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A backcasting approach

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DOI
10.1016/j.cities.2019.05.034

Publication date
2019

Document Version
Final published version

Published in
Cities

Citation (APA)
González-González, E., Nogués, S., & Stead, D. (2019). Automated vehicles and the city of tomorrow: A backcasting approach. *Cities*, *94*, 153-160. https://doi.org/10.1016/j.cities.2019.05.034

Cities 94 (2019) 153–160

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Automated vehicles and the city of tomorrow: A backcasting approach

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ARTICLE INFO

Keywords:
Automated vehicles
Urbanisation patterns
Urban planning
Backcasting
Policy goals

ABSTRACT

The introduction of Autonomous Vehicles (AVs) into cities may fundamentally transform the design and use of cities. On one hand, AVs offer the potential to reduce the urban space requirements for roads and parking, creating more space for high-quality, liveable areas. On the other hand, greater motorisation and the availability to perform leisure or work activities while travelling in AVs could increase the number of trips and travel distances, encouraging urban traffic congestion and sprawl. These diverse, and sometimes conflicting, estimates and opinions give rise to considerable uncertainty among urban policy decision-makers, sometimes leading to planning inaction. This paper aims to shed light on the opportunities that AVs offer in delivering attractive, healthy and sustainable urbanisation patterns. This paper employs a backcasting approach to investigate whether and how the potential impacts of AV implementation can support or threaten a range of urban development policy goals. This approach enables conflicts between policy goals to be identified. The findings point to the need for mixed-use development policy, the clustering of urban facilities and services, the restriction of motorized access in cities and the adoption of shared high-quality multimodal transport.

1. Introduction

The evolution of urbanisation patterns is highly influenced by transport planning and *vice versa* (see for example Kasraian, Maat, Stead, & van Wee, 2016). This was already apparent at the end of the 19th century when the emergence of railways spurred new urban growth (Baron, 2015). Rail networks changed the structure and hierarchy of cities, both by increasing development around stations (Baron, 2015; Begg, 2014) but also a process of suburbanisation around many cities (Couch, Petschel-Held, & Leontidou, 2008). Likewise, the increase of private car ownership has resulted in substantial changes in urban form and land use leading to more dispersed settlements, reinforcing suburbanization processes in cities across North-America, Australia and Europe (Besussi, Chin, Batty, & Longley, 2010; Victorero-Solares, Nogués, & Horner, 2010). This suburbanization has resulted in urban sprawl.

The rapid development of fully Automated Vehicles (AV), expected to be introduced in the next 10–30 years (Milakis, Snelder, van Arem, van Wee, & Correia, 2017), will undoubtedly have a significant impact on the urban mobility and development patterns over the next decades. AVs offer opportunities to be a safer, more flexible, more inclusive and sustainable mode of transport than the private car of today (Alessandrini, Campagna, Delle Site, Filippi, & Persian, 2015; Anderson et al., 2014; Begg, 2014; Burns, 2013; Fagnant & Kockelman, 2015; Milakis, van Arem, & van Wee, 2017). However, AVs may also create or exacerbate various problems for the city, including increases in car-dependence, urban sprawl, physical inactivity, security problems (hacking) and public transport decline (Cavoli, Phillips, Cohen, & Jones, 2017; Gruel & Stanford, 2016; Milakis, van Arem, & van Wee, 2017; Thomopoulos & Givoni, 2015; Zakharenko, 2016).

Most urban policy decision-makers have not yet started to plan for AV introduction (Cavoli et al., 2017). Meanwhile, studies on AVs and their consequences for urban and regional development emphasize the urgent need to identify future configurations of the land use and transport system (Begg, 2014; Dupuis, Cooper Martin, & Rainwater, 2015; Gruel & Stanford, 2016; Lyons, 2018; Stone, Ashmore, Scheurer, Legacy, & Curtis, 2018) in order to steer the introduction of AVs and avoid undesirable effects (Cohen & Cavoli, 2019).

Future studies, especially ones involving backcasting, are useful when dealing with complex, uncertain and long-term developments such as the introduction of AVs (Banister, Hickman, & Stead, 2007; Broman & Robèrt, 2017; Neuvonen & Ache, 2017; Phdungsilp, 2011). In contrast with more commonly used forecasting approaches, backcasting provides a way of imagining a desirable future and identifying a set of core goals on which key decisions can be made. The approach also helps to generate key priorities and actions that are needed to achieve a

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https://doi.org/10.1016/j.cities.2019.05.034
Received 19 September 2018; Received in revised form 13 May 2019; Accepted 25 May 2019

particular vision. This allows new options to be generated, going beyond what could be expected from forecast-based approaches, particularly in the case of non-linear or disruptive development (Dreborg, 1996; Höjer & Mattsson, 2000).

This paper explores the potential opportunities and threats associated with AVs towards socially, environmentally and economically sustainable urbanisation patterns by using a backcasting approach. This method provides a way of identifying the critical policy goals that will influence the introduction and use of AVs in the future.

This paper is structured in four sections: Section 2 presents the backcasting approach and methodology followed in the study. Section 3 provides the definition of the basic principles that would underlie the city of tomorrow. Section 4 identifies the opportunities and threats of AVs by reviewing and confronting the potential impacts of AVs on land use and urban form with each of the desired values of the city and presents policy goals and first insights of potential measures. Finally, section 5 summarises the main conclusions and presents future directions for further research.

2. The backcasting approach

Planning for long-term developments (i.e. more than 10 years) such as the implementation of AVs, requires strategic planning or visioning studies (i.e. forecasting and backcasting) based on the consideration of future scenarios. Forecasting focuses on the construction of diverse scenarios which can be developed from the extrapolation of the present situation and trend analyses (Banister et al., 2007; Wangel, 2011). By considering plausible alternative paths, forecasting approaches obtain dystopian, desired or business-as-usual scenarios. Conversely, backcasting develops an ideal scenario, and looks to the present with the aim of identifying the critical decisions and steps to achieve this desirable future (Banister et al., 2007; Broman & Robèrt, 2017; Carlsson-Kanyama et al., 2003; Neuvonen & Ache, 2017; Phdungsilp, 2011). Backcasting emerged in the 1970s as a new method to search for development paths that overcome the limitations and failures of forecasting predictions due to transitions in technology and society (Vergragt & Quist, 2011). To date, most future studies that consider AVs have mostly used a forecasting approach (Heinrichs, 2016; Milakis, Snelder, van Arem, van Wee, & Correia, 2017; Townsend, 2014; Zhang & Guhathakurta, 2018; Zmud, Tooley, Baker, & Wagner, 2015).

In early stages of new developments, the main aim of backcasting studies is to inform policy decision-makers about the key decisions and policy goals that should be taken. In this context, the think-tank models or expert-led backcasting, performed by interdisciplinary research teams and experts respectively, are useful and commonly used (Carlsson-Kanyama et al., 2003; Robinson, Burch, Talwar, O'Shea, & Walsh, 2011). These types of backcasting are more concerned with setting and reaching policy goals. Meanwhile, the newer participatory backcasting approaches involve stakeholder and public participation in the process, which is intended to achieve stakeholders and citizens' buy-in (i.e. to engage them to adopt) to help achieve a particular vision (Neuvonen & Ache, 2017; Vergragt & Quist, 2011).

Another frequently used backcasting approach is the targeted method which involves the analysis and identification of core features associated with a future vision and the definition of policy goals to accomplish the vision. This is a frequently used approach, along with path-oriented ones which focus on the development of policy measures and paths (Neuvonen & Ache, 2017; Wangel, 2011).

In this paper, a think-tank model and first stage of the target-oriented approach is used. This involves the definition of the core values of the driverless city of the future, carried out through a literature review of the most cited desirable values of international urban agendas, scientific documents and participatory studies focus on visions of future cities. The second step comprises the analysis of the potential impacts of AV introduction in terms of opportunities and threats for each core value. The third step involves the identification and definition of the key urban planning and policy goals in order to reach the desired driverless city. These goals are based on the key values identified in the second step.

3. Envisioning the city of tomorrow

Urban sprawl is a feature of urban development in many cities around the world, much of which has been driven by the increases in the ownership and use of private cars. Increases in mobility has fostered dispersed settlements located further away from cities on large plots of land. Despite the attractiveness of these locations and environments for some, this form of development has had negative social, economic and environmental impacts. The quality of urban and countryside areas has been affected by pollution, high consumption of land and resources, social segregation, noise, congestion and parking problems (Alessandrini et al., 2015; Couch et al., 2008). Compact urban development (or the concept of the compact city) has been proposed as a way of tackling the problem of urban sprawl in documents such as the New Urban Agenda (UN, 2017) or the Urban Agenda for the EU (EU, 2016). The compact city concept refers to dense, mixed use development that is well served by active transport modes (i.e. cycling and walking) and mass transport, thereby reducing the need for motorized modes of transport and minimizing negative environmental effects such as transport emissions or land consumption (OECD, 2012; Williams, 2014). However, the concept is not uncontested. For example, some authors have pointed out the lack of empirical studies to support certain claims associated with the concept (Echenique, Hargreaves, Mitchell, & Namdeo, 2012) or drawbacks due to excessive compactness of the city (Gaigné, Riou, & Thisse, 2012; Perrels, 2007).

The UN's New Urban Agenda sets out principles of “sustainable integrated urban development” for the next 20 years (UN, 2017). These principles relate to social, economic and environmental dimensions. The social dimensions refer to issues of equality, cultural diversity, education, food security, health and well-being safety. The economic dimensions refer to productivity, competitiveness and decent work for all. The environmental issues refer to clean energy, biodiversity, sustainable use of resources, consumption and production and urban resilience. Among the priority themes related to urban development in the EU's Urban Agenda are the sustainable use of land and sustainable and efficient urban mobility (EU, 2016). The use of land refers to stewardship of the environment and the improvement of the quality of life, by focusing on reducing urban sprawl, regenerating brownfields and on renaturing or greening urban areas. With regards to urban mobility, the document emphasizes public transport, active mobility (walking, cycling), inclusive and equalitarian accessibility, and local and regional connectivity.

Increasing urbanisation trends along with the rapid development of new information and communication technologies (ICTs) during recent years, have given rise to a great variety of new concepts of desirable patterns of urban development. Examples of this variation include Smart growth or Transit Oriented Development (TOD) (focusing on transport issues), smart cities (focusing on technology issues), eco-cities and zero-waste cities (focusing on environmental issues) and the sharing city (focusing on societal, economic and transport issues) (Khan & Zaman, 2018; Williams, 2014).

Other recent studies have also attempted to define the key

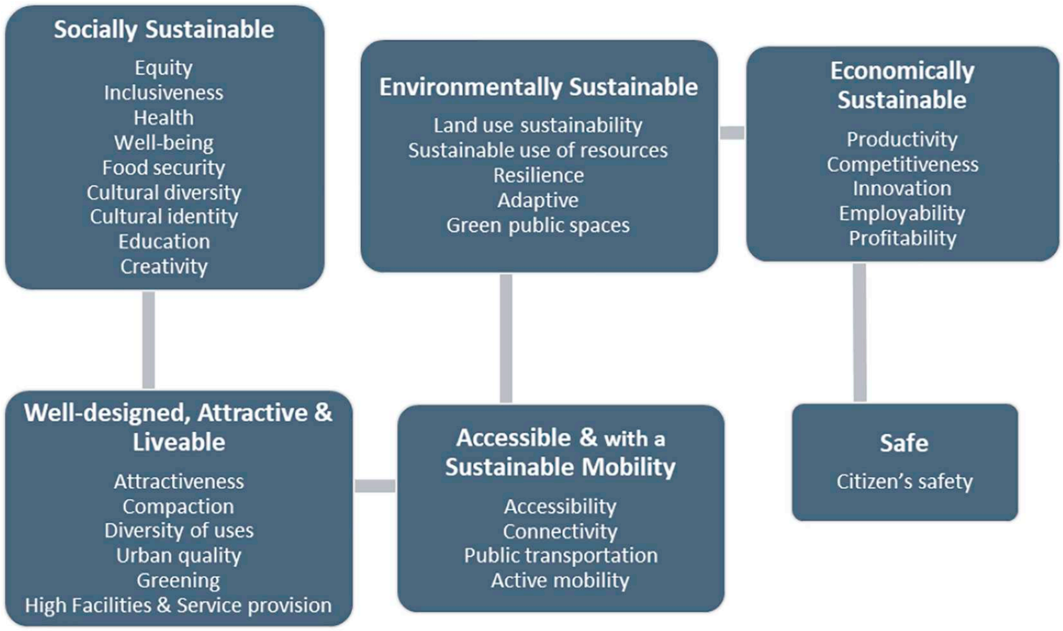

Fig. 1. Summary of most cited core values for the city of tomorrow.
Source: own work compilation from Carlsson-Kanyama et al. (2003), EU (2016), Joffe and Smith (2016), Khan and Zaman (2018), Neuvonen and Ache (2017), Ortegón-Sánchez and Tyler (2016), UN (2017) and Williams (2014).

characteristics of the future city (e.g. Ratckliffe & Krawczyk, 2011). Williams (2014) has defined a set of possible successful urban forms by 2065, differentiating between existing and new development places, under the assumption that there is not a unique answer for different places and problems. Several features of the future city were identified, such as sustainable land use and resource use, adaptation to climate change, efficient management of infrastructures, social equality and accessibility and economic performance, while pointing out the inadequacy of dispersed developments.

As regards studies on participatory visioning of future cities, the work by Carlsson-Kanyama et al. (2003) has identified a set of common goals for European cities. These include a greener environment, more compact development with denser structures, high levels of accessibility to public spaces, efficient use of natural and energy resources, an extensive network of public transport and infrastructure for non-motorized modes. A range of goals for future urban development has also been developed for various cities (see for example Joffe & Smith, 2016; Neuvonen & Ache, 2017; Ortegón-Sánchez & Tyler, 2016).

In summary, social, economic and environmental factors are the aspects most commonly considered in describing the desired cities as expected, since those aspects are the core dimensions of sustainability. However, other new aspects related to accessible and active mobility, urban design or safety are considered additional and relevant to the definition of key aspects of the city of tomorrow. These are summarised in Fig. 1.

4. Towards the city of tomorrow: opportunities and threats of AVS and policy goals

Despite the great increase of academic research and grey literature on the implications of AVs, there are few investigations centred on the impacts on the role of urban form (Stead & Vaddadi, 2019). The potential opportunities and threats of AVs in relation to the achievement of the most commonly cited urban goals that appear in the literature reviewed above (Section 3) are discussed in more detail below.

4.1. Socially sustainable cities

Social sustainability stands for an equal, inclusive, healthy and diverse society, which have the same opportunities as regards access to public services such as education, medical assistance, housing, culture and so on. This core value could be both positively and negatively affected by AVs.

On one hand, AVs could increase equity and inclusiveness by increasing accessibility for various societal groups such as disabled, elderly or young people, especially in areas with low levels of public transport service (Alessandrini et al., 2015; Gruel & Stanford, 2016; Milakis, Snelder, van Arem, van Wee, & Correia, 2017; Papa & Ferreira, 2018). On the other hand, AVs may increase social inequality if private AVs (PAVs) are only affordable for the wealthy (Milakis et al., 2018), or if investments in public transport are reduced, which may have significant impacts on low-income groups (Cavoli et al., 2017; Cohen & Cavoli, 2019). The use of public transport is also dependent on the overall market share of shared AVs (SAVs) compared to PAVs (Greenblatt & Shaheen, 2015; Soteropoulos, Berger, & Ciari, 2018). To address this issue, the following policy goal proposed is to *Promote high-quality multimodal public transport* (G1) which includes AVs and mobility-as-a-service (MaaS) systems (Table 1).

The segregation of residential areas from other land uses, due to the revalorization or increase of land prices in central areas of the city (Zakharenko, 2016), has implications for equality and inclusiveness. One of the ways to address this is to redevelop and regenerate urban centres, especially where space can be reallocated from existing parking and roadspace. The second policy proposed is to *Ensure equal access to* *housing in the city* (G2), paying special attention to the avoidance of the proliferation of urban sprawl. This goal could be achieved through measures related to subsidies to vulnerable citizens and incentives to develop social housing for example.

In the case of public health, AVs can offer more opportunities for door-to-door travel and potentially increase the time people are prepared to travel. This could increase more sedentary lifestyles and lead to higher rates of obesity and heart problems (Cavoli et al., 2017; Milakis, van Arem, & van Wee, 2017; Thomopoulos & Givoni, 2015). At the same time, there could be health benefits, such as more rapid emergency transport due to sensors and automated connections between vehicles (Papa & Ferreira, 2018). In light of these issues, the third policy goal identified is to *Delimit motorized access to certain core areas* (G3). Exceptions can be made for emergency transport or for people with impaired physical mobility. This policy will help to promote public health and equal access to the centre due to the development of infrastructure for active mobility.

As regards cultural aspects, the implementation of AVs could present new opportunities to reinforce the identity of cities by improving the character and morphology of core areas that have previously been used for parking and that are freed by reducing parking demand (Dupuis et al., 2015; Heinrichs, 2016; Milakis, van Arem, & van Wee, 2017; RPA, 2017; Zhang, Guhathakurta, Fang, & Zhang, 2015). To take advantage of this opportunity, a fourth policy goal is proposed: *Renewal and regeneration of core central urban areas* (G4). This will also be strengthened by policy goal G3 (see above).

4.2. Well-designed, attractive and liveable urban areas

One of the key opportunities of AV is the potential to improve urban liveability as a result of the release of a large amounts of public space formerly devoted to parking and roadspace as a result of the reduction of the number of circulating cars and parking requirements, especially in the situation of shared AVs.

Estimates of the number (and impacts) of circulating vehicles vary significantly, mainly due to different assumptions about the penetration rates of PAVs or SAVs. On the one hand, a completely shared fleet may reduce the number of circulating vehicles substantially, whereas a fully individually owned fleet may increase the total number of vehicles on the road. A study by the Institute of Transportation Studies at the University of California Davis predicted that the total number of circulating vehicles could rise by up to 2.1 billion PAVs by 2050, while with the introduction of SAVs could reduce the expected number by more than three quarters (Fulton, Mason, & Meroux, 2017). Similarly, a study by Stanford University on the implementation of SAVs in New York concludes that approximately 70% of the current taxi fleet could satisfy the city's total taxi demand (Zhang & Pavone, 2016). Estimates for the International Transport Forum point to a possible reduction of 90% of circulating vehicles to achieve the same levels of mobility where high-capacity public transport and SAVs for 8 and 16 passengers are used (ITF, 2015). This study (and others such as Meyer, Becker, Bösch, & Axhausen, 2017) suggests that lower penetration rates of SAVs (50% of all AVs) could still achieve a reduction in the total AV fleet. Any reduction in fleet circulation will have impacts in terms of space needed for traffic and infrastructure, including roadspace (Heinrichs, 2016) and central reservations. Some of this space could be converted into infrastructure for active modes, such as cycling or walking.

The reconfiguration of the transport infrastructure will involve the creation of new pick-up and drop-off areas as well as recharging stations. The location and amount of pick-up and drop-off spaces will influence the use of AVs vis-a-vis other transport modes as well as the amount of urban space required for vehicles (both moving and stationary). Pick-up and drop-off points could be concentrated at specific points in the city, which could promote greater use of SAVs and active modes. Alternatively, pick-up and drop-off points could be located at transport hubs (e.g. stations; park & ride areas) to encourage walking and cycling for the 'last mile', as well as public transport. Clearly, the size and use of AVs is also related with the location and type of charging stations.

Much of the release of urban space is related to the reduction of parking demand. It is currently estimated that almost a third (31%) of land in the central areas of large cities in the US is used for parking (Shoup, 1997). In this case, the implementation of SAVs can result in very significant space savings. Dupuis et al. (2015) report that the current street parking could be reduced by around 50%, with even higher reductions with the introduction of SAVs. Zhang et al. (2015) also report a reduction of up to 90% of parking demand at a lower SAV market penetration rate of 2%. Milakis, van Arem, and van Wee (2017) conclude that the reduction could be in a range between 67 and 90%. In the US context, this could mean a saving of up to 1.4 million acres nationwide (0.57 million hectares or 700,000 football fields) by 2040 (RPA, 2017). Parking space can also be lowered by parking automation, thereby reducing the space required for aisles, ramps and circulation space which can result in space savings of up to 60% in multi-storey car parks (Alessandrini et al., 2015, Begg, 2014; Heinrichs, 2016; Nourinejad et al., 2018). This provides an opportunity to improve the attractiveness, liveability and urban quality standards of cities by reconverting residential areas and public spaces as well as infrastructure for active modes of transport (Milakis, van Arem, & van Wee, 2017; Shoup, 1997; Sousa, Almeida, Coutinho-Rodrigues, & Natividade-Jesus, 2018). At the same time, the reduction or elimination of minimum parking requirements in urban planning regulations could reduce the cost of urban development, restrain urban sprawl and reduce automobile dependency (Shoup, 1997). To achieve this, five policy goals for urban centres are proposed: *Promoting mixed land uses* (*G5*); *Delimitating attractive core areas* to improve quality of life (G6); *Promote shared mobility over privately-owned vehicles* (*G7*); *Ensuring active mobility* (*G8*); *Establishing urban quality standards* with respect to development of attractive, well-designed green areas and larger spaces (G9); *Parking policy* which eliminates parking minimum standards (G10). In the case of peripheral areas, areas could be freed from parking and traffic could be redeveloped at higher densities with new facilities. The following policy goal is proposed: *Promote mixed land uses* (*G5*), and to improve the urban standards, especially regarding social facilities.

Clearly, opportunities to repurpose the city will not be equally distributed, given that parking needs are spatially diverse (Zhang et al., 2015). Transport hubs, employment centres and parking belts outside the centre might accommodate most parking demand (Alessandrini et al., 2015; Heinrichs, 2016). In the case of parking belts, Zakharenko (2016) estimates that 97% of the total daily demand could be supplied in these spaces. In this case, urban peripheries could be negatively affected. As a result, the following policy goal is proposed: *Parking policy* (G10) to avoid an excessive concentration of parking lots and encourage a balanced distribution associated to multimodal hubs.

4.3. Accessible areas based on sustainable mobility

To promote more sustainable modes of transport, policy is focused on achieving high levels of accessibility to services and activities for citizens, the use of an efficient and affordable public transport well connected with all modes, the enhancement of safety and the development of infrastructure for active forms of transport.

The improvement of accessibility is guided by promoting equal and inclusive access for all, offering opportunities for a wide range of the population, including the young, the elderly and the disabled (Alessandrini et al., 2015; Gruel & Stanford, 2016; Milakis, Snelder, van Arem, van Wee, & Correia, 2017; Papa & Ferreira, 2018) while reducing the overall demand for mobility at the same time. In order to do so the following key policy goals are proposed: *Promote a high-quality multimodal public transport system* (G1); and *Ensure equal access to mobility services* (G11).

The improvement of connectivity and efficiency of AVs is due to development in ICTs (information and communication technologies). On one hand, this can enable vehicles to search for the most efficient routes and operate in platoons, thereby reducing roadspace requirements (Heinrichs, 2016) and reducing accidents (Milakis, van Arem, & van Wee, 2017; Thomopoulos & Givoni, 2015). However, the large-scale implementation of private AVs, could lead to an increase in circulating vehicles, aggravating congestion in major cities (Fulton et al., 2017). In this context, two major goals are proposed: *Promote a high-quality multimodal public transport system* (G1); and *Promote shared mobility over privately-owned vehicles* (G7).

Public transport could potentially be negatively affected by the implementation of AVs. Frisoni et al. (2016) argue that the investments required for the development of new infrastructures could result in reductions in public transport funding. Meyer et al. (2017) warn that the comfort and speed of SAVs could reduce the attractiveness of public transport, especially in rural and small areas, although other authors argue that the use of public transport could be increased in certain policy contexts, largely dependent on decisions influencing the market share of shared AVs (SAVs) over PAVs and the costs of SAVs (Greenblatt & Shaheen, 2015; Milakis, van Arem, & van Wee, 2017; Soteropoulos et al., 2018). In order to address these issues, the following policy goals are proposed: *Promotion of a high-quality multimodal public transport system* (G1), which as mentioned above includes SAVs and mobility-as-a-service (MaaS); and *Promote shared mobility over privately-owned vehicles* (G7). Policy measures to achieve this goal should focus on the discourage of the use of private AVs, such as taxes or fees or educational campaigns, on the prioritization of the development of SAVs through market incentives, ensuring that SAVs complement rather than compete with public transport services (Cohen and Cavoli, 2019).

As regards active forms of mobility, greater use of AVs could potentially reduce walking and cycling for some or all journeys (Cavoli et al., 2017; Milakis, van Arem, & van Wee, 2017; Soteropoulos et al., 2018; Thomopoulos & Givoni, 2015). Milakis, van Arem, and van Wee (2017) and Soteropoulos et al. (2018) estimate an increase in the share of walking if the costs of short AV journeys are high. In order to increase opportunities to encourage active mobility, new infrastructure could be developed by reallocating roadspace due to the reduction of circulating vehicles (Heinrichs, 2016). To promote active mobility, the following policy goals are proposed: *Delimit motorized access to certain core areas* (G3) and Ensure active mobility (G8), as also proposed above.

4.4. Environmentally sustainable land use

The introduction of AVs can potentially contribute to the more efficient use of land and resources (Cavoli et al., 2017; Dupuis et al., 2015; Fulton et al., 2017; Milakis, van Arem, & van Wee, 2017; RPA, 2017; Shoup, 1997; Sousa et al., 2018; Zakharenko, 2016; Zhang et al., 2015). For example, former parking areas could be reallocated for public use. On the other hand, the use of private AVs could lead to the same or even worse levels of congestion (Fagnant & Kockelman, 2015; Litman, 2018; Milakis, Snelder, van Arem, van Wee, & Correia, 2017) and the demand for more space for traffic and higher energy consumption as a result, thereby jeopardizing environmental goals. To address these issues and maximize the benefits, the following policy goal is proposed: *Encourage the introduction of SAVs over privately owned* AVs (G7). This could be supported by economic incentives to automobile companies to develop SAVs, together with economic and regulatory tools to discourage the use of PAVs, such as purchase taxes and single-occupancy fees.

An increase of vehicle miles travelled (VMT) and commuting distances, should private AVs dominate (Fagnant & Kockelman, 2015; Milakis, Snelder, et al., 2017), could lead to more dispersed settlement patterns and an intensification of urban sprawl (Begg, 2014; Cavoli et al., 2017; Litman, 2018; Zakharenko, 2016). This would also aggravate land and resources consumption per capita. According to Zakharenko (2016), cities could expand substantially in this situation, particularly in areas where land rents are lower. To address this issue, the policy goals proposed are: *Promote mixed land uses* (G5) to reduce the need to travel; and *Regulate urban growth* (G12). Planning measures such as zoning play a key role in delimiting the type of urban development, density and location of the built-up area. Likewise, other measures which penalise the development of dispersed settlements could be helpful.

As noted above, AVs can potentially increase VMT and commuting, partly as a result of more comfortable trips (in which other activities than driving could be performed) but also due to piloted parking and faster trips due to platooning. The extent of these increases will greatly depend, among other things, on the introduction of SAVs. For example, Milakis, Snelder, et al. (2017) estimate an increase of up to 23% of vehicle-kilometre travelled by 2030 and up to 71% by 2050. Similar estimates are reported by Fagnant and Kockelman (2015). On the other hand, the introduction of SAVs could lead to reductions of commuting VMT by up to 7% for certain types of families (Zhang & Guhathakurta, 2018). Clearly, SAV fares play a key role in these estimates: the higher their cost the lower the average increase in VMT. This is the case for scenarios in which users bear all costs of driving, resulting in reductions of 35% in VMT (Childress et al., 2015). The following policy goals is proposed in this context: *Encourage the implementation of SAVs over PAVs* (G7). Measures such as empty-cruising fees, mileage-related taxes or single-occupant fees could be effective (Gruel & Stanford, 2016).

4.5. Economically viable cities

Former parking areas in inner city areas could be used for new economic activities (Milakis, van Arem, & van Wee, 2017), thereby promoting economic competitiveness and urban vitality. These areas could also benefit from increases in property values in the city centre (Zakharenko, 2016) which would in turn benefit land owners and local administrations. According to Clements and Kockelman (2017), the total land value of parking spaces in the US account for $4.5 trillion which would be worth even more if converted into other urban functions. Conversely, AVs could potentially imply large reductions of governmental revenues from parking fees, traffic and parking fines. In theory, increased incomes due to the reduction of congestion and accident costs (Thomopoulos and Givoni, 2015) could be used to balance these budget deficits. In this context, the following policy goals are proposed: *Encourage the implementation of SAVs over PAVs* (G7); *Promote mixed land uses* (G5); *Establish urban quality standards*(G9) and *Restrict parking* (*G10*), particularly to balance the spatial distribution of parking. In this sense, the implementation of new tax-related policy measures to discourage the use of private AVs, such the ones mentioned before, could help administrations to obtain new revenues that could improve social infrastructures and services, which in turn encourages the economic profitability of the city.

Table 1
Core city values, AV implications and Policy goals for the city of tomorrow.

Most cited core values for the city of tomorrow		AVs opportunities & threats		Policy goals
		Sign	Description	
Socially sustainable cities	Equity and inclusiveness	+	Increase mobility for elderly, children, disabled and unlicensed people	Ensure equal access to mobility services (G11)
		−	Reduction of public transport	Promote a high-quality multimodal transport system (G1)
		−	Expansion of the city-Sprawl would cause segregation	Mix land use (G5); Restrict motorized access (G3); Regulate urban growth (G12)
		−	Revalorization or increase in real estate values in the centre could cause segregation of population	Mix land use (G5); Ensure equal access to housing in the city (G2)
	Healthy/active society	+	Less vehicles imply less pollution, therefore less illnesses	Promote shared and public mobility (G7)
		−	Door-to-door services would imply less walking and cycling, causing health problems	Delimit motorized access to core areas (G3); Delimitate attractive core areas (G6); Ensuring active mobility (G8)
	Cultural identity	+	Recovery the character and morphology of core areas within the city centre destined to parking areas	Delimitate attractive core areas (G6); Promote regeneration and renewal over new developments (G4); Ensure urban quality and morphological standards (G9)
	Cultural diversity	−	Revalorization or increase in real estate values in the centre could cause population segregation	Mix land use (G5); Ensure equal access to housing in the city (G2)
Well-designed, Attractive and liveable urban areas	Attractiveness, Urban quality and liveability	+	Reduction of parking demand would enable a reconversion of free space into attractive and high-quality areas	Promote shared mobility (G7); Ensure urban quality standards (G9); Mix land use (G5); Delimitate attractive core areas (G6)
		+	More walkable and cycling cities	Delimit motorized access to certain core areas (G3); Ensure active mobility (G8)
		+	Reduction of parking demand would enable refilling areas and improve social facilities	Promote densification – compaction (G12); Improvement of social facilities (G9)
		−	Large parking lots	Promote a balanced distribution parking policy (G10); associated to multimodal hubs
	Green public spaces: greening	+	Reduction of parking demand would enable a reconversion to green public areas	Promote shared mobility (G7); Development of green infrastructures (G4)
Accessible areas based on sustainable mobility	Accessibility	+	Increase mobility for elder, children, disabled and unlicensed people	Ensure equal access to mobility services (G11); High-quality multimodal transport system (G1)
	Connectivity	+	Platooning in segregated lanes means more free space	
		−	Need to locate new hubs to interchange between modes	High-quality multimodal transport system (G1)
	Efficiency	−	Congestion Private AVs vs Reduction vehicles SAVs	Promote shared mobility (G7)
		+	More efficient vehicles and platooning which lead to less space occupied by circulating vehicles	Develop high-quality multimodal transport system (G1)
	Public transport	−	Reduction of public transport	Develop high-quality multimodal transport system (G1)
		+	Increase of public transport use for interurban trips	
	Active mobility	−	Excessive use of AVs would imply less walking and cycling	Delimit motorized access to certain core areas (G3): Ensure active mobility (G8)
		+	No need for traffic lanes and central reservations	Promote shared mobility (G7)
Environmentally sustainable	Land-use sustainability	−	Expansion of the city-Sprawl would cause inefficient use of land	Mix land use (G5); Restrict motorized access (G3); Control urban growth (G12)
		+	Renaturing or greening urban areas thanks to the reduction of parking demand	Promote shared mobility (G7); Establish urban quality standards: Develop green infrastructures (G9)
	Sustainability of resources	−	Increase of VMT imply high land, energy and resource consumption	Mix land use (G5); Restrict motorized access (G3); Control urban growth (G12)
		−	Expansion of the city-Sprawl would cause inefficient use of resources	Mix land use (G5); Control urban growth (G12)
		+	Less vehicles imply less energy consumption	Promote shared mobility (G7)
Economically viable	Profitability	+	Revalorization and profitability of well-located new free areas	Mix land use (G5); Establish urban quality standards: Improve social infrastructures and public activities and services (G9); Restrict parking (G10)
		−	Reduction of public incomes related to traffic taxes, fines, fees, etc.	
Safe, human-centred	Citizen's safety	−	Interaction with conventional vehicles, pedestrians and cyclist during transition	Ensure a safe transition for pedestrians, cyclists and road users (G13)
		+	Less and more efficient vehicles would imply less accidents and reduce the need for segregated lanes, medians, etc.	Promote shared mobility (G7); High-quality multimodal transport system (G1)

4.6. Safe, human-centred cities

A critical issue concerning the introduction of AVs in cities will be the transition phase in which AVs operate alongside conventional vehicles, cyclists and pedestrians, which could potentially lead to higher, rather than lower, accident rates (Thomopoulos & Givoni, 2015). To address this risk, the main policy goal proposed is: *Ensure a safe transition* (G13) by employing measures such as the regulation of dedicated lanes for AVs (Litman, 2018). However, once AVs have reached a high share of circulating vehicles, especially for public or shared services, the accident rate may fall (Cavoli et al., 2017; Gruel & Stanford, 2016; Milakis, van Arem, & van Wee, 2017; Papa & Ferreira, 2018). At this stage it would be possible to eliminate segregated vehicle lanes and central reservations. Carriageway widths could also be reduced, which would free more space for pedestrians and cyclists.

5. Conclusions

Transport policy and infrastructure development have strong impacts on the form of urban development. Thinking about the future of cities therefore requires close attention to transport policy (see also Alessandrini et al., 2015). Urban planning has a key role in shaping the transition to the take-up and use of AVs. Planners and urban policy-makers need to start to prepare adaptive plans and programmes to anticipate to these future changes (see also Papa & Ferreira, 2018). Backcasting approaches can help to anticipate the type of planning measures that could be most beneficial and reduce any adverse outcomes (as also discussed by Stead & Banister, 2003).

This paper has identified the key concepts and values of city development based on a review of future studies and urban agendas, highlighting the relevance of the three dimensions of sustainability (social, environmental and economic). The potential impacts of AV introduction on urban form and spatial distribution has been reviewed and analysed in terms of opportunities and threats for each core value. This analysis provides a better understanding of the critical policy goals needed if AVs are to contribute positively to the quality of future urban development.

The findings point to the importance of mixed land-use policy, the improvement of urban facilities and services, the need to restrict vehicle access within and outside the city, the adoption of shared mobility services, and a high-quality multimodal transport system. This set of basic principles can help policy decision-makers, as well as other relevant stakeholders and actors, to understand and make decisions about the introduction of AVs. In a context of more participative governance, urban stakeholders in cooperation with public authorities, have a key role on developing these policy frameworks and goals. These can be used as a foundation on which to formulate policy options and then particular courses of actions, including packages of policy measures (see also Gonzalez-Gonzalez et al, in press).

Further research is still needed to identify and validate potential policy measures and also to examine the implications for different countries and continents, given their different policy procedures, measures and levels of public acceptability (see also Stead, 2008). This paper merely intends to open the debate on how urban and transport policies could be developed to promote more attractive, liveable and economically successful cities using the introduction of AVs as a catalyst for positive change.

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