Rescuing transport from inequities:
How can ACT contribute to a more inclusive transport system?

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Abstract

The massive investment in, and development of, automated and connected transport (ACT) technology development has triggered much debate about the potential positive and negative impacts of this breakthrough technology. Multiple studies have explored the potential direct implications for users in terms of road safety, 'productive' travel time, mobility of the elderly and physically less mobile persons, as well as indirect impacts such as reduced emissions and freed road space. Through a critical review of the literature on ACT deployment types and discussions with an expert working group on the wider impacts of ACT implementation, this chapter examines four distinct deployment types of ACT technology and their opportunities and threats in transitioning toward inclusive transport systems. Of the four types, we posit that ACT-based public transport has the greatest potential to contribute to a more inclusive mobility future. Examining the case of Singapore using policy documents, academic literature and interviews with representatives of public and private sectors and academia, the chapter draws policy recommendations for governance towards more inclusive ACT innovation and deployment.

Keywords: inclusive mobility, transport inequities, sustainability, automated transport, connected transport, ACT-based deployment types, public transport

Introduction

The role of Automated and Connected Transport (ACT) has been widely discussed in the last decade as a potential remedy to the problems cities and transport systems are facing, such as traffic congestion, air pollution, accidents and car-oriented development. This chapter explores the possible contribution of ACT in making the current surface transport system more inclusive and, thus, more sustainable in its broadest sense. For this, we take a people-centered perspective. This perspective asks whether people – in all their diversity – receive adequate service from all transport modes jointly to meet fundamental human needs and wants (Martens, 2017). Hence, the core question we ask is: whose service is being improved by the introduction of ACT in its various forms?

Drawing on the extensive literature on transport equity and transport-related social exclusion (Lucas, 2012; Martens and Lucas, 2018), we will focus our exploration on the following poorly served population groups: low-income households, people with (motor, sensory, or cognitive) impairments, women, children and youth. In addition, we take geography into account, as residential location also strongly shapes a person's mobility and accessibility. The literature shows that a substantial share of these groups is currently poorly served because they have no or limited access to a (reliable) car for financial, legal or ability-related reasons (Mattioli et al., 2017), while the transport means and systems available to them often do not provide a high level of mobility and accessibility. The lack of access to a car is not inherently problematic, but decades of car-oriented investments and urban developments have made it *de facto* challenging to access destinations without a car in much of the developed world. ACT can potentially improve the situation for a broad range of people and thus contribute to a (more) inclusive transport system (Herzogenrath-Amelung et al., 2015; Blyth et al., 2016; Bonnefonet al., 2020). Yet, a positive contribution is unlikely to come from a focus on automated and connected transport. What is needed is an ACT future deliberately shaped to create an inclusive transport system. Hence, in this chapter, we explicitly adopt the perspective of disadvantaged groups to scrutinize whether different forms of ACT-based transport enhance their mobility and accessibility.

The chapter is structured as follows. In section two, we discuss how all transport modes are, to some extent, exclusionary by nature. This argument is also accurate for ACT. Despite its potential to make regular (private) motorized vehicles more suitable for a wider range of users, ACT will not be able to serve everyone under all circumstances. Hence, in the following sections, we discuss various possible ACT deployment types, differing in automation level and level of sharing.[1] Here, we use the term partial automation (in other words, low-level ACT) for Levels 2, 3 and 4, and full automation (high-level ACT) for Level 5 only (SAE, 2021). We limit the discussion on shared ACT to sequential sharing, as in 'not traveling with others', while collective mobility, i.e. sharing rides with unknown others, refers to ACT use in all forms of public transport (i.e., both regular and on-demand services). The emphasis is on how these deployment types may work out for different people, who vary widely across multiple socio-demographic dimensions, live in a range of spatial contexts, and differ in their ability to access each ACT deployment type. This exploration concludes that ACT-based public transport, in various forms, has the most potential to contribute to an inclusive transport system. In the last sections we explore how Singapore, one of the countries at the forefront of the ACT revolution, plans to enhance public transport services through ACT-technologies. We conclude the chapter with a general reflection on governments' role in introducing the ACT in light of the possible futures that might or might not unfold if the ACT introduction is left unchecked.

The following sections are based on a critical review of the literature on different deployment types of ACT-based transport to extract their possible implications for different underserved population groups. We also engaged in multiple open-ended discussions with diverse experts within the WISE-ACT COST Action working group on Wider Impacts and Scenario Evaluation of Autonomous and Connected Transport. For the Singapore experience in introducing ACT-based technologies in public transport, we reviewed academic and grey literature, including policy documents on planning and transport and the websites of Singapore's government ministries, including the Land Transport Authority. Fifteen interviews were carried out with ACT-based

[1] This chapter, including the four different deployment types, are partially an outcome of the discussions throughout the WISE-ACT COST Action working groups and to some extent, the WISE-ACT survey that proposed different scenarios including private and shared ACT vehicles. Since some of the ACT deployment types we distinguish are likely to be introduced in parallel, we use the term deployment types instead of scenarios.

transport practitioners from the public sector, private sector and academia in Singapore. From the literature and interviews, we derived the rationales, objectives, policies and actions undertaken by the government, often in collaboration with actors in academia and the private sector, in introducing ACT-based technologies in public transport.

The exclusionary character of transport modes

Transport planning and policy would have been much less complicated if one mode of transport fitted all. However, people vary greatly in their needs, wants, concerns, constraints and preferences. All transport modes exclude some people. For instance, walking or cycling a considerable distance may not be an issue for most people, while for others, even a short walk may be troublesome (Curl and Fitt, 2018; Park and Chowdhury, 2018). Likewise, using public transport may be challenging for people with physical and mental impairments despite intervention efforts towards inclusive designs (Martens, 2018). This exclusionary character of transport modes often leads people to choose more comfortable, practical (door-to-door) and personal modes of traveling, such as private cars, whose adverse impacts on sustainability have been discussed in transport and urban research for decades (Banister, 1999; Newman and Kenworthy, 1999). Yet, private cars are only available to some due to financial barriers and social norms, even in more affluent countries (Uteng, 2009). Even if financial barriers were taken away, especially for young people and individuals with various impairments, driving a conventional car would not be possible. This is also the case for some share of older adults, who may face the prospect of having to stop driving as their abilities decline as they age (Dellinger et al., 2001; Rosenbloom, 2010).

While the current debates lead to an understanding that automated and connected transport holds the potential of eliminating the challenges of active mobility for all as well as some of the exclusionary characteristics of the car and of public transport services, it is unlikely that all people will be able to use a fully automated ACT vehicle. For instance, approval would be needed from caretakers for children and youth to use ACT for reasons of safety, personal security, and privacy (Koppel et al., 2021). Likewise, ACT may exclude some adults with low technological literacy and/or without access to a bank account or credit card, as using ACT is likely to require digital skills (Milakis and van Wee, 2020). ACT technology may widen the already existing digital divide, potentially exacerbating socio-spatial inequalities (Thomopoulos and Givoni, 2015). Other conditions, such as distrust of technology that is usually driven by the fear that Artificial Intelligence (AI) will be unable to prevent accidents, that personal data will be leaked due to cyber-attacks, or the AI will fail to perform its main tasks (Cugurullo and Acheampong, 2023), may also impede the ACT use among some share of the population.

However, the most important barrier to private ACT uptake will be financial in character. Even in wealthy countries, a substantial share of adults currently does not have adequate income to finance car ownership (e.g., Allen and Farber, 2021) or even a subscription to a car-sharing system, while some others suffer from forced car ownership combined with often unreliable access to a car (Currie and Senbergs, 2017; Mattioli, 2017). Even if ACT vehicles can become more affordable in the long term, global car ownership trends suggest that ownership of an ACT vehicle will not be within easy reach for a substantial share of the population. Shared ACT services may also be unattractive for low-income individuals considering that current car-sharing services are predominantly used by better-off citizens (Kim, 2015; Polydoropoulouet al., 2021; Kumar Mitra, 2021). Therefore, we can argue that the wider adoption of ACT technology will be affected significantly by financial barriers, as discussed in the following sections under different ACT deployment types.

This exclusionary character of ACT (and other transport modes) should be carefully considered as governments decide on their role in shaping ACT futures (Shiftan et al., 2021). Hence, this fundamental understanding shapes the analyses that follow.[2]

Deployment type 1: Privately-owned partially automated ACT vehicles

ACT technology is developing rapidly, but for the foreseeable future, the technology is still likely to require a driver to take control of the vehicle at some point. As long as this is the case, private cars remain accessible only to people who are able to drive. Hence, partially automated ACT vehicles are most likely to enter the market as regular, mostly privately-owned, vehicles (even if these vehicles might also be used in public transport and for sharing services). Here, we explore the possible contribution of such privately-owned partially-automated ACT-vehicles towards an inclusive transport system.

The introduction of limited yet reliable driver support may have some positive benefits. These driver support technologies are likely to enhance the mobility and accessibility of some drivers who find driving for long hours, over longer distances or in particular traffic situations stressful. ACT-technologies may support the elderly to continue driving for a longer period of time, as the technological support offered by higher automation levels (Level 3 or 4) may enhance their driving confidence (Parker et al., 2001). They may also benefit women drivers who tend to self-regulate more than their male counterparts (Gwyther and Holland, 2012).

On the other hand, non-users may be negatively affected by the deployment of private ACT vehicles. Disadvantages of ACT technologies may include increased car use, riskier driving behavior (due to behavioral adaptation), and additional risks during take-over requests, potentially culminating in increased danger for unprotected road users, i.e. pedestrians, cyclists and users of other small (motorized and electric) vehicles. Yet, ACT technologies also offer promise. Safety benefits could especially be reaped if vehicle speed were externally controlled, much like currently is the case for some types of micro-mobility (e-scooters) (Tice, 2019). Maintaining speed limits is a proven method for decreasing crashes and creating safer neighborhoods, with benefits for especially young children, youth, older adults and individuals with impairments.

From a sustainable urban development perspective, ACT technology may lead to increased car use, which may trigger a new wave of car-oriented development and possibly urban sprawl. Following the domino effect, new developments, especially in suburban and peri-urban areas, may grow without proper public transport, possibly leading to a reduction in accessibility to

[2] For a more extensive discussion on possible deployment types please see Martens et al. (2021).

opportunities for people without access to a car. Despite the efforts to reduce car ownership in cities worldwide, ACT technologies may increase the attractiveness of owning a car and could thus reverse the achievements of sustainable mobility thinking in recent decades.

This discussion brings us to the role of governments in harnessing the potential of ACT technology for a more inclusive transport future, as the introduction of low-level ACT vehicles may have detrimental equity impacts if left to the market. Governments could mitigate some equity implications by introducing some level of protection to unprotected road users through external speed control. Governments may make this obligatory and can introduce speed control on every new vehicle with ACT technology (Levinson, 2018). This would, in the long term, calm the traffic and support healthier, quieter, safer neighborhoods and cities. In addition, governments could control urban sprawl and require adequate public transport services for new urban developments, although current planning practices show that public authorities have been only modestly successful in this respect.

In conclusion, the introduction of privately-owned partially automated ACT-vehicles is unlikely to represent much progress towards an inclusive transport system. Some small share of users may experience enhanced mobility and, thus accessibility for certain trips. Unprotected street users, i.e. pedestrians, cyclists, and users of other light-weight vehicles, may benefit if ACT-technology is leveraged to control vehicle behavior in mixed traffic. The latter, however, will not occur automatically with the arrival of low-level ACT and would require government intervention.

Deployment type 2: Privately-owned fully automated ACT vehicles

Fully automated vehicles that do not require a driver, whatever the circumstances (i.e, Level 5 automation), remain the long-term promise of ACT technology. While fully automated vehicles are tested in different cities across the globe, their integration into regular mixed traffic will take a long time. Yet, full automation may take over the streets at some point in different built environment settings. Here, we explore whether fully automated privately-owned cars can contribute to a more inclusive transport system.

The introduction of fully automated ACT private vehicles is likely to increase the share of the population that can benefit from car-based mobility and accessibility, which can be seen as a step towards a more inclusive transport system, especially given the car-oriented built environments in cities around the world. Yet, these benefits may not be broadly shared among groups such as youth, mobility impaired, older adults, low-income persons and women.

As discussed earlier, low-income groups already have limited resources to purchase and maintain private cars, let alone own fully automated vehicles with most certainly higher market values. The possibility of imposing full automation on all private vehicles for safety reasons (Sparrow and Howard, 2017), should the technology be widespread in the future, may substantially increase the costs related to car ownership and may thus potentially increase the gap in private car ownership between low and higher-income groups (Mobile Lives Forum, 2021). Even if it proves that ACT vehicles are as affordable as regular private cars, introducing advanced technologies may increase the maintenance costs of second-hand cars, which is again relevant for especially low-income households (Currie and Senbergs, 2007). Therefore, insisting on a complete transition to fully automated private ACT vehicles may even increase the financial barrier for low-income households to own a (reliable) car, *ceteris paribus*.

For the younger populations who are financially dependent, the cost of ACT will likely be a challenge. In some households, this may be mitigated by sequential car sharing among household members, with youth using ACT vehicles under 'parental controls' (similar to internet and TV use). Such a model may increase the use of fully automated vehicles among some youth. Yet, sending vehicles back and forth between various users and destinations can come at a (substantial) cost and thus may be less prevalent than is sometimes assumed, especially outside urbanized areas where distances are long (Litman, 2020). Moreover, there may be privacy and safety concerns (Costantiniet al., 2020; Kyriakidiset al., 2020) for minors using fully automated vehicles.

While sequential sharing within households could work well in high-density urban areas due to shorter distances between destinations, ACT may increase traffic and replace much of the short-distance walking and cycling trips in urban areas, bringing about unsustainable mobility consequences. To some extent, this can be addressed by policies that restrict car use, such as parking management schemes, congestion charging schemes and the like.

One population group that may benefit (substantially) from fully-automated ACT vehicles includes individuals with motor-related, sensory-related, or cognition-related impairments as well as the elderly. In fact, it is estimated that fully automated vehicles may increase the demand among these populations, with estimates suggesting that total vehicle kilometers traveled could rise by as much as 14% (Harper et al., 2016). The benefits of ACT use will obviously only accrue for people who are technologically literate and can afford an ACT vehicle. Without subsidies, ACT vehicles will likely not be in reach for a substantial share of this group in light of the strong correlation between impairments and income (Kavanagh et al., 2015).

Women constitute a fourth group warranting explicit discussion. For women, both income and cultural norms limit car access (Beyazit and Sungur, 2019). Moreover, concerns over social safety restrict women's travel by other transport modes, especially in the evening and night hours and in particular areas. Although it is difficult to predict its impacts on social norms, fully automated ACT may increase the social safety of traveling for women, which is often seen as a barrier to employment by women and their spouses, fathers, or sons in patriarchal societies. Furthermore, especially in middle- to high-income households, fully automated vehicles may free women from some chauffeuring tasks, thereby reducing the burden related to the "mobility of care" (De Madariaga, 2013).

Taken together, the above suggests that the (market-driven) deployment of privately-owned fully automated ACT-vehicles may deliver a (modest) contribution to a more inclusive transport system. The benefits of improved mobility and accessibility are most likely to be reaped by a (substantial) share of people with a range of impairments (including some of the elderly), provided they have the financial means for private ACT vehicles and are sufficiently tech-savvy. Very modest benefits may be reaped by a small segment of youth. Given the expected costs of ACT-vehicles, low-income households have little to gain from a market-driven introduction of fully automated vehicles.

Deployment type 3: Sequential sharing of fully automated ACT vehicles

The third deployment type we explore is the sharing of fully automated vehicles. Fully automated ACT sharing may be realized on a large scale relatively faster than fully automated private ACT because its introduction is likely to be driven by large corporations. As is the case with today's car-sharing schemes, these companies will offer automated vehicles with a support service, which may take away some of the concerns regarding ACT use. Moreover, thanks to the recent proliferation of sharing systems, not only carsharing but also e-scooters, and their adaptability across many countries, the sharing culture that is already in place among some share of the population may assist in the early adoption of ACT sharing. Therefore, in this section, we discuss the ways in which sequential sharing of fully automated ACT vehicles could contribute to an inclusive transport system. We limit the discussion to *sequential* sharing, in which users travel individually in a fully automated vehicle but do *not* share their travel in ACT vehicles with unknown others.

Compared to the first two deployment types, ACT-based sequential sharing would bring more actors into the ACT eco-system (Shaheen et al., 2020). One of them is the large companies that have the (financial) ability to offer a diverse vehicle fleet, matching the fluctuating needs and wants of the population in a service area. Providing a range of vehicles and car-sharing subscription schemes could make ACT use economically viable and attractive. Yet, three barriers might still limit the use of ACT-based sharing services and, thus, the mobility and accessibility benefits it may bring to a range of population groups.

The first barrier is cost. Research shows that using regular, non-ACT car-sharing services is very modest among low-income households, mainly because of the high out-of-pocket costs for each trip (Clark and Curl, 2016; Forth Mobility, 2020; Shaheen et al., 2017). While an ACT-sharing services maybe cheaper, given possible efficiency gains in fleet maintenance thanks to automation, out-of-pocket costs for each trip are likely to remain substantial, which will limit its use among low-income households. These out-of-pocket costs are also likely to be an inhibiting factor for youth, as discussed above, suggesting that uptake of ACT-based sharing among youth is likely to be limited to children from higher income groups.

ACT-based sharing services may be attractive for a substantial share of people with sensory impairments, such as people with visual impairments. This group may indeed substantially benefit from ACT-based sharing services, provided the entire trip is taken care of, from the point of ordering an ACT-vehicle, to finding the ordered vehicle in the street, to wayfinding from the moment of exiting the vehicle. For people with other types of impairments, shared ACT-services may still present barriers related to the design of the vehicle and the streetscape. Some individuals may require assistance with getting in and out of a fully automated vehicle, especially if they are traveling with a wheelchair or other mobility devices. Companies that provide sequential sharing may support these specific users with dedicated personnel, either within vehicles or remotely, through differentiated vehicle designs based on needs. This support might also ease caretakers' concerns regarding the lack of control and supervision in a fully autonomous vehicle (Kyriakidiset al., 2020). This underscores that the introduction of shared ACT should be accompanied by regulatory regimes regarding vehicle design and support services to guarantee inclusive ACT deployment. The need for such regulations is underscored by experiences with ride-hailing services (Young and Farber, 2021).

The third barrier relates to the spatial and temporal availability of ACT-based sharing. Since sharing works especially well in areas of high demand, it is less likely that ACT-based carsharing will be readily available in areas and at times with low demand, such as lower-density areas (suburbs, peri-urban areas), small communities (small towns and villages), and possibly also low-income neighborhoods. While the possibly lower costs of operating and maintaining a shared ACT-fleet in comparison to a regular car fleet may (slightly) increase spatial and temporal availability, this will certainly not guarantee universal availability. Indeed, while in high-demand areas, an abundance of shared ACT vehicles may typically be expected, guaranteeing availability within minutes, the longer distances, in combination with a lower density of shared ACT vehicles, will result in a longer lead time in low-demand areas. This may lead to the well-known vicious cycle in the suburbs, peri-urban and rural areas, with people preferring private (ACT-) vehicle ownership, leading to less demand for shared ACT vehicles, potentially leading to less supply and longer waiting times, which in turn would further encourage private car ownership.

This brief analysis suggests that shared ACT-services, while theoretically holding some promise for the environment, sustainability, and livable cities (Nikitaset al., 2021; Marsden et al., 2019), have, at best, a modest contribution to an inclusive transport system. This points to a need to include the criteria of social sustainability – which includes addressing accessibility and existing social needs (Lopez et al., 2019) – in the governance of ACT deployment. From the groups poorly served by the current transport system, only some segments of people with impairments and some lower-income people may benefit from a shared ACT future, and only if governments guarantee and enforce the universal design of ACT-vehicles and related digital apps. Other groups, especially the majority of low-income households and people living in low-density areas, are unlikely to reap many direct benefits from ACT-based sharing. A shared future could, however, have an indirect positive contribution towards a more inclusive transport system. Potentially, ACT-sharing could lead to an increase in car-free and car-lite lifestyles in higher-density areas, with people combining ACT-sharing with walking, cycling and public transport(see the section on Singapore's transport strategy using walk-cycle-ride journeys). Such a development could strengthen an inclusive urban design and increase investments in 'active' and public transport modes, which in turn would improve mobility and accessibility for people with no or limited access to a (private, ACT) car, with possible impacts also beyond highly urbanized areas.

Deployment type 4: ACT-based public transport

In this section, we explore the potential contribution of ACT-based public transport to an inclusive transport system. In contrast to the sequential sharing of ACT-vehicles, ACT-based public transport includes all services that may be used by multiple non-related people at the same time. 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.

Low levels of automation in public transport, i.e. Level-2 and Level-3, which are already widely available (e.g., adaptive cruise control, lane keeping, and acceleration and braking assistance), can reduce operating costs as a result of reductions in fuel use and wear and tear on vehicles (Wadud, 2016) and can also enhance passengers' on-board comfort, with (marginal) positive benefits for all road users (Guo et al., 2020; Guo et al., 2021). Level-4 automation would bring even further cost savings.

Fully automated public transport (i.e., Level 5) opens up an entire range of new possibilities that partial automation cannot bring. The primary benefit would be reduced labor costs, which currently account for about 40%-70% of public transport operational costs in developed countries (Tirachini, 2020). Beyond mere cost savings, eliminating the need for a driver or operator opens up possibilities to radically re-envisage public transport. Although job losses would be inevitable in the short-term, new jobs would be expected to emerge with new demand in AV-related services and manufacturing. The unemployment rate gap in the early years of ACT deployment may be lower than anticipated (Groshen et al., 2019). In the absence of the driver, the introduction of Level-5 automation can enhance the ease of use and operation of on-demand services.

Once full automation becomes practically and financially feasible, the most likely model to evolve would consist of both regular schedule-based public transport and on-demand services (Martin, 2019). Assuming no change in existing budgetary limits, full automation can be employed to improve scheduled public transport services by offering improved frequencies and service hours and expanded coverage. These regular services may be complemented with on-demand services (on-vehicle attendants rather than drivers), especially in low-density neighborhoods, peripheral areas and/or where the topography poses challenges for the elderly and individuals with impairments (Patel et al., 2021). On-demand feeder services are already offered in some locations and present a suitable operational model for fully automated vehicles (Böschet al., 2018). They are also part of Singapore's policy, where on-demand services complement mass public transit. For both regular and on-demand services, full automation may also improve passenger comfort (due to smoother vehicle operation) and reliability (due to automated control of on-schedule operation). In all cases, these advancements are likely to benefit people who are currently poorly served by the existing transport system (Etminani-Ghasrodashti et al., 2021). The improvements may increase ridership among these population groups, as well as among people now using other means of transport, potentially triggering a virtuous cycle.

Based on the discussion of the four deployment types, Table 1 provides an overview of possible government interventions that may steer the different deployment types towards an inclusive transport system (see also Cohen and Cavoli, 2019). It can be noted that for privately-owned ACT vehicles, there are substantially fewer policy tools available that can be applied to achieve broad-based inclusivity, whereas, in the case of ACT-based public transport, this possibility is maximized.

Table 1: Possible policy interventions to steer ACT towards inclusivity

Areas of intervention	Policy	Privately owned partially automated ACT vehicles	Privately owned fully automated ACT vehicles	Sequential sharing of fully automated ACT vehicles	ACT-based public transport
Vehicle and system design accessibility	Speed limit for ACT vehicles	√	√	√	√
	Universal design of vehicles			√	√
	Inclusion of additional paratransit fleets			√	√
	In-vehicle security measures (for minors, emergency situations)			√	√
	User design interfaces on apps and vehicles (including for blind, hearing impaired users, etc.)	√	√	√	√
	Ability to order vehicles without using digital technology (e.g. through telephone)	√	√	√	√
Urban design accessibility	Universal Design for infrastructure (drop-off points, stations, curb design, unobstructed pavements, etc.)	√	√	√	√
Spatial planning accessibility	Restricted use in dense urban areas	√	√	√	
	Ease of transfers: Incentivize connectivity to (and across) public transport modes	√	√	√	√
	Ensure provision of service to urban peripheries, low-income neighborhoods, etc.			√	√
Economic tools for accessibility	Utilizing cost savings to improve service quality, especially for inclusivity				√
	Enhance affordability through (targeted) subsidies			√	√

Source: The authors

Singapore case: ACT-based public transport in action

Given the potential of ACT-based public transport to contribute to a more inclusive transport system, one question emerges: how governments can promote the adoption of ACT-technologies, especially in existing and new public transport operations? Hence, in this section, we explore how Singapore, one of the leading countries in ACT-readiness and ACT-experimentation, is seeking to leverage ACT-technology to enhance its public transport system.

Singapore's transport vision

A 2018 report by McKinsey finds that Singapore's public transport is among the top-ranked cities, scoring highly in all five key dimensions of availability, affordability, efficiency, convenience and sustainability (Knupfer et al., 2018). Singapore's pursuit of a high standard of public transport complements its long-standing policy of restricting private car ownership and use. Coordinated planning of land use and public transport infrastructure has served to optimize density around such infrastructure. This helped to secure high usage of public transport services and has resulted in compact and efficient land use. Singapore's public transport provision consists of a well-connected and growing metro network – the Mass Rapid Transit (MRT) – and a comprehensive bus network. In addition, taxi, ride-hailing and ride-sharing services are provided by the private sector and regulated by the government.

Singapore's vision for the future transport system is laid out in the Land Transport Master Plan 2040 (LTA, 2019). This plan envisions a convenient, well-connected and fast transport network through inclusive infrastructure. This vision is expressed through the goals of "20-minute towns" and a "45-minute city", jointly referring to a transport and land use system that allows people to complete most journeys in those timeframes using walk-cycle-ride combinations. These two goals are part of the plan's "transport for all" vision, which focuses on inclusive accessibility to everyone (LTA, 2019). It is upon this foundation and emphasis on public transport that Singapore considers its ACT transport strategies.

ACT-technologies are being considered as part of this vision for a car-lite future and as one of the ways to address demographic, urban and transport challenges facing Singapore. These challenges include an aging population, a shortage of operators for buses and other vehicles, and the need for more efficient use of land reserved for transport, given land scarcity. The aging population requires a rethink about how public transport can be made accessible for all, both in terms of physical distance to public transport stations and stops, as well as in vehicle design.

Given these challenges, high-quality public transport is to be enhanced by automated mobility technology to achieve greater efficiency and connectivity, thereby delivering greater accessibility and convenience for everyone. ACT is expected to improve the already high-quality public transport system in several ways: optimization of schedules for service quality improvement; broadening choices for travelers based on their needs and preferences for travel modes, cost, and environmental footprint of their trips; enhancing accessibility through greater flexibility of timings and drop-off and pick-up locations, shorter waiting and travel times, extending reach and service timing of transport services; and addressing supply-demand mismatches of fixed schedule services on low demand routes such that service is available only when needed. Given these potentials, Singapore is investing substantially in ACT-based public transport (see LTA website: http://www.lta.gov.sg/).

Promoting ACT-based public transport

Singapore sees the potential of ACT technologies in a range of sectors, including last-mile freight delivery and surveillance. Among the many initiatives is also a concerted effort to explore and test the potential of ACT-based public transport. Singapore has developed an AV deployment roadmap with three phases for the introduction of automated (public) transport: test-beds, town-deployment, and country-wide deployment. The roadmap is supported by abroad ACT-ecosystem that seeks to gradually introduce ACT-based public transport. As a key part of the ACT-ecosystem, Singapore's Land Transport Authority (LTA) has active cross-sector experimentations supporting the development of ACT-based public transport. These include:

- Collaborations with industry partners to test shared, on-demand, first-and-last-mile and intra-town self-driving transport concepts.
- Partnership with the Energy Research Institute at the Nanyang Technological University (ERI@N) to develop automated bus technologies, including self-driving bus trials for fixed and scheduled services (LTA, 19 Oct 2016).
- Collaboration with ST Kinetics to develop automated vehicle technologies for two 40-seater electric buses to serve fixed and scheduled services for intra- and inter-town travel (LTA, 10 Apr 2017).

Guidelines and regulations

A sound legal framework is considered essential in creating and maintaining trust among the wider public regarding ACT-trials. Hence, the trialing of automated vehicles in Singapore, whether in the public transport system or otherwise, needs to adhere to mandatory regulations such as having comprehensive insurance coverage; having a 'black box' data recorder that collects video footage and other data that can assist in investigations in the event of accidents; and real-time transmission of location and operational status to LTA's ACT vehicles monitoring system (LTA website).

Singapore has also established a comprehensive set of national guidelines called the Technical Reference (TR 68) to support the safe deployment of automated vehicles. First published in 2019 and revised in 2021, the guidelines cover four aspects: basic behavior, safety, cybersecurity principles and assessment, and vehicular data types and formats (LTA, 3 Sep 2021).

Trials

Singapore has conducted various trials with ACT-based public transport, using a range of vehicles in different settings such as business parks, university campuses, and leisure destinations. Notable examples of trials with regular passengers include:

- Fully automated shuttles with a capacity for 12 people were trialed in 2019 for a year at the National University of Singapore. The shuttles have built-in ramps and can accommodate a wheelchair.

- On-demand driverless minibuses and shuttles were trialed in 2019 for three months on the island of Sentosa.
- Trials for on-demand 10- and 26-seater driverless buses for fare-paying travelers were carried out in 2020 in the Singapore Science Park 2 and Jurong Island.

Larger scale trials for dynamically routed and on-demand busses and shuttles are planned for three areas: Punggol, Tengah and the Jurong Innovation District. These are, respectively, an established residential district, a greenfield residential district, and a business park district. Since 2019, the testing area has been gradually expanded to cover the entire western region of Singapore, consisting of more than 1,000km of public roads.

Research

A final component of Singapore's ACT-ecosystem consists of (academic) research. Singapore's focus on applying automated mobility technology in public transport has generated a stream of research. Some of these studies have analyzed the interplay and combination of ACT-based public transport with other modes towards better coordination across transport system services, including first and last-mile connectivity (Mo et al., 2021; Chong et al., 2011). For instance, Shen et al. (2018) find that preserving existing high-demand bus routes while replacing low-demand bus routes with shared AVs potentially enhances service quality and efficiency, consumes fewer road resources, and is financially sustainable. Another subset of studies focuses on rider-oriented design aspects of ACT-based public transport (Cornet et al., 2019). Ongelet al. (2018) examine the use of an automated semi-rapid transit system with platooning capabilities that also incorporates Universal Design Standards to improve the service quality and efficiency of the transit systems. The study by Lim et al. (2021) explored the benefits of a "virtual companion" communication system for individuals with autism and disabilities and proposed ways on how it can be used in ACT-based public transport. Yet another subset of studies on public preference and acceptance of ACT-based public transport (Chnget al., 2021; Kurniawan et al., 2021) provides directions for designing ACT systems that are more responsive to user requirements.

Lessons

The Singapore efforts underscore that more development and testing are necessary before ACT-based public transport can be offered on a wider scale. Singapore holds an interesting balance between maintaining flexibility towards ACT-based transport innovation and experimentation and being intentional in directing some of these efforts to respond to its transport, demographic and societal challenges. Its public goals of inclusivity and accessibility through a high standard of public transport provision and a "car-lite" future shape its adoption of ACT-transport. Arguably, this focus on public transport, in effect, prioritizes a range of public values such as equity accessibility and civic life (all relating to social sustainability), and also environmental sustainability, well-being and quality of life (Docherty et al., 2022; Soh and Martens, 2023). This Singapore study provides an example of placing public goals front and center in considering future mobilities rather than enabling the introduction of market-driven technologies that mostly benefit people with the ability to pay.

Discussion and Conclusions

In this chapter, we investigated whether or not ACT-technologies could provide enhanced mobility and accessibility for individuals who tend to be relatively poorly served by the current transport system. We employed a human-centric approach focusing on the least represented groups in society and the ways in which they could benefit from more widely available ACT-technology. We explored the potential contribution of different ACT 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 different ACT levels, distinguishing between partial automation (Level-4 or lower) and full automation (Level-5). Finally, we have reviewed the policies undertaken in Singapore as good practices that help the city attain its goal of a more inclusive transport system.

We argue that the ACT deployment type is definitive in generating sustainability and inclusivity benefits. Partial and full automation of private vehicles may generate more environmental burdens by encouraging car use and leading to more car-centric built environments. At the same time, especially full automation may enhance inclusion by making private car use more available to individuals who lack the ability to drive a conventional car. Yet, the anticipated costs of private ACT as well as possible legal requirements will limit the benefits to only a small proportion of people underserved by existing transport systems. Hence, both partially and fully automated private ACT vehicles are unlikely to serve middle to low-income populations living in less-developed parts of the world.

Fully automated sequential sharing services, on the other hand, may provide larger benefits towards an inclusive transport system. However, if the delivery of these services is left to the market, they will remain too expensive for a substantial share of the underserved population, thus raising equity concerns. Moreover, they are likely to be offered mainly in high-demand areas, which are often already relatively well-served by cycling infrastructure and public transport services. Benefits could be more widely spread if such sharing services were regulated to guarantee inclusive design and subsidized to guarantee availability and affordability to a wider share of the population.

Our analyses revealed that most environmental and social sustainability benefits are likely to accrue when ACT technologies are adopted in public transport operations. Provided public transport budgets remain intact (or are expanded), modest quality benefits may already be reaped if current driver support 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, which may reduce costs, improve user comfort, and reduce vehicle emissions (Cohen and Hopkins, 2019; Thomopoulos et al., 2021). Full automation may further increase the availability and quality of public transport, in terms of frequencies, operating hours, and coverage area, as well as convenience and comfort, through a combination of schedule-based and complimentary on-demand services. These improvements may also lead to a virtuous cycle of mutual feedback between increased service, ridership and revenues, with multiple social and environmental sustainability benefits. Given that the other ACT deployment types present significant use barriers for a range of population groups, we conclude that ACT-based public transport offers the most potential towards an inclusive transport system. While this holds for developed car-oriented societies, it is also the most promising direction for emerging economies and countries of the Global South, where the vast majority of the population is unlikely to have access to a private (ACT) vehicle in the foreseeable future.

The kind of ACT-based future transport system that will emerge will depend not so much on technology but on policy. The case of Singapore underscores the potential role of governments in leveraging ACT-based technologies towards a more inclusive transport system. The Singapore experience is comparable to other experiments worldwide, showing that fully automated public transport is still some years away. Yet, Singapore stands out in two respects. First, it is moving towards a comprehensive ACT ecosystem, which provides a rich infrastructure for ongoing experimentation with ACT-based (public) transport. Second, and more importantly, it is committed to employing this ecosystem for the greater public good rather than merely for private profit.

Singapore is experimenting with a range of technologies, such as precision docking, platooning and real-time fleet management, all of which may improve the quality of public transport services. While these are small steps, they can contribute to a more inclusive transport system by improving the cost balance of public transport. Small improvements may attract new riders and thus increase revenues, as well as reduce operational costs. If these revenues and reduced costs are funneled back into the public transport system, modest ACT may well assist in creating a virtuous cycle and thus contribute to a more inclusive transport system.

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