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Autonomous vehicles: The next jump in accessibilities?

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Autonomous vehicles are expected to offer a higher comfort of traveling at lower prices and at the same time to increase road capacity - a pattern recalling the rise of the private car and later of motorway construction. Using the Swiss national transport model, this research simulates the impact of autonomous vehicles on accessibility of the Swiss municipalities. The results show that autonomous vehicles could cause another quantum leap in accessibility. Moreover, the spatial distribution of the accessibility impacts implies that autonomous vehicles favor urban sprawl and may render public transport superfluous except for dense urban areas.

1. Introduction

Fully autonomous vehicles (AV, NHTSA-Level 4 (National Highway Traffic Safety Administration (NHTSA), 2013)) promise a fundamental revolution in mobility. They are expected to make traveling safer (Fagnant & Kockelman, 2015; Kockelman et al., 2016; Litman, 2015), cheaper (Bösch, Ciari, & Axhausen, 2016), more comfortable, more sustainable (Anderson et al., 2014; Brown, Gonder, & Repac, 2014; Fagnant & Kockelman, 2015; Kockelman et al., 2016; Wadud, MacKenzie, & Leiby, 2016), and thus to substantially reduce the generalized costs of travel. They will open car travel to children, elderly and the disabled (Anderson et al., 2014; Burns, 2013; Fagnant & Kockelman, 2015; Lutin, Kornhauser, & Lerner-Lam, 2013). Depending on the scenario, they may also trigger a substantial reduction of the total vehicle fleet (Bösch et al., 2016; Bösch, Ciari, & Axhausen, 2016; Burns, Jordan, & Scarborough, 2013; Chen, Kockelman, & Hanna, 2016; Fagnant & Kockelman, 2014; International Transport Forum, 2015; Zachariah, Gao, Kornhauser, & Mufti, 2014; Zhang, Spieser, Frazzoli, & Pavone, 2015) and substantial road capacity gains (Brownell, 2013; Fernandes & Nunes, 2010; Friedrich, 2015; Tientrakool, Ho, & Maxemchuk, 2011).

If all those assumptions are to become true, autonomous vehicles will not only revolutionize transportation, but dramatically change the urban form. By substantially reducing the generalized cost of travel, they may induce substantial amounts of additional travel demand (Gucwa, 2014; Hills, 1996) and boost a new wave of suburbanization and urban sprawl (Glaeser & Khan, 2003). This research is a first attempt to explore such impacts of autonomous vehicles at a large scale, here for Switzerland. By studying how autonomous vehicles change the accessibility levels (Hansen, 1959) of the Swiss municipalities, it builds upon previous research (Anderson et al., 2014; Heinrichs, 2015) by offering further insights on the shape of future AV-cities and the prospects of public transportation.

To date, only few attempts have been made to study the impact of autonomous vehicles on accessibilities. For example, Kim, Rousseau, Freedman, and Nicholson (2015) used an activity-based model to study the travel behavior impact of autonomous vehicles for the Atlanta, GA, region. Assuming a 50% increase in highway

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capacity, they observe an increase in accessibility for the entire Atlanta region including downtown Atlanta. However, the model only considers highways, which is a major limitation, because as shown by Friedrich (2015), in an AV-regime, (non-arterial) roads where intersections determine the flow capacity may become major bottlenecks. Moreover, in many other studies, highways are assumed to see even higher capacity increases than proposed by Kim et al. (2015).

In a second approach, Childress, Nichols, Charlton, and Coe (2015) used the Puget Sound activity-based transport model to study the impact of autonomous vehicles on the Seattle, WA, region, for four different scenarios. They assumed a 30% capacity increase on roads and 35% shorter perceived travel times when riding an autonomous vehicle. Moreover, they assumed a shared taxi scheme, however, operating at current taxi prices and therefore neglecting the substantial drop in operating costs due to self-driving technologies (Bösch et al., 2016). They observe substantial increases in travel demand (20%) for the scenarios with privately owned autonomous vehicles, but an even more extreme decrease (−35%) in travel demand for the scenario with a fleet of shared autonomous vehicles, which is probably due to the high prices assumed. For all scenarios, accessibility increases for the whole area including downtown Seattle, WA, were observed. Again, however, the assumed capacity increases likely are too low and were not differentiated between different street types. Moreover, assuming current taxi prices biases the resulting impacts for a shared autonomous vehicle scheme.

In addition, both studies neglect travel demand by new user groups and empty rides of autonomous vehicles. Yet, as indicated in earlier studies (Anderson et al., 2014; Fagnant & Kockelman, 2015; Lutin et al., 2013), these two factors account for a major share of the expected new demand. Therefore, it can be expected that including such effects in the analysis will yield different accessibility impacts.

One step into this direction has already been taken by Liu, Kockelman, Bösch, and Ciari (2017), who addressed the problem from the perspective of mode shifts and empty rides. Using an agent-based simulation approach, they predict that if fleets of shared autonomous vehicles can be operated at relatively low prices, they will also attract a large number of former public transport users and generate a substantial amount of empty rides. However, they do not consider any changes in road capacities or additional travel demand generated by new user groups.

The research presented in this paper addresses these limitations by considering different levels of capacity increases, differentiating between street types and including additional travel due to new customer groups and empty rides.

2. Background

2.1. Autonomous vehicles

Autonomous vehicles can drive without a human driver. However, different levels of autonomy can be differentiated. This work assumes autonomous vehicles of NHTSA level 3 and 4 (National Highway Traffic Safety Administration (NHTSA), 2013), i.e. vehicles which can self-drive in some or all situations.

Fully autonomous vehicles have substantial direct impacts on road traffic. In the following, some impacts, which are important for the work presented in this paper, are introduced in more detail.

2.1.1. Capacity impacts

One impact of autonomous vehicles are capacity gains on the road network. Based on traffic flow theory, Friedrich (2015) suggests capacity gains of up to 80% on highways and of up to 40% on urban roads compared to today if all vehicles on the road were fully autonomous. In his estimates, increases in road capacity result from shorter reaction times of autonomous vehicles compared to humans. Yet, he still allows for a time gap to the next car, which is assumed to be acceptable for human passengers (0.5s), and he assumes the same basic design of vehicles as today. Neglecting those restrictions, Tientrakool et al. (2011). suggest a capacity gain of up to 270% compared to today's highway capacity level. They assume a situation with 100% autonomous and fully-connected vehicles. Such capacity impacts can be seen as optimistic, technically possible capacity gains. Other approaches by Brownell (2013) or Fernandes and Nunes (2010) suggest a capacity increase of up 80% for urban roads and 370% for highways as the technically possible upper limit. For this work however, these estimates are considered as too high as they require special driving maneuvers.

2.1.2. New user groups

As autonomous vehicles do not require any driver, they provide car travel also for people who are not able or allowed to drive today (Lutin et al., 2013). Considered in this work are elderly, children and adults without a drivers license, because they represent the largest groups of additional users.

2.1.3. Modal shift

Shared autonomous vehicles can provide the door to door, individual travel experience of private cars at low prices and without the financial burden and hassles of private car ownership (sunk capital, taxes, insurances, repairs) (Johnson, 2015). In addition, they allow passengers to perform non-driving activities during the ride. Comfort-wise, this makes traveling with shared autonomous vehicles very competitive if not superior to today's forms of both conventional car ownership and public transportation. Thus, a substantial modal shift towards such new services can be expected.

2.2. Accessibility

Accessibility describes for a place, how well it is connected to opportunities such as work places, leisure and shopping opportunities. It is a key indicator of the social and economic attractiveness of a place, influencing its future development. Accessibility was first proposed by Hansen (1959) as a concept for describing the quality of transport services in an area. More formally, accessibilityA_i of a place i is defined as the sum of all available social and economic opportunities X_j weighted by the generalized cost c_{ij} of reaching them. Different weighting functions $f(c_{ij})$ can be used, for example to differentiate the accessibilities of different modes. Often, the generalized cost of travel is simplified to travel time alone.

$$A_i = \sum_{c_{ij}} X_j \cdot f(c_{ij})$$

As travel costs are usually independent of the travel direction (A to B costs the same as B to A), the accessibility of a place also describes, how well this place can be reached from any other place. In this sense, accessibility also describes the economic value and prospects of a place.

Based on the New Economic Geography (Krugman, 1991), Duranton and Puga (2003) propose three ways, in which higher accessibility leads to increases in productivity: It minimizes mismatch on the job market and therefore allows a higher degree of specialization; it allows to share the investments for example in universities or infrastructure among more beneficiaries; and it provides a higher number of peers or early adopters for any new idea, thus increasing creativity and the probability of new products to succeed.

Moreover, Weis (2012) has shown that historically, changes in

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