putting them in the larger framework of an inclusive transport system. The various issues are analyzed through this inclusion lens, which cuts across Tasks 4-6, highlighting the potential contribution of autonomous and connected transport to an inclusive transport system, but especially highlighting the risks it poses to further exacerbate the exclusionary nature of current transport systems around the world.

A broader analysis regarding privacy and security concerns (i.e. Task 5) emerging from the deployment of ACT can be found in WG#1 Thematic Report.

The report is intended for a broad professional audience. Hence, we have made relatively sparse use of references to the literature. For more information on various aspects of autonomous and connected transport, we kindly refer to various review papers and edited volumes on the topic (ASTRA, 2020; Milakis et al., 2020; European Commission, 2020; Gyergyay et al., 2019; Bagloee et al., 2016; Shiftan et al. 2021; Raposo et al. 2019; Thomopoulos&Givoni, 2015).

The report is based on inputs from WG#2 members, other WISE-ACT members, EU and other research projects, as well as academic and professional literature. The final responsibility for the content of thisreport obviously rests only with the authors and does not represent official views of the COST Association or the European Commission.

ACT scenarios explored in the report



Overview of the major expected impacts of various ACT deployment scenarios on various target groups.

Contribution to inclusive transport system by group

	Scenario or deployment type	Low income	Young	Older	Disabled	Women	Without driving licence	Living remotely	Digitally unconfident	Unprotected road users
Chapter 3	Privately-owned partial automated ACT-vehicles	0	0	+	+	0	0	+	0	?
Chapter 4	Privately-owned fully automated ACT-vehicles	0	+	++	++	0	++	++	0	?
Chapter 5	Sequential carsharing services	?	+	+	+	+	++	0	0	+
Chapter 6	Partially automated ACT-based public transport	+	+	+	?	+	++	0	?	?
Chapter 6	Fully automated ACT-based public transport	++	++	++	?	+	++	+	?	?

Legend

0	The ACT scenario will have no or only few positive mobility and accessibility benefits for members of the group
+	Some part of the group is likely to enjoy increased mobility or accessibility in the ACT scenario
++	A substantial share of the group is likely to enjoy increased mobility or accessibility in the ACT scenario
?	Unclear whether the ACT scenario will contribute positively (or negatively) on the mobility and accessibility of group members

Notes

1. The evaluation concerns accessibility benefits. That is, the ability of people to reach (further) destinations to fulfill their activity needs and wishes. Some of this benefit might also come via a safety benefit. For example, the accessibility of vulnerable road users (or those who do not have access to car) might improve, if cycling and walking is safer.

2. The impact assessment for groups is based on the ceteris paribus principle. For example, even if older people are statistically more likely to be disabled (compared to other age groups), the assessment considers the difference due to age and not due to impairment.

Chapter 1: Introduction

Autonomous and connected transport (ACT) has been heralded as offering tremendous opportunities to improve our current transport systems. A large body of literature suggests that ACT-technologies have the potential to increase road safety, make travel more enjoyable and convenient, reduce congestion, require less space, reduce the need for parking in urban environments, make private car travel accessible to a much wider range of the population, reduce the costs of public transport operations, and so on. Aiming at addressing the three MoU Tasks (Tasks 4-6) of the WISE-ACT WG2, this report will explore possible contribution of ACT inmaking the current transport system more inclusive. The focus is largely on land transport, but similar challenges apply for air and waterborne transport (see other WISE-ACT reports for more information about additional impact on other transport modes).

In order to do so, we aim at understanding and highlighting through a people lens the social challenges introduced by ACT. This is distinctly different from what is common in much of the transport field. Historically, both transport research and transport planning and policy have been organized around transport modes. The debates and literature around autonomous and connected transport seem to follow this pattern and thus strengthen, rather than modify, this modal bias. This is highly problematic, as the focus on transport modes goes hand in hand with a focus on the functioning of the various transport systems, rather than on the service people – in all their variety – receive from all transport modes together to meet fundamental human needs and rights, namely mobility and accessibility.

This modal bias is most strongly reflected in the literature and policies regarding the car-road system. Much of the efforts in this domain, especially in the second half of the 20th century, have focused on providing a well-functioning road system, typically equated with a congestion-free network of highways. More recent literature on sustainable transport has tended to focus on the environmental externalities caused by transport or on modal shift away from single-occupancy car use, with little attention for the needs of population groups with limited car access and an already high usage of more sustainable modes. Like in the traditional car-focused perspective, here too, success has been measured without much concern for the transport service that differently positioned people across socio-economic groups receive from proposed interventions (Martens, 2015).

The problematic nature of these approaches has, of course, not gone unnoticed. Since the late 1990s an increasing body of literature has focused on patterns of transport disadvantage as they result from the focus on system performance (e.g., Lucas, 2012). This literature, and in particular the research on transport-related social exclusion, has highlighted that current transport systems do not provide adequate service to a substantial share of the population and that disadvantaged groups suffer disproportionate harm from the current transport system raising fundamental ethical and equity concerns (Thomopoulos et al., 2009; van Wee, 2011; Thomopoulos& Grant-Muller, 2013). A range of disadvantaged groups have been identified, including low-income households, ethnic minorities, single-parent households, youth, a substantial share of the older adults, the disabled. While these groups face a range of travel-related challenges, one common denominator is that they often have no or limited access to car-based transport or, if they have, struggle to afford it (Mattioli et al., 2017).

Building on this extensive empirical work are more recent calls for fairness and justice in the transport domains. While the discussion is ongoing and the exact parameters of such a fair transport system will depend on the situation and context, some agreement seems to be emerging. This agreement suggests that a fair transport system at the very least provides every person with a sufficient level of accessibility (Martens, 2017; Pereira et al., 2017), with some authors arguing for more ambitious goals (see e.g., Sheller, 2018; Verlinghieri&Schwanen, 2020; Martens, 2021). The notion of just sustainabilities (Agyeman et al., 2016) adds another layer to this argument, underscoring that adequate accessibility for all has to be achieved within environmental boundaries at both the local level (notably air and noise pollution) and the global scale (notably climate change). Vision Zero adds the demand that transport systems should, above all, be safe and secure not jeopardizing people's lives in the pursuit of speed or accessibility.

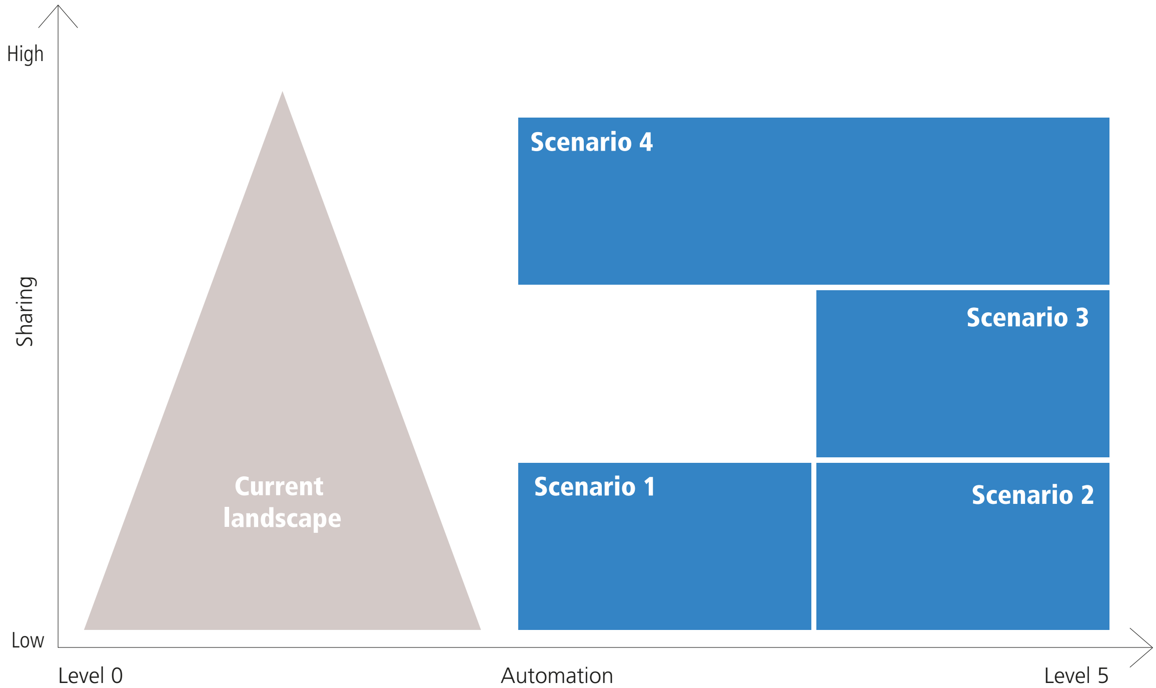
The emergence of autonomous and connected transport offers opportunities and threats to the development of such an inclusive transport system (Herzogenrath-Amelung et al., 2015; Blyth et al., 2016; Bonnefon et al., 2020). It is clear, however, that a positive contribution is unlikely to come about if the focus of analyses and policies is on autonomous and connected transport itself. **What is needed is an ACT-future that is shaped by the deliberate intention to create an inclusive transport system.** In this report, we employ this perspective and critically reflect on some of the discussions and challenges in relation to the introduction of autonomous and connected transport in current societies.

The report is structured as follows. Following this introduction, we reflect on the inevitably exclusive nature of every transport technology or transport mode (Chapter 2). While ACT vehicles may serve a wider range of users

Figure 1: ACT scenarios explored in the report

To what extent can ACT futures contribute to a more inclusive transport system?

How could governments steer the development of different ACT fut ures so as to enhance their contribution to a more inclusive system?

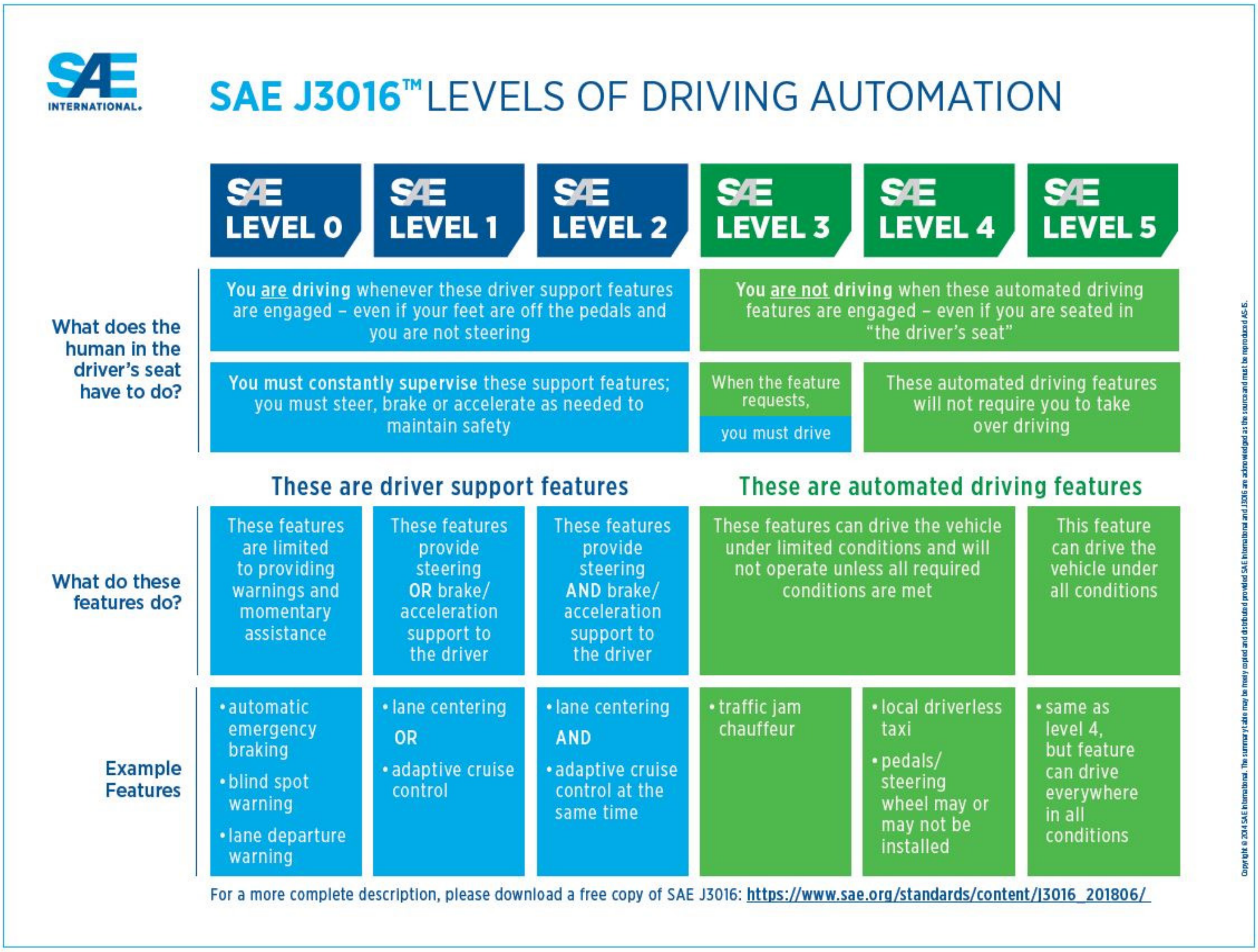


than regular motorized vehicles, they will not be able to serve everyone under all circumstances. This fundamental insight shapes the discussion in the remainder of the report. In Chapters 3-6, we discuss various possible scenarios for the introduction of ACT, differing in automation level and transport mode. For each scenario, we explore the possible implications for the transition towards an inclusive transport system that serves all people. These scenarios extend the discussions which took place among WG participants during the development and design of the WISE-ACT survey (2018-2020). Accordingly, the matrix in **Figure 1** maps these scenarios based on their automation levels and the level of sharing of vehicles by multiple users. The emphasis is thus on the way ACT futures may work out for different people, varying widely across multiple socio-demographic dimensions, living in a range of spatial contexts, and differing in terms of the extent to which they might be able to gain access to ACT in various scenarios. The discussion about each of the ACT futures is not intended to be exhaustive, but to highlight key concerns and issues taking into account the WISE-ACT WG2 MoU Objectives. In each case, we explore to what extent different population groups could experience enhanced mobility and accessibility with the introduction of ACT and identify groups unlikely to reap any benefit of such introduction. We end the report with a general reflection on governments' role in the introduction of ACT, in light of the possible scenarios that might or might not unfold if ACT introduction is left unchecked (Chapter 7).

ACT automation levels referred to in this report follow the Level of Driving Automation Standards by the Society of Automotive Engineers (SAE) International (**Figure 2**), ranging from Level-0 (no automation) to Level-5 (fully autonomous vehicle) (SAE, 2018; Shuttleworth, 2019).

Obviously, we are very much aware that any ACT future may generate a host of impacts and these impacts will shape how societies respond to and shape ACT's role in society. The desire for more livable cities, concerns over traffic safety, air quality, climate change, health, sedentary lifestyles and obesity, congestion, and more, will likely (and hopefully) shape any possible ACT future (Singleton, 2020). These concerns are important and indeed should shape ACT futures. Yet, the focus in this report is narrower, as it seeks to answer two key questions. First, to what extent can ACT futures contribute to a more inclusive transport system? And second, how could governments steer the development of different ACT futures so as to enhance their contribution to a more inclusive system?

Figure 2: SAE International Level of Driving Automation Standards



Industry outlook

Ensuring that Autonomous and Connected Transport is inclusive features as a constant challenge not only for policy makers and academics, but also for the wider industry. In fact, the pace of technological development is significantly faster than the pace of policy development about new mobility services (Alexiou, 2021):

> **"Right now, the technology is way ahead of the policy"**
>
> Dr Nicholas Giudice

Yet, a number of companies have already realised the importance of offering not only automated and connected transport services, but also inclusive ones. Uber for example uses technology to address accessibility and reliability needs of travellers with visual or auditory disabilities through WAV (Wheelchair Accessible Vehicles), since reliability has been found to be a crucial acceptance factor of such new mobility services (Kyriakidis et al., 2020). Their connected transport WAV service is supported by e.g. anti-discriminatory policy, upfront cashless payments, service animal provisions. Equally, Skedgo which is a Mobility-as-a-Service (MaaS) provider through their tech-enabled platform deployed across several continents, offers a wheelchair-friendly routing service to travellers on the autistic spectrum. World Bank data confirm that around 15% of the global population, namely 1 billion people, have some kind of disability which also affects their daily mobility and in turn their accessibility (Thomopoulos and Witzel, 2021). Similarly, Uber has launched an anti-harassment campaign in France to increase personal security by offering features such as share your itinerary with your preferred contact, phone number anonymisation, emergency button.

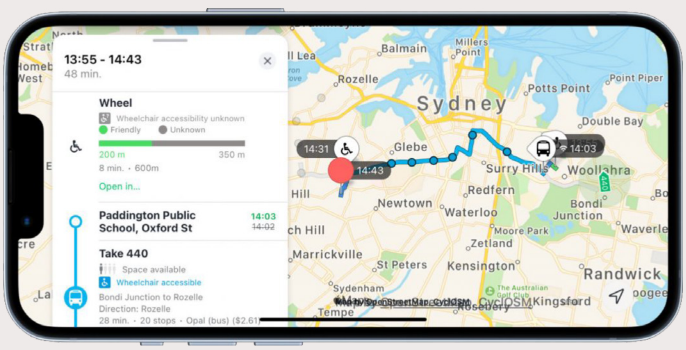


Figure 3: Wheelchair route planning via TripGo in landscape mode (Source: https://skedgo.com/app-accessibility/)

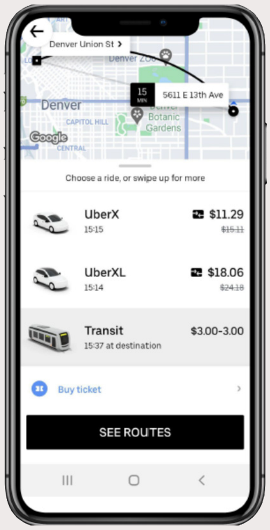


Figure 4: Uber services tested through pilot projects across urban and rural areas in France, Germany, United States to address transit gaps (Source: Púčiková, 2021)

Nevertheless, a primary international concern with direct implications on delivering inclusive transport is the ongoing digital divide. The persistent digital skills divide between the Global North and the Global South (DGSI, 2021; Thomopoulos and Karanasios, 2014) is unavoidably affecting the take-up of automated and connected transport services by less tech-savvy travellers who may lack essential readability and usability skills to use such technologies. Fostering the Universal Design approach across all stages of the planning and design process of digital applications and services is certainly one of the ways towards universally inclusive transport as advocated by the H2020-INDIMO project (Giorgi et al., 2021). Developing and testing relevant toolkits and policies contribute towards the anticipated direction, but it remains to be seen at what level they will be adopted at a global scale and whether they will indeed lead to a more inclusive transport system. It is apparent that governments have a key role to play to achieve such goals.

Chapter 2:
The exclusionary nature of ACT

The future of ACT is highly uncertain, as it is currently in the process of being shaped by a multitude of actors (Thomopoulos&Givoni, 2015; Acheampong and Cugurullo, 2019). Yet, the history of transport has emphasized one key dimension of any transport innovation: the virtually inevitable exclusionary nature of any transport technology. Thus, before discussing various ACT futures, it is important to explore the potentially exclusionary nature of autonomous and connected transport.

The potentially exclusionary nature of transport technologies is a result of the match between the (changing) characteristics of the technology and the highly diverse abilities of people. People differ tremendously in their characteristics, concerns, (created) constraints and (shaped) preferences. The implication of this is that there is (for now) no single transport mode that serves all people. This holds for all 'modes', from walking to cycling to driving to public transport. For instance, while most people can walk without problems for a substantial distance, some people may have trouble to cover even small distances (whether on foot or by a human-powered wheelchair). This may especially affect some older adults, individuals with physical or mental disabilities, and individuals with chronic health problems, who may face difficulties not only in accessing nearby services, but also the nearest public transport stop and hence more distant destinations (e.g.,Curl&Fitt, 2018; Park & Chowdhury, 2018). And while most people have the physical and mental abilities to use public transport services, such services are not suitable for all, even if all efforts are made to make them accessible to wheelchair users and others experiencing various kinds of disabilities. For instance, people with severe cognitive limitations may have difficulty navigating a public transport system, while people with fear of crowds may want to avoid busy public transport altogether, even after all efforts have been made to make public transport systems more accessible.

The exclusionary nature of the traditional (non-autonomous) car-based travel is even more clear. Even if financial barriers were taken away, the traditional car will never be a suitable means of transport for people lacking the abilities necessary for driving a large motorized vehicle. This holds for the very young, but also for a substantial share of adults due to various disabilities. The latter includes an increasing number of older adults, who may face driving cessation as their abilities decrease (Dellinger et al., 2001; Rosenbloom, 2010). The same decrease in abilities may also affect older adults' ability to cycle (Ryan et al., 2016), underscoring the exclusionary nature of this transport mode as well as related forms of micro-mobility (Fitt & Curl, 2020; Xiaodong et al., 2020; Saud &Thomopoulos, 2021).

At least in theory, autonomous and connected transport offers the promise to address some of these exclusionary characteristics of the car. At face value, ACT may enable virtually all people to use motorized vehicles, whether they are privately owned or shared. Yet, it is more likely that the exclusionary nature of any existing transport mode will also apply to autonomous and connected transport. Indeed, the assumption that all will be able to use a fully autonomous car is very unlikely to hold. For one, the use of ACT by the children and youth (below age 14 or so) will obviously be subject to the approval of their caretakers, who may not all agree on independent ACT use, for reasons of safety, personal security, privacy or otherwise. Likewise, ACT, and specifically shared ACT service, is likely to require substantial digital skills and the ability to make online payments (thus requiring bank accounts or credit cards) (Milakis&van Wee, 2020), which may exclude some share of the adult population clearly raising equity concerns. Other conditions, such as distrust of technology, certain forms of physical disabilities and particular phobia, may also prevent people from using ACT.

But the exclusionary nature of ACT is likely to reach beyond the (very) young and people with various cognitive disabilities. Indeed, the most important individual barrier for ACT uptake will, of course, be financial in character also linked with the Value of Travel Time (VoTT). Even in wealthy countries, a substantial share of adults currently does not have adequate income to finance car ownership or even a subscription to a car-sharing system, while another share of the population suffers from the undesirable state of forced car ownership (Currie &Senbergs, 2017; Mattioli, 2017). There is little reason to assume that this financial barrier for car ownership or car use will disappear once autonomous and connected transport will replace regular, self-driven, vehicles. This is especially the case in the short term as the early adopters of AVs are likely to be wealthier at different scales (wealthier countries, which also have the lower rate of road traffic incidents, and wealthier individuals within those countries). Such a trend is already observed during the slow transition to Electric Vehicles (Thomopoulos& Harrison, 2016) and is anticipated that it will continue since ACT should evolve in parallel with low carbon transport (Alonso Raposo et al., 2019). While economies of scale in combination with competition may limit the retail price of privately-owned ACT vehicles in the long-term, ownership and maintenance of second-hand ACT vehicles is still likely to be much more expensive than a conventional second-hand car because of the vulnerability of the abundance of digital technologies in ACT vehicles. Shared ACT services, in turn, may be unattractive for low-income individuals as current carsharing services, which are predominantly used by better-off citizens (Kim, 2015;

Polydoropoulou et al., 2021). Although full automation could change this image, it still depends on how affordable ACT would be in the future. Hence, whatever ACT future will play out, the financial barriers for ACT uptake are likely to be substantial (see below). Moreover, other dimensions such as (cyber-)security (Katrakazas et al., 2020; Sanguino et al., 2020) and technology literacy that are likely to affect ACT's attractiveness are also investigated in other WISE-ACT Thematic reports (e.g.WG1, WG5).

This exclusionary nature of ACT (as well as other transport modes) should be taken carefully into account as governments decide about their role in a future of ACT from a user perspective (Shiftan et al., 2021). Hence, this fundamental understanding has shaped much of what follows in this report.

We aim at understanding and highlighting through a people lens the social challenges introduced by ACT, transport service people – in all their variety – receive from all transport modes together to meet fundamental human needs and rights, namely mobility and accessibility.

Chapter 3:
Scenario 1 – Privately owned partially automated ACT vehicles

3.1 Introduction

ACT technology that supports drivers of buses, trucks and private vehicles has been around for a long time (e.g. Automated Cruise Control). Technological advances are expected to take this support to the next level, while for the foreseeable future still requiring a driver to be able to take control of the vehicle at some point. For Level-2 automation, driver readiness would be required at alltimes, while for Level-4 automation this might be required in particular (complex) environments or under particular weather conditions (Wu et al., 2021). From the perspective of inclusiveness, the difference between these levels of automation is limited. As long as a driver has to be able to take over the vehicle, private cars remain accessible only to people who are able to drive and thus out-of-bounds for anyone else. These low levels of automation (henceforth referred to as 'low-level ACT') also do not allow for driverless carsharing services and thus provide no fundamental cost benefit for providing this service. In contrast, partial automation does hold some promise for ACT-based public transport services, but we will discuss this in a later chapter. Hence, in what follows, we explore the possible implications of the introduction of privately-owned partial automated ACT-vehicles for a possible transition towards an inclusive transport system.

3.2 Mobility and accessibility in the low-level ACT scenario

First, it is important to determine whether low-level ACT may increase the share of the population to benefit from the high level of mobility and accessibility afforded by the car. Small benefits may be expected here. Limited driver support may enhance the mobility and accessibility of a small subset of drivers, who find driving for longer hours or over longer distances stressful (see WG3 report for the ACT impact on the logistics sector). Uncertainty over whether to take-over the vehicle will be necessary at some point during a trip may create stress among some of these drivers, eliminating the benefits of automation. It seems fair to say that any limited level of automation will primarily enhance car-based mobility and accessibility for people who are already confident drivers. They may enjoy a small increase in car-based accessibility, as possible barriers for car use for a subset of trips is reduced. Benefits for current drivers are most likely in terms of perceived comfort and accessibility, as driving in congested traffic may become less stressful and long-distance trips become more feasible (permitting multi-tasking), or less tiring. In contrast, low-level ACT's contribution to increasing the share of people that feel comfortable driving is likely to be limited.

Given that low-level ACT is unlikely to provide enhanced mobility or accessibility for people who currently lack access to cars and are often poorly served by the existing transport system, and while it might be a (necessary) development stage towards fully automated ACT, there might not be a role for governments to actively promote the introduction of these ACT vehicles through substantial investments or prioritization of ACT-based travel from an individual vehicle perspective. For instance, suggestions to develop and reserve dedicated lanes for private ACT vehicles would be completely misplaced in light of the profile of the population likely to be served by such dedicated infrastructure: higher income people who already have access to a (low-level ACT) car and are already enjoying high levels of mobility and accessibility. Even replacing existing lanes by premium for-pay ACT-only lanes seems difficult to defend if governments would take the goal of developing an inclusive transport system seriously. From the latter perspective, road space should be reserved for modes that enhance mobility and accessibility for people who are currently poorly served regardless of their automation or connectivity level, rather than for private ACT-vehicles that primarily serve people already enjoying a high level of mobility and accessibility.

3.3 Low-level ACT impacts on other travelers

The introduction of private ACT may also have impacts beyond the users of the technology. Indeed, ACT introduction may enhance the safety and comfort of unprotected street and road users, i.e., pedestrians, cyclists and users of other (motorized) two-wheeled vehicles, thereby potentially generating mobility or accessibility benefits for people who currently do not have access to a private car. On closer scrutiny, limited automation of vehicles is likely to be a double-edged sword depending on the type of journey i.e. commuting or non-commuting (Thomopoulos et al., 2020).

On the positive side, these ACT technologies can reduce the danger posed by vehicles and thus enhance safety for unprotected road users. The contribution of ACT to an inclusive transport system is likely to be limited as long as some share of the vehicle fleet continues to consist of regular vehicles. Yet, when a substantial share of the vehicle fleet has some level of automation, opportunities to enhance safety for unprotected road users may increase. Safety benefits could potentially be possible if vehicle speed would be externally controlled, much like currently is the case for some types of micro-mobility (e-scooters) where some cities use geofencing technology to restrict driving speeds in particular areas (Tice, P. C., 2019). In combination with automatic emergency braking, external speed control may substantially enhance the safety in mixed road user environments, potentially enhancing the safe mobility and thus accessibility for young children, youth, and some share of older adults, whether by foot, bicycle, or public transport. Even if only a part of the vehicle fleet would comply with ACT standards for speed control, this would offer a substantial opportunity for literally 'calming' traffic, as ACT vehicles would also affect speeds (and possibly behaviour) of other vehicles on the road. However, such an impact would often be only local depending on the context, with positive traffic calming impacts especially likely on streets and roads with few traffic lanes and with designs already geared to limit speeding. It will also depend on the vehicle fleet composition, with positive impacts less likely in contexts with high shares of two-wheeled motorized vehicles. The latter also suggests that mobility and accessibility benefits for unprotected road users are most likely if speed control applies to all new (heavy) motorized vehicles, including various types of two-wheeled motorcycles.

On the negative side, some of the more advanced ACT technologies may reduce the drawbacks of driving (time spent behind the wheel) influencing the Value of Travel Time, which may lead to increased car use, riskier driving behaviour (i.e.,behavioural adaptation) and additional risks during take-over requests, potentially culminating in increased danger. Moreover, increased car use may trigger a new wave of car-oriented development, possibly leading to a reduction in accessibility to opportunities for people without access to a car. The latter is particularly likely to occur in more suburban and peri-urban environments, where the private car currently accounts for the vast majority of trips and popular support for car-oriented policies is thus more likely. Further increase in car ownership may weaken the already limited support for public transport in these contexts, strengthening the existing spiral of increased car dependence in these areas. The same dynamics may occur in the rapidly urbanizing cities of the Global South, as the emerging middle class embraces car ownership and use and may wish to reshape the urban environment to serve their transport 'needs' at the expense of people with no or limited access to a (ACT) vehicle. However, ACT introduction will likely be much more difficult in these locations, as multiple modes tend to use the same road space and road markings are often poorly maintained or absent. Even cities and regions that have been moving away from car-based transport in recent years may see a renewed increase in car volumes in response to increased popularity of driving triggered by more advanced ACT technologies. While cities may manage to contain car ownership and use among their own citizens through investments in sustainable mobility (enhanced walkability, cycling infrastructure, public transport priority, restrictive parking policies), they may face a sharp increase in incoming car-based traffic due to the attractiveness of ACT for suburban and peri-urban residents, creating renewed pressure to redesign the streetscape to serve the 'technology of the future' – and keep the amenities offered by the city accessible to the entire region. If (local) governments indeed respond by enhancing ACT-based access to cities, much like they did in the 1960s and 1970s for regular cars in cities of the Global North, these dynamics may well reduce mobility and accessibility of people without access to a (ACT) car, certainly if living outside the dense urban cores, as low-level ACT vehicles become increasingly common.

These two sides of the double-edged sword point at the crucial role of government, not in enabling or promoting low-level ACT vehicles as this is likely to occur 'spontaneously' through the market, but in leveraging their potential for a more inclusive transport future mitigating equity implications. Low-level ACT technologies can potentially be used to provide some (decent) level of protection to unprotected road users. The 'predator' can potentially be turned into a 'guardian' of traffic calming. But these benefits will not emerge spontaneously. Since low-level ACT is already increasingly available, it is important to make external speed control the default for these vehicles as soon as possible. This can be done by requiring vehicle producers to add technology for external speed control on any vehicle with some level of ACT, in combination with the obligatory agreement of anyone purchasing such a vehicle to accept external speed control wherever and whenever it is introduced. By doing so, external speed control is introduced 'one vehicle at a time', very much like the proposal to introduce 'pay-per-kilometer' one electrical vehicle at a time (Levinson, 2018). Rather than wait till a critical mass of low-level ACT vehicles is on the road, tacit support for external speed control can thus slowly emerge, thereby potentially avoiding political and popular opposition that is virtually inevitable if external speed control would only be introduced on an already large number of ACT vehicle owners at some future point in time. The latter is also aligned with broader climate targets and environmental implications through eco-driving.

3.4 External speed control

For the introduction of external speed control, it is obviously not enough to only regulate vehicle requirements. Indeed, for this scenario to play out positively for other people than only the users of ACT vehicles, governments will have to take on a much stronger regulatory role than is currently the case. Experiments with external speed control date back to the 1990s (Oei&Polak, 2002), long before the emergence of highly accurate GPS technology, but have never been implemented so far except in some pilot experiments. Current experiences with speed (and parking) control for micro-mobility can serve as a testbed for much larger and complex efforts of managing speeds of large numbers of heavy, and potentially high-speed, vehicles. External speed control of ACT vehicles will thus require a well-developed governance structure that is able to successfully and reliably manage ACT vehicle behaviour across a wide variety of streetscapes, built environments and circumstances, so that such a scenario is only likely in countries with very high governance abilities. Remotely controlled ACT vehicles with different levels of automation are being tested in selected cities and may pave the way to external speed control with benefits for vulnerable road users (Kyriakidis et al., 2020). While geofencing makes such speed control theoretically easy to develop and cheap to introduce and maintain, it will clearly require substantial testing and finetuning. Geofencing is unlikely to be perfect, so that risks may occur especially at the boundaries of speed regimes. Hence, the role of government would lie in support for research to extensively test external speed control. The need for such research poses substantial risk of foot-dragging among vehicle manufacturers, who would likely see external speed control as having a negative impact on their ability to market and sell cars. This suggests that substantial funds for independent academic research on this topic would be needed to make progress. Such extensive testing would also be needed to avoid the introduction of unsafe external speed control systems, which may backfire if functioning poorly and potentially creating risks.

Even if external speed control would be widely adopted and would show high level performance, external speed control is unlikely to completely solve traffic safety issues related to the high speeds of heavy vehicles. While ACT vehicles may not speed if externally controlled, neither these cars nor the speed control regimes are likely to be completely flawless or may experience failures at some point, implying that also ACT vehicles with external speed control may cause crashes leading to death or injury among unprotected users as well as others. Moreover, while ACT vehicles' behaviour may be tightly controlled, pedestrians and cyclists may show less predictable behaviour, possibly posing challenges for ACT vehicles to respond in an adequate manner. This implies that the introduction of (low-level) ACT does not eliminate the need to make environments with mixed users – pedestrians, cyclists, micro-mobility, low-speed low-technology electric vehicles, and heavy motorized vehicles – safer. Many studies, including an OECD report (ITF, 2016), underscore that a future of zero road deaths can only be achieved if speeds are reduced to 30km/h in mixed environments – a goal embodied in notions such as 'Vision Zero' and 'Duurzaamveilig'. Lower speeds for motorized vehicles also have benefits beyond safety, including lower levels of noise and a more pleasant urban environment for pedestrians and other street users (children playing, people chatting, people sitting outside, etc.). Given the fallibility of any technology, such speed reductions are also necessary in an ACT future. The fact that it will take decade(s) before the entire vehicle fleet (cars, trucks, buses) will achieve low-level ACT only underscores the continuing need to redesign streetscapes to achieve Vision Zero. Hence, governments should not be diverted by the promise that technology alone will deliver zero road deaths.

Chapter 4:
Scenario 2 – Privately owned fully automated ACT vehicles

4.1 Introduction

This scenario embraces the promises made since 2015: fully autonomous vehicles that no longer require a driver under all circumstances. Recent disappointments with autonomous driving suggest that such a scenario is still years away. Yet, at some point in time technology may indeed eliminate the need for a driver in (virtually) all environments and under all (weather) circumstances (Level 5). In this scenario, it is assumed that such technology will be available and will be provided by the market, without any government intervention regarding the sale and purchase of fully automated ACT vehicles. Such a scenario is likely to impact the use of private vehicles, public transport vehicles, as well as vehicles for freight transport. In what follows, we reflect only on the former, while we address the potential of fully automated ACT technologies for carsharing and public transport in subsequent chapters.

4.2 Car-free individuals bound to benefit from a fully-fledged ACT private vehicle

Let us again first reflect on the share of people that could gain access to car-based mobility and accessibility in this fully automated ACT scenario. Fully automated ACT private vehicles may indeed increase this share, as we will discuss below. In the current situation, in which people with access to a car receive premium service from the transport system at the expense of other road users without (continuous) access to a car, this implies a possible increase in the number of people enjoying a high level of mobility and accessibility, which can be seen as a step towards a more inclusive transport system (as more people are enjoying a sufficient – and even high – level of mobility and accessibility). While some of this may backfire due to increased congestion (see below), a car-free individual gaining access to an ACT vehicle is likely to enjoy substantial private 'marginal' benefits. Yet, this large private benefit is not likely to be reaped by most of the individuals with currently limited access to a private car: youth, mobility disabled (including some share of the older adults), low-income persons, women and immigrants.

Low-income individuals

The group of low-income persons is hardly likely to reap any benefits, since ACT vehicles will be expensive to own and maintain. Low-income households will certainly be among the last to gain access to fully automated ACT vehicles. If fully automated ACT would become obligatory (for safety reasons, like safety belts) (Sparrow & Howard, 2017), it may result in an increase in the costs of new cars, which may exacerbate inequalities between low and higher-income groups (Mobile Lives Forum, 2021). Even if these increases may be avoided through economies of scale and a competitive car market, ACT is likely to impact the cost of ownership of second-hand cars, which is particularly relevant for low-income households. It may well be that the complex technologies installed in ACT vehicles will increase the maintenance costs of second-hand cars or, if not well-maintained, negatively impact their reliability. In the first case it would decrease the affordability of car ownership, in the latter it would reduce its benefits (Currie &Senbergs, 2007). Thus, a fully automated ACT scenario, certainly one in which regular or low-level ACT cars are outlawed, may well *decrease* the share of low-income households owning a car. In any case, ACT ownership among this group will only marginally be shaped by the technology, and much more by income policies and the way mobility is priced. The former falls outside the mobility domain. The latter is highly uncertain. As it has been discussed for at least two decades in the Global North (Niskanen& Nash, 2008), it is highly likely that some form of kilometer pricing will be introduced at some point in the future to cover the cost of road maintenance and management, which may decrease the affordability of car use among low-income households, particularly those living in more remote locations (especially peri-urban and rural areas).

Young individuals

The financial barrier of ACT use is also likely to affect the young, most of whom will have to depend on their caretakers to cover most of their mobility expenses. Even if fully automated ACT vehicles could be shared between family members, sending vehicles back and forth between various users and destinations will come at a (substantial) cost and thus may be less prevalent than is sometimes assumed in the literature (Litman, 2020). It is unlikely that possible reductions in parking expenses (as the ACT vehicle can be sent to a 'free' parking place) will compensate for such increased motoring costs, as most people currently park for 'free' for most of their trips (Shoup, 2017), and parking at a distance will increase motoring cost and increase the uncertainty about vehicle availability when the need occurs. 'Free' parking at a distance may actually lead to a convergence of the experience of public transport and car use, as in both cases scheduling becomes an integral part of trip making. The sequential use of ACT vehicles by multiple household members may make the scheduling requirements of public transport seem like a small challenge, as at least decisions can be made without taking other household members' schedules into account. Moreover, the use of a single vehicle for multiple users is practically feasible especially if distances are relatively short and if activity schedules do not show too much overlap.

The above suggests that sequential vehicle sharing is more likely to occur in urban settings or other areas with relatively high densities (short distances) and among households with more flexible activity schedules (people with higher education working in 'creative' industries rather than essential workers with little control over working hours). Within-household sharing of ACT vehicles may thus occur in some subset of households for some subset of trips (e.g. school-run), including trips where chauffeuring by caretakers was already relatively common (in evening hours, in weekends). It is unlikely to serve a large share of youth for the entire set of their trips. As said, most opportunities may especially lie in high density environments, where people are already relatively well-served by public transport or bicycle infrastructure. Hence, the tentative conclusion seems to be that fully automated ACT will only enhance mobility and accessibility for a small share of youth, and in particular youth living in more advantaged households. Note that this assessment does not even take into account the possible reluctance of some caretakers to let youth under their custody make use of driverless ACT vehicles in light of possible technical failures or unexpected events (for instance, extreme weather events or police checks) or privacy concerns (Costantini et al., 2020; Kyriakidis et al., 2020). It also ignores other considerations of caretakers, such as their enjoyment of quality time while driving or otherwise escorting their children or other dependents to their destinations.

Disabled Individuals

The third group that may benefit (substantially) from fully automated ACT vehicles encompasses people currently prevented from driving a regular or low-level ACT because of motor-related, sensory-related, or cognition-related disabilities. This group also includes people who have lost the ability to drive at an older age, which is likely to increase in absolute numbers with the ageing of the population in virtually all countries. Given the increase in life expectancy, an increasing share of the older population is living well beyond the point at which they are still able to drive to all desired or required destinations. ACT may enable private car use for some share of these populations, whether older or not, provided they are computer-savvy and have adequate income to afford an ACT vehicle. Given the strong correlation between disabilities and income (Kavanagh, 2015), ACT may actually be out of reach for a substantial share of people with disabilities, especially for people facing disabilities from a relatively young age. At the same time, if people with disabilities are able to make use of fully automated ACT, it may well enhance employment opportunities, thereby also potentially increasing their incomes and ability to afford an ACT vehicle later in life (Raphael & Rice, 2002; Baum, 2009). For the elderly, some of the processes leading to driving cessation may also create barriers for using ACT, especially if a reduction in cognitive abilities is the prime cause of driving cessation. Cognitive abilities are likely to be a significant barrier in the early stages of ACT introduction but may be less of an issue as the user-friendliness of ACT interfaces improve and as familiarity with the technology increases over time. Taken together, this implies that fully automated ACT vehicles may enhance mobility and accessibility for a substantial share of people currently excluded from driving because of disabilities but it will depend by the country specific context (Kyriakidis et al., 2020) will certainly not provide a solution for this entire population.

Women and immigrants

Beyond these three groups, also women and immigrants currently have a relatively low level of access to a private motorized car.

In the case of women, both income and cultural norms shape car access. Indeed, in a range of cultural contexts women often experience restricted access to a (household) car, either because the car is 'assigned' to male household members or because (individual) car use is considered to be inappropriate for women (Beyazit&Sungur, 2019). It remains to be seen whether the introduction of fully automated ACT-vehicles will reduce these barriers. The income barrier is slowly changing due to women's increased participation in the labor force and reduction in gender disparities in education and work-related remuneration. These societal changes are expected to increase women's access to cars but are unlikely to be affected directly by the introduction of fully automated ACT-vehicles. The impact of ACT introduction on social norms is difficult to predict and unlikely to be the sole factor in the changing cultural norms regarding women's freedoms and related use of various means of transport. However, if fully automated ACT would make car use more acceptable among women, it may trigger a positive spiral where increased car access will improve women's accessibility to employment, increasing their participation in the labor force and potentially their incomes, which subsequently may reduce the financial barrier for car access among women.

Immigrants currently also face substantial barriers for car access. Like in the case of women, an additional factor is at work in addition to the income barrier. In the case of immigrants, the barrier is related to their difficulties in obtaining a (valid) driving license, which is partly related to the costs of driving lessons and partly because of language issues which make it difficult to pass the (theoretical) part of a driving test. Given this specific barrier, immigrant groups may benefit from the introduction of fully automated ACT vehicles, provided the requirement of a driving license is eliminated altogether or replaced by a more modest technical test or 'riding test'. Such a shift would reduce the cost of obtaining a 'riding license' but may still pose a barrier if language remains a key issue in passing such a technical test. Moreover, in some context migrants may be reluctant to use regular cars because of concerns of being stopped by the police due to racial profiling policies among (traffic) policy. If the introduction of fully automated ACT would change the police practice of (supposedly random) checks of vehicles (common in some countries), this barrier to owning and using a private ACT-vehicle may also be reduced. Even if the introduction of fully automated ACT may thus lower the barriers to car use among immigrants, the barrier – high cost of car ownership and use – will remain in place or even be exacerbated as suggested above.

Chapter 5:
Scenario 3 – Sequential sharing of fully automated ACT vehicles

5.1 Introduction

Fully automated ACT sharing might happen on a large scale more quickly than fully automated private ACT. This is so, because ACT sharing will come with a support service, including a call center, responsible for the operations and maintenance of the vehicles. This back-up support may assist early introduction, before ACT is near-fully flawless. Hence, in a third scenario we explore to what extent widespread introduction of sequential sharing of fully automated ACT vehicles could contribute to an inclusive transport system. We limit this scenario to *sequential* sharing to distinguish it from ACT-based public transport services, which we will discuss in the next chapter of this report. In a sequential sharing service, users travel individually in a Level 5 vehicle but do *not* share their travel in ACT vehicles with unknown others.

5.2 Owning a private vehicle versus using sharing services

Some studies and advocacy organizations have suggested that the introduction of ACT vehicles offers the possibility of serving all current (car) trips by ACT-based car sharing services. Such a (bright) future is sometimes also depicted in futuristic images, in which people order a car – sometimes specified in terms of number of places or the possibility to carry goods or even design – when and where it is needed, with ACT vehicles moving from one customer to the next, swiftly and without any friction or congestion. Simulation studies have shown the tremendous possibilities of such a theoretical scenario (e.g. Narayanan et al., 2020; Li & Liao, 2020; Martinez and Viegas, 2017), yet these studies are typically based on the extreme assumption that (virtually) all private car trips (and sometimes also all public transport trips) will be replaced by ACT-based carsharing.

Might such a scenario actually unfold in the future? The current experiences with carsharing seem to suggest otherwise. Even after nearly three decades of working systems *"carsharing remains niche, and while many people like the idea in general, they appear to consider carsharing to not be advantageous as a means of transport in terms of cost, flexibility, and comfort"* (Pakusch, 2021). These experiences make a bright sharing future unlikely. Indeed, we expect that such a 'full sharing' scenario is unlikely to unfold without severe restrictions on car-ownership across various socio-economic groups (Krueger et al., 2016; Acheampong et al., 2021). There are a number of reasons why it is unlikely that the vast majority of people will give up private cars with the arrival of an ACT-based sharing system. First, frequent use of carsharing services is expected to remain more expensive than the costs of ownership and use of a private (ACT-) vehicle. Currently, regular carsharing is not likely to be more economical than car ownership and use unless carsharing subscription holders do not rely on a vehicle for full-time commuting (Duncan, 2011). Thus, unless structural changes are introduced in the way vehicle ownership and use is priced, owning a private (ACT-)vehicle is likely to be cheaper than frequent use of carsharing services, certainly in contexts where public transport, cycling and walking currently do not offer high-quality accessibility. Second, even if private ownership would imply higher private costs than frequent use of ACT-based carsharing, these higher private costs will still pose only a modest financial burden for a large share of the more well-to-do population. For them, the convenience of owning their own ACT-vehicle is likely to outweigh the possible savings of using ACT-based carsharing. After all, the use of carsharing will introduce scheduling needs and some level of uncertainty regarding the availability of a vehicle. These inconveniences are likely to be higher in less dense environments, as ACT-vehicles are likely to be less abundant and will have to travel over larger distances to reach the next customer, resulting in a higher need for planning ahead. These are, of course, also the environments where private ownership of an (ACT-) vehicle is relatively cheap and convenient, in part because of parking place availability. Third, the use of a sharing service also implies that any goods that are transported have to be taken in and out of the vehicle (Thomopoulos et al., 2020), which may create a barrier for some share of the population (for instance, parents with children who may still use a child seat in an ACT-vehicle, but often also store a stroller and other personal child accessories in their vehicle). Fourth, some share of the population may still want to own a car for reasons of status or other considerations.

Since it is unlikely that most governments will make as drastic a step as intervening in people's right to hold property and thus are unlikely to directly restrict vehicle ownership, it may be expected that a substantial share of the population will opt for private ownership of an ACT-vehicle for the reasons mentioned above and more, assuming that it is affordable. Governments may, obviously, indirectly affect (ACT-) vehicle ownership, for instance through parking regulations (Guo, 2013; Weinberger et al., 2009), taxes on vehicle ownership (Ghate& Sundar, 2013), or restrictions on the total number of vehicles in a certain area (Liu et al., 2020), but this will not lead to the radical shift from ownership of (ACT-)vehicles to carsharing use, certainly not across all types of urban, suburban and rural environments. Thus, ACT-based carsharing is likely to function in an environment with (a substantial number of) privately-owned (ACT-)vehicles, limiting the potential benefits of ACT-based sharing (see below).

5.3 Learning from existing shared services

The concept of sequential ACT-based carsharing is obviously not an entirely new idea. Such an ACT-based service can build on a range of earlier experiences. It can build first and foremost on two main types of shared fleet services already in place in many cities (and some towns) in the world: (1) traditional, station-based shared fleet, where the vehicle is picked up and dropped off by the user at the same station-based location; and (2) free-floating shared fleet, where the vehicle is dropped off at the user's destination, wherever it may be (provided it is within the service area of the shared fleet) (Fagerberg, 2019). The experiences with both models provide some pointers for the potential of ACT-based sharing.

Carsharing have taken off in station-based mode, in part because of technological limitations and in part because station-based sharing is easier to manage for the carsharing company as the vehicles are located in specific locations allowing a quicker and easier access to all vehicles and a more efficient maintenance and repair services. However, it is less convenient to the user, as the user might need to reach the station using another form of transport to pick up and/or drop off the vehicle and will have to pay for the service until returning the vehicle to its home station. This implies that the user will have to pay for the period the vehicle is parked at the destination end of the user's trip and possibly also for parking. While station-based sharing has grown rapidly over the past three decades, for all of these reasons its ability to attract a large number of users has been limited (Kopp et al., 2015). Nonetheless, research shows that traditional sharing can reduce car ownership while still offering car-based access to users when needed and in certain circumstances (Martin &Shaheen, 2011; Duncan, 2011). ACT-based sharing offers the promise to eliminate the key drawbacks of station-based systems.

The more recently introduced free-floating carsharing services provide a more flexible option to the user (Kopp et al., 2015). The main advantage lies in the fact that the user only has to pay for the actual use of the vehicle and not for idle time. An additional advantage is that users do not have to reserve a vehicle upfront. These advantages of free-floating carsharing have as a flipside the clear drawback of uncertainty about vehicle availability, both in time and space. Moreover, free-floating sharing is restricted to defined geographical service areas so that users with destinations outside the service area do have to pay for idle time. Like station-based sharing, free-floating car-sharing schemes have demonstrated a slight reduction in private car ownership (Becker et al., 2018). Here too, ACT-based sharing may eliminate the uncertainty over vehicle availability, as the vehicle could be sent to the user wherever and whenever they are needed. However, unless ACT-based sharing is rolled out over very large geographical areas, restrictions on the service area might remain a key issue, with use outside a service area possibly offered at a substantially higher price and uncertainty about the availability of a carsharing vehicle for the return trip.

Ride-hailing and app-based taxi services can also serve as a model for ACT-based sharing. Platforms like Uber, Lyft, Bolt, former Careem or worker-cooperative The Drivers Cooperative (ride-hailing) and Gett or Yango (taxi-hailing) are basically offering sequential carsharing, but with the inclusion of a driver. While the latter sets these platform services apart from regular and ACT-based carsharing, the fact that the car arrives at a defined location at the request of the customer makes the services very similar to ACT-based sharing. So, in a way these hailing services can be seen as forerunners of ACT-based carsharing and indeed Uber's long-term vision is based on ACT-vehicles rather than regular-cars-with-a-driver (Chapman, 2020; Shetty, 2020). Hence, when envisioning an ACT-based carsharing scenario, the lessons learned in studies of these hailing services are also worth taking into consideration.

5.4 Potential of and barriers to carsharing services

The potential for ACT-based sequential sharing is enormous, at least in theory. In contrast to currently existing carsharing services, ACT-based carsharing could be offered by large companies that have the (financial) ability to offer a vehicle fleet adjusted to the needs and wants of the population in the area that it is serving. Vehicles could differ in terms of their size and their ability to carry (oversized) luggage. This can include small vehicles with only one or two seats specifically suited for urban circumstances, but also large vehicles for groups. This could potentially enhance the attractiveness of carsharing over private car ownership, as people could request a vehicle that would best and most economically respond to their specifications without compromising their personal security. If indeed adopted as the choice by many, the cost of using carsharing services could drop significantly, making them a more viable option for people who currently cannot or struggle to afford a private vehicle or use of traditional carsharing or hailing services.

This possible ACT future is very different from the current situation. In spite of their sometimes rapid growth, the contribution of both regular carsharing services and hailing services to a more inclusive transport system have been limited so far (Clark & Curl, 2016; Forth Mobility, 2020). Four key barriers to these services can be distinguished, affecting various groups in different ways, as we will discuss below. Some of these barriers can be reduced by ACT-based carsharing, while others are likely to remain in place, certainly as long as (ACT-based) carsharing is provided by-and-large on a commercial basis (with some in-kind support from governments, mainly in terms of free parking). Hence, at the end of this chapter we reflect on possible government interventions that could increase the role of carsharing as part of an inclusive transport system.

Barrier #1 – Legal requirements for using shared ACT

The first limitation that affects possible use of regular sharing services (but not ride-hailing or taxi-hailing services) flows from the logical and reasonable requirement that carshare users hold a valid driving license. Moreover, and partly related, carsharing services often set minimum age limits for its users, something that may also apply to hailing services (Le Vine et al., 2014). For these reasons, young people (typically below the age of 24 years) have been excluded from the independent use of carsharing altogether and may be restricted to use the apps of hailing services. Furthermore, the requirement to hold a driving license affects low-income and immigrant populations disproportionately, as they are less likely to have a (valid) driving license. The latter may also hold for women, although the gap in driving license holders among men and women has been shrinking rapidly in most countries (and in some countries, young women are now more likely to hold a driving license than men) (Kuhnimhof et al., 2012).

The benefit of fully automated ACT-based carsharing is clear: once vehicles are fully automated a driving license is no longer needed and also people without a driving license, particularly vulnerable users, can benefit from the services (Thomopoulos&Givoni, 2015). This may even hold if ACT would require driver take-over only in exceptional circumstances, such as multiple sensor failure or extreme weather events. Since such cases will be extremely rare, ACT-based sharing for non-drivers might still be possible in light of backup provided by a remote controller. Such backup might also ease concerns of people who feel uncomfortable to travel in a vehicle without any responsible person (Guo et al., 2020). Furthermore, it might reduce concerns among caretakers to send young people under their supervision with an ACT-vehicle, a concern flowing from the lack of control and supervision caretakers expect when using a fully automated private ACT vehicle (Kyriakidis et al., 2020).

This underscores, as mentioned before, that ACT-based sharing may be earlier available to non-drivers than privately-owned ACT vehicles, providing some advantages to a possibly significant share of the population (but note that privately-owned ACT vehicles could also be provided with a service package including emergency support). In spite of these possibilities, it remains to be seen whether ACT-based sharing will indeed be possible to children who may have the ability to travel (walk, cycle) independently – an ability that was common at very young ages in the not-so-distant past (Hillman et al., 1973). Contrasting with the challenges of automation faced in the past, regulations regarding independent elevator use among children in many countries (Kellerman, 2018) raise doubts whether independent carsharing use will be allowed at a very young age. While such use is theoretically possible even for very small children if on both ends of a trip an adult takes care of the child, it is likely that some limitations will stay in place and that ACT-use among children will not be left entirely at the discretion of responsible caretakers.

Barrier #2 – Cost

The second barrier applies to regular carsharing as well as ride-hailing and taxi-hailing services: cost. Out-of-pocket costs for trips with non-ACT car-sharing services are already too high to be attractive for low-income households and the predominant users of such services tend to be white, male and middle-class individuals (Clark & Curl, 2016; Forth Mobility, 2020). An ACT sharing service, either station-based or free-floating, might be even more expensive than non-automated services due to the costs of owning and maintaining an ACT fleet, which will be amortized through the service's cost. The higher costs of a shared full-fledged ACT trip will thus result in an even lower uptake among low-income households, exacerbating equity concerns. It is only when ACT-based carsharing becomes a choice of many that the service may become more attractive to some share of low-income users (see above).

It has further been found that sharing services of micro-mobility modes such as bikes and e-scooters, which are much less expensive than carsharing (and may even provide a quicker transport in certain situations; McKenzie, 2020) are being used *"disproportionately by more privileged populations, such as people with higher incomes and more education and people who are male, nondisabled, white, and/or younger"* (Dill & McNeil, 2020; Tyndall, 2017; Fitt& Curl, 2020; Saud &Thomopoulos, 2021). This suggests that even if ACT-based sharing may be cheaper than current carsharing (perhaps because of the elimination of operators' costs and optimization of the vehicle fleet), it might still be expensive for low-income users deterring their use.

Barrier #3 – Ability

The third barrier – ability – applies mostly to regular carsharing services, to a large extent to ride-hailing, and to a lesser extent to taxi-hailing services. Some individuals, especially those with physical disabilities and those less confident to ride in a vehicle without a capable person (in private vehicle) or personnel (in public transport) might be unable to use a fully-fledged ACT carsharing services. For example, paraplegic individuals might require assistance with getting themselves and the wheelchair into and out of the vehicle; physically disabled persons might need assistance with storing their belongings in (the back of) the car; and children might need assistance buckling themselves. These situations demonstrate how a full-fledged ACT vehicle might exclude some groups from utilizing its services increasing equity challenges in practice.

An ACT service that provides human support either within the vehicle itself or with a remote controller might make its services accessible for a larger share of the population, including youth and elderly, as assistance is always available. This support might also ease caretakers concerns regarding the lack of control and supervision in a full-fledged ACT vehicle (Kyriakidis et al., 2020), by being able to provide assistance in cases of emergency and other unforeseeable situations. However, a human support within the vehicle will add high costs to an already likely expensive service, while a distant support-center will not be able to provide assistance to individuals who might need physical help.

Without any regulation, ACT-based carsharing vehicles may not be suitable for all and may exclude a wide range of people with disabilities (see WG1 Thematic Report for more information). This is certainly probable in the introduction stage, when ACT vehicles are likely to be autonomous versions of existing car models. Requirements regarding design of shared ACT will thus be necessary. The experiences with ride-hailing services underscore this (Young &Farber, 2019).

Barrier #4 – Spatial availability

The fourth barrier relates to the spatial availability of ACT-based sharing. Currently carsharing services operate within a certain service area where the demand is relatively highand operations are profitable, a phenomenon also seen in bike and e-scooter sharing (Duran-Rodas et al., 2020). Ride-hailing and taxi-hailing services might not be subject to such service areas, although there is high clustering of these services too in high demand areas, but they have more flexibility to travel to destinations outside the high demand areas. In a scenario where ACT sharing services are limited to a service area, its service will only be relevant for a small portion of all trips made by a population. On the other hand, if it does not have a service area, it will be extremely difficult and costly to manage and to guarantee availability within reasonable time everywhere and at any time. From the inclusion perspective, it is then likely that ACT-based carsharing will be less available in areas where it is less used: low-income neighborhoods and lower density areas (suburbs, peri-urban areas) and small communities (small towns and villages). Thus, if *left to the market* alone ACT-based sharing is likely to strengthen ongoing processes of spatial fragmentation. On the one hand, high-quality services might be provided in dense and thriving urban areas, possibly triggering a reduction in private car ownership and use, which in turn may generate opportunity to redistribute the road space in favor of walking (Cugurullo et al., 2020), cycling and parklets. This may further enhance the qualities of these areas, possibly intensifying processes of gentrification. On the other hand, less attractive services might be offered outside these urban cores and in particular in more peripheral areas, which increasingly become the realm of low-income population groups. Certainly, in suburbs and peri-urban areas this creates a vicious cycle that encourages/maintains (forced) private (ACT-)vehicle ownership, leading to less demand and so even less supply. In low-income areas, it implies that low-income socio-economic groups might not only have to spend relatively more of their income on (ACT-)vehicles, but they will also have to spend more of their time to use ACT-based sharing services (i.e., longer waiting times).

5.5 Dynamic interplay between ACT-based sharing and (regular) public transport

As long as ACT-based sharing is not the solution for all trips, regular public transport remains a crucial part of an inclusive transport system as has been highlighted at the WISE-ACT workshop in Budapest (2018). Yet, it may be seriously impacted by the advent of ACT-based sharing services. Certainly, if shared ACT can be offered against competitive prices as suggested by a recent study (Bösch et al., 2018), it will compete with regular public transport because of the superior service it may provide (depending on the circumstances, such as service frequencies, urban densities, distances, and priority for public transport). A recent study shows that ridesharing services may decrease public transport use by 10% (Erhardt &Mucci et al., 2021). Impacts will be much higher if shared ACT is subsidized. Another study shows that transportation network services (like Lyft, Uber and taxis) compete with public transport, walking and biking more than with the private car, with 60% of those using these services acknowledge they would have otherwise used public transport, walked, cycled or not conducted the trip at all (Malalgoda&Hoom Lim, 2019), affecting public transport ridership and likely reducing its revenues.

Nonetheless, carsharing might provide a viable and more convenient option to those not owning a car (if they can afford these more expensive services), and to those owning a vehicle but preferring these services in certain situations including where parking is expensive or limited at the destination or to avoid drinking and driving (Schaller, 2018). However, it has been demonstrated that an automated carsharing services might only cause a small shift away from the private vehicle, while causing a significant shift away from the use of public transportation, *"leading to an overcompensation of the positive modal shift effects by the negative modal shift effects"* (Pakusch, 2021). It might then be assumed that shared fleets based on fully-fledged ACT might not significantly reduce the number of private vehicle ownership, but rather negatively impact public transport ridership (Milakis et al., 2020). This poses a risk for public transport service levels if the current approach (i.e., evaluating monetary worthiness to justify service) to determine public transport service levels persist.

5.6 Possible government interventions in sharing future

Though the first barrier – the need for a driver license to use a carsharing service – will be eliminated with the use of a fully automated ACT vehicle, the other three barriers – cost, ability and spatial availability – still need to be overcome if a more inclusive ACT-based carsharing system is to be achieved. These barriers might be addressed with governmental interventions, as the examples described below.

<u>Cost:</u> Because the cost of ride sharing is still anticipated to be high for a number of socio-economic groups, the service is currently not viable to (most) low-income groups. Experiences with (indirectly) subsidized free-floating carsharing (Tyndall, 2017) suggest that subsidies have to be substantial to be relevant for low-income households in order to improve mobility and accessibility for whom car-ownership and use is currently unaffordable. Whether this can work depends on the subsidy model. Generally, a universal subsidy on ACT-based car sharing may attract mostly higher-income car owners, while still remaining too expensive for low-income individuals. Recent experiences with advanced, smartphone based, on-demand public transport services suggest that the market for shared services is limited among car owners (REF#). Instead (inexpensive) sharing services will likely decrease public transport use and thus its fare-based income (see section 5.5), leading to additional costs if public transport service is maintained, which would probably be required as part of an inclusive transport system.

A possibly more suitable intervention could be personalized ACT-based sharing subsidies, so that shared ACT vehicles will become accessible specifically to low-income households. There are two feasible personalized subsidies options that will promote an inclusive transport system: one model is that of very targeted subsidies to ACT services, not only in terms of recipients, but also in both space and time and only towards trips where public transport does not provide a reasonable alternative and partly as a feeder system to public transport. However, such a system is likely to require a lot ofpersonal information from possible beneficiaries of the system, leading to serious privacy considerations. In the second model, eligible persons would receive a personal budget which they could use for ACT-based carsharing (and possibly also for regular public transport), so that they can make use of it as they see fit. The advantages of such a personal budget would be that users can themselves decide whether to use ACT-based sharing as a feeder for regular public transport or as a door-to-door service. A monthly km-budget for using ACT-based sharing at a low-price could be identified, regulated and subsidized, for different categories of people, on certain criteria. This could model the ACT carsharing mostly as a feeder, zonal, transport service, limiting its extensive use as a long-distance individual transportation mode. This could also help reduce private vehicle ownership and avoid the negative impact on public transport service levels. Relevant trials are already taking place in selected cities (e.g., in the UK and the US).

<u>Ability:</u> There are already regulations in place in certain countries that promote accessible service to those with disabilities and other accessibility challenges (see for example the American Disability ACT and its impact on taxis, limousines and paratransit services; Easter Seals Project ACTION, 2005). Such regulations ensure that the dispatchers and drivers hold sufficient understanding of the different needs of individuals with disabilities and are able to assist with these needs. Additional regulations take it even further, requiring a certain percent of all rides hailing services fleets, like Uber and Lyft, to be accessible

to those with disabilities (in New York for example a new law requires that 25% of these companies' vehicles will be wheelchair accessible by 2023; Hawkins, 2018). Governments should consider similar regulations to be enacted with the first introduction of ACT-sharing services that will ensure a more equitable access to these services. Nonetheless, as specified above, such accessible services might add costs to the service, which might make it less affordable to other population groups.

<u>Spatial Availability:</u> More remote and low-income neighborhoods may not be very profitable for carsharing services, which might lead privately owned (ACT-) carsharing services to want to operate in highly dense areas with higher profit margin (Mobile Lives Forum, 2021). To address this void and assure that all locations receive an adequate, or at least a minimal service standard to ACT-based carsharing, local governments should consider different ways to make sure these services are offered everywhere within their jurisdictions. Possible policies include incentive programs offered to carsharing companies (such as tax breaks, lower parking rates, etc.) to encourage their operations in less profitable locations, and/or by providing subsidies to low-income individuals so they may better utilize these services and create a market within which carsharing companies can operate. It may also be achieved through regulations where a carsharing company seeking to offer a service in a particular jurisdiction must commit to serve also low-income or low-density neighborhoods within that jurisdiction. The latter approach has been adopted with success to bike and e-scooter sharing by a range of local authorities across the world.

Chapter 6:
Scenario 4 – ACT-based public transport

6.1 Introduction

So far, we have discussed the introduction of automated and connected technologies for individual transport, either private or shared. In this chapter, we explore the potential contribution of ACT-based public transport. Drawing on Walker (2012) and others, we understand public transport services here as regular *"vehicle trips, open to all passengers, with the capacity to carry multiple passengers whose trips may have different origins, destinations and purposes"*. Public transport in these terms is thus not only public (i.e., open to all) but also collective (i.e., potentially serving multiple non-related people in a single ride) in nature. This sets ACT-based public transport apart from the previously discussed sequential sharing of ACT-vehicles, which is open to all but does not serve multiple unrelated people simultaneously. In what follows, we will explore how partial and fully automated ACT technologies may reshape public transport and how these possible changes may contribute to a more inclusive transport system.

6.2 Regular public transport in a world of partial automation

Even if full automation is still far away, public transport may benefit in multiple ways from partial automation technologies. Benefits will depend on the level of automation, as we will discuss briefly below. Irrespective of the exact level, automation can lead to cost savings in the operation of public transport services. The main contribution of partial automation towards an inclusive transport system thus depends on the way these cost savings are fed back (or not) into the system. We first describe the possible ways in which automation can be enhanced in public transport operations and then reflect on the ways cost savings can be utilized.

ACT technologies for low levels of automation, i.e. Level-2 and Level-3, are already widely available. These driver-support technologies include adaptive cruise control, lane keeping, and acceleration and braking assistance. These can be employed in all types of public transport; trams, light rail, metro systems and heavy rail, but the benefits may be expected to be most significant for bus-based public transport services. These ACT technologies can enhance passengers' on-board comfort, with (marginal) positive benefits for all users (Guo et al., 2021a; Guo et al., 2021b) but substantial benefits for people with severe motion sickness. The effective use of adaptive cruise control and acceleration and braking assistance can reduce fuel use and wear and tear on vehicles, with modest cost savings depending on circumstances, estimated at around 5% of operational costs (Wadud et al., 2016).

More substantial cost savings can be reaped when Level-4 automation is introduced in public transport operations. Level-4 automation allows operation of a vehicle without the presence of a human, provided vehicle operation is limited to predefined areas and vehicle speeds are when operating in a mixed traffic environment (see Chapter 1). Some modest public transport services making use of Level-4 automation already operate for over a decade in some limited mixed traffic environments (e.g., Heathrow Airport, ParkShuttle in the Netherlands; Sadler, 2016). Improvements in ACT technology offer opportunities for much more widespread implementation, provided that the two conditions mentioned before are still met: ACT employment in predefined areas or on predefined corridors only and low vehicle speeds when in mixed traffic. Fulfilling these conditions enables driverless operation while guaranteeing safety for other road and street users. These conditions imply that ACT technology can be applied in two different types of public transport services.

The first and most obvious possibility for ACT implementation relates to public transport operating in a (nearly) fully controlled environment. This includes metro systems and some (suburban) rail systems around the world (Paris RET for instance). These systems typically operate on dedicated infrastructure and with complete (grade) separation from other types of traffic. Fully automated metro systems are already operating in multiple cities around the world (e.g. London). The implementation of these advanced technologies is expected to increase substantially in the near future. Such investments, if employed in existing services, can possibly reduce operational costs and enhance passenger experience (through an improved driving performance of the vehicle). One study analyzing 23 metro lines estimated a cost reduction of 10-15%, with automated metro lines capable of operating at higher service frequencies per hour and at a higher level of reliability, which may also increase ridership and thus fare revenues (Cohen et al., 2019).

Level-4 automation also offers opportunities for implementation in road-based public transport. While the recent focus in ACT technology has led to multiple trialswith small-scale 'shuttle' services (see the WISE-ACT Atlas; Canitez et al., 2018), Level-4 technology might be more successfully and effectively employed in existing public transport operations. Indeed, the benefits may be substantial for public transport services running on dedicated lanes with mixed traffic operations limited to junctions or short line segments. Such types of operations have become more common over the past decade and include bus rapid transit systems (BRT) and advanced light rail transit systems (LRT). These systems offer opportunities if dedicated lanes are not located on the curbside, but in the median of a road. The latter type of operations limits conflicts with pedestrians and cyclists along the corridor to junctions only, while also largely eliminating possible conflicts with vehicles parking, unloading or exiting properties. If median separated lanes are prepared for ACT technology, they can be used for high-speed automated operation of buses or light rail vehicles. At stations and junctions, these ACT-vehicles can operate at low speeds to guarantee safety, while still proceeding in driverless mode. This model can work well for lines running on dedicated lanes of significant length and with substantial distances between stops. Frequent stops with low-speed automated driving might severely reduce overall operating speed, with detrimental impacts on a line's frequency, capacity and ability to attract passengers, thus potentially eliminating the advantages of any cost savings. However, on suitable corridors, ACT-based BRT or LRT could also be combined with mixed traffic operations at the beginning or end parts of a line, where a driver would take over the vehicle. This could still deliver substantial labor cost savings, if combined with careful driving scheduling and the drivers only operating the vehicle in the mixed-traffic part(s) of the line. Level 4 ACT based tourism travel has been projected as an early adopter of such services, although more research is required (Cohen & Hopkins, 2019; Thomopoulos et al., 2020).

Like in the case of automated metro or suburban rail systems, ACT-based BRT or LRT may lead to substantial cost reductions, which can be fed back into the larger (public) transport system with the aim of enhancing the level of inclusion. An example of possible benefits is presented in a recent feasibility study about equipping a BRT line in Istanbul with autonomous technology (ISTKA, 2013). The study explored the possible contribution of only adding technology that is already available (e.g., adaptive cruise control, collision warning/collision avoidance, V2V communication, roadside unit, and lane keeping assistant). The study found possible fuel reductions of 5-10% and a possible reduction in labor requirements by a third to a half. The latter could be achieved by using convoys of vehicles, with only one driver in the vehicle leading the convoy. Such an option may offer significant benefits to address crisis situations such as the COVID-19 pandemic. Moreover, the technologies were estimated to increase the capacity of the system by at least 45% (ISTKA 2013). More advanced ACT-technology that would allow driverless operation of single vehicles as described above could obviously offer even greater cost savings.

The major benefits of partial automation in public transport services will depend on the use of any cost savings. Obviously, if cost savings are used to reduce public transport operations budgets, benefits will be limited to improved passenger experience (as mentioned above), possible improvements in service reliability (as vehicles speeds can be adjusted so as to remain on schedule) and possibly limited increases in ridership and thus increase in fare revenues (which may again be used to reduce public transport subsidies). Such a use of cost savings is obviously at odds with the goal to deliver an inclusive transport system, as more rather than less expenditure on public transport will be needed to deliver sufficient accessibility to people without access to a car in most contexts around the world. This implies that any cost savings should be fed back into the (public) transport system. If this latter approach is adopted, there are two possible strategies.

The first strategy would use cost savings to assist passengers in using public transport. In this scenario, vehicle drivers or operators will become public transport attendants eliminating any negative employment implications due to automation in transport. Such attendants can enhance social safety in the vehicles and on stations, assist passengers with payment and route finding, and assist passengers with disabled mobility accessing and exiting vehicles. This use of cost savings will especially enhance ease of movement for people with motor and cognitive disabilities, with possible additional modest benefits on service operating speeds. Regular and predictable presence of attendants is relevant for people who need assistance to board vehicles, as only in that case can pre-booking of assisted trips be avoided, which is essential for improving people's freedom of movement. In the case of personal security, attendants' presence could be targeted to evening and night hours as well as 'problematic' stations or lines. Such a use of cost savings would be less suitable to serve people requiring assistance but may benefit especially women and elderly who more frequently avoid traveling in evening and night hours (Hine & Mitchell, 2017).

In a second strategy, reductions in labor and other costs will be used to improve service frequency, service hours or service coverage of public transport. Increases in service frequency and service hours on existing lines may substantially enhance mobility and accessibility of those living within proximity of such lines. It may also substantially enhance ridership, leading to an increase in fare revenues, which can again be fed back into the system. An increase in service coverage may provide access to people previously deprived of any public transport (for instance, in more remote suburban areas) and may serve previously unserved destinations.

Both strategies will enhance the level of inclusiveness, but in different ways. In a more general sense, Level-4 automation may increase the (political) support for high quality public transport services on additional (BRT) corridors. The poor level of public transport services on many corridors currently suffers from a vicious cycle: low quality service leads to low ridership that leads to high costs per passenger that leads to limited political support for public transport (improvements). If ACT technology would make it possible to provide a substantially higher level of service against a substantially lower cost (primarily due to reduced labor costs), this may strengthen (political) support for public transport investments, in existing or new corridors. If successful, such services may enter a virtuous cycle, with high quality service attracting high ridership, increasing revenues and strengthening political support, possibly resulting in additional service improvements – in the selected corridors or beyond. In more general terms, ACT-based public transport, if implemented on a substantial scale and in conjunction with other measures, could possibly stop the vicious cycle that has been at work for decades in public transport in many regions across the world – although its impact is likely to occur mostly in more dense (sub)urban areas.

These two strategies – increased service supply (increased frequencies, longer service hours, increased coverage) or improved customer service (personnel in stations or on-board to serve passengers) – will both contribute to a more inclusive transport system, as mobility and accessibility for a range of groups may be improved. Which strategy will provide the largest contribution towards inclusion will depend on the circumstances, notably the existing characteristics of the public transport system, land use patterns, as well as population composition (e.g., a young or elderly population).

6.3 ACT-based fully automated public transport

Fully automated public transport opens up an entire range of new possibilities that partial automation cannot bring. Indeed, if fully automated ACT becomes reality, driverless road vehicles can become the workhorse of future public transport systems, even more than is currently the case, as fully automated ACT-vehicles can run without a driver in mixed traffic anywhere. This opens up a range of possibilities for regular public transport operations, but also opens the door for a radically different type of public transport. We will discuss these two possibilities here separately, although they are likely to occur in tandem once Level-5 automation becomes a reality.

For regular public transport operations, full automation will imply a major cost reduction, substantially higher than what is possible under partial automation. Labor costs currently account for about 40%-70% of public transport operational costs in developed countries (Tirachini, 2020). Since labor costs can (potentially) be reduced across all current operations, the savings of full automation can be substantial. Even if ACT-based public transport systems will also introduce new labor and other costs, such as those associated with vehicle deployment and management, technology maintenance and repair, and technical road assistance, substantial reductions in operational costs may be expected. This opens opportunities for enhanced public transport services, even more than in the case of partial automation and even within current budgetary limits. An ACT based public transport system might also be safer, more efficient and highly reliable, which might attract additional riders. Such a system, for example, could communicate with the entire public transport network and assure the timely arrival and departure of vehicles to prevent riders from missing their connection lines and avoiding extensive waiting times.

If cost reductions are combined with existing standards for operational cost per passenger kilometer, full automation may make it (politically) possible to offer public transport services on corridors currently lacking supply, as no dedicated infrastructure is necessary given that fully automated ACT-vehicles can run in mixed traffic anywhere. Any extension of service, whether in terms of increased frequency, extended service hours, or extended coverage, is likely to increase public transport ridership, leading to more revenues and thus more support for public transport. In other words, the virtuous cycle that may be triggered somewhat by partial automation is much more likely to occur with full automation. New and expanded services may substantially enhance the mobility and accessibility of car-less people living in poorly served areas, as well as providing accessibility to jobs and services in these locations. Clearly, full automation is likely to support and strengthen public transport operations, with all positive impacts for inclusion.

Beyond merely cost savings, the complete elimination of the need for a driver or operator opens up possibilities to radically re-envisage public transport. Currently, most public transport runs on a fixed route with a fixed schedule. This implies that users have to adjust to the transport servicerather than vice versa, while also requiring frequent changes between lines. Full automation provides the opportunities for the offering of a complete on-demand public transport system, where the supply adjusts to the user, in terms of both space and time. Such an on-demand system would consist of simultaneous sharing of ACT vehicles and so is very different from the sequential sharing model described in Chapter 5. Simultaneous sharing of on-demand services has existed since at least the early 1970s. Currently, such on-demand services are limited in terms of geographical coverage and operating hours and are often of poor quality. Moreover, they tend to be open for particular user groups only. More recently, 'smart' technologies have triggered a new wave of on-demand services (Spiro, 2020), but these services too are still limited in scope. Level-5 automation would make it possible to radically revamp the entire public transport system and offer all services on-demand, using vehicles of different sizes depending on demand and (built environment) context. Such a model is particularly attractive from the passenger perspective, as it may entirely avoid the need for transfers (even at the cost of some modest walking distance). For such a sharing model to contribute to an inclusive transport system, it would have to take into account the differential abilities of users, including digital skills and accessibility of vehicles. The latter may become a major issue for people with motor or sensory disabilities (wheelchair users, visually disabled), especially if the sharing model moves away from the use of (accessible) public transport stops. Additionally, any negative health implications due to reduced physical activity (e.g. less walking) will have to be taken into account (Curl &Fitt, 2018).

While such a public transport system consisting of simultaneous sharing of ACT-vehicles can theoretically provide door-to-door service for all trips, it is highly unlikely to emerge as the only type of public transport service in any ACT future. Indeed, the adoption of a complete on-demand model for ACT-based public transport seems unlikely in most urban environments. The high densities in large cities will require transport systems that are highly space efficient. On-demand services also have a limited ability to 'scale' – simultaneous sharing becomes inefficient if the sharing is done with many people. This also underscores that a sharing model will tend to work with (relatively) small vehicles, which can only deliver limited overall capacity on heavily used corridors even if fully automated. Hence, in dense urban context regular public transport services using large vehicles equipped with ACT technologies will be required to deliver a high level of accessibility for all users.

These observations are confirmed by recent research. Bösch et al. (2018) analyzed suitable operational models for a future of full autonomous vehicles, focusing on the competitiveness of their cost structures. The study showed that regular public transport (in its current form) will remain economically competitive where demand can be bundled to larger units. In particular, this applies to dense urban areas, where public transport can be offered at lower prices than when employing simultaneous sharing. However, the study also found that where substantial bundling is not possible due to low demand, simultaneous sharing may serve travel demand more efficiently and at lower cost.

The most likely model to develop once full automation becomes practically feasible is a model consisting of both regular, schedule-based, public transport and on-demand services. In comparison to the current public transport system, this model can offer a substantial contribution to an inclusive transport system. Given existing budgetary limits, full automation can be employed to offer better passenger services (on-vehicle attendants rather than drivers), expanded service levels (frequencies and service hours), and expanded coverage. In addition, full automation may improve passenger comfort (due to smoother vehicle operation) and reliability (due to automated control of on-schedule operation). In all cases, these advancements will benefit people who are currently poorly served by the existing transport system – across all modes. The improvements may increase ridership among these population groups, as well as among people who now may use other means of transport, potentially triggering a virtuous cycle. The latter depends, however, on the attractiveness of private ACT-vehicles and sequential ACT-based sharing, which in turn will be heavily shaped by policies of governments at all levels.

Chapter 7:
Conclusions and recommendations

7.1 Conclusions

In this report, we have explored how the arrival of ACT-technologies may contribute to the delivery of a more inclusive transport system. Such a system has been defined as a transport system that at the very least provides every person with a sufficient level of accessibility. Many contexts around the world do not yet feature such an inclusive transport system, which especially limits the mobility and accessibility of (substantial shares of) low-income households, children and youth, people with disabilities (motor, sensory or cognitive), immigrants and ethnic minorities, women, and people with limited digital skills. Moreover, these groups are particularly at risk when living in low density or remote geographical settings.

We have explored the potential contribution of different ACT scenarios and deployment types to an inclusive transport system: privately owned ACT-vehicles, sequentially shared ACT-vehicles, and ACT-based public transport. We have also explored the implications of diffident ACT levels, distinguishing between partial automation (Level-4 or lower) and full automation (Level-5).

The results of this analysis show that ACT can have a modest or substantial contribution in the move towards an inclusive transport system (**Figure 2**). The contribution is mostly negligible in case of partial automation of private vehicles – and may even be detrimental if partial automation leads to more car users and thus to more hostile built environments. Therefore, it is crucial to focus on the transition phase as highlighted in the WISE-ACT MoU (WISE-ACT, 2017). Full automation of private vehicles may make this mode of transport suitable for a larger share of the population, although cost constraints as well as possible legal requirements will limit the benefits to a small share of the people poorly served by current transport systems. Fully automated sequential sharing services, on the other hand, may provide larger benefits. However, in case the delivery of these services will be left to the market, they will remain too expensive for a substantial share of the underserved population raising equity concerns and are likely to be offered only in high demand areas – which are often already relatively well served by cycling infrastructure and public transport services.

The most benefits are likely to accrue when ACT technologies are adopted in public transport operations. Provided public transport budgets remain intact (or are expanded), modest benefits may already be reaped if current technologies are applied on a larger scale in public transport operations (across modes: heavy rail, metro, light rail and bus). Substantial benefits can be reaped if dedicated public transport infrastructure and vehicles are prepared for Level-4 automation, particularly for non-commuting journeys (Cohen & Hopkins, 2019; Thomopoulos et al., 2020), something which some public transport authorities are considering. Full automation may further increase public transport provision, in terms of passenger support, service level and coverage area. This scenario may also lead to a virtuous cycle of mutual feedback between increased service, ridership and revenues. However, whether such a scenario may play out will depend not on technology but on policy. Virtuous cycles in public transport have always been possible, certainly in dense environments and on high demand corridors, but transport, land use and other policies have made it virtually impossible for such cycles to occur during much of the past seven decades.

The figure below (**figure 5**) presents an overview of the major expected impacts of various ACT deployment scenarios on various target groups. Note that we present here the dominant (and, most often, the direct) impact of the technology.

7.2 Policy recommendations

ACT introduction for the benefit of society requires governance innovation across a broad range of issues, including amongst others control algorithms, communication protocols, legal liability, legal and AI law more broadly. Policies and interventions that enhance the inclusiveness of the transport system are part of that broader effort. Some of these more general governance issues surrounding ACT introduction are discussed in more detail in the WG1 Thematic Report but are also closely related to inclusion. Figure 6 offers an overview of that broader effort, which includes:

- **Audits of algorithms.** Algorithms can be biased in multiple ways. Particularly relevant for inclusion are collision avoidance algorithms (the well-known trolley problem, relevant across all ACT deployment types) and vehicle dispatch algorithms (particularly relevant for both sequential and simultaneous ACT-based sharing). Audits of algorithms are regular procedures regarding algorithms that exist in some other fields of automation, such as aviation. Regulation establishes a body and process that audits automation algorithms, which also involves methods to check for bias, check for other exclusionary effects, and even for second-order undesired effects – as they can be tied to simulation tools. Timely conducted audits, for example, before getting the permit to operate, would be a good policy integration move.

Figure 5: Overview of the major expected impacts of various ACT deployment scenarios on various target groups.

Contribution to inclusive transport system by group

	Scenario or deployment type	Low income	Young	Older	Disabled	Women	Without driving licence	Living remotely	Digitally unconfident	Unprotected road users
Chapter 3	Privately-owned partial automated ACT-vehicles	0	0	+	+	0	0	+	0	?
Chapter 4	Privately-owned fully automated ACT-vehicles	0	+	++	++	0	++	++	0	?
Chapter 5	Sequential carsharing services	?	+	+	+	+	++	0	0	+
Chapter 6	Partially automated ACT-based public transport	+	+	+	?	+	++	0	?	?
Chapter 6	Fully automated ACT-based public transport	++	++	++	?	+	++	+	?	?

Legend

0	The ACT scenario will have no or only few positive mobility and accessibility benefits for members of the group
+	'Some part of the group is likely to enjoy increased mobility or accessibility in the ACT scenario
++	'A substantial share of the group is likely to enjoy increased mobility or accessibility in the ACT scenario
?	'Unclear whether the ACT scenario will contribute positively (or negatively) on the mobility and accessibility of group members

Notes

1 The evaluation concerns accessibility benefits. That is, the ability of people to reach (further) destinations to fulfill their activity needs and wishes. Some of this benefit might also come via a safety benefit. For example, the accessibility of vulnerable road users (or those who do not have access to car) might improve, if cycling and walking is safer.

2 The impact assessment for groups is based on the ceteris paribus principle. For example, even if older people are statistically more likely to be disabled (compared to other age groups), the assessment considers the difference due to age and not due to disability.

- **Data sharing regulation for experiments** is another important battlefield for inclusive transport future. Whatever type of ACT-based services will be offered in the future, it will take multiple on-road experiments to get these smoothly working. Right now, there is limited regulation mandating the transparency of these experiments, and the public sector currently frequently assumes the role of the underdog – often requesting that the data be shared but is left in the dark (see WISE-ACT Data Management Reports by country for more information). This puts public sector in the position where there are no points to act on in steering the technological trajectory or to guide it more deliberately towards implementations that serve the wider public – such as various forms of ACT-based public transport – as all the problems are kept hidden and companies (including those implementing ACT technology in public transport services) defend it by arguing for protecting their intellectual property.

- **Regulation for accountable public participation** in development of EU, national, or regional roadmaps for ACT development and deployment. Public participation is important across all policy domainsbut tends to receive a backseat especially in the transport domain. For ACT technologies to be implemented for greater inclusion, representation of a broad range of users and non-users is of the utmost importance. There is broad experience in other domains, such as urban planning and redevelopment, with successful processes of public participation, using a range of in-person and digital means. At the very least, ACT experiments should be fed by a broadly composed stakeholder forum that can reflect on goals, targets, key performance indicators, as well as on the way and areas where experiments are being conducted.

The analysis of the potential contribution of ACT-futures to an inclusive transport system presented in this report underscores that ACT technology will enhance transportation inclusiveness only if supported by targeted policies. The analyses give rise to the following policy recommendations:

- **Do not pamper private ACT.** The analyses show that privately owned ACT-vehicles, certainly if not fully automated, will do little to enhance inclusion. Hence, from an inclusion perspective, governments should be less concerned to 'miss out', assuming that being late in ACT introduction would create an economic disadvantage. While this may be true to some extent, these impacts should not be overstated. Low-level ACT will arrive everywhere and certainly in wealthy countries. Given their limited societal benefits beyond vehicle-to-vehicle traffic safety there is little reason to pamper these vehicles. Governments should make sure that the introduction of this new technology translates into societal benefits, while refraining from subsidies or (infrastructure) investments as these will flow to people already well served by the current transport system.

- **Focus on public ACT rather than private ACT.** The analysis above shows that most benefits of automation for inclusion may be expected when implemented in public services, notably (regular) public transport operations. Beyond limited experiments with driverless shuttles, governments have been slow to embrace the potential of ACT for cost reductions and service enhancements in public transport. This is a domain where active stimulation would be in place, certainly in the highly volatile context created by the covid-19 crisis. Governments could develop a multi-year investment plan for retrofitting services taking into account labor force implications, starting with 'low hanging fruit', especially where the role of the driver in passenger experience is limited (e.g., metro systems). Public private partnerships for enhanced bus-based automation technologies would also be a promising and societal beneficial investment.

- **Meaningful experiments with ACT-based public transport.** Rather than experimenting with Level-4 automation in small shuttle services operating in mixed traffic, much more potential lies in experiments with automation on services with dedicated rights-of-way. Governments could start with feasibility studies, as the one conducted in Turkey, and move swiftly to experiments focusing on e.g. tourism, if such studies present promising potential.

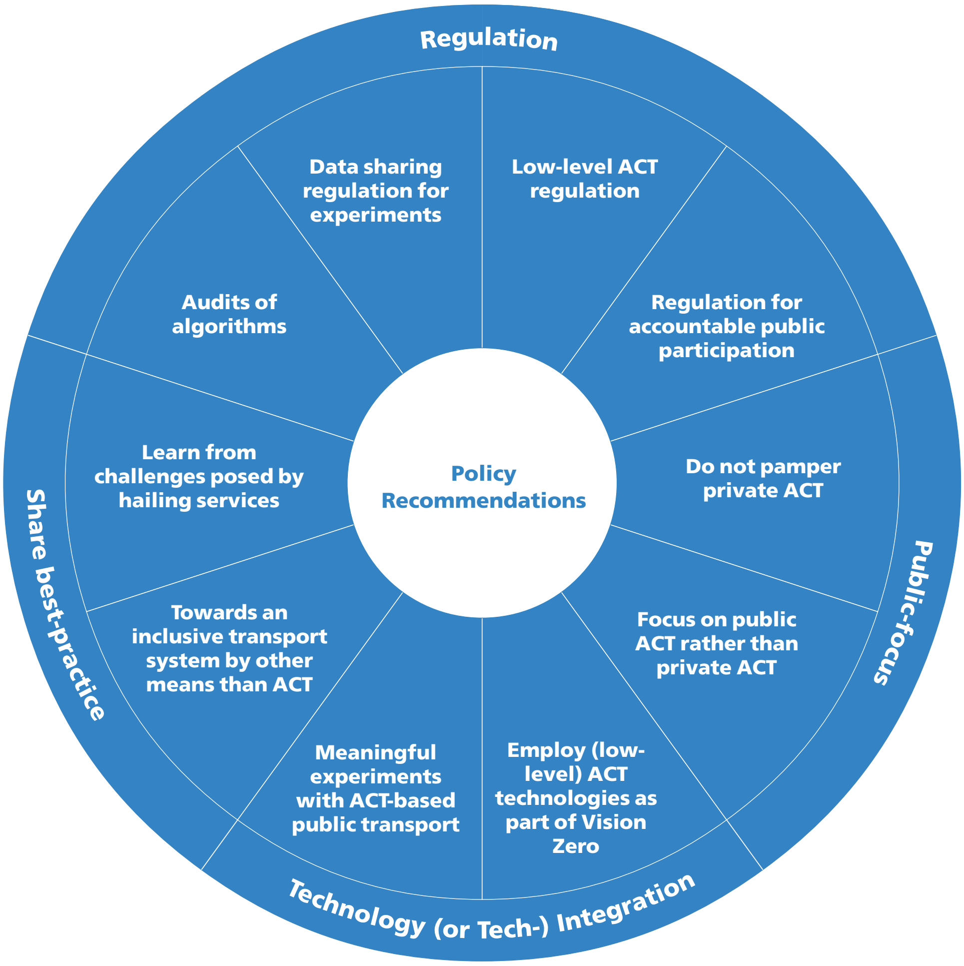
- **Low-level ACT regulation**. Low-level ACT for highway contexts is already available and is likely to deliver traffic safety. Governments do not have to support the development of these technologies, as they already exist and the market incentives for (further) developing them are enormous. Governments should rather focus on proper regulation of the use of these low-level ACT-technologies and especially on guaranteeing a safe transfer to a regular driving mode. In addition, legal liability should be clearly ascribed.

- **Learn from challenges posed by hailing services.** Hailing services are a precursor for ACT-based sharing, whether sequential or even simultaneously. These services have brought benefits to a range of users, but have also generated a number of problems, most notably a decrease in public transport ridership and increased congestion. This offers an excellent opportunity to test how such services may contribute (more) to an inclusive transport system and how this can be achieved through a mixture of careful regulation and financial incentives or subsidies. Recent experiences with hailing-based public transport services can thus not only enhance inclusion, but also prepare governments for a future of fully autonomous sharing. More experiments are warranted to obtain lessons for a range of (geographical) circumstances and for a range of users in diverse socio-economic groups (in particular people with disabilities and with limited digital skills).

- **Employ (low-level) ACT technologies as part of Vision Zero.** Car companies are primarily concerned with the safety of vehicle users and much less with the safety of unprotected road users. The latter is thus a duty for governments. National governments, in international cooperation, should require ACT-vehicles to have standardized external speed control protocols so that technologies of geofencing and automation can be used for the safety of all street users and not merely for the vehicle users themselves.

- **Towards an inclusive transport system by other means than ACT.** The introduction of ACT technology might make private vehicle ownership and use (much) more attractive than is currently the case. The analyses in this report underscore that the benefits of these technological advances will be reaped by only a share of the population, similarly to the case with the introduction of the regular car. Governments should avoid repeating this past mistake and deliberately embark on a path towards an inclusive transport system. This implies continuing the path embraced by some cities and regions in recent years, with more space for pedestrians, cyclists and public transport. The arrival of (fully automated) ACT does not eliminate the importance of these steps to achieve a fair transport system that serves all.

Figure 6: Overview of policy recommendations to make transport systems more inclusive.



7.3 Recommendations for research

The findings in this report are mostly based on existing literature and explorations of 'what if' pathway analysis based on WISE-ACT WG2 expertise. Clearly, any work on the future in general and the future of ACT in particular will be speculative in nature. Yet, more targeted research can assist in gaining a deeper understanding of the possible contribution of ACT technologies towards an inclusive transport system. More research is particularly warranted on the following topics:

- **Potential cost savings of ACT implementation in public transport.** Only a few studies have analyzed (possible or observed) cost savings of automation in public transport. Most of this work has focused on rail-based services (metro). More work on this issue is urgently needed, as a better understanding of the savings may enhance governments' willingness to engage in experiments. Experiments, in turn, will generate more and better knowledge. If cost savings prove to be substantial, such research might speed up ACT adoption in public transport, which may lead to further cost reductions thanks to economies of scale.

- **Potential of advanced on-demand services in low demand areas.** Recent experiments with on-demand service have typically been conducted in high demand areas. From a perspective of an inclusive transport system promoting spatial equity, knowledge is particularly lacking on the costs and (societal) benefits of on-demand services in areas not or poorly served by public transport. Such studies can generate a knowledgebase for future ACT implementation in these contexts, thereby potentially preparing the ground for swift deployment once full automation becomes available. While often hardly on the radar of academics or policy makers, these areas pose a major challenge for developing an inclusive transport system.

- **Technical possibilities and acceptance of external speed control.** External speed control is already common for shared e-scooters. In light of the enormous benefits in terms of traffic safety, noise and air pollution, and reductions in fuel use, research is urgently needed on its potential for (large) motorized vehicles. Since vehicle manufacturers will have little incentive to conduct such research, government funded (academic) research on this topic is warranted. Research should focus on the technical possibilities and risks (e.g., communication failures, transition between speed regimes, cyber-attacks), user acceptance, legal liability, as well as perspectives of key stakeholders like insurance, car leasing, and delivery companies.

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