The Future of Bicycle Use in the Context of Automated Vehicles

Seminar Project

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***Abstract* — Autonomous vehicles (AVs) represent a potentially huge change to our urban space and transportation systems. At the same time, an increase of bicycle use in the future is desired. Using a causal network, this research investigates how the changes expected with AV development will affect influencing factors for bicycle use. This research found that bicycle use will remain roughly the same with AV development or potentially increase, assuming a private use of AVs. Among the main critical factors for the future of bicycle use in the context of AVs are firstly a cyclist's objective and subjective safety. AVs are expected to be safer, but also allow higher speed, which has direct effects on cyclists. Secondly, the travel time ratio will undergo major changes, affecting bicycle competitiveness towards motorized road traffic. Finally, the expected gain in urban space will bring a real chance for developing bicycle infrastructures, although a high AV market penetration is required for this effect to be seen. However, interactions with non-motorized users may hinder AVs to exert their full potential, mainly regarding capacity gain. This challenge, among others, will have to be taken into account by policy makers when making decisions concerning AV implementation in urban settings.**

I. Introduction (*Heading 1*)

Automated vehicles (AVs) are expected to operate on swiss roads within the next 15 to 25 years and radically change the transportation system (Schweizerischer Bundesrat, 2016). Simultaneously, bicycle traffic is increasingly supported by communal policies. Many cities in Switzerland have set a goal to increase urban bicycle use in the next 10 years by substantial amounts. E. g. The city of Bern has set the goal, to increase the share of cyclists from 11% to 20% by 2030 (City of Berne, 2015). The city of Zürich wants even to double by 2025 the share of cyclists compared to 2011 (City of Zürich, 2012). This leads to the idea, that urban bicycle traffic will still be present in the long-term future. This working paper will estimate the future trend of using the bicycle as a mode of transportation in cities, while taking into account the rise of AVs. Furthermore, this study will explore which influencing factors are most likely to undergo important changes with the implementation of AVs. These factors will need to be taken into account when introducing AVs into urban settings.

For this, the most important influencing factors for bicycle use will be identified and their links to several aspects of individual car traffic will be represented in a causal network figure. These aspects will drastically change depending on the implementation scenario, further impacting bicycle influencing factors and therefore further impacting bicycle use.

The study area is limited to the urban space. AVs do not necessarily need a human driver, however, different levels of autonomy can be differentiated. This paper only considers SAE level 4 and 5, i.e. vehicle is able to self-drive in all situations (Society of Automobile Engineers (SAE), 2014). In addition, this paper assumes that cyclists will always be identified as such from AVs, which is not the case today.

II. Background

AVs promise a fundamental revolution in road traffic. As human error contributes to 90% of crashes today, AVs are expected to highly increase road safety (National Highway Traffic Safety Administration (NHTSA), 2008; Schweizerischer Bundesrat, 2016). AVs will be digitally connected with each other, so they can anticipate each other's intentions. This opens the possibility for less spacing and, consequently, better use of existing road infrastructures (Fagnant and Kockelman, 2015). With increased capacity and safety, AVs also have the potential to increase speed (Meyer et al., 2017). Furthermore, AVs promise to use less space, because they have the ability to adapt optimally to the dimensions of road infrastructures. AVs will also have a different parking needs (Schweizerischer Bundesrat, 2016). They are expected to make travelling cheaper (Bösch et al., 2017) and, by allow the passenger to use the travel time for other activities than driving, improving their comfort (Ernst Basler und Partner (EBP), 2017). This may increase attractiveness of rural municipalities and, therefore, support urban sprawl (Meyer et al., 2017). With AVs, researcher see a rise in travel demand caused by three reasons: they provide mobility to the elderly and disabled, they open possibility for empty rides and, they create induced demand by improving capacity and ride comfort (EBP, 2017).

Hence, the predictions on the traffic volume are more varied. If AVs are used as a private good, as is the case with conventional cars today, they are likely to stimulate additional travel by creating empty rides. Additionally, privately owned vehicles have high fixed costs and low variables cost, encouraging owners to maximize their driving in order to "get their money's worth" (Litman, 2018). Other researchers emphasize the potential of AVs to reduce vehicle travel distance by establishing a vehicle-sharing scheme. These shared AVs would be owned by fleets, serve

Table 1: Influencing factors for bicycle use and their weight

Chosen influencing factors for bicycle use		Product	% AS	SVI (2015)
s	Infrastructures for rolling bicycles	676	7.7%	High
p	Traffic safety and feeling of security	570	5.7%	High
j	Availability of the bicycles and their technologies	504	7.1%	High
q	Hindrance frequency and travel time ratio	480	4.8%	High
k	Competing alternatives of other means of transport	441	6.3%	Intermediate
o	Parking costs and budget for promotion	408	7.1%	Intermediate
l	Speed regimes and traffic control	399	5.7%	High
d	Distances	336	4.2%	High
r	Infrastructures for parked bicycles	336	4.8%	High
c	Topography	240	4.8%	High

Sources: SVI, 2015; own research

passengers on-demand and cooperate with public transportation. The term “Mobility-as-a-Service” (MaaS) is often used in relation with these kinds of business model (EBP, 2017). A well implemented system of shared AVs has the potential to drastically reduce vehicle fleet sizes and increase occupancy rates (EBP 2017; International Association of Public Transport, 2017). Moreover, the relation between the variable and fix cost in this case leads to a fall of vehicle travel (Millard-Ball, 2016).

The share of bicycle trips in 2015 for the city of Zürich was 13% and 15% for the city of Bern, taking into account the main mean of transport (Städtevergleich Mobilität, 2015). This mode of transportation generates almost no emissions and generates minimal dangers for other road users. By promoting bicycle traffic, cost savings can be made in the health sector and in public expenditure for mobility (Bicycle conference Switzerland, 2012). Furthermore, bicycles are one of the solutions proposed to the achievement of capacity limits of urban transport systems (Dieterle, 2004). For this reason, cities aim to increase bicycle use.

III. Methodology

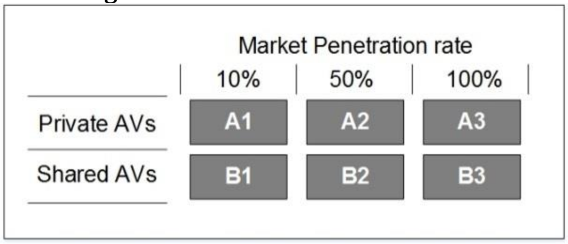
A. Influencing factors for bicycle use

The influencing factors for bicycle use in swiss agglomerations have been defined in 2015 in a research by the SVI (Swiss Association of Transportation Engineers). This work will base its research on these factors. It will sort the most critical factors affecting bicycle use, i. e. factors, that affects the most other factors and are at the same time the most sensible to change. This will be done by creating an impact matrix, which evaluates qualitatively the relationship between factors in the overall system “bicycle use”. From this matrix the active and passive sum can be found for each factor. The active sum shows how important a change in this factor is for the stability of the system. A high passive sum means that the factor is strongly affected by an important change in the system. The multiplication of the active sum with the passive sum of a factor gives its product, which gives information about its criticality. A variable with a high product strongly influences other variables, but is, simultaneously, strongly influenced by a change in the overall system (Vester, 2002). This work will focus on the 10 factors for bicycles that have the biggest product. These factors are to listed in Table 1. To confirm the meaningfulness of this choice, the results are compared to the relevancy assessment of the SVI study (2015).

B. Scenarios

The impacts of AVs on bicycle use depends on many factors of how AVs will be implemented. This study will differentiate two main states. In scenario A, AVs remain in private possession and use, while scenario B describes a state, where a system of Shared-AVs is in place. Both scenarios are further divided in three, according to different market penetration levels (cf. figure 1).

Figure 1: Scenarios for the research



Source: own research

Each scenario is represented as a causal network (cf. Figure 2, p.4). They all rest upon a current-state model, which expresses, by means of percentages, the value of interactions in-between variables. The causal network shows how variables for motorized road traffic are connected to each other as well as with factors for bicycle use. In addition, it indicates the weight of each interaction. If, for example, variable *speed* increases by *x* %, then factor *p* (Traffic Safety) decreases by 75% of *x* (cf. Figure 2).

In Figure 2, three feedback loops, two negative and one positive, can be identified (they are labeled with “-” and “+” signs, respectively). They give the system an iterative characteristic, making it difficult to set a value to each variable. This could be overcome by inserting a value for the variable *capacity utilization rate* and reinserting the new value after the iteration. The results in each case rely on the third iteration. Further iterations assign improbable high values to variables which are part of the positive feedback loop.

The scenarios differ from each other by the inputs set on five variables of motorized road traffic (cf. Table 2). The inputs are in form of numbers between -2 to +2. For example, scenario A3 expects a significant increase in traffic safety, so the variable *traffic safety* get assigned a value of +2. These values, as well as those weighting the relations, have been assumed by the author.

The variables *Vehicle distance travelled, Capacity utilization rate*, *Travel time* and *Speeds* concern the average in motorized road traffic, i.e. cars and AVs mixed. The variable *Traffic safety* includes all crashes including a motorized vehicle, whereas *Comfort* and *Private investment costs* are only related to AV users. This last variable is different between both scenarios. In scenario A it concerns the investment costs users have to pay to acquire an AV whereby in scenario B it concerns the membership price for using Shared-AVs.

Table 2: Inputs for the scenarios

A1		B1	
Traffic Safety	0	Traffic Safety	0
Vehicle Distance Travelled	1	Vehicle Distance Travelled	0.5
Capacity Utilization rate	0	Capacity Utilization rate	0
Space Requirement	0	Space Requirement	0
Comfort	1.5	Comfort	0.5
PIC*	2	PIC*	0.5

A2		B2	
Traffic Safety	1	Traffic Safety	1
Vehicle Distance Travelled	1.5	Vehicle Distance Travelled	0
Capacity Utilization rate	-0.5	Capacity Utilization rate	-0.5
Space Requirement	0	Space Requirement	-0.5
Comfort	2	Comfort	0
PIC*	1	PIC*	-1

A3		B3	
Traffic Safety	2	Traffic Safety	2
Vehicle Distance Travelled	2	Vehicle Distance Travelled	-1.5
Capacity Utilization rate	-2	Capacity Utilization rate	-2
Space Requirement	-2	Space Requirement	-2
Comfort	2	Comfort	0
PIC*	-0.5	PIC*	-2

Sources: own research. * PIC = Private Investment Costs

C. *Valuation of bicycle use*

The inputs shown in Table 2 inserted in the causal network (cf. Figure 2) give every factor for bicycle use a qualitative value. They do not have a unit and are only meaningful when compared to each other. The estimation of the future bicycle use in swiss cities comes from the sum of these factors, weighted with their share of active sum (cf. Table 1). For this calculation, the active sum of each factor (also those not present in the causal diagram) has been considered. In addition, every value has been divided by the number of its inputs, in order for the variables to be comparable.

$$Velonutzung = \sum_{i,j} ij$$

i = Value of factor

j = Share of the total active sum

IV. Results

The results show that bicycle use is expected to increase in any future case, except for scenario B3. This is due to a balance between the factors rather than to a general trend. Scenario B3 assumes a high occupancy rate as well as a decrease in the number of vehicles on the road (International Association of Public Transport, 2017). The only vehicles present are fully automated taxis, which are interconnected with each other, maximizing road capacity use. Thus, there is a lot of space free for bicycle infrastructure and, therefore, factors *r* and *s* are significantly positive. However, reducing the number of vehicles in the model also leads to a considerable increase in speed and decrease in travel time for motorized traffic. This negatively affects factor *l* (Speed regimes and traffic control) and *q* (Hindrance frequency and travel time ratio).

In scenario A, the bicycle use rises with the share of AVs. This is due to the constant increase of the amount travel demand and therefore vehicle distance traveled, affecting the travel time and indirectly the speeds and resulting in high values for factors *q* and *l*. Scenario A3 stands out from A1 and A2 because it adds the benefits of less space consumption for motorized traffic (factors *r* and *s*). The valuation for the future bicycle use for all scenarios can be seen in the following table.

Table 3: future bicycle use per scenario

Scenario	A1	A2	A3	B1	B2	B3
Value of bicycle use	0.11	0.12	0.17	0.03	0.02	-0.03

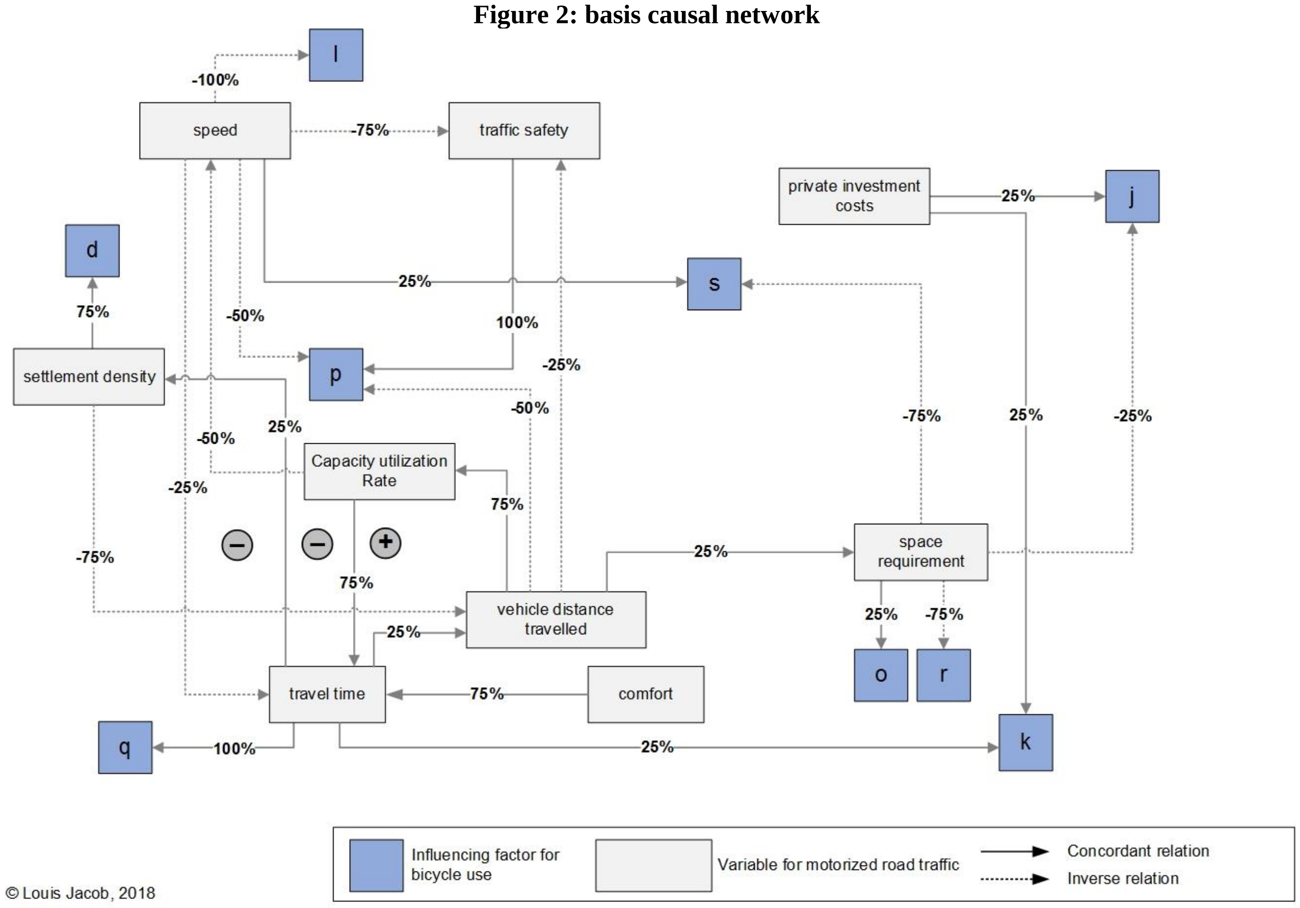
Source: own research

V. Discussion and Policy Recommendation

A. *Significant influencing factors*

As shown in the previous chapter, there are some factors that will represent a larger significance for the future use of bicycle in cities. This will allow policymakers to know where to place their focus when implementing AVs.

Figure 2: basis causal network



Firstly, this study confirms the results of earlier findings, that travel time ratio towards motorized road traffic plays an important role for bicycle use (Rietveld and Daniel, 2004; Fietsberaad, 2006). A better travel time ration for bicycle must be provided towards autonomous vehicles, especially if they are introduced as a private good. This can be reach by providing direct routes and reducing the number of stops (Rietveld and Daniel, 2004). In the causal diagram the significance of the travel time ratio is driven by the 100%-relation with travel time of motorized traffic (cf. figure 2).

Secondly, the results emphasize the importance of traffic safety for bicycle use. Although overall traffic safety increases with the implementation of AVs, the objective and especially the subjective safety of cyclists might be jeopardized by the increase of either vehicle distance travelled or speed. In this study, particularly the aspect of reduced cyclist safety due to the speed differences (factor *l*) stands out. Although the relation to the variable *speed* in the causal network can be judged as too high (100%), it turns out that the difference in speed between cyclists and motorized traffic matters more for the mode transportation choice in favor of the bicycle (Rietveld and Daniel, 2004). SVI (2005) argue that speed reduction is the most effective measure to enhance cyclist safety. With a high level of safety and possibly low amount of traffic, political pressure may develop to increase the maximum allowed speeds. This must be avoided, as it has a strong negative effect on future bicycle use.

Thirdly, the bicycle will benefit from a lower space requirement for motorized vehicles. However, this potential can only be utilized when all vehicles using the infrastructure are automated (EBP, 2017; Litman, 2018). Therefore, this profit mainly occurs in scenario A3 and B3.

B. *Problem by implementation*

The implementation of AVs in urban settings might be difficult because of cyclists and pedestrians. In theory, road user's decision-making in interactions is based on formal priority rules and regulation. However, in application, official traffic rules are often replaced by informal ones (Vissers et al., 2017). While interacting with each other in dense areas road users apply non-verbal communication based on signs, eyes contact and movement (Risto et al., 2017). This might be very difficult for AVs to understand and participate. To achieve many of the benefits, especially the more efficient use of road capacity, high AV shares are required among all types of traffic modes (Fagnant and Kockelman, 2015). However, their safety-first behavior and greater propensity to follow traffic regulations may put them in a disadvantage while interacting with other road users. Non-motorized road users gain an incentive to ostentatiously behave as if they had no expectation that motorized vehicles could be dangerous. This may limit the benefits of AVs in dense urban areas (Millard-Ball, 2016). Taniberg et al. (2017) argue that cyclists, at least in Copenhagen, do already exhibit a dominant behavior towards cars by using speed, movement and grouping together. Once they learn to exploit the caution of AVs, the quality of driving through a city will be even more hampered (Millard-ball, 2016).

Communal policymakers will probably have to negotiate a compromise between maximizing the benefits of AVs on one hand and traffic quality for cyclists and pedestrians on the other hand. It must be ensured that the priority is given to the non-motorized traffic, because good quality for cyclists and pedestrians has often been linked with a high quality of life (Walter, 2017). Furthermore, more research about AVs, notably concerning their behavior while interacting with other road users, and the behavior of other road users themselves towards AVs, is recommended.

C. *Review on the results*

AVs will certainly have a significant impact on bicycle traffic. However, the results found in this study extremely simplify reality and have therefore to be considered with skepticism. Representing the complex interactions occurring in urban traffic with language and diagram is very difficult. Moreover, the number of variables as well as the number of scenarios studied in this work are limited. Furthermore, qualitative assumptions have been made when describing the relation between variables and when estimating changes due to the implementation of AVs. In addition, the research rests on factors for bicycle use of today; nevertheless bicycle traffic is also expected to change, for example, with an increasing share of e-bikes. Finally, they are some trends concerning the whole society, which makes predictions difficult. Data production is permanently increasing. How are we going to deal with it? What will be the future spending capacity of users and, therefore, their budget for mobility?

VI. CONCLUSION

Many important factors for bicycle use are affected by the changes caused by AV implementation. Cities promise an increase in bicycle share, maintaining the bicycle as an important mode of transportation. The results show that bicycle use is likely to follow an increasing trend, also with an introduction of AVs in the market. Especially in scenarios where AVs are used as a private good. The high traffic volume to be expected increases travel time and decreases speed. This will make the bicycle more competitive. Estimations are less positive for scenarios, which are based on an implementation of shared AV fleets. Especially when the market penetration is high, AVs have much shorter travel time than bicycles and the expected lower amount of vehicle due to high occupancy rates increases their speed, negatively affecting the safety of cyclists. Furthermore, the smaller space requirement for motorized road traffic with the development of AVs brings opportunities to build more and wider bicycle infrastructures. Nonetheless, this advantage only occurs with a high share of AVs.

However, they are many further aspects, which can hinder the implementation of AVs in urban settings. Interaction with non-motorized users is one of the big issues AVs will have to face. To fully optimize their potential regarding capacity and traffic flow, AVs must be the only vehicle using the roads. Moreover, AVs will have a safety-first behavior, disadvantaging them while interacting with other road users and making it impossible to fully exploit their potential. Policies will certainly have to make a compromise between exploiting the potential of AVs and promoting non-motorized traffic. At this point, it is important to guarantee quality for cyclists and pedestrians, because they are directly in relation with urban living quality.

Lastly, the results of this research confirm earlier findings, which focus on the importance of travel time ratio and safety for cyclists. These factors must also account for AVs if future policies want to support bicycle use.

VII. LITERATURE

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