COULD AUTONOMOUS VEHICLES HELP CITIES TACKLE TRANSPORT EVILS AND ACCELERATE THE TRANSITION TO SUSTAINABLE MOBILITY?

A GUIDED TOUR OF THE SOCIAL SCIENCE LITERATURE FOR PLANNERS, URBAN INNOVATORS AND DECISION MAKERS

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Photo: Ditte Bendix Lanng

INTRODUCTION

Planners, urban innovators and decision makers across the world have begun to ask themselves the question: What might autonomous vehicles entail for cities and citizens? Concurrently, the same cities and professionals are struggling to determine viable paths to more sustainable urban transport.

Of the recent research on autonomous vehicles, only a small part is based on social science. Three-quarters of the research consists of contributions from mathematics, computer science and engineering. Although this research is groundbreaking and valuable, it has limited applicability in terms of guiding the policies that will address the mobility challenges of the future.

In order for planners and authorities to navigate the many uncertainties that arise in the encounter between a hypothetical disruptive technology and the complex material, economic and social considerations that characterize urban policies, social science is needed.

In this report, we try to summarize the main views and findings in the social science research on autonomous vehicles and their use in cities.

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WILL AUTONOMOUS VEHICLES HELP CREATE INCLUSIVE, SUSTAINABLE CITIES?

The autonomous vehicles (AVs) of the future have long been announced as imminent. For planners, citizens and mobility researchers alike, the situation is such that we cannot say when fully autonomous cars will become a reality, we do not know how quickly they might eventually be phased in, and we do not know the relevant size or use cases for such a car fleet. Despite the temporal uncertainty, the prospect of AVs is reshaping conversations about urban innovation and planning.

If introduced at scale, AVs will in all probability place new demands on urban infrastructure and transport regulation. This necessitates that planners, urban innovators and decision makers be equipped to make decisions about whether AV technology can help create the urban spaces and transport services that support cities' needs and priorities.

Mobility scholar Mimi Sheller sounds a warning about the transition away from carbon dependence and the polluting technologies that power vehicles today. She writes that even if a green transition does take place, we may find ourselves depending on other technologies that are perhaps 'green' – but also culturally and socially problematic in ways that are even more troubling than current technologies.[1]

THE AV RESEARCH LITERATURE

While the engineering literature is well developed, the social science insights into automated transport have lagged behind and are only now emerging[2] – giving planners and educators a short time to develop a coherent understanding of the potential benefits and risks.

Scientific studies on the potential of AVs range from computer models exploring theoretical potentials in a virtual reality where all modelled road users are digitally connected autonomous cars to conceptual discussions of AVs' implications for messy urban environments where space is scarce and contested and where human behaviour and the presence of vulnerable road users – cyclists, pedestrians, children and city dwellers who live their lives in the city – create a complex social environment that AVs would need to navigate in order to become an integral part of city traffic.

THE CHALLENGE OF IDENTIFYING STABLE, RELIABLE POINTS OF REFERENCE

These different types of studies represent knowledge at dissimilar levels of analysis and contribute findings that might lead to conflicting conclusions.

Architect and urban planner David Rouse writes in a comment that the research literature allows for utopian as well as dystopian imagined futures depending on how AVs are deployed.

> 'In the utopian scenario, the vehicular fleet consists of shared electric AVs, leading to fewer cars, reduced congestion and carbon emissions, and improved air quality, all accompanied by compact development patterns in which walking, biking, and transit thrive.
>
> In the dystopian scenario, the vehicular fleet consists of privately owned, gasoline-powered AVs and zero-occupancy ('zombie') cars roam the streets, resulting in increased congestion, severe reductions in other transportation modes, deteriorating air quality, and more sprawl as people choose to live in the hinterlands and have their cars drive them to work.'
>
> David Rouse, 2019, p. 2

'PERHAPS THE QUESTION SHOULD BE "WHAT COULD AVs LOOK LIKE IN OUR CITY?" '

The literature points to a number of areas where autonomous cars, under the right circumstances, can solve some of the challenges of the current transport system, for example, traffic accidents caused by inattentive or risk-prone drivers, limited mobility for citizens who cannot drive a car themselves, and the need for cheaper and less cumbersome public transport. Practical experience with AVs is still very limited, and the theoretical prospects are hypothesized across publications and fields, while rigorous empirical data to nuance and concretize the conditions most likely to foster the realization of the hypothetical potential are only slowly emerging.

However, as many authors point out, benefits are not achieved in a vacuum but in specific contexts with concrete social, cultural and geographical characteristics. In such complex relational systems, benefits cannot be meaningfully described as the universal and predetermined effects of a single technological innovation but must be seen in the context of social learning and systemic transformations of existing relationships and dependencies in the broader sociotechnical system.

In contrast to descriptions of AV technology as a means of solving problems, there are critics who argue that industry stakeholders present the introduction of AVs as a natural and inevitable matter of course, as a goal in itself, and as more straightforward and risk-free than experience so far suggests.

A MEANS, AN END OR A MESSY ENDEAVOUR – AV TECHNOLOGY IS NOT YET SETTLED

In the words of science and technology researcher Jack Stilgoe, it would be wrong to describe AV technologies only as either a means or an end: '[technologies] create as well as solve problems and they allow for the emergence of unanticipated futures.'[3]

"I would urge us all to remember that 'AVs' are not yet settled. The interpretive flexibility of this technology is an opportunity for planners to get involved in defining and shaping rather than just using this technology. Perhaps the question should be 'What could AVs look like in our city?''

Jack Stilgoe in Porter et al., 2018, p. 777

'AUTONOMOUS VEHICLES' is a widely used, nonspecific term for vehicles that are automated at some level, but AVs' implications for cities depend on specifics in the implementation related to e.g., ownership, ridership and power source. Therefore, it is essential to be specific about which type of AV is referenced[4], for example:

CONNECTED[5]: Connectivity typically implies Vehicle-to-Vehicle (V2V) technology where vehicles are aware of and/or communicates with each other and Vehicle-to-Infrastructure (V2I) technology where the car can analyze and respond to digital signals in its surroundings[6].

ELECTRIC: Some authors specify that they are referencing AVs that are electric (EAV)[7], but power source is often not addressed.

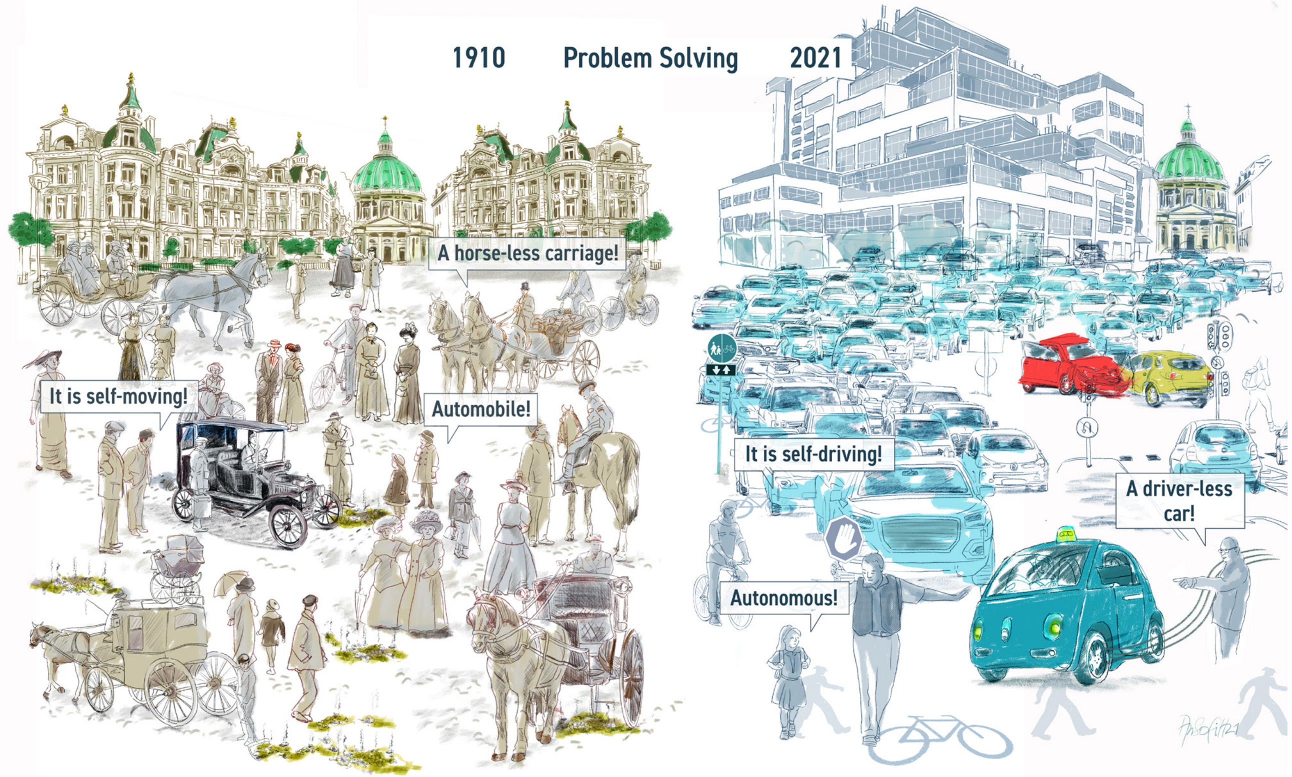
SHARED: Some researchers discuss AVs impacts based on whether they are implemented as shared (SAV), rather than privately owned/exclusively used vehicles[8]. SAV can mean shared ownership or shared ridership - leading to different effects.

COULD AVs SIMPLY BE THE NEXT VERSION OF VEHICLES INUNDATING THE CITY ...

A productive point of departure for discussing AVs' urban implications is, in most places, the car-based city. A rough characteristic of the car-based city is that the car allows us simultaneous swiftness, comfort and flexibility in moving anywhere at any time. However, the dominance of cars also involves unsustainable practices, congestion, mobility injustices, serious health issues, fatalities, spatial inequality and sprawl.

AUTOMOBILITY 'LOCK-IN'

Sociologist John Urry has written about the automobility system.[9] He describes it as a socially and economically locked-in system in which social practices, markets and economies, built environments (cities), and behaviour sustain and reproduce what could be called a 'car system'. Billions of actors and processes related to technological developments, lifestyles, markets, industries, and land uses are closely connected to automobility, forming a sociotechnical system that is relatively stable – or 'locked in'– and therefore, under current conditions, close to impossible for societies to break away from. Suburbanization, or increased commuting distance, is an example of how widespread access to cars has shaped automobility lock-in and durability.[10]



By Anne-Sophie Helger. Copyright: Ditte Bendix Lanng

At the beginning of the 20th century academics and technologists welcomed the cleanness and controllability of the first stages of motorized road transport. These horseless carriages seemed to promise to solve the pressing transport issues of that time: No more need for shipping fodder and manure or for the smelly and demanding horses.
However, while the replacement of horsepower with gasoline led to cleaner more efficient cities, the emergence of the car-centric city did not fundamentally alleviate cities´ growing pains. On the contrary, cars brought new and huge problems for the functionality, sustainability and livability of cities.

… OR WILL THEY PROVIDE AFFORDABLE, INCLUSIVE MOBILITY EVERYWHERE AND FREE UP URBAN SPACE IN THE PROCESS?

A central focus for a large part of the social science literature on AVs is the dynamics of how AVs will affect and possibly transform the complex sociotechnical system that urban mobility constitutes. AVs can be understood to possess transformative potential because the value they offer resonates with stresses in the existing system and hence may result in the transformation of otherwise locked-in practices.

AVs are, in parts of the literature, imagined as a replacement for – or a supplement to – existing forms of mobility. By some, they are imagined as potential solutions to many of the challenges – or systemic stresses – related to the car system. Examples of such potential AV benefits range from the alleviation of congestion and pressure on road capacity to reductions in costs, mobility poverty, traffic accidents, energy consumption and space scarcity in cities.[11]

At this point, none of the proposed benefits of AVs have been demonstrated under real-life conditions as the technology is not yet mature enough to be implemented at scale or in complex urban environments. Because of this, the potentially transformative innovation that AVs represent is, as Jack Stilgoe pointed out, still being worked out in a process that is open to other actors in the sociotechnical system, such as planners and urban innovators.

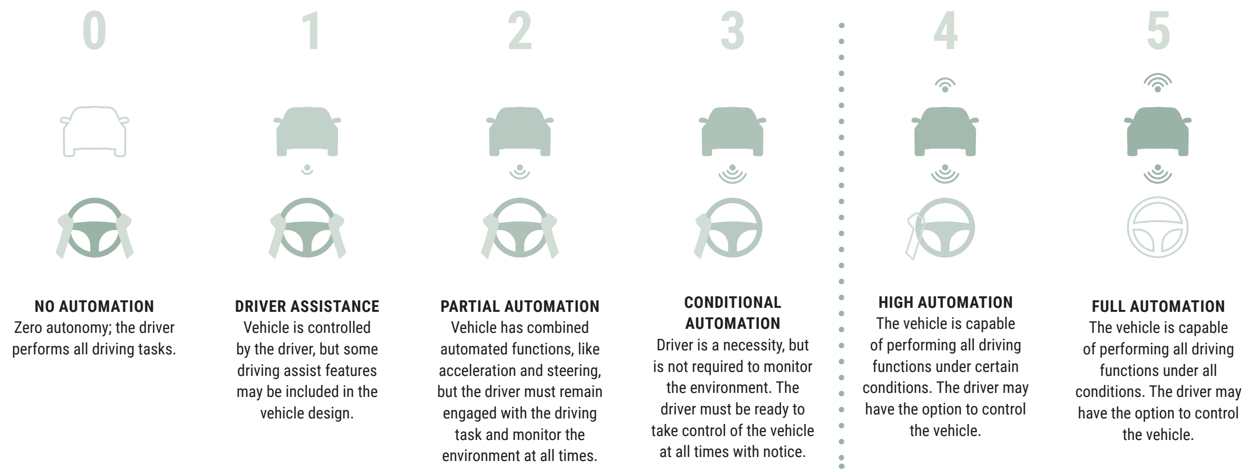
UNCERTAINTY AND PLANNING

While it is not possible to predict the specific implications of AVs for cities, it is possible to review the effects and concerns proposed in the literature in order to describe a spectrum of plausible outcomes related to specific problems in the existing system.

AUTONOMOUS technologies are divided into so-called SAE levels on a scale from 0 to 5. SAE stands for 'Society of Automotive Engineers', and the SAE definition is frequently used to indicate the degree of vehicle autonomy. It is only at levels 4 and 5 that a vehicle can function without a driver on board, and it is these two levels in particular that are associated with the disruptive potentials addressed in this text.

The following pages discuss five such spectra, focusing on:

1. Infrastructural benefits and road capacity
2. Reduced parking and the use of public space
3. Environmental impact and energy consumption
4. Transport justice and social inclusiveness
5. Traffic safety and new systemic risks



By Anna Nurup & Fredrik Busk. Copyright: Ditte Bendix Lang

1. INFRASTRUCTURAL BENEFITS: COULD AVs REQUIRE LESS ROAD SPACE AND IMPROVE TRAFFIC FLOW?

Photo: Creative Commons CC0 / Pxhere

When looking at the allocation of space in cities today, we see that much of it is taken up by cars and car infrastructure. Despite this, traffic congestion is a problem in most cities, and efforts to reduce demand or improve road capacity and manage traffic flows are a crucial part of city planning and governance.

AVs' SMALLER SPATIAL FOOTPRINT

Researchers suggest that AVs might reduce the road space needed for each vehicle in traffic. The improved utilization of road space is made possible by the fact that AVs can drive closer together because the reaction time of the human driver is taken out of the equation and the digital communication between vehicles and between vehicles and infrastructure facilitates an optimized flow of traffic.[12] Generally, the literature suggests that AVs are likely to have a positive impact on road capacity.[13] Further, AVs do not need traffic signs, road markings or traffic lights. Ideally, this would lead to more road space being available for cyclists and pedestrians or allow the reallocation of road space for other purposes. Also, the aesthetics of cities would potentially be less dominated by car traffic-related practicalities.

COMPLICATING FACTORS

Many of these potentials are based on the premise that AVs are flawlessly digitally connected – something that will require governments and AV manufacturers to agree on common communication standards and protocols.[14] Also, the potentials are based to varying degrees on the assumption that all or a large proportion of vehicles are AVs and that vehicles have no interaction with non-connected road users like pedestrians or cyclists.

If, instead, AVs did interact with other road users in such a fluid environment, they would need to stop when a human moves in front of them. If vehicles were to make frequent stops to allow cyclists and pedestrians to cross, this would interfere with the digitally optimized flow of traffic and reduce the efficiency of the system.[15]

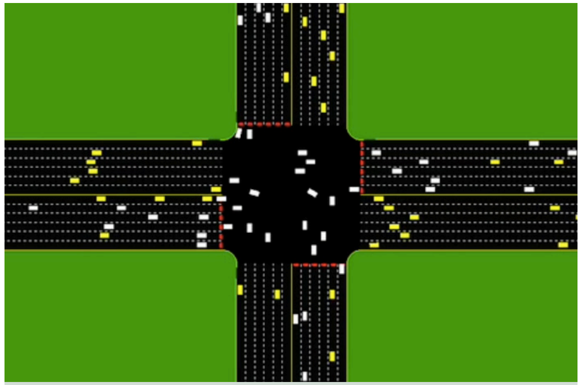


Illustration: AIM-project / University of Texas at Austin

Researchers from the University of Texas at Austin have developed a virtual system for autonomous intersection management that allows AVs to cross an intersection in both directions at the same time.

AV INFRASTRUCTURE COULD INSPIRE A RENEGOTIATION OF CITIZENS' ACCESS TO URBAN SPACE

Depending on how AVs and humans interact, planners might need to separate AVs from pedestrians and cyclists to ensure safe and optimized traffic, creating dedicated roads where only AVs are allowed.[16]

Transport researcher Todd Litman, however, speculates that such separation could restrict access for human drivers, cyclists and pedestrians and that these non-AV users would likely question how many resources should be dedicated to AV infrastructure.[17] Alternatives might include building fences or borders or moving AVs underground like the metro system. However, driving through an underground tunnel could reduce the value of travel for AV users and would reduce the flexibility of door-to-door transportation.

James Harris, a manager in sustainable urban planning, argues that roads reserved for AVs might not be compatible with a city infrastructure that, he suggests, should prioritize active and public transportation.[18] Planners must consider whether prioritizing AVs might benefit only some citizens and whether doing so risks maintaining or even worsening accessibility and safety challenges. As academic and mobility professional Robert Martin points out, the infrastructure built for AVs will define their urban effects, and the visions for AV infrastructure vary depending on the incentives of the actors involved in the decision-making process.[19]

On the grounds of some of these challenges, Litman suggests that AVs will only have modest impacts on road capacity within the next couple of decades, and he asserts that large changes in our road infrastructure should not be promoted until the benefits of AVs have been demonstrated.[20]

In sum, the research suggests that there is a potential for increasing road capacity when studying AVs in a situation where AVs are dominant. However, for this potential to translate into benefits in cities, planners will need to consider the entire system and all road users – a process that could open up conversations about how access to urban space should be distributed and negotiated in future urban mobility systems.

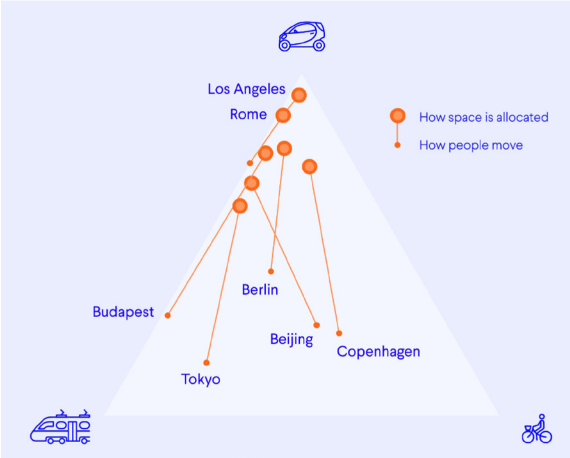


Illustration: Michael Szell

MOBILITY TRIANGLE:
To illustrate how cars are prioritized in cities, urban data researcher Michael Szell mapped spaces allocated to different mobilities and compared them using modal share statistics. He found that in large cities such as Berlin, Tokyo and Budapest, the majority of citizens use active and public transport, while a significant part of the urban space occupied by transport is mainly used to accommodate cars (including parking).[21]

2. POTENTIALS FOR FREEING UP URBAN SPACE – COULD AVs REDUCE PARKING IN CITIES?

Parking requires considerable space in cities. According to most studies, AVs have the potential to reduce the need for parking in cities, but only provided that the fleet is shared.[22] A shared fleet implies that users do not have access to a specific, private vehicle but can request service, for example via an app.

FACTORS THAT COULD REDUCE THE NEED FOR PARKING

If AVs were shared, there would be fewer vehicles in need of parking.[23] AVs could move across the city to pick-up spots for customers, thereby removing the need for parking as we know it. They could park closer together and could also park outside a city, entering it only when in active use.[24] In a scenario where AVs are deployed alongside human-driven cars, transport modellers Zhang and Wang (2020) found that parking could increase in suburbs and decrease in cities.[25]

REPURPOSING OF SPACE

The parking space freed up in cities could be used for greening them, for active modes of transport and for other urban purposes.[26] Urban planning researchers Tan Yigitcanlar, Mark Wilson and Md Kamruzzaman speculate that fuel stations could also be removed if AVs were electric and charged at parking areas. Further, they imagine that if AVs became shared and people gave up their privately owned cars, then garages, driveways and cul-de-sacs could change into community-building environments in the suburbs.[27] Land use for motels and pitstops might become obsolete, as people can sleep, work and rest in an AV.[28]

AVs WILL NEED FACILITIES TOO

To understand the implications for cities, some authors emphasize that parking in cities is not just storage for vehicles but also reflects the logistics of inner-city traffic in other ways that affect the facilities that AVs may need, if, for example, consumer behaviour is factored in.[29] A shared fleet of AVs would entail a need for many pick-up spots, and high demand may require large spaces in the city where AVs can wait to pick up customers, requiring perhaps even more space in crowded areas than we see today.[30] If people can choose to pay to have an AV waiting for them outside a shop, they may do so in order to get some of the benefits of a private car – like leaving the groceries there while running an additional errand.

Photo: Hannah Villadsen

CAR USE in cities is increasingly being regulated by restricting access to parking. For such an approach to be efficient and politically feasible, attractive mobility alternatives must be made available to citizens. Some suggest that autono-mous mobility on demand could offer such an alternative.

SHARED VEHICLES AND REALLOCATION OF PARKING SPACE

The demands that the parked cars put on city centres is well described and not new. Urban planning researcher Donald Shoup describes how the rise in car ownership in the 1930s resulted in large on-site parking lots in or near buildings[31]. Car parking required more space than previous transport modes and in cities throughout the world squares and avenues have been converted into parking areas.

WILL CONSUMER PREFERENCE FOR PRIVATE CARS SHIFT TO SHARED AVs?

The reduction in parking-space will largely de-pend on whether AV ownership is shared or private. If a significant share of riders prefers owning a private AV environmental researcher Hamish Cambell suggest that we might not see any of the benefits[32]. Private AVs could park outside cities, but a scenario where cars enter as well as leave cities to park during rush hour would result in an increase in congestion and overall vehicle kilometres travelled.

Questionnaire surveys studying potential consumers' attitudes find that most respondents expect to own rather than share an AV[33]. Fur-ther, cars are used for all sorts of activities that would not be appropriate when sharing cars e.g., transporting messy tools, storing gym clothes etc.[34], meaning that reducing car ownership to the function of moving from A to B may not adequately capture consumers' motivations[35].

'If a policy is judged by its consequences, off-street parking requirements are a catastrophe.'

(Shoup, 2018, p. 13)

Photo: Creative Commons CC0 / Pxhere

INFRASTRUCTURE supporting automobility has been creating as well as responding to demand.

3. ENVIRONMENTAL IMPACT OF AVs – ARE AVs A GREEN TECHNOLOGY?

Cities and municipalities are increasingly acting as core players in reducing CO_2 emissions and particulate matter from traffic. Depending on how AVs are deployed, they may help or delay the transition to a sustainable transport system. AVs' environmental impact depends mainly on two factors: Whether they are electric and whether they reduce or increase the overall demand for car travel.[36]

ELECTRIFICATION

It is not generally assumed in the literature that automation will automatically lead to a larger proportion of electric vehicles, but the environmental implications of AVs are – as is the case with road transport generally – to a large degree determined by whether or not their operation is based on renewable energy.

Photo: Creative Commons CC0 / Pxhere

AV EFFICIENCY

AV researchers William Morrow and colleagues list factors that might limit AVs' energy consumption compared with conventional vehicles.[37]

Firstly, if AVs have a much lower or no risk of traffic accidents, vehicles can be lighter and thus would require less energy per kilometre driven. This potential, however, will likely only be relevant in a situation where AVs and non-AVs do not mix.

Secondly, as AV engines are regulated automatically, the energy loss that occurs when human drivers use gears, accelerators and brakes suboptimally can be eliminated.

Further, households may currently purchase vehicles that are larger than daily use necessitates in order to be able to use the car for multiple needs. Autonomous car-sharing arrangements could facilitate the appropriate dispatching of a fleet of different vehicle types, i.e. small pods to carry individuals and larger cars to meet other travel needs.

Finally, AVs do not have the same limitations in relation to handling complex information, so knowledge about queuing, optimal route planning and speed can be fully utilized to limit energy consumption.

David Burton / Alamy stock photo

AUTOMATION does not presuppose that vehicles are electric.

ENERGY CONSUMPTION AND PROBABLE EFFECTS ON VEHICLE TRAVEL DEMAND

The most uncertain, and the most significant, determining factors for AVs' environmental impact are the effects of the choices made by consumers, businesses and legislators.[38] It is possible that travel time will be perceived as less of a burden, meaning more people might be willing to travel longer distances. This could lead to changed settlement patterns, more dispersed land use (urban sprawl) and ultimately more vehicle kilometres driven.[39]

Studies of an urban autonomous mobility service requested via an app indicate an increase in vehicle kilometres driven in cities compared to the status quo (when the same trips are taken) because vehicles would need to travel unoccupied between customers and the fleet would have to adjust vehicles' locations to reduce waiting times (fleet balancing).[40]

CURRENTLY UNDERSERVED GROUPS COULD INCREASE TRAVEL DEMAND

Disabled people or children, who are currently excluded from travelling by car on their own, would be able to use the service. This could result in a more inclusive form of automobility but would likely also lead to a rise in demand. Finally, the extent of ridesharing and the competitive effects on public transport usage will have a significant effect on the number of kilometres travelled.[41]

THE ENVIRONMENTAL OUTCOME IS HIGHLY DEPENDENT ON IMPLEMENTATION AND POLICY

As outlined here, the environmental outcome depends on a range of interconnected factors and choices. To illustrate this, sustainable transport researcher Austin Brown and colleagues estimated the maximum positive and negative effects on energy consumption based on existing knowledge.[42] In the best-case scenario, where all saving initiatives are fully implemented, an energy saving of around 90% is achieved. In the worst-case scenario, where only the increased driving is actualized, energy consumption is increased by 150%. If both types of effects are actualized, there is a marked reduction in energy consumption, as the reduction in energy consumption per kilometre more than compensates for the extra kilometres.

POTENTIAL DRIVERS OF INCREASED TRAVEL

- Fleet balancing
- Trips between drop-off and pick-up
- Induced demand (e.g. sending the vehicle home to park…)
- New demand from currently underserved groups
- Lower perceived cost of travel time and consequent urban sprawl

PROSPECTIVE EFFICIENCY GAINS

- More lightweight vehicles due to low (no)-risk roads
- Optimal engine operation
- Optimal match of vehicle type to trip requirements
- Optimal route and speed planning
- Transcending current barriers to ridesharing (e.g. cultural and transaction costs and perceived safety)

Adapted from Brown et al., 2014

4. TRANSPORT JUSTICE AND MOBILITY POVERTY – COULD AVs MAKE TRANSPORT MORE INCLUSIVE?

Social inequalities are embedded in the automobility system, and the lack of access for citizens who have low incomes or health problems or who cannot get a driver's license has social consequences, especially in highly car-dependent societies or areas.[43] The distances and barriers inherent in the sociotechnical fabric of the car regime can render cars necessary to gain access to services, social networks and job opportunities.

Mobility poverty:
'The process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services and social networks, due in whole or in part to insufficient mobility in a society and environment built around the assumption of high mobility.'

(Kenyon et al., 2003, p. 210)

SYSTEMIC DRIVERS OF MOBILITY INEQUALITY

The design of road crossings, or the lack of proper road crossings, may prioritize space and time for car-driving to the extent that non-car users have very poor options for traversing the city and reaching destinations in a safe, convenient and affordable manner.[44] Also, users of public transport may be under-prioritized in terms of the resources and infrastructure allocated for public transport – but also in cultural terms: the associations of cars with success, freedom and masculinity led one observer to state that in most communities the narrative is that 'losers take the bus'.[45]

AVs AS A POTENTIAL SOLUTION

In a more preferable future, AVs bring solutions to some of these inequalities. Since driving skills may not be necessary, the literature suggests that AVs have the potential to increase mobility options for non-drivers, such as the elderly, children, and people with visual impairment.[46] Hence, people with disabilities could acquire the opportunity to move around independently, and the elderly could have increased mobility and freedom. Assuming that AVs are shared, transport could become cheaper – providing access for people with lower income – and also become available to most people through a Mobility-as-a-Service platform, providing more equal mobility levels.[47]

Photo: Ditte Bendix Lanng

Excerpt from a mural painted during an urban development project with public AVs in Aalborg, Denmark

POTENTIALS AND RISKS: AVs ARE NOT IN THEMSELVES DEMOCRATIC OR INCLUSIVE – BUT THEY CAN BE IMPLEMENTED IN WAYS THAT ARE

While AV technology has the potential to create more equal access, some researchers speculate whether AVs could lead to new markets in mobility that reproduce existing social inequalities.[48] If the shared AV system allows it, some customers may be able to pay extra to be picked up faster than others. Affluent people might be able to pay more for lanes dedicated to faster travel, resulting in a kind of privatization of access to public roads. In a scenario where roads are shared between low- and high-paying customers, the low-paying customers' AVs may be programmed to pull over to make room for the high-paying customers.

Further, the literature proposes that the various actors involved will likely have economic incentives that may not support a socially equitable AV network. Companies providing shared AV services will seek profitable markets. This could lead them to target areas with the highest-paying customers.[49] The prevalence of such a strategy could in turn lead to systemic discrimination against groups and communities that are less desirable as customers.

THE ROLE OF PUBLIC TRANSPORT POLICY

A cherry-picking of the most profitable areas by private autonomous mobility providers would potentially lead to a situation where AVs cut into the market share and economic sustainability of public transportation services, with marginalized territories and communities becoming even less accessible.[50]

Considerations about the division of tasks between private companies and public authorities are crucial for how the mobility system is financed and regulated, as well as for requirements for public access, social inclusion and geographical distribution.[51] Public transport has historically been a leader in the automation of transport, but this is not the case with AVs to the same extent. AV development has hitherto been largely driven by private companies and business models, which do not have the same obligations to establish an open, multimodal system with general public access.[52]

In an exploration of the principles governing transport planning, mobility justice expert Karel Martens finds that the question should not be 'whether transport planning should be based on principles of justice, but on which principles of justice it should be based.'[53] Martens observes that for the last fifty years the focus of transportation planning and policy has been on the performance of the transport system and ways to improve it. Much less attention has been paid to the people actually using – or failing to use – that transport system.

The emergence of AVs re-actualizes this issue as the disruptions that AVs could cause open up the possibility of social inequalities' being either reproduced or transformed.

'While the definition of a fair transportation system as a system that provides a sufficient level of accessibility to all under most circumstances may not seem radical in character, its consequences for transportation planning could not be more radical.'

(Martens, 2017, p. 151)

5. TRAFFIC SAFETY AND SYSTEMIC RISKS – COULD AVs RESULT IN A SAFER TRANSPORT SYSTEM?

Photo: Ditte Bendix Lanng

Traffic safety is one of the most frequently voiced incentives to introduce AVs, since human error is the leading cause of accidents, accounting for 95% of global cases (KPMG, 2020), often in combination with traffic violations.[54] Unlike human drivers, automated systems are not distracted, they do not drive under the influence, their reaction time is negligible, and they can be programmed to respect speed limits.[55] Based on this logic, it is foreseen in large parts of the literature that AV transport can be developed to be significantly safer than the road transport we have today.[56]

There is currently enormous public support for regulations against drunk driving, and if AVs become superior drivers to humans, Robert Sparrow and Mark Howard argue that human drivers could essentially become equivalent to drunk robots – flawed, unsafe and unreliable. Governments should therefore consider whether it is responsible to let humans drive at all.[57]

WILL AN AV TRANSPORT SYSTEM BE FREE OF SAFETY ISSUES?

The dichotomy between the error of human inattention and the infallibility of inherently systematic computers is compelling, but according to some researchers, the assumption that fewer human risk factors will automatically reduce the number of accidents is too simplistic. An uncritical acceptance of this premise could mean that insufficient attention is paid to the new systemic risks that may result from:

1. The sociotechnical immaturity of AV technology,[58]
2. Increased risk of hardware and software failures,[59] including breakdowns in sensor integration and signals,[60]
3. The risk of cybercrime,[61]
4. Increased risky behaviour due to trust in the technology.[62]

In a transition period where AVs and human drivers share road space, additional types of risks may arise;[63] for example, drivers may take inspiration from digitally connected AVs driving closer together even though this is not safe for human drivers. This illustrates the point that not only are engineers facing the challenge of making AVs respond to human drivers' behaviour, but human drivers and other road users will need to learn to understand AVs too. Going forward, new human behaviours will need to be established if more and more non-human behaviour becomes part of city traffic.[64]

'I'M NOT SURE THAT WE'RE EVER... GOING TO ACHIEVE AN L5 LEVEL OF AUTOMATION...'

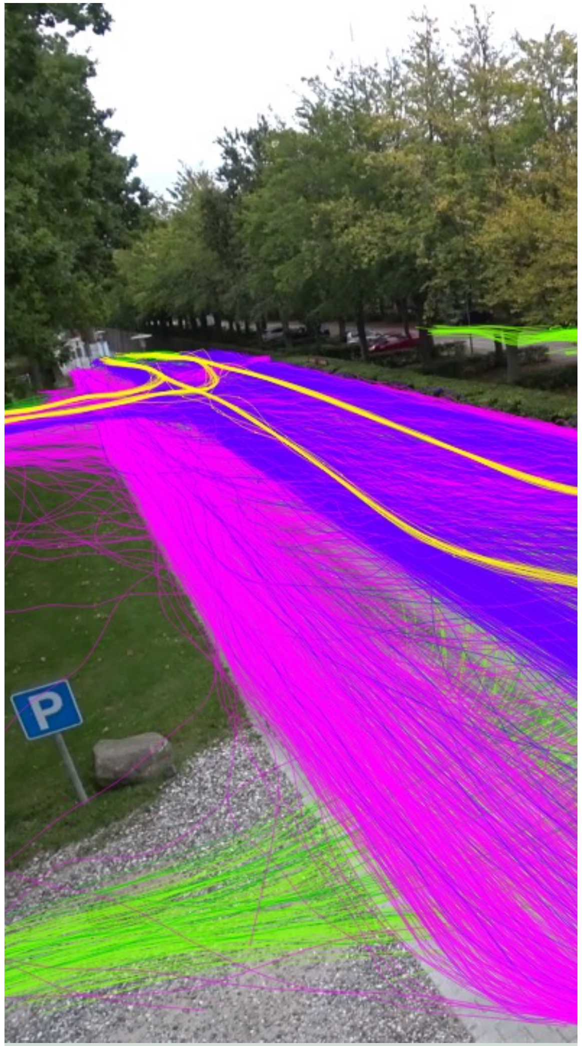
John Krafcik, CEO of Waymo, 2018

Even if all motorized vehicles were to be fully automated, city traffic would still consist of a mix of automated and non-automated actors, as human beings on foot or on a bike will continue to populate streets, paths and squares. Most publications dealing with the implementation of AVs assume they will at some point be able to operate safely and fully autonomously in mixed traffic,[65] but in recent years manufacturers and industry observers have become more hesitant in their predictions because real-life traffic complexity has proven more difficult to simulate and predict than initially anticipated. Industry leader Waymo's CEO publicly expressed doubt in 2018 that unconditional automation – SEA level 5 – is achievable,[66] and Tesla's CEO acknowledged in 2021 that the task is more challenging than forecasted.[67]

SAFETY DEFICIENCY AS A POTENTIAL DRIVER OF PLANNING DECISIONS

As the complexity of safe AV development and implementation is understood with greater nuance, a different idea about AVs is beginning to emerge. On this view, AVs are not expected to be introduced as a fully-fledged system replacing the existing one. Rather, a question arises about how specific vehicle types, use cases and locations can gradually build up an understanding of the safety profile and planning implications of AVs.

According to some researchers, authorities' willingness to dedicate separate road space and set up infrastructure that simplifies the environment for AVs will have a significant im-pact on how quickly AVs can operate safely and efficiently.[68] Such planning decisions will influence how AVs develop while also raising the question of whether cities and citizens will find AV benefits compelling enough to offset the disadvantages of creating new barriers between different modes of transport to accommodate AVs' current road safety deficiencies.



Rawmobility.dk

Video capturing different road users' trajectories in traffic can be used to visualize differences in how human and automated road users occupy road space and interact.

THE PIVOTAL ROLE OF PLANNERS, URBAN INNOVATORS AND DECISION MAKERS IN ENVISIONING DESIRABLE AV FUTURES

> ‘Planners are uniquely placed and especially responsible for leading public conversations that place socially and ecologically just mobilities at the centre of transport futures. Developing core principles for sustainable futures to underpin the deployment of technology will surely be vital in preventing public policy from being ensnared by the bright gadgetry of shiny new technology.’
>
> Porter, 2019, p. 755

In the previous pages, we have described AVs’ potentials in relation to specific prevalent challenges in urban mobility and tried to factor in social and cultural unknowns. We have highlighted the different perspectives that the literature in the field offers in order to enable planners to identify the span of plausible outcomes and the most essential points for attention in working with the introduction of AVs.

From this review, it seems fair to suggest that a one-sided emphasis on fully automated mobility – conceptualized as the natural endpoint in an inevitable technological evolution – is misleading and disregards the conditionality of automation and AVs’ complex relationships with their contexts.[69]

An alternative approach would be to embrace this conditionality and emphasize the roles of planners and decision makers in shaping the contexts and conditions on which AVs’ relevance and consequences will depend. In any case, the global trajectory of AVs will have different implications in local realities, depending on factors such as culture, mobility systems, user groups, national politics, local infrastructure, land use patterns and institutional arrangements.[70]

THE REALITY FOR PLANNERS: NAVIGATING UNCERTAINTY, HARD PROBLEMS AND SYSTEMIC INERTIA

This understanding of AVs’ potentialities places authorities and urban innovators in a position that is of course not without challenges: On the one hand, they have a central and open task of designing framework conditions and requirements for AVs in specific contexts. On the other hand, they face a situation where AV technology is fluid and not yet settled, where impactful, innovative, and sustainable mobility planning is notoriously challenging within a transport system shaped by the ubiquity of privately owned cars and related socio-technical lock-ins.

To break down this complexity and provide possible landmarks, on the next page we focus on three key considerations for planners in the field of AVs.

THREE KEY TOPICS FOR REFLECTION AND THREE SUMMARIZING QUESTIONS:

SYSTEMIC TRANSFORMATIONS

We have highlighted the presuppositions, in the studies that support the most optimistic predictions of AVs' impacts on future sustainable mobility, that AVs are shared, electrical and connected.

However, each of these assumptions is conditional on changes in behaviour and infrastructure, which are themselves a matter of social transformation. In relation to shared mobility, for example, we have seen the complexity of breaking away from private car ownership at scale.[71] The cultural, emotional, practical and infrastructural anchoring of private car use and ownership is one of the core reasons for the lock-in to the car-based system. This means that a transition to sharing is not in itself an obvious side effect of automation. This leaves us with the question:

If a desirable future urban scenario with AVs implies electrification, shared ridership and connectedness, then how can planners, urban innovators and decision makers help ensure that these features become reality in their city?

PROBLEM-SOLVING IN THE CITY

We have considered whether AVs can help solve problems in the car-based city, such as levelling out social and spatial inequalities, limiting urban sprawl and land use for roads and parking, and preventing people from being harmed by road accidents and emissions.

The literature review illustrates how the introduction of autonomous vehicles cannot be tackled in a vacuum, i.e. as a technical issue alone, separated from political priorities, social practices and the markets to which urban mobility is linked.

Technological and social systems are evolving together in intricate ways, and the potential benefits of AVs that presuppose conditions that we cannot predict or that exist mainly in corporate storytelling should not be taken for granted in the planning effort as a matter of course. This leaves us with the question:

Under what specific conditions and in what specific areas can AVs be introduced in cities so that the damaging effects of the current mobility system are not maintained or even exacerbated?

UNCERTAINTIES ABOUT AVs

It is noteworthy that even AV manufacturers are vague about how the technology will develop. AVs come with the airy promise of remedying urgent urban problems, but they also entail massive uncertainty and a demand for new infrastructure. This challenge is not unique: AVs represent just one of many topics where the forecast-based, predict-and-provide approach to transport planning, which has been prevalent in recent decades, falls short because the uncertainty about the future is such that demand cannot be predicted with a sufficient degree of confidence to provide a suitable basis for planning and investment decisions.[72] In this situation, it seems necessary to avoid being drawn into planning for the technology and to focus instead on planning for the kinds of societal outcomes that planners are tasked with trying to support.[73] We pose the question:

How can AVs most productively contribute to urban development if the transport planning paradigm changes from 'predict and provide' to 'decide and provide'? That is: What specifically do we want AVs to contribute?

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