Autonomous driving, the built environment and policy implications

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ABSTRACT

This article seeks to clarify how autonomous vehicles (AV) could affect urban planning and the built environment, to what extent these effects are compatible with municipalities' existing objectives, and what lessons can be drawn from that. The paper combines a systematic review of the literature, a quantitative online survey and qualitative interviews with representatives from urban transport planning authorities in Germany. Four concrete 'use cases' were applied to structure the survey.

Results show that respondents are rather skeptical about the compatibility of AV with existing transport and urban planning objectives, above all to strengthen non-motorized transportation and to promote public transportation. Particularly, automating private motorized travel appears not to match municipal planning perspectives. On the contrary, transport planners think that shared autonomous vehicles as a complement to public transport systems are more appropriate to support urban development strategies. Their most prominent concern with respect to AV is the expectation that car travel will increase with AV, propagating problems like congestion and negative environmental effects. However, survey respondents expect that effects differ quite strongly depending on how AV will occur.

As a lesson, the study suggests that different AV use cases should receive specific attention to explore their potentials and challenges. The study likewise suggests to, given the discrepancy between the objectives of urban transport planning and federal government‘s policy focus, consider consolidating the communal strategic positions on research and development priorities. The results indicate a demand for studies that demonstrate how AV can respond to more fundamental challenges and goals that city planner's face. Given the wide range of potential implications, the study suggests to broaden the debate from its present primary focus on the transport planning domain to city planning and development.

Keywords: autonomous driving, systemic analysis, transportation planning, transportation policy, built environment

1. INTRODUCTION

Autonomous driving has started to receive attention not only by the research community but also by planning practitioners and policy makers concerned with transport and urban planning. There seems to be great concern and perhaps even greater uncertainty about how autonomous vehicles in cities may possibly affect a core domain of city planning: the interaction of the transport system with land use and the built environment.

Visions of integrating autonomous vehicles into the urban transport system so far essentially refer to the development of the vehicle technology itself, the effects on traffic flow and potential benefits with respect to safety, congestion or emissions. Effects on parking as a result that autonomous vehicles (AV) can park themselves or remain in the transportation network while awaiting their next passenger have been modelled and showed significant impact on inner city street space usage (e.g. Pavone, 2016, Fagnant and Kockelman, 2015; Brownell and Kornhauser, 2014). Only a few studies or papers have explored the effects on land use (Anderson et al., 2016, Chapin et al., 2016; Heinrichs, 2016; Heinrichs and Cyganski, 2015; Litman, 2015), primarily in a U.S. context. They identify possible impacts on road and movement space itself such as adjustments in lane widths and layouts, removal of signage or the need for drop-off and pick-up areas. The studies highlight redevelopment opportunities in urban areas dominated by surface parking and wide roadways. And they sketch that autonomous driving may potentially alter the trade-offs that household's make between choosing location and daily mobility and thus may take an effect on long term land use patterns.

However, the debate is so far led by the question "about how the built environment might need to adapt over time to accommodate AV" (Chapin et al., 2016) rather than to address uncertainties about the future in a more proactive sense. While this does not mean that uncertainty about the future would be dissolved for good, such a proactive approach could be the basis to "develop business models and policy paths that are flexible and resilient" to uncertainties (Lyons, 2016). With respect to autonomous driving and its relation to the built environment, dealing with this uncertainty first of all requires a common and transparent understanding about plausible use cases and scenarios (including their development pathways) of the technology and its implications (Heinrichs, 2016; Fraedrich et al., 2015). The specific effects on the built environment and – what might be of even greater importance in this regard – how this could inform and support urban policy interventions and planning have not been sufficiently explored so far.

This paper responds to these needs and questions. It seeks to clarify (1) the state of knowledge about the likely effects of autonomous driving on the built environment, (2) whether autonomous driving appears to be 'desirable' i.e. compatible with existing frameworks from a planning perspective, and (3), how, to what extent and with what direction urban transport and city planning will need deal with these effects.

To address these questions, the paper combines a systematic review of the state-of the art literature, a quantitative online survey and qualitative interviews with representatives from transport planning authorities in Germany. The results will help planning actors and institutions to get a clearer picture on the potentials and constraints of AV in urban areas, and how to deal with implications of autonomous driving in the context of urban environments. The paper will pinpoint policy areas that may require priority attention. It goes beyond current knowledge (1) by differentiating impacts of autonomous driving on the built environment depending on use cases, thereby clarifying specific potentials and challenges, and (2) by providing 'near time' urban planning policy guidance for a yet distant uncertain development.

The structure of the paper is as follows. Section 2 provides a state-of-the-art literature review on the impacts of AV on the built environment. Section 3 outlines the methodology. It defines a set of concrete use cases that served as the basis for the online survey, provides information on the structure and respondents of the online questionnaire, and explains the focus of the qualitative follow-up interviews. Section 4 presents the empirical data gathered in the online survey (4.1) and the qualitative interviews (4.2). Section 5 discusses the findings with respect to the questions outlined above, summarizes the results and gives a conclusion.

2. Autonomous driving and its possible implications on the built environment: a literature review

Mobility and the built environment are closely connected with each other. Urban form and the distribution of different land uses play an important role on mobility decisions, and, to a considerable degree, dictate what forms of transport shape the transport systems (Cervero and Kockelman, 1997). Compact city forms with high density and mixed uses provide good preconditions for short trips and efficient public transportation, promoting also walking and cycling, and often making daily car use unnecessary. Sprawling and sparsely populated urban structures, on the other hand, discourage non-motorized travel. In turn, the availability and use of designated transport modes strongly influences land use patterns, their densities and the necessary infrastructures. The residential suburbanization of the latter half of last century was thus, to a great extent, encouraged by car availability and the expansion of the transport infrastructure for motorized passenger transport (Apel, 2003).

Fully automated driving will entail a completely new transport system, which will not only bring new possibilities and new types of transport provision, but is also likely to strongly interact with the built environment and, therefore, touch the domain of city planning. This connection is so far not well-understood. Visions of autonomous driving and its integration in urban areas primarily concentrate on the development of the technology and the direct effects of alternative transport systems on traffic flow, safety, resulting emissions, among many others (Heinrichs, 2015; Fagnant and Kockelman 2015; for instance). Nevertheless, only a few existing studies investigate the link between AV and urban form, land use, urban infrastructures and the implications for city planning (see Milakis et al., 2017a (for an explorative literature review). These studies, primarily conducted in the form of consulting experts, indicate several areas where AV are likely to influence the built environment. Among the key themes are (1) changes in the required road space (right-of-ways and travel lanes) and infrastructures (signage, etc.), (2) effects on the location, form, and amount of parking, (3) interactions with the mobility of cyclists and pedestrians, (4) opportunities for redevelopment of land-use, and (5) land-use changes and residential relocation.

Some studies argue that AV will require city and transport planners to rethink the design and dimensions of road space and infrastructure. Based on a visioning workshop with urban planners, Chapin et al. (2016) identify a number of aspects in this regard. Firstly, AV may lead to changes in the required road space, in particular affecting right-of-ways and travel lanes and the design intersections. Secondly, AV are likely to affect access time, as they would make it possible that users be picked up and dropped off very close to their origins and destinations. Thirdly, AV may also lead to a substantial diminution of the requirements for signage and signalization, as this information could be provided wireless in real-time (Chapin et al., 2016). Along these lines, some authors postulate, that intersections would no longer require traffic lights or stop signs, relying instead on computer programs that communicate directly with the vehicles on the road (Begg, 2016) and/or on digital signage, e.g. in the form of high quality digital maps (Wagner et al., 2014). On the basis of expert interviews on the policy implication of AV, Wagner et al. (2014) confirm the effect on roadway infrastructure, but raise doubts about infrastructure adapting rapidly enough to keep pace with the development of AV.

Nevertheless, and despite the aforementioned possibilities, AV will still have to interact with pedestrians and cyclist. Thus, to a greater or lesser extent, signage will still be required, reducing the potential impact of the changes in this regard. Changes in signage are not expected to be the main implication of the interaction among automated motorized traffic and non-motorized transportation. Alessandrini et al. (2013) argue that AV will have positive effects in terms of road safety, as well as, of confidence of cyclist and pedestrians, by reducing intimidation of the latter in the knowledge that vehicles are being driven correctly. Thus, this “freedom from fear” should certainly improve non-motorized travel. On the contrary, the increased number of pick-up / drop-off areas and free flow intersections could hinder pedestrian and bicycle travel (Chapin et al., 2016).

Other studies point out the possible effect on location, form, and amount of parking. AV technology promises vehicles that can drop riders off and park themselves, making the need for nearby parking much less important for a large number of land-uses. In this context, while some studies address park efficiency gains (via autonomous parking) in parking houses (e.g. Kummerle et al., 2009; Mitchell et al., 2010; Heinrichs, 2015; Heinrichs and Cyganski, 2015; Li and Shao, 2015), it is unclear whether these efficiency gains shall be proved economically relevant. Provision of private parking infrastructure (e.g. parking houses) in dense urban areas is expensive. Therefore, it is possible that the provision costs of parking infrastructure exceed the travel costs to free (or more convenient) parking spaces - along the same line, it is also possible than cruising without a driver for short periods of time be more convenient than paying an expensive parking fee. As a result, it can be expected that the demand for parking lots be relocated to sparsely populated areas, where parking space is not a scarce good (Chapin et al., 2016; Zakharenko, 2016). Furthermore, the development of autonomous taxi-like vehicles ("Vehicle on Demand"; Wachenfeld et al., 2015) would also result in a significant reduction of the demand for parking lots in city centers (Heinrichs, 2015). For example, the OECD / ITF study (2015), addressing the replacement of privately owned by shared autonomous vehicles, estimated a potential reduction in the parking requirements of ca. 6 %-16 % for Lisbon, Portugal. Similar results are founded in Zhang et al. (2015).

Given the many changes to the urban environment regarding road use and parking space, some studies address the potential for redevelopment opportunities in urban contexts. Alessandrini et al. (2013) suggest that the new parking requirements should free urban space, which can be used to improve livability of urban environments. Examples of more sustainable public space use include reassigning road and parking space to (segregated) public transport lanes, broader or better sidewalks and bike paths, parks and green areas (Hass-Klau, 2014; Chapin et al., 2016). Additionally, Chapin et al. (2016) considered the implementation of fixed stops for AV, in order to facilitate getting on and off the vehicles without affecting the traffic flow.

Another possible effect associated with autonomous driving relates to longer term land-use changes, in terms of (residential) location choice. Economic literature suggests that households make a trade-off between commute-time, wage/income, living costs, etc., when selecting housing and working locations (So et al., 2001; Bhat and Guo, 2007; among many others). Since house-prices and rent are lower with increasing distance from city centers, a consumer may get access to superior dwellings outside cities (or in their suburbs). But they must then accept lower wages in the rural area or larger commuting times in exchange of higher wages in the cities (Alonso, 1964). Autonomous driving may affect this trade-off. Relieving the driver from driving tasks enables them to engage in other activities during the travel, which may be deemed more appealing or meaningful by the passengers (Silberg et al., 2012; Heinrichs, 2015; Cyganski et al., 2015). This would lead to a reduction of the subjective value of travel time savings (SVTTS) for users of AV (Smith, 2012; Zmud et al., 2016; Milakis et al., 2017b). Thus, a lower SVTTS would result in a willingness to drive longer distances with an impact on the choice of destinations (shopping, leisure, training places) and ultimately even on the choice of residence location (Bahamonde-Birke et al., 2017). Hence, a reduced SVTTS could lead to substantial changes in the settlement structure and to an intensified suburbanization (Childress et al., 2015; Milakis et al., 2017a). This, in turn, would further increase motorized transportation, as well as fuel consumption, pollutant emissions, and consequently the demand for transport related measures (infrastructure, management). Nevertheless, Wagner et al. (2014) raise doubts about claims that vehicle automation technologies would affect commuting patterns. Other technologies developments outside of vehicle automation, like maturing telecommuting technologies, could have a greater impact on travel and urban development patterns. Along this line, it is to be expected that a potential revaluation of the SVTTS would impact on distinct user groups (i.e. given the potential alternative uses of the travel time) and transportation modes differently (e.g. the potential appear to be larger in the case of passenger cars than in public transportation).

Finally, some studies address the impact of autonomous vehicles in the opposite way: that is not how AV are likely to affect cities, but how cities (and city planning) provide conditions for AV. For instance, Heinrichs (2015) considers different city typologies and how different types provide conditions for different forms and applications of AV. Nevertheless, Wagner et al. (2014) interviewed several actors and entities in this regard, reporting that the majority has not yet begun the discussion about how managing the transition to AV operation. Along these lines, Guerra (2016) presents a review of the regional transportation plans (RTP) of the American's twenty-five largest metropolitan areas, showing that none has incorporated self-driving cars and only one mentions the new technology in their current planning documents. As he points out, this is almost certainly not because the planners be unaware or skeptical about self-driving cars. Instead, uncertainty about autonomous vehicles' impacts, their timeline and the gap between future potential impacts and day-to-day investment decisions are mentioned the principal reasons for self-driving cars do not being considered in RTPs. In general terms, although planners follow existing research and develop modeling and other scenarios, it is perceived that existing research does not yet provide sufficient, actionable information to direct investments or planning priorities. In their literature review paper on policy and society related implications of automated driving technology, Milakis et al. (2017b) also revealed the manifold open research questions and uncertainties and suggested to differentiate between different stages of implications – thus indicating that effects of AV have to be considered on a systemic level and not in their singular characteristics. However, we would additionally suggest including experts' perspectives in this process to gain a more comprehensive understanding of the system itself (in its particular spatial form, e.g. urban environments). Thus, valuable hints on directions of future research could be expected.

3. Methodology

It can be assumed that the impacts of a large scale introduction of AV in urban environments will go far beyond the direct implications on vehicle flow and usage primarily discussed in the current literature. Rather, fundamental impacts on the organization of urban transport systems and the urban space can be expected. Against this background, competent planning authorities will have to develop suitable responses and strategies that deal with the new technology. While their perspectives and objectives on the topic are of particular relevance, they have so far been addressed only marginally.

To pick up these aspects, an empirical study was carried out amongst the members of the Association of German Cities' expert commission on transport. The Association of German cities is Germany's largest national federation of municipalities and understands itself as the cities' voice and advocate for local self-government (Deutscher Städtetag, 2016). The expert commission on transport consists of 48 members of different urban transport and city planning authorities. The members of the commission are responsible for the strategic transport planning tasks in their cities. Such strategies need to address how to deal with current and future trends including automation of the transport systems.

The study applied a mixed-method design in the form of an explanatory sequential design (Creswell, 2014) using a quantitative survey and qualitative in-depth interviews. The interviews should thus help to deepen and explain the results from the quantitative part of the study as well as draw upon selected aspects in a more differentiated way (Plano Clark and Creswell, 2008).[1] The survey was designed as an online survey. A preliminary online survey was sent to members of the commission for comments. A revised version of the questionnaire was circulated in September 2016 and yielded a response from 24 cities (50% of the members of the commission[2]). In adherence with data protection guidelines, the survey was conducted in an anonymous form. This implies that the name and position of the respondents and the name of the city they work for are not known. However, the survey included a question on the field(s) of professional activity of respondents to get an indication of their professional focus.

The results were jointly discussed in a dedicated session of the expert commission in fall 2016. Following this, four in-depth interviews were conducted with experts from municipalities that are already carrying out or considering activities on autonomous driving. The interviews were conducted in January and February 2017 – three were realized via telephone, one was a face-to-face conversation. They were audio-taped and subsequently transcribed and evaluated. Special focus was put on similarities between the cities' perspectives (respectively the experts' perspectives) on autonomous driving in relation to objectives of activities and need for actions.

In line with previous studies that emphasized the need to specify and differentiate autonomous driving in relation to different development paths (see Fraedrich et al., 2015; Heinrichs, 2016; Wachenfeld et al., 2016), four different uses cases of autonomous driving

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[1] Though there has been an ongoing discussion for decades whether the often differing methodological, epistemological/theoretical paradigms of quantitative and qualitative approaches actually allow it to combine them (see Tashakkori and Teddlie, 2003) we decided to use a rather pragmatic but nevertheless also very common approach (see Johnson and Omwuegbuzie, 2004).
[2] As this is the entire population of transport city planning authorities dedicated to automatization in Germany, the responses are not treated as a sample but as a census of a small population.

were defined to correctly address the point that the effects of AV are likely to differ substantially depending on the form or type of use case[3]. They are defined as follows:

- **Autonomous Park Pilot (APP)**: After all passengers get off, the vehicle can travel alone to a predetermined parking and from there back to a given pick-up address.

- **Shared Autonomous Vehicle (SAV)**: A Shared Autonomous Vehicle is a vehicle that drives its occupants without a driver. Users can no longer drive themselves in such a vehicle, as there are no steering wheels or pedals.

- **Private Autonomous Vehicle (PAV)**: On request or if necessary, the vehicle can take over the driving task. During this time, the driver does not have to pay attention to the traffic and can execute other activities.

- **Autonomous Delivery Vehicle (ADV)**: A small self-propelled vehicle, which may, if required, also drive on footpaths or cycle paths, takes over the last mile for goods deliveries to customers or to parcel boxes.

From the overall 24 respondents of the questionnaire, six are representatives from large cities with 500,000 inhabitants or more; 18 respondents work in medium sized municipalities with 50,000 to 500,000 inhabitants. It has to be noted though, that, as individual persons were consulted, the responses reflect the opinion of the interviewees and do not necessarily depict a coordinated response from across the administration of the municipalities.

Figure 1 illustrates the field of professional activity given by the survey participants. As can be seen, multiple answers were allowed. The majority of the respondents are engaged in municipal transport planning and development activities, as well as physical planning and design of streets and squares. Other prominent fields of activities – alongside transport in general – include traffic management and public transport. In addition, quite a number of respondents are engaged in other activities. This category (referred to as ‘Other’ in figure 1) comprises activities like city planning, landscape planning and environmental planning. In summary, all respondents are working on subjects with relevance to the planning of future transport systems with presences of AV. The listed fields of professional activities suggest that a majority of the survey participants work directly on transport topics. This indicates that these respondents have primarily an urban transport planning perspective. In addition, this may be an indication that the topic of AV is currently primarily seen and dealt with as a transport planning concern. However, quite many activities reported by the respondents relate to other urban planning subjects. Therefore, while we can expect a strong urban transport planning perspective in the responses to our questions in the subsequent sections, we may not confine it to the transport realm alone.

[3] However, the four use cases are not mutually exclusive in two ways: first, they could as well evolve parallel to each other and therefore be complementary rather than competitive (see Fraedrich et al 2015). Second, they only present a small selection of possible scenarios of autonomous driving – there are in fact many more that are conceivable, but the ones that were chosen for this study should present likely developments of AV in the city by having been widely discussed in the current literature on autonomous driving at the same time.

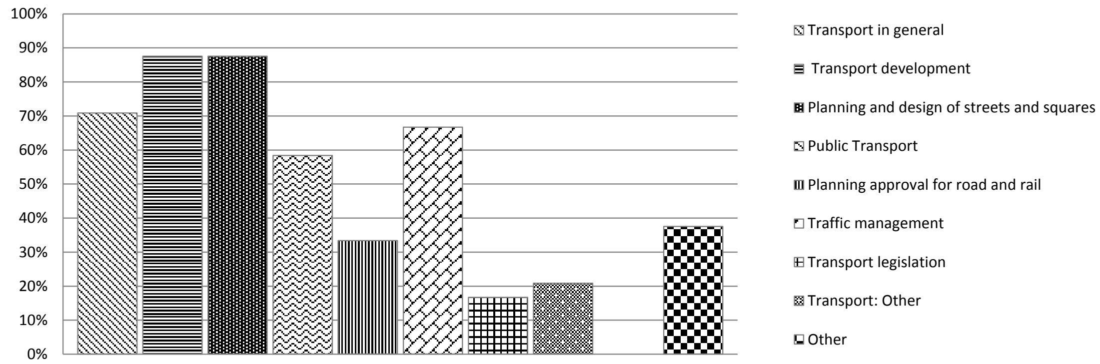


Figure 1: Field of activities of the survey participants

To gain a more comprehensive view on how autonomous driving is currently dealt with in German municipalities, we specifically approached urban transport planning actors from four large cities (more than 500,000 inhabitants) where autonomous driving is already a topic (e.g. in the form of testbeds, pilot projects or policy papers). The respondents – all of them employed in the urban transport and planning departments of their local government and in leading positions – were directly involved in the ongoing activities. The following were the respective working fields of the interviewees: (1) head of city development plan in a department of transport politics, (2) head of the transport department, (3) team leader in the section on forecast, commercial transport and environment in the city's department of transport planning, and (4) head of a department of road maintenance, intelligent transport systems and automotive. With these four experts, we conducted qualitative guided interviews.

4. THE PERSPECTIVES OF CITY-PLANNERS: RESULTS FROM THE EXPERT SURVEY AND SUBSEQUENT INTERVIEWS

This section presents the results of the quantitative survey (Section 4.1) and introduces results of the qualitative interviews that were carried out subsequently to the survey (Section 4.2).

4.1. Quantitative expert survey

In a first block of questions, the respondents were requested to indicate whether activities related to the introduction of autonomous vehicles have already been conducted in their cities, are currently being carried out or are planned in the near future. The results indicate that such activities have only been conducted so far in about one third of the cities, and that no major differences can be observed (for our sample) between big (more than 500,000 inhabitants) and medium-sized cities (between 100,000 and 500,000 inhabitants) regarding the realization of such activities.

Respondents were requested to state the five most important goals for urban transport planning in their respective municipalities. The results are pictured in Figure 2.

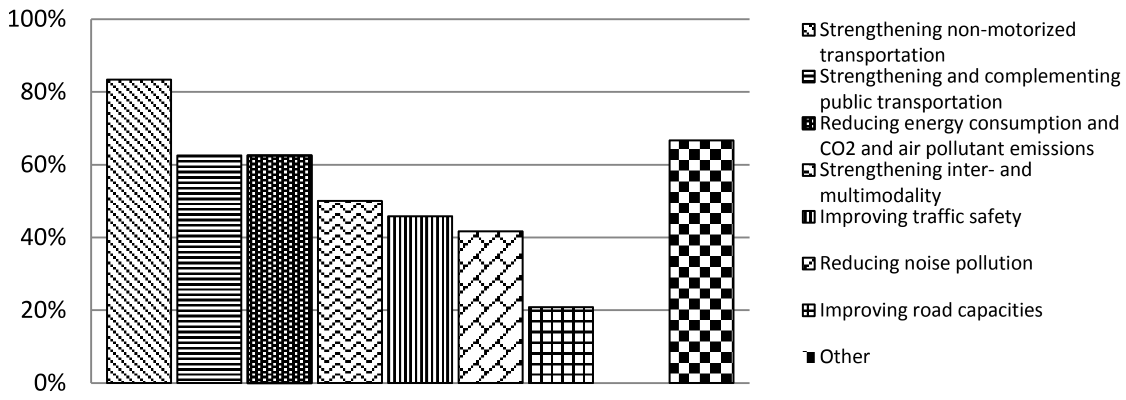
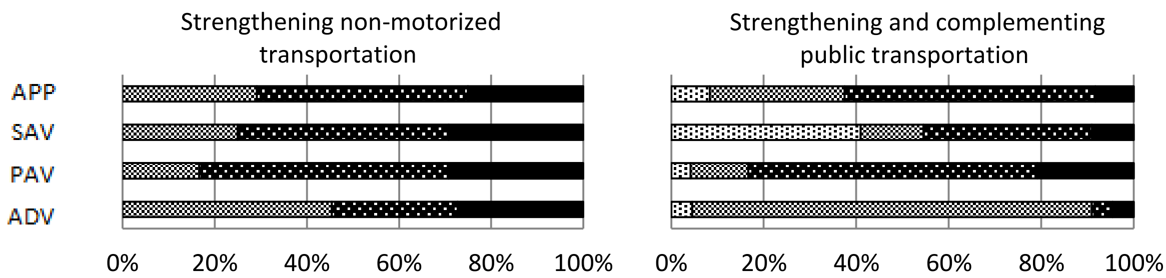


Figure 2: Stated objectives of urban transport planning in the municipalities

The following three objectives could be identified as most important for the urban transport planners: strengthening non-motorized transportation (83 % of the mentions), strengthening and complementing public transportation (63 %) and reducing energy consumption, CO_2 and air pollutants emissions (63 %). Furthermore, strengthening inter- and multimodality as well as improving traffic safety and reducing noise pollution are also among the primary targets in about half of the cities. On the other hand, only about 20 % of the interviewees considered the improvement of traffic flow and road capacities as a major objective (which is, on the other hand, one the most mentioned aspects in the current debate on autonomous driving). Some cities are also targeting other objectives (including, for instance, reducing motorized traffic and travel time, reducing the rate of motorization, guaranteeing equal access for impaired people, increasing the accessibility of urban districts, etc.). These goals represent 67 % of the mentions, but no common denominators among them could be established. In summary, the focus of urban transport planning appears to be set on the reduction of private transportation and its negative externalities as well as assuring the persistence and development of public transport.

In a second block, the respondents were asked to consider the aforementioned use cases and to assess how these could contribute to the achievement of the objectives presented in Figure 2. Subsequently, we only include goals accounting for more than 20 % of the responses and picture them in Figure 3 (for the abbreviations of the use cases please refer to section 3 above).



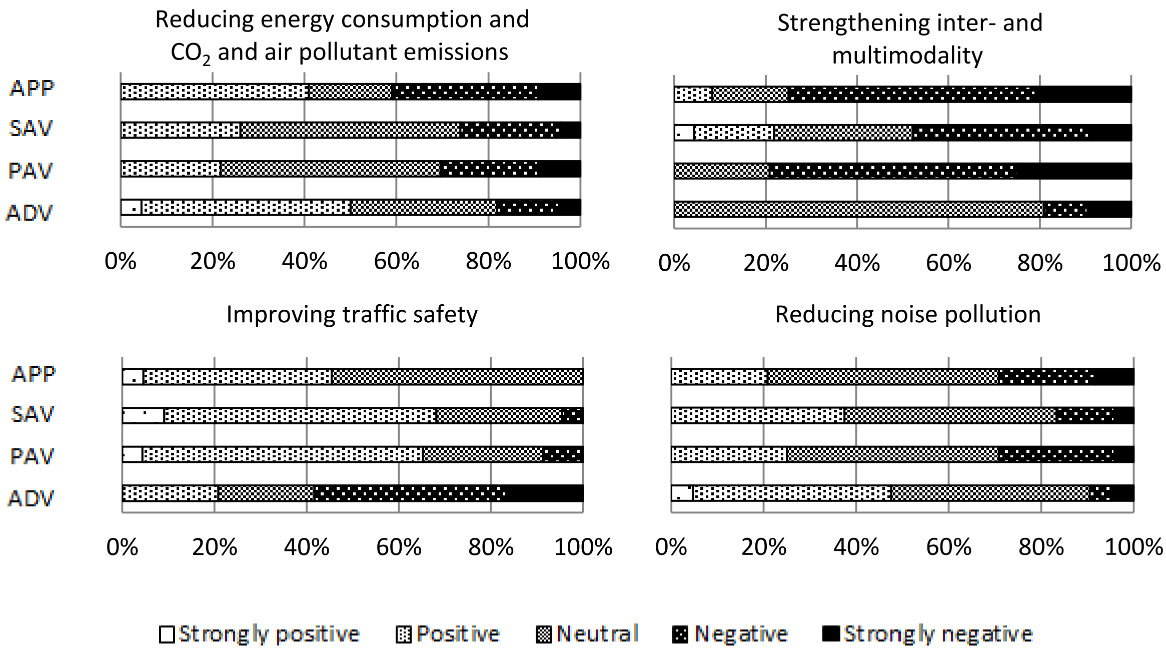


Figure 3: Stated contribution of the different use cases to main planning objectives

The results indicate that the majority of the experts expect rather negative consequences from AV with respect to their cities' primary goals in association with the introduction of autonomous vehicles. At the same time, respondents differentiate in their assessment clearly between the four use cases. The introduction of AV appears to be particularly in conflict with the objective to strengthen non-motorized transport (a major objective in 83 % of the participating cities). None of the experts saw a potential for improvement in association with any of the considered use cases; moreover, the vast majority did expect not a neutral but negative impact. These negative assessments also dominated the topics of strengthening and complementing public transportation, strengthening inter- and multimodality and reducing pollutant emissions. Notwithstanding, some experts (though not the majority) could envisage autonomous vehicles contributing positively to the goals, especially in association with shared autonomous vehicles (SAV). Overall, positive effects induced by automation were only expected with regard to objectives deemed as less important in the previous block, such as increasing traffic safety, and improving traffic flow and infrastructure capacity (the latter are not included in Figure 3 due to their low importance). The respondents' opinions regarding the impact of automation on reducing noise pollution were divided.

The assessment of the overall contribution of the considered use cases in relation to the goals of urban transport development in general are shown in Figure 4.

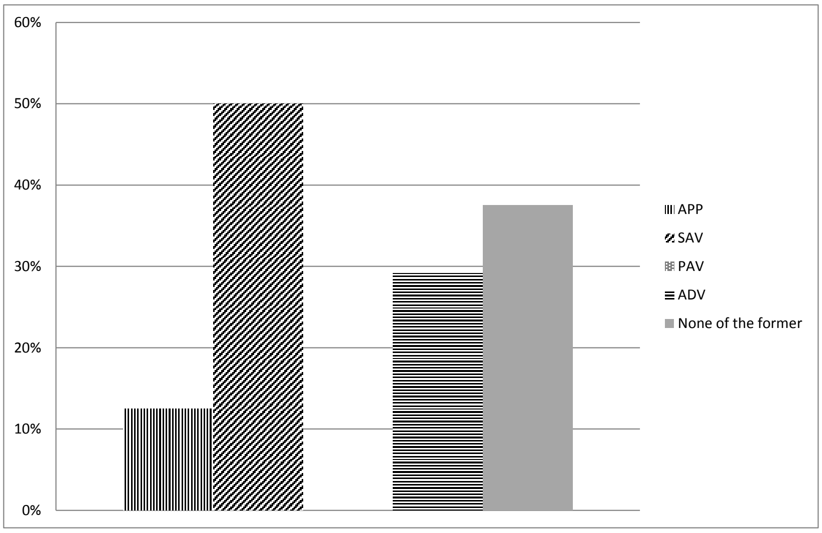


Figure 4 - Can autonomous vehicles contribute to achieving urban transport planning objectives?

As illustrated, 50 % of the respondents believed that SAV could have an overall positive impact on the objectives of the cities. In contrast, none of the respondents associated PAV with a positive contribution to urban and transport planning objectives. Moreover, 40 % of the interviewees did not expect that any of the use cases could have an overall positive impact on the cities' goals. The results reflect that many of the potentials currently associated with autonomous vehicles (e.g. reducing costs, improving road capacities, etc.; Fagnant und Kockelman, 2016) do not seem to be in line with the objectives of the city planners but rather conflict them.

In a third and final block, respondents were asked to evaluate the need for actions and measures in several areas in order to enable autonomous vehicles to contribute effectively to the objections of the cities. These areas were addressed considering the fields of action depicted in Table **1**:

Area	Field of action
Transportation planning	- Update of traffic and local massive transit development plans - Adjustment of strategies to support non-motorized transportation - Adjustment of current economic and business concepts - Development of prediction tools and integrated transportation models considering autonomous vehicles
Traffic control	- Revision of rights-of-way (road pricing, exclusive lines, no vehicles areas, etc.) - Adjustment of speed limits - Adjustment of traffic priorities
Infrastructure planning	- Securing, adapting and certifying road infrastructure for autonomous vehicles - Adjustment of current road infrastructure plans - Redesign and transformation of the road place (lane widths, bus stations, drop-off and pick-up areas, etc.)
Urban planning	- Update of urban development plans - Update of land-use plans - Revision of parking policies - Development of new spatial concepts for parking (decentralized parking facilities, drop-off and pick-up areas, etc.)

Participation	- Opening and encouraging the societal debate on autonomous vehicles regarding possible new uses for urban space - Opening and encouraging the societal debate on autonomous vehicles in order to increase acceptance in the population
Other aspects	- Creating and setting up test fields for autonomous vehicles (for both private and public transportation) - Definition of data standards and data requirements

Table 1 – Potential fields of action regarding an implementation of AV

The following table how immediate respondents see the need for action. For this purpose, Table 2 summarizes the average of the different fields for actions in a given area.

Area	Short-term	Mid-term (3-10 years)	Long-term (10 – 20 years)	No actions required
Transportation planning	13.2%	48.8%	17.8%	20.1%
Traffic control	7.9%	34.9%	14.3%	42.9%
Infrastructure planning	16.0%	41.9%	21.2%	20.9%
Urban planning	12.2%	45.2%	22.0%	20.6%
Participation	32.6%	39.5%	9.3%	18.6%
Other aspects	48.8%	25.6%	16.3%	9.3%

Table 2 – Immediacy of actions regarding an implementation of AV as stated by the respondents

Apart from creating and setting up test fields or the definition of data protocols, the interviewees did not see major short-term need for action with regard to automation. However, promoting the participation of the civil society in the societal debate around autonomous vehicles is regarded as important in the short and medium-term. The majority of the respondents believed that automation should be addressed in the medium-term at the level of transportation, infrastructure and urban planning. It is surprising, however, that 16 % of the planners considered changes in road infrastructure as a short-term necessity, especially when lower proportions identify a short-term need for action in the areas of transportation and urban planning). Finally, a large proportion of the respondents stated that no actions would be required at all regarding traffic management and control. These findings diverge from recommendations found in the transportation literature (e.g. Smith, 2012; Bahamonde-Birke et al., 2017) which point out that autonomous vehicles can cause substantial changes in the attractiveness of the alternatives and thus in the modal partition, This would make it necessary to rethink and reevaluate current traffic control and management measures.

4.2. Qualitative interviews

The quantitative survey revealed a general skepticism that autonomous vehicles would benefit the cities. However, as only about one third of the questionnaire participants stated that their cities have been engaged or are planning to engage in activities related to autonomous driving, one could assume that the critical views are in part due to a lack of knowledge about the potentials of the technology. The interviews with transport planners from four large cities were conducted to gain a more differentiated view on the topic. City governments in all four cities have already started to implement activities with respect to

AV, which permitted an informed perspective on specific requirements for action and whether existing infrastructure needs to be redeveloped. The respondents displayed a positive attitude towards automated driving in general. However, they also raised concerns about potential challenges and risks that might come along with the implementation of the technology that we will discuss in this section.

Activities in the four cities include the inclusion of the topic in strategy documents by the city governments and planning for pilot projects or testbeds in the field of smart mobility and intelligent transport systems. In some cases, these projects are already ongoing for several years. Perhaps a unifying aspect across the cities is the objective to connect AV activities to public transport enhancement (see below). In contrast to this joint goal, the interview participants expressed different views on the needs for infrastructure investments. One interviewee stated that his city government currently links considerations regarding the requirements of AV with possibilities to fund them. The other respondents were in general more skeptical in terms of adapting the infrastructure to allow AV to better ‘fit in’, although their arguments slightly differed. While a lack of possible funding for large scale investments seems to be a prominent challenge for all of them, one participant explicitly stated that “*it is not the infrastructures that have to adapt to autonomous vehicles but rather the other way round*”. This perspective reveals the general concern of all the interviewed planners. While they see the potentials that AV offer in terms of safety or efficiency, they also perceive potential negative implications like an increase in individual motorized traffic and a decrease of public transport mode use in case local governments did not actively promote a development path for AV in urban areas that is in line with their objectives. In general, considerations in relation to infrastructure development seem to be more closely linked to digitalization projects and testbeds than to automated driving ‘only’.

The interviews revealed four overarching concerns across all four municipalities. They are briefly presented below.

Municipalities as driving and steering forces

All respondents indicated that the planning authorities in their city have played a major role in pushing, organizing and implementing activities related to automated (and connected) driving. However, municipalities seem to focus on steering and regulating the activities rather than on “just” being part of research projects, testbeds or pilots. The planning actors stated that they are in general more interested in integrated concepts than in technology-driven projects. One interviewee summarized this view in this way: “*New technologies are not ends in themselves but have to adapt to what serves the city. And in the end, it is the municipalities that have to implement it.*”

Other important actors in relation to activities on automated driving are – first and foremost – the local public transport companies, but also industry and economic actors, research organizations and others with whom they collaborate in different initiatives.

Strengthening, supporting and (re)developing public transport as a major goal

Respondents emphasized that a central task for municipalities is securing livelihoods and welfare services. Thus, to strengthen and (re)develop public transport services was stated as a major goal in all four interviews. Transport planners share the opinion that autonomous on-demand vehicles can be a valuable complement to public transport systems, e.g. in areas with lower demand. In their view, this is also a significant potential for technology dissemination. Complementing rather than replacing existing public transport was seen particularly important to "*prevent cannibalization*" (by other actors), to increase the attractiveness of public transport modes through flexible "*on-demand*" offers and to use existing infrastructure efficiently, specifically with respect to mass transport modes.

Fighting potential increase in car use and its negative effects

Interviewees were very concerned that AV technology would lead to an increase in individual motorized traffic. The reasons behind are that cars could be more easily accessible for everyone, be used more intensively during the day to serve all members of a family, or drive around empty for redistribution purposes. The respondents thus expressed less interest of their cities to engage in activities and projects that would promote individual autonomous vehicles. To counterbalance this threat, they expressed the need to focus on the system as a whole rather than engaging in AV for motorized individual travel. A general consensus among the planners was that automation of vehicles should go along with electrifying their powertrains.

Municipalities' objectives versus federal policy and industry interests

The respondents mentioned that while federal policy's focus currently is on safeguarding Germany as a production location through pushing AV technology ("*mostly technology funding*") as well as safety and efficiency gains, the municipalities have different goals. These are geared towards securing the cities' welfare system and guaranteeing livable cities' for all its inhabitants. These objectives have not gained sufficient attention in the debate on AV so far. Respondents expressed a strong need to consolidate and articulate strategic city's positions and to enter into the debate on research and development priorities for AV. They mentioned the Association of German Cities as the main actor to achieve these consolidated positions. However, they saw the challenge that currently not enough local governments are seriously engaged in discussions and activities around AV and thus do not see too much pressure. This statement connects to the results of the quantitative survey where around two third of the respondents stated to not have been involved in activities on AV so far and a majority only saw a need for action in the mid- or long-term.

5. URBAN PLANING POLICY FOR AUTONOMOUS VEHICLES: DISCUSSION and RECOMMENDATIONS

This paper aims at clarifying (1) how autonomous driving could affect the built environment, (2) to what extent these effects are deemed as 'desirable' i.e. compatible with existing frameworks from a planning perspective, and (3), how urban transport and city planning will need to deal with the aforementioned implications. With respect to the first question, the literature review showed that autonomous driving has the potential to affect the built environment in many ways. Among the key themes are changes in the required road space (right-of-ways and travel lanes) and infrastructures (signage, etc.), effects on the location, form, and amount of parking, interactions with the mobility of cyclists and pedestrians, and changes in land-use and residential relocation.

The survey and the qualitative interviews added some instructive insights on these effects. Firstly, the respondents made clear that the effects on the built environment cannot be separated from deliberations on the impacts on mobility and traffic. The most prominent concern is that AV are likely to increase the attractiveness of private motorized transportation, increasing existing problems like congestion and negative environmental effects. Secondly, and related to the previous point, the survey demonstrated that planners expect the effects to differ quite strongly depending on how autonomous driving will occur. While all respondents of the survey expected the use-case private autonomous vehicle to not positively contribute to urban development, SAV and ADV got a more positive response. This underlines the importance of differentiating impacts of autonomous driving on transportation systems and the built environment depending on how the technology is likely to be adopted. Thirdly, the survey highlighted the importance of infrastructures as a concern of planners with respect to AV. It raises questions whether AV in the different forms will require additional infrastructure and what planning measures and investments the transition from a 'hardware' to a 'software' driven transport infrastructure will require.

Regarding the second question, urban transport professionals were rather skeptical about the compatibility of AV with existing transport and urban planning objectives. Almost 40% of the respondents in the questionnaire doubted that AV – in any form described in the different the use-cases – are suited to support the primary planning objectives of their cities. The main goals – as identified by the survey respondents – are strengthening non-motorized transportation, strengthening and complementing public transportation and reducing energy consumption, CO_2 and air pollutants emissions. Particularly, the development of private autonomous vehicles travel does not seem to be in line with the goals of city planner regarding the strengthening of non-motorized and public transport. On the contrary, autonomous on-demand vehicles (shared autonomous vehicles), as part of public transport systems, could be a meaningful complement to urban development strategies. Across all use-cases, the survey results exhibited that some respondents showed slightly higher optimism with regards to the potential of AV to support energy as well as safety and environment related objectives. Nevertheless, the overall assessment of AV contribution to these goals is at best mixed.

In a way, these results suggest that from the perspective of participants in this survey, AV as a technological solution may fall too short to overcome fundamental challenges associated with transport in urban areas. While they could imagine the technology to help fix problems like traffic congestion, optimizing flow or re-routing vehicles or optimizing parking, it is perhaps less capable of addressing more fundamental concerns such as congestion and an excessive number vehicles using the road system, which would require a shift of people onto public transport or cycling/walking to be overcome.

Interestingly, the survey reveals that the respondents on average did not see the immediate need to take action to prepare for the 'arrival' of AV and to steer the introduction of the technology in the desired direction. Only a few planners stated that urban and transport planning should be adjusted, while the majority identified that this is rather a concern for the more distant future. This assessment perhaps comes a bit as a surprise, when taking into consideration that industry and the federal government in Germany is likewise pushing the case of AV quite strongly. Given that planners are rather skeptical regarding the possible contribution of the technology, one would expect a more proactive perspective.

A possible explanation for this reluctance is that professionals and city administrators are uncertain if and when the technology will be mature enough to be seriously considered and what development path it will possibly take. Currently, a lot of the activities around autonomous driving are framed as ‘test fields’ or ‘living labs’. Technologies are still being developed and trialed. The lack of clarity whether the technology will definitely work and solve problems and improve city services may well be a reason why planners tend to be reluctant to prioritize AV as a topic on their planning agenda.

This brings us to the third question of this article. A first lesson from this survey is that from the urban transport planning perspective, the different use cases of autonomous vehicles seem to differ in their potential implications and, thus, should receive specific attention by planning. Obviously, it occurs that automation may be a promising complement to public transport in the form of SAV. As noted in the interviews, autonomous on-demand vehicles could increase the attractiveness of the public transport supply as feeder modes in areas with lower and fluctuating demand. Planning at the municipal level could start thinking about actions on how to explore this potential. On the other hand, the uptake of AV technology for motorized individual travel raises concerns about increasing car travel and associated negative effects. Local planning could start discussing how this ties into existing strategies to manage car use in cities including parking. Looking at freight, there is yet little clarity and understanding about the possible implications. Activities therefore should start with exploring potential applications and their impact on cost structures, transport and the environment.

A second lesson from the study is the discrepancy between the objectives of urban planning, the federal government‘s policy focus and the priorities of the industry. The survey illustrates that objectives at the municipal level are to increase public transport and non-motorized travel. To this end, planners see a higher potential of automation with respect to the public transport system. Federal government and industry arguments currently appear to attach a high visibility to the automation of cars, related to the arguments of improved safety, better traffic flow and increased energy efficiency. In addition, they tend to strongly focus on securing industry’s competitiveness.

Given this ‘mismatch’, local planners and administrators in Germany should start to consider preparing, consolidating and communicating their strategic positions – as was also argued for in the interviews. This could be done individually as well as collectively, as done elsewhere already. Particularly, a joint position by local governments would be needed to influence current federal policy on research and development priorities with respect to autonomous driving. This seems to be particularly important because the survey shows that the concerns of local transport and urban planners have been not well addressed so far.

A third lesson from the survey addresses the type of knowledge that city planning requires from current research and development activities. One of the biggest concerns highlighted in the study is that any action with respect to AV needs to go beyond demonstrating how to solve specific, practical problems. Rather, studies are required that show and demonstrate how technology can indeed respond to more fundamental challenges and goals that city planners face. Related to this, they should provide 'near time' urban planning policy guidance for a yet (perhaps) distant uncertain development.

To conclude, we have gathered and interpreted current perspectives and expectations of planning professionals on the implications of AV and their opinion on how transport and city planning will need to deal with them. Since the respondents primarily engage in urban transport planning and to a lesser extent in city planning activities, the results may well reflect a transport planning perspective. Given the focus on this particular group of professionals and the comparatively small size of the sample, findings should not be over-interpreted or over-generalized. Nonetheless, the study results provide valuable hints to local governments for their short, medium and long-term plans for urban transport and city development. As the technology will continue to evolve and provide options to solve challenges, local authorities and their urban transport and city planning professionals should be clear and have an agenda on how these potentials may be of use for realizing objectives for urban development. The results of this survey can be a good starting point for developing such an agenda. But it also leaves many questions open, for example what specific types of action are needed and suited to ensure that autonomous driving supports sustainable transport planning in cities. Because of the possible far reaching (second and third order) effects, AV will likely influence broader local development objectives like local economic vitality, social inclusiveness, or attractiveness and livability of public spaces, Therefore, this agenda setting should not be a concern from the transport planning domain alone but rather a multi-sectoral undertaking. This requires placing the debate on autonomous driving, the built environment and the policy implications in a wider urban development context.

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