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Implications of automated vehicles for accessibility and location choices: Evidence from an expert-based experiment

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ABSTRACT

In this paper, possible accessibility impacts of fully automated vehicles (AVs) are explored. A conceptual framework for those impacts is developed based on the model of four accessibility components (i.e. land use, transport, temporal and individual) of Geurs and van Wee (2004). Q-method is applied among a sample of seventeen international accessibility experts to explore heterogeneity among experts with respect to the impacts of AVs on accessibility, and study different views and clusters of experts. Q-method statements are deductively categorized according to four accessibility components of the conceptual framework. Three viewpoints were extracted, indicating that experts expect AVs to influence accessibility through all four accessibility components. Viewpoint A expects that accessibility benefits stemming from AVs will be highly uncertain, mainly because of induced travel demand that will likely cancel out travel time and cost savings of AVs in the long term. Viewpoint B anticipates that accessibility changes because of AVs will have two opposing implications for urban form: densification of city center and further urban sprawl. Finally, viewpoint C expects that those who can afford an AV will mainly enjoy AVs benefits, thus AVs will have more negative than positive implications for social equity.

1. Introduction

Automated vehicles could have significant implications for cities and transport systems. Milakis et al. (2017b) identify three stages of sequential impacts after introduction of AVs: first order (traffic, travel cost and travel choices), second-order (vehicle ownership and sharing, location choices and land use, transport infrastructure) and third-order (energy consumption, air pollution, safety, social equity, economy and public health). This paper focuses on the implications of AVs for accessibility and the location choices.

Thus far, only few studies have explored these impacts using quantitative modeling methods. Childress et al. (2015) used an activity-based model in Seattle, WA to simulate a transport system entirely based on AVs and to explore possible accessibility changes. These researchers concluded that the introduction of AVs could enhance accessibility across the region, particularly in rural areas. A second study explored land use impacts of automated driving from an urban economics perspective (Zakharenko, 2016), concluding that automated driving could induce two divergent land use dynamics in the city. Reduced transport costs could cause cities to further expand, while reduced parking requirements could enhance density of economic activity at the center of the cities. Similarly, Gelauff et al. (2017) using simulations of a spatial general equilibrium model (LUCA) in the Dutch context concluded that automated vehicles could induce both urban dispersion and concentration effects. Dispersion of population in suburban areas resulted when more productive use of car travel time was assumed in the model. Concentration of population resulted when most public transport services (i.e. bus, trams, metro) were replaced by door-to-door shared automated mobility services. Papa and Ferreira (2018) employed Geurs and van Wee's (2004) definition of accessibility to identify critical governance decisions that could steer impacts of AVs on the four accessibility components (i.e. land use, transport, temporal and individual) toward an optimistic or a pessimistic future with respect to the possible benefits for the society. Beyond these studies, some theoretical and empirical work has been done in the related area of Intelligent Transport Systems (ITS) by Argiolu et al. (2008, 2013), showing that these systems have significant impacts on location preferences of office-keeping organisations within urbanised areas. However, literature so far has not provided empirical evidence about potential impacts of AVs on accessibility and the location choices (see e.g. van Wee, 2016; Anonymous, 2017).

Our study aims to fill this knowledge gap by exploring these impacts through an expert-based approach. AVs are a radical and potentially even a disruptive innovation, and it is very difficult to forecast the

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implications of such innovations, as well as the transition path and penetration rates. What is going to happen, depends – among others – on path dependence, (potential) lock-in, coincidence, and many more factors, as explained by evolutionary economics (see Rammel and Van den Bergh, 2003). It is much easier to explain from hindsight what has happened and why, than it is to accurately forecast what is going to happen, especially in case of disruptive innovations. Therefore, we argue it is better to explicitly explore heterogeneity among experts, and study different views and clusters of experts.

To this end, we apply the Q-method among a sample of international accessibility experts to explore possible impacts of AVs on accessibility and the location choices. The Q-method is considered appropriate in this case because it allows capturing heterogeneity in subjective viewpoints regarding a particular topic. Other methods to explore expert opinions generally strive for reducing heterogeneity among experts. The Delphi method, for example, is even designed to reduce heterogeneity among respondents by presenting preliminary results in a second (or even third) round of expert elicitation, aiming to explore reasons for heterogeneity and next reduce it.

In this study, we focus on the impacts of fully automated vehicles (SAE level 5; SAE International, 2016) and we take into account possible synergistic effects of vehicle automation and vehicle sharing. Fully automated vehicles can perform all dynamic tasks of driving (e.g. monitor the driving environment, steering, acceleration/deceleration), in all conditions (e.g. highways, urban streets). They can travel both occupied and unoccupied (e.g. to park or reposition themselves in the case of shared automated vehicles). This study does not distinguish between autonomous and cooperative vehicles (i.e. vehicles that can communicate with each other and/or with the infrastructure). Below, we analyze our conceptual framework on accessibility and location choice impacts of AVs (Section 2), we describe the Q-method and how we applied it in this study (Section 3), and we present the results of our expert-based experiment (Section 4). We close this paper with the conclusions (Section 5).

2. Conceptual framework

Our conceptual framework is based on Geurs and van Wee (2004), who define accessibility as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)" (Geurs and van Wee, 2004: 128) and identify four components of accessibility: land use, transport, temporal and individual. The supply and demand for opportunities (e.g. jobs, shops and health) and the competition for those opportunities within a specific area describe the land use system. The transport system expressed as the disutility of travel in terms of travel time, cost and effort describes the transport component. The temporal availability of opportunities (e.g. open and closing times of stores) and the temporal constraints of individuals (e.g. people may have to work a fixed amount of hours at specific working place) describe the temporal component. The personal needs, opportunities (which can vary according to, for example, income or educational level) and abilities (e.g. physical conditions which might constrain access to specific travel modes) describe the individual component. The land use and transport components form the basis, a first layer, for accessibility and are less easy to change in the short term, while the temporal and individual components form a second layer that is more susceptible to change in the short term. The four components of accessibility interact with each other (see Geurs and van Wee, 2004: Fig. 1, p. 129). For example, the land use component determines to a large extent travel patterns and therefore influences the transport component. Also, the individual component determines the availability of time for an individual and therefore her temporal constraints (individual component).

AVs could influence all accessibility components and subsequently the location choices of people and firms while location choice could affect back accessibility (see Fig. 1). First, the transport component could be affected by changes in travel effort, time and the marginal value of travel time savings, and cost associated with vehicle automation. Second, the individual component could be affected because people that are currently unable to drive could reach activities by (shared) AVs. Third, the temporal component could be affected, for example because people might be able to accomplish activities on the move or (fully) AVs might be able to accomplish certain activities themselves, thus overcoming temporal restrictions of opportunities (e.g. closing times) and individuals (e.g. working hours). Finally, the land use component could be affected because people, firms, shops, services might chose to relocate, compensating for example lower travel costs with more distant location or choosing a more central location taking advantage of self-parking capability of AVs.

In addition to the impacts above, AVs may also influence accessibility via developments in shared mobility. Given that (SAE level 5) AVs can pick-up and deliver passengers autonomously, there is, in principle, no longer a need for personal car ownership. Hence, the trend in AVs is intrinsically linked with the trend in shared mobility, which is reflected in the conceptual model. For example, apart from their possible impacts on car ownership levels, shared automated systems may also meet individuals' travel demand needs with higher flexibility and lower costs compared to existing bus or taxi services, thereby affecting the transport and individual components of accessibility.

3. Method

3.1. Q-method procedure

The Q-method can be used to reveal and understand the variety in subjective viewpoints regarding a particular topic. Given that our objective is to explore the heterogeneity (rather than consensus) among experts regarding the impacts of AVs on accessibility, the Q-method was considered an appropriate method. Typically, the Q-method is not used for this type of purpose, but rather to explore heterogeneity in viewpoints on topics on which a more or less mature debate has evolved (Watts and Stenner, 2005), but we think there is not any mathematical or wider methodological objection for its use in this case.

The procedure of the Q-method encompasses four steps. First, the concourse needs to be defined. In typical Q-studies, the concourse reflects all statements of opinion expressed in communications (in text or verbally) regarding a particular topic (Brown, 1980). Often, the concourse contains too many statements and needs to be reduced to a manageable size (for the next step), while keeping (as much as possible) the complete variety of opinions. The resulting selection is called the Q-sample, and typically contains 30–60 statements (Watts and Stenner, 2005).

In the second step, the Q-sample is included in a rank-ordering task, which is administrated among a set of strategically selected participants. The statements do not have to be completely ordered, but a partial ordering, using a forced distribution, suffices (Brown, 1980). With respect to the condition of instruction, participants are usually asked to indicate their level of (dis)agreement with each statement. The resulting rank-orderings are referred to as Q-sorts and reflect the various viewpoints regarding the subject under study.

In the third step, common viewpoints are revealed by subjecting the Q-sorts to a (by-person) factor analysis (Brown, 1980). By applying the factor analysis participants with similar Q-sorts (viewpoints) are clustered together (i.e. they will load on the same factor). Next, a rotation method can be applied to achieve simple structure. Based on the resulting factor loading matrix, common viewpoints can be revealed by computing the (standardized) factor scores.

In the fourth and final step, the factor scores are used to interpret each viewpoint. Ideally, the interpretation of the factors is supported by comments made by participants (in response to open questions) who belong to (i.e. load on) the respective factors.

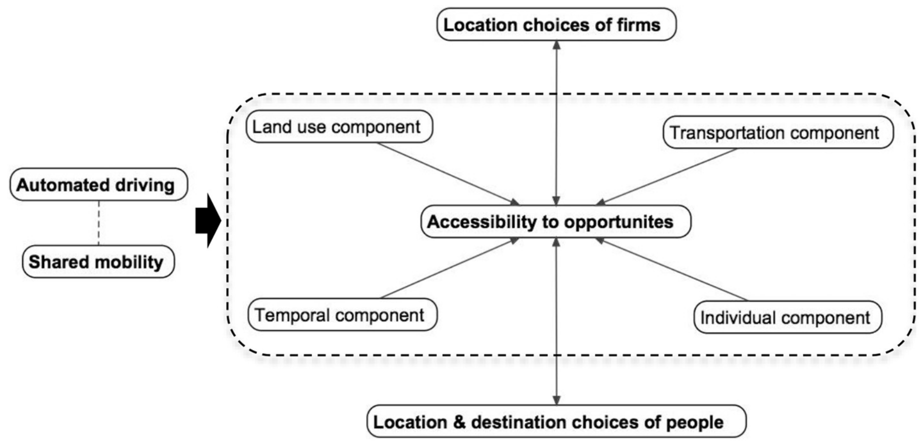

Fig. 1. Conceptual diagram of potential impacts of automated driving and shared mobility on accessibility and the location choices of people and firms.

3.2. Application

While, on a generic level, we followed the four steps described in Section 3.1, our application of the Q-method deviated in two important respects. Firstly, instead of defining the concourse as the collection of opinions regarding a particular topic, we considered the possible effects of AVs on accessibility as the concourse. Secondly, instead of asking participants to indicate their level of (dis)agreement with the statements of opinion, we required participants to indicate the perceived (relative) likelihood that the various effects would occur in the future. As a result of these choices, our viewpoints do not reflect different positions within a (ongoing) discussion regarding a particular topic (as is the case in a typical Q-study), but instead reflect various future scenarios regarding the possible impacts of AVs on accessibility. Beforehand, we were not certain whether the Q-method could (also) be used to this end, but given the coherence of the resulting viewpoints, we believe the results are valid.

To identify the concourse, we used a recent review paper on policy and society related implications of automated driving (Milakis et al., 2017b). This paper provides a comprehensive overview of assumptions as well as academic literature on a series of possible AVs impacts (i.e. traffic, travel cost and travel choices, vehicle ownership and sharing, location choices and land use, transport infrastructure, energy consumption, air pollution, safety, social equity, economy and public health). From this paper, 91 statements related to the impacts of AVs were derived. The four components of accessibility described in the conceptual framework (see Section 2) were used to deductively categorise the various statements. The categorization ensured that all possible accessibility effects through different components (i.e. land use, transport, temporal and individual) are included in the analysis. The categorization also allowed us to make a selection of statements within each category that adequately covered the variety of effects present in that respective category. As such, we were able to reduce the concourse to a representative set of 38 statements/effects of AVs on accessibility.

The set of 38 statements were included in an online survey containing the Q-sorting task.[1] As mentioned above, respondents were required to indicate the relative likelihood of the various effects. The adopted scale ranged from −5 (least likely) to +5 (most likely). This survey was pilot-tested to see whether all statements were sufficiently clear. Based on these results several small modifications were made.

Accessibility experts were invited to complete the survey. We deliberately selected accessibility experts (only) because our focus is on accessibility implications. We selected these experts regardless of their current knowledge on fully automated vehicles, because we have the experience that most transportation experts with a focus on societal and behavioural aspects of transportation know about these vehicles, and certainly about SAE level 5 vehicles, the 'ultimate stage' of automated driving. We defined as accessibility experts those scholars that have published at least 3 Scopus-listed peer-reviewed articles having in the title, abstract, or keywords the term accessibility. We invited experts that focus their research on any field of (transport-related) accessibility. This criterion yielded a total of 59 experts. Seventeen of these experts responded to the survey and were included in the analysis (29% response rate). All participants were affiliated to universities and most had a background in planning/geography.

After completing the Q-sorting task the participants were asked to motivate their extreme positions in the Q-sorting task (statements positioned under −5 and +5) via several open questions. Finally, additional questions were included related to their affiliation, the (perceived) overall impact of AVs on accessibility and a normative statement regarding the desirability of AVs being adopted by society. These concepts could not be considered as part of the definition of our concourse (which related to specific impacts of AVs) and were therefore not included in the Q-sorting task. However, we believed profiling the emerging clusters on these dimensions could aid in the interpretation of the viewpoints.

To assess whether the respondents did not randomly sort the statements, we examined the survey response times. These indicated that, with the exception of one respondent, all respondents took at least 10 min to complete the survey indicating that they were seriously engaged with the survey. In addition, 14 respondents (out of 17) provided answers to the open questions, which were posed after the Q-sorting task, indicating that in general respondents were not strongly affected by survey fatigue.

In line with Q guidelines, the 17 Q-sorts were subjected to a by-person factor analysis using Principal Component Analysis, after which Varimax rotation was applied to achieve simple structure (the software package SPSS 24 was used to perform the analysis). It should be noted here that, within a Q-study, the factor analysis is based on the transposed data matrix, where respondents represent columns (variables) and statements/items represent rows (observations/units). As a result, the factors represent clusters of individuals with similar rank-orderings (Q-sorts) and the factor loadings indicate the extent to which each individual has expressed a certain viewpoint/factor.

Solutions with different numbers of factors extracted (1–4) were tested. Based on the criterion that at least three persons should significantly load on a factor to identify a shared perspective (Brown, 1980), the 3-factor solution was considered optimal. Table 1 presents the (rotated) matrix of factor loadings of the 3-factor solution. These loadings indicate the extent to which each individual has expressed a certain viewpoint/factor. As can be seen from the table, nine respondents loaded (> 0.4) uniquely on the first factor, and three each on

[1] The online Q-sorting software Flash-Q was used to this end.

Table 1
Matrix of factor loadings (after Varimax rotation).

	Factor		
Person	A	B	C
1	0.831		
2		0.791	
3	0.802		
4			0.607
5	0.451		
6	0.768		
7	0.419		
8	0.773		
9	0.646		
10		0.527	
11		0.695	
12			
13	0.626		
14	0.419		0.429
15			0.686
16			0.761
17	0.576		

Note: factor loadings < 0.40 are suppressed.

the second and third factor (in the 4-factor solution only two persons loaded on the third factor).

To reveal the viewpoints standardized factor scores were computed for each factor (using the regression method). These scores approximately range from −2 to +2, reflecting respectively the positions of −5 and +5 in the original Q-sorting task. The standardized scores are shown in Table 2 and are used in the next section to interpret each viewpoint.

4. Interpretation of the viewpoints

For each of the three viewpoints the underlying narrative could be interpreted clearly. These interpretations are provided below and include the accessibility component(s) that each viewpoint emphasizes as well as the underlying factors through which AVs are considered to influence accessibility.

4.1. Viewpoint A: AVs will lead to induced travel demand, offsetting the accessibility benefits

This viewpoint focuses on the transportation component of accessibility. It underlines the notion that AVs will increase travel comfort (2),[2] travel safety (3), and will allow people to perform activities while travelling (38), thereby lowering the value of time (5). Consequently, experts belonging to this factor expect AV users to choose more distant locations to live, work, shop, and recreate (16), leading to increasing travel demand (9). Moreover, experts expect AVs to facilitate the development of ride/vehicle-sharing services (22) by reducing operational costs and by offering people lower cost (23) and more flexible (24) travel services. Increases in shared automated vehicle services could increase travel demand because of empty cruising of these vehicles, which is required in order to serve the next traveler. In turn, travel demand increase is expected to balance out travel time (14) and cost savings (15) of AVs in the long term. In the end, experts with this viewpoint do not believe that AVs will reduce congestion delays (6).

Finally, this viewpoint dismisses any additional effects on the land-use component of accessibility. Hence, experts consider further densification of existing city centres (18) or the elimination of extensive parking lots in suburban areas (20) as relatively unlikely.

[2] The numbers appearing in parenthesis in Sections 4.1 to 4.4 represent the corresponding statement number in Table 2. In this case, (2) represents statement 2 in Table 2 (i.e. AVs will increase travel comfort).

4.2. Viewpoint B: AVs will have opposing land-use implications (densification and sprawl)

This viewpoint emphasizes the land-use component of accessibility. AVs will facilitate the development of ride/vehicle-sharing services (22), while shared automated vehicles will lead to lower car ownership levels (35). Thus, there will be less need for off-street parking spaces (21) and suburban parking lots (20). Related to this, experts expect densification of existing city centres (18), in parallel with the development of new peripheral centres (19) and suburbanization in more remote areas (17). Hence, AVs are expected to have two opposing land-use implications at the same time: densification of city center and further urban sprawl.

Contrary to the first viewpoint, this viewpoint considers it relatively unlikely that AVs will reduce the value of time (5), even though the notion that people can conduct activities while travelling is emphasised (38). Finally, this viewpoint does not consider it very likely that investments on cycling facilities will be gradually reduced after introduction of AVs (13). Hence, AVs are not regarded as competition of the bicycle.

4.3. Viewpoint C: AVs will result in direct user benefits (for the lucky few)

This viewpoint emphasizes the individual component of accessibility. It focuses on the short-term user benefits of AVs; AVs will allow travellers to undertake activities on the move (38). AVs will also increase travel comfort (2) and safety (3), while reducing travel times (7). However, this viewpoint stresses that these benefits will not be equally distributed. Experts expect that AV users will enjoy higher levels of travel safety compared to drivers of conventional vehicles (30) and that the first AVs in the market will be very expensive (28). Yet, they consider it relatively unlikely that AVs will negatively influence investments in travel modes such as bicycle (13) and public transport (12) that are accessible to vulnerable social groups.

Hence, this viewpoint expects that those who can afford an AV will mainly enjoy AVs benefits, but AVs will not compete with travel modes that offer access to opportunities for vulnerable social groups. Overall, this viewpoint expects AVs to have more negative than positive implications for social equity (26), probably interpreted as differences in levels of accessibility across the population.

Finally, experts subscribing to this viewpoint consider it relatively unlikely that AVs will result in lower value of time (5) and thereby induced demand (9), as expressed by viewpoint A. It also does not emphasize the possible (long-term) land-use implications of AVs (18 and 19), as emphasised by viewpoint B.

4.4. Consensus across viewpoints

While the viewpoints show clear differences concerning the likely effects of AVs on accessibility, it is also worth noting the areas of agreement. First of all, several of the direct user benefits of AVs, which are most strongly emphasised in the third viewpoint, are generally supported across the three viewpoints. Specifically, all three viewpoints expect that AVs will allow people to undertake activities on the move (38) and that they will increase comfort (2) and travel safety (3).

There also seems to be agreement on the economic benefits of AVs. In general, AVs are not expected to bring significant economic benefits to individuals (32) or the society (33). Only in the second viewpoint are they expected to lead to some productivity gains (34).

Finally, AVs are generally not expected to increase housing affordability (31). Such an effect may be expected because of reductions in off-street parking requirements, which both viewpoint A and C do not anticipate (21). It seems that all experts consider this line of reasoning as too far-fetched.

Table 2
Standardized factor scores of the 3-factor solution (viewpoints A, B and C).

Statement	Factor		
	A	B	C
Transport component of accessibility			
1. The fixed costs will be lower for owners of automated vehicles (AVs) than of conventional vehicles.	−1.6	−1.2	1.2
2. AVs will increase travel comfort.	0.5	0.4	2.0
3. AVs will enhance travel safety.	0.5	1.0	0.6
4. AVs will increase travel time reliability.	−0.6	0.8	0.1
5. AVs will lead to lower values of time.	0.7	−1.3	−1.0
6. AVs will reduce congestion delays.	−1.9	0.5	0.4
7. Self-parking capability of AVs will result in reduced travel times.	−0.5	0.6	1.5
8. AVs will increase fuel efficiency.	−0.1	1.6	0.4
9. AVs will increase vehicle travel demand.	1.6	0.6	−0.8
10. AVs will significantly reduce operational costs for vehicle/ride-sharing services.	0.9	−0.4	0.2
11. Buses will be gradually replaced by automated vehicle/ride-sharing services.	−0.2	−0.8	−1.2
12. Investments on public transport infrastructure will be gradually reduced after introduction of AVs.	−0.6	−0.6	−1.7
13. Investments on cycling facilities will be gradually reduced after introduction of AVs.	0.0	−1.8	−1.5
14. Possible increase of vehicle travel demand in the longer term, will balance out travel time savings of AVs.	1.4	−0.3	−0.2
15. Possible increase of vehicle travel demand in the longer term, will balance out travel cost savings of AVs.	1.8	−1.1	0.4
Land use component of accessibility			
16. AV users will choose more distant locations to live, work, shop, and recreate.	1.9	0.2	−1.4
17. AVs will induce a new suburbanization wave to more remote areas.	0.4	0.8	0.0
18. AVs will lead to further densification of existing city centers.	−1.5	1.2	−0.8
19. AVs will induce development of new peripheral centers.	0.1	1.4	−2.4
20. AVs will lead to elimination of extensive parking lots in suburban areas.	−1.4	2.0	0.0
21. AVs will reduce off-street parking requirements.	−0.5	0.5	−0.9
Individual component of accessibility			
22. AVs will facilitate development of ride/vehicle-sharing services.	1.0	0.9	−0.7
23. Shared automated systems will meet individuals' travel demand needs with lower cost compared to today's bus and taxi systems.	0.4	−1.2	−0.2
24. Shared automated systems will meet individuals' travel demand needs with higher flexibility compared to today's bus and taxi systems.	0.6	−0.5	1.0
25. AVs will be replaced more frequently than conventional cars.	−0.2	−1.6	0.4
26. AVs will have more negative than positive implications for social equity.	0.0	−0.7	0.9
27. AVs will offer social groups that are currently unable to own or drive a car the opportunity to reduce their current accessibility limitations.	−0.4	−1.3	−0.2
28. First AVs in the market will be very expensive.	1.5	0.1	1.2
29. Safety benefits of AVs will be evenly distributed among different social groups.	−1.6	−0.3	0.4
30. Owners of AVs will enjoy higher levels of travel safety compared to drivers of conventional vehicles.	−0.2	−1.2	2.0
31. AVs will increase housing affordability.	−1.4	−1.0	−0.7
32. AVs will bring significant economic benefits to individuals.	−0.8	−0.2	−0.2
33. AVs will bring significant economic benefits to society.	−0.8	−0.9	−0.6
34. AVs will result in productivity gains.	−0.6	0.4	−0.2
35. An increase in shared automated vehicle services will lead to lower car ownership levels.	0.2	1.1	0.3
36. Full vehicle automation will directly lead to job losses for various professions such as taxi, delivery, truck driver, garages.	0.8	1.3	0.1
Temporal component of accessibility			
37. AVs will be able to do activities without a driver (e.g. pick-up the children from school or the groceries).	−0.3	0.5	0.3
38. AVs will allow people to undertake activities on the move (e.g. working, sleeping, eating).	0.9	0.6	1.4

4.5. Overall impact on accessibility and desirability of AVs

To assess the overall impact of AVs on accessibility as well as the desirability of introducing AVs across the three viewpoints, two separate questions were posed after the Q-sorting task. To relate the results of these questions to viewpoint-membership, each respondent with a factor loading of at least 0.40 on a factor was allocated to that respective viewpoint. Thus, respondents with no substantial loadings (< 0.40) or with double loadings were excluded (2 in total).

Table 3 presents the mean scores of the two additional questions across the three viewpoints. In line with the 'induced travel demand' storyline, viewpoint A disagrees slightly with respect to the statement that AVs will substantially increase accessibility (M = 2.0) and also does not regard the introduction of AVs as particularly desirable from a societal point of view (M = 2.8). Viewpoint B takes a more positive position about overall accessibility impacts of AVs (M = 3.7) and the importance of AVs for our society (M = 4.0). This is in line with the expectations of viewpoint B for important land use changes both at the center and the outskirts of the cities. Viewpoint C is the most optimistic about both the accessibility impacts (M = 4.3) and the importance of AVs for our society (M = 4.3). This position is to certain extent congruent with the storyline expressed by this viewpoint. Viewpoint C does indeed expect substantial benefits for the AV users, yet benefits are not expected to be equally distributed among different social groups. While

Table 3
Mean scores of overall AV impact and desirability across the three viewpoints.

	Viewpoint A (n = 9)	Viewpoint B (n = 3)	Viewpoint C (n = 3)	Kruskall-Wallis test	df	p-Value
Fully automated vehicles will substantially increase accessibility (1 = Strongly disagree - 5 = Strongly agree)	2.0	3.7	4.3	7.98	2	0.018
It is important for our society to introduce fully automated vehicles in the transport system (1 = Strongly disagree - 5 = Strongly agree)	2.8	4.0	4.3	6.23	2	0.044

the numbers in each viewpoint are relatively small, the differences are large enough to reach statistical significance.

5. Conclusions and discussion

In this paper, we explored possible accessibility impacts of fully automated vehicles. We developed a conceptual framework for those impacts based on the model of four accessibility components (i.e. land use, transport, temporal and individual; see Geurs and van Wee, 2004). We used this conceptual framework to apply the Q-method among a sample of seventeen international accessibility experts. We explored heterogeneity among experts with respect to the impacts of AVs on accessibility, and study different views and clusters of experts. Below, we present the conclusions of our study.

Experts expect that AVs will influence accessibility through all four accessibility components. The viewpoints emphasize the four accessibility components to various extents. Viewpoint A focuses on changes in the transportation component of accessibility, while viewpoints B and C emphasize the land use and individual component respectively. The temporal component of accessibility crosses all viewpoints, with experts expecting that AVs will allow people to undertake activities on the move.

Accessibility benefits stemming from AVs are highly uncertain and not expected to be equally distributed among different social groups. Experts' viewpoints share the view that AVs will offer direct benefits to their users in terms of travel comfort, safety and the opportunity to undertake activities on the move. Yet, according to viewpoint A these benefits will be associated with increased travel demand, because of peoples' relocation to outer areas and the proliferation of automated vehicle-ride sharing services. Travel demand increase is expected to balance out travel time and cost savings of AVs in the long term. Several studies have concluded that automated vehicles could induce travel demand increases because of changes in destination choice, mode choice and mobility (see e.g. Childress et al., 2015; Correia and van Arem, 2016; Fagnant and Kockelman, 2015; Gucwa, 2014; Levin and Boyles, 2015; Milakis et al., 2017a). In this regard, a recent study by Fraedrich et al. (2018) has also shown that the expected induced travel demand (and associated congestion) is the most prominent concern among planners. Shared automated vehicles could result in additional increase of vehicle use because of empty cruising to serve next traveler (Fagnant and Kockelman, 2014, 2016; International Transport Forum, 2015). Moreover, viewpoint C expects that those who can afford an AV will mainly enjoy AVs benefits, thus AVs will have more negative than positive implications for social equity. However, all viewpoints agree that AVs will not have adverse effects on investments for public transport and cycling facilities that could offer access to opportunities for vulnerable social groups.

According to the experts accessibility changes because of AVs will have two opposing implications for urban form: densification of city center and further urban sprawl. Viewpoint B expects that shared automated vehicles will reduce car ownership levels and thus parking demand. A reduction of off-street parking spaces is expected to lead to further densification of the city center. Several studies have also suggested that shared automated vehicles can replace conventional vehicles and thus parking demand from about 67% up to over 90% (see Boesch et al., 2016; Chen et al., 2016; Fagnant and Kockelman, 2014; Milakis et al., 2017b; Spieser et al., 2014; Zhang et al., 2015). Moreover, Zakharenko (2016) concluded that reduced parking requirements because of automated vehicles could enhance density of economic activity at the center of the cities. According to Gelauff et al. (2017), concentration of activities could also be the result of replacement of traditional public transport services by door-to-door shared automated mobility services. According to viewpoint B, AVs are expected to lead to further suburbanization of cities. Childress et al. (2015) concluded in an activity - based modeling exercise in Seattle, WA that accessibility enhancement because of automated vehicles is expected to be higher at the outskirts of the city. Gelauff et al. (2017) found that automated vehicles could lead to further dispersion of Dutch cities when more productive use of time on-the-move was assumed in their spatial general equilibrium model. Moreover, viewpoint B believes that suburban parking lots will be substantially reduced and new peripheral centers will be created. Correia et al. (2016) suggested that existing suburban employment, retail and recreation centers could grow into significant peripheral centers in the future to serve demand of AV users that will choose to relocate to exurban areas.

Overall, some experts expect substantial increases in accessibility because of automated vehicles and believe that it is important for our societies to introduce AVs in the transport system (viewpoints B and C). Other experts (viewpoint A), on the other hand, believe the individual benefits of AVs will lead to increased demand, which, on the long term, will offset the travel time and cost savings. These experts are more pessimistic about the accessibility benefits and the desirability of AV implementation in the transport system.

Finally, some (methodological) reflections on the limitations of this study are in order. While the number of participants in this study is not very high (17 accessibility experts), it is in line with typical numbers used in Q-studies, namely between 10 and 40 (Dryzek, 2005; see also Raje (2007) for a study in the transport domain). In principle, a Q-study can even focus on a single person who would sort the (same) Q-set according to different conditions of instruction (Brown, 1980). In the end, the low number of respondents should not be considered problematic given the objective of the Q-study, which is to reveal the existing viewpoints regarding a topic and not to assess the relative proportions of the viewpoints in the population. Since a shared viewpoint can already be revealed if two respondents sort the statements in a similar fashion, the sample size does not need to be very high. That being said, we cannot exclude the possibility that (coincidentally) a cluster of similarly-minded experts did not respond to our survey and that, as a result of this, a viewpoint has not been revealed. Additionally, we cannot exclude the possibility that survey fatigue of the survey participants might have influenced their responses. We are not aware of any literature on survey fatigue in the case of Q-method. Yet, the fact that 14 (out of 17) respondents in the survey provided extensive motivations in the questions posed after the Q-sort shows quite convincingly that survey fatigue was not a major issue in our survey.

A final methodological remark: above we explained why we think that Q-method can be used for our purpose. Because the results reveal three clear viewpoints that can be interpreted well we feel confident about our methodological position.

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