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ABSTRACT

Autonomous vehicles (AVs, here self-driving and driverless vehicles, SAE *(1)* levels 4 and 5) are becoming more clearly a reality. Potential services based on AVs, their detailed design for optimal performance, and their consequences for the transport system are of increasing importance. This paper investigates policy combinations for a world with such services. The policy measures investigated are pricing of public transport (through subsidies), pricing of private motorized transport (through taxation or mobility pricing), and the organization of AV services (monopoly vs. oligopoly, with or without ride-sharing). Further, the perception of travel times for autonomous private cars is considered.

All combinations of policies (respectively two to three levels each) are implemented in a simulation to determine their synergies. The applied model is the agent-based transportation simulation framework MATSim. The scenario employed for the tests is the agglomeration of Zug, Switzerland.

The results suggest that, given the current spatial distribution of the demand and the current transport system, none of the tested AV services is able to improve the system. All tested systems lead to an increase in total vehicle kilometers travelled and a decrease of the average accessibility. It could be shown however, that using cost savings by public transport automation to reduce its price has a positive effect.

Therefore, this paper suggests that policy makers are critical when assessing the promises of future transport services. To invest the benefits of automation into an improvement of the existing transport system might be a very good alternative.

INTRODUCTION

Autonomous vehicles (AV), in this paper driverless and self-driving vehicles (SAE *(1)* level 4 and 5), promise to revolutionize the transport system. The possibility of driverless relocations in shared vehicle systems, a substantial cost reduction in public transport operations *(2)*, and driving transformed into productive time are just a few of the revolutionary features expected from AVs (for a comprehensive overview see *(3)*).

Such fundamental changes of the transport system were topics of early papers on AVs (e.g. *(3–5)*). Recently however, the focus shifted to more detailed questions. While insight on the required fleet sizes to serve a city *(6–10)*, or the organization of new services *(11–14)* is background knowledge on the possibilities offered by AVs, they are years, maybe decades away from implementation.

Thanks to this background knowledge however, it is now possible to return to the fundamental question of transport system organization: Given all these new opportunities, but also given the current system as a starting point, and given financial and political constraints, how should the future transport system optimally be organized?

This paper aims to assess different possibilities AVs allow for future transport services given their benefits and costs for society. It evaluates policy measures available to policy makers to influence and shape the transport system, in order to make the most out of the benefits AVs could possibly bring.

Finding the optimal combination of policy measures is a classic optimization problem *(15–17)*. A target function is evaluated in a multi-dimensional space of possible measures and their respective implementation ranges. It is evaluated in an appropriate model of the transport system, meaning that it has to be able to represent the system dynamics and responses to the proposed policy measures. At the same time, it should be fast enough to test many policy combinations.

While an appropriate model is certainly most important, another fundamental part is the definition of the possible policies *(15)*. Policy makers have the following possibilities to influence the transport system: Through direct management, they can optimize the usage of existing infrastructure (e.g. traffic management), or, assumed sufficient financial means, they can provide new or extend infrastructures and/or public transport services. Using taxes (incl. mobility pricing) and subsidies, they can change the costs of certain modes versus others and of the transport system overall, and using legislation, they can regulate the organization and usage of the transport system (e.g. speed limits, priority lanes, etc.). And finally yet importantly, using advertising campaigns, they can (try to) influence general attitudes towards different modes.

The third element is the definition of the target function. The goal of any transport system should be to move people and goods fast, cheap, easy, safe, and sustainable. An optimal transport system maximizes all these targets at the same time. However, as long as safe and cheap beaming is not possible, trade-offs need to be assessed and priorities need to be set. While endless variations in target weighting exist and any choice can be debated, the list of goals per se is manageable and indicators can be found *(18)*.

In summary, as literature shows *(15–17)*, combining the available possibilities to influence the system with a comprehensive target function and an appropriate transport model effectively allows identifying optimal transport policy strategies.

While the above is an established methodology, attempts applying it to investigate how a socially optimal AV based transport system could and should look like are very limited so far. Literature is so far mostly restricted to either describing the system qualitatively or focuses on detailed, mostly operational questions.

This study is an attempt to fill this gap. Starting from the current system and considering financial and legislative constraints, this paper focuses on policies to influence the price existing transport services and the organization of future, AV-based transport services. Given the importance of the value of travel time in AVs, but also its uncertainty, these policies are tested against three assumed perceived travel times in AVs.
This set is evaluated against two performance indicators (instead of a single target function). These are the average achieved accessibility *(19, 20)* representing the positive contribution of the transport system, and total vehicle kilometers traveled (VKT) representing the costs and externalities produced.
The methodology is applied to the region of Zug, Switzerland. The region is modeled with an agent-based transport model (MATSim, *(21)*), which, given its ability to represent single individuals (agents), is particularly suitable to investigate the impact of policy measures. In fact, the impact at the systemic level is the consequence of individual reactions to the policies.

In this paper, the next section describes the methodology, the chosen policy measures and objectives in more detail. The section *Transport Model* introduces MATSim and describes the Zug model. Next, specific sections present, and discuss the results. The section *Conclusion* presents policy recommendations based on the results and concludes the paper.

METHODOLOGY

The methodology followed was proposed by May et al. *(15)* for the development of optimal integrated transport policy strategies. They applied it to different European cities to evaluate combinations of transport policies. Here, given that it is unknown when AVs will be available and to account for the many other uncertainties on the future transport system however, a simplified version of the original methodology is used. The temporal aspects of the policy measure staging are neglected and the policies are less detailed.

The methodology consists of three parts:
First, development of possible policy measures including a respective range for each policy.
Second, definition of an appropriate objective function that evaluates how well different combinations work.
Third, their application in a model of the transport system.
With an analysis of the full policy ranges, not only the optimal strategy can be identified, but also the transport system's sensitivity to the different individual policy measures can be evaluated.
The model used is a MATSim scenario of the Swiss area of Zug. An introduction to MATSim and a description of the scenario follows in the next section.

Policy Measures

The selection of policy measures depends not only on the system characteristics, but also on external restrictions. On top of the obvious ones, such as physical feasibility and financial restrictions, the required political support is also a major condition, if not the most important one. The policy measures proposed here were designed and selected with this in mind.
As mentioned earlier, the number of possible ways for policy makers to influence the transport system are limited. Investments in services or infrastructure, influencing price through taxes (incl. mobility pricing) or subsidies, legislative measures, direct traffic management, and public campaigns are the main ones. The policies investigated are selected from this set. Most policy measures allow for a continuous or near-continuous range in their application. For simplicity

however, only discrete levels were investigated here.

Policy Measures for Existing Modes

Existing modes include mass transit public transport (PT), the slow modes (SM) walk and bike, and motorized individual transport (MIT). For PT and MIT, the respective autonomous version is assumed (aPT and aMIT).
The two policy measures aPT pricing and aMIT pricing were selected. Other possible measures are not further investigated either for their political and/or financial feasibilities (e.g. infrastructure projects), or for their impact being difficult to quantify (e.g. advertisement campaigns). A closer investigation of other possible measures should be part of future work.
These two are complemented by different assumptions on the possible comfort changes through automation.

- *Pricing of aPT* represents any policy measures increasing or decreasing the user price of aPT. The main policy lever is the level of subsidies. The automation of aPT (busses) was estimated to half its production cost *(2)*. As today subsidies cover 50% of the cost of Swiss PT *(22)*, the following three levels of aPT subsidies are investigated: No subsidies, which results in the same price for aPT as for PT today (0.27 CHF/km *(2)*); the same relative level of subsidies (50%) as today, which results in half the price for aPT as for PT today (0.13 CHF/km); and the same absolute level of subsidies as today, which results in a free at the point of use aPT.
- *Pricing of aMIT* aims at increasing or decreasing the average cost per distance for aMIT. The main policy instruments to achieve this are taxes (e.g. on fuel or vehicles) or mobility pricing (for areas or road categories). Bösch et al. *(2)* found the cost of aMIV to be similar to today's MIV costs. Therefore, two possibilities were assumed here: first, a similar level of taxes and/or mobility pricing as today which results in the same marginal cost of aMIV as MIV today (0.18 CHF/km *(2)*); and second, new taxes or mobility pricing for aMIV in the range of 25% of today's cost of MIV, resulting in 0.22 CHF/km.
- *Comfort changes of aMIT* is not actually a policy measure, but represents the expected benefit of autonomous driving technology to transform driving into productive time. It thus reduces the negative value of travel time (VOT) in aMIT. Three levels are investigated here: The same VOT as today, that is as if driving (23.29 CHF/h *(23)*); the same VOT for aMIT as for PT (14.43 CHF/h *(23)*); and, given that other passengers represent for most people a negative factor of traveling with PT *(24)*, a 25% lower negative VOT for the individual aMIT as for PT, resulting in 10.82 CHF/h.

Organizational Form of Future Modes

Future modes represented here are all based on autonomous taxis, which can be operated as a traditional taxi service (aTaxi) or as a ride-sharing service (RS). They can be operated by a public agency or by a private company, which can provide different comfort and price levels. Other models and forms of future modes, such as for example autonomous mini-buses, point-to-point shuttles, etc. are neglected here.
The future form of organization of such services is an important question policy makers should start to think about. If they will wait too long before taking action, the market will organize itself. This might result in a suboptimal system from a societal point of view.
To represent these different forms of organization, the following services are proposed as "policy measures": a monopoly aTaxi or RS service organized by a public agency or private company;

and an oligopoly in which different suppliers compete with different products. While offering the same service, the private monopolist requires a profit beyond the cost of the capital employed, while this is optional for a public provider.

Following the above assumptions, negative VOT is assumed to be the same for RS as for PT, while for aTaxis it is assumed 25% less negative (more comfortable). The monetary prices per passenger kilometer (PPKM) for the services follow *(2)*. The fleet sizes for the services were estimated based on *(10)*. They found that for a good level of service, one aTaxi could replace four private cars. Here, the monopolist's fleet has to serve 25% of the population with such a level of service. Therefore, 25% of 25% of the current car fleet of Zug (96'000 *(25)*) results in 6'000 aTaxis. For RS, a 33.3% smaller fleet was assumed (4'000 vehicles). In the competitive situation, each of the providers is assumed to have a fleet of one third of the respective monopolist (rounded up to the next 500 vehicles). This results in total 6'000 aTaxis (three providers) and 4'500 RS AVs in the area (total 10'500), which increases to total fleet by 75% resp. 162.5% compared to the monopolistic cases. This is realistic, as each provider requires a substantial fleet to offer a good service in the area.

This results in the following four cases:

1. A *monopoly* service offering 6'000 aTaxis for *individual transport* (VOT: 10.82 CHF/h, PPKM: 0.46 CHF/km).
2. A *monopoly* service offering 4'000 AVs for *ride-sharing* (VOT: 14.43 CHF/h, PPKM: 0.30 CHF/km).
3. An *oligopoly* of services competing for customers, represented here by six products, three different experiences (VOT as above, -25%, and +25%) and matching prices (price as above, +25%, and -25%) and each with RS (1'500 vehicles per service) or as aTaxis (2'000 vehicles per service).
4. No AV-based service (base case).

This results in (3 x 2 x 3 x 4 =) 72 different transport scenarios. The policy measures and their ranges, as well as the assumed levels of comfort of aMIT are summarized in Table 1.

TABLE 1 Overview of the policy measures investigated in this paper.

Policy measure	Level 1	Level 2	Level 3
Pricing of aPT	No change to today	-50%	-100%
Pricing of aMIT	No change to today	+25%	-
Comfort changes of aMIT	No change to today	as PT	as PT - 25%
Future modes	None	Monopoly (aTaxi / RS)	Oligopoly (6 services: 3 comfort-price levels, aTaxi / RS)

Performance Indicators

Instead of a single objective function, two performance indicators are used. The first, average accessibility, represents the performance of the system in providing access to opportunities *(19)*. The second is total vehicle kilometers travelled (VKT), representing monetary and social costs of the transport system *(18)*. While more detailed analysis is required for the assessment of individual solutions, the reduction to these two indicators allows comparing the solutions without politically influenced weights (as it would be the case for single target function values). A third factor calculated for the monopolist scenarios is profitability. This gives hints on the potential interest private actors might have to become an operator and if subsidies would be necessary.

Total VKT are often used in transport studies as the direct and single indicator to calculate various costs of the system. Examples range from the pure monetary cost (fuel and vehicle cost per VKT), health cost (accidents per VKT), negative externalities (noise per VKT), to ecologic costs (e.g. CO_2 per VKT) *(18)*.
Here, for each case, the total VKT are provided directly as a proxy for the overall cost of the transport system. They are calculated as the sum of VKT of all modes.

The accessibility of a location is the number of opportunities reachable from that location weighted by the generalized travel costs (here represented by travel time) to reach them *(19)*. It represents in one number the ability of a given transport system to provide access to economic and social activities, and thus to provide local attractiveness and support local growth *(26)*.
In this paper, the average accessibility is calculated of all hectares in the analysis area with at least one trip originating. It is also the average across all modes, weighted by their modal share. For each of these hectares, their own opportunities are included in the calculation with an access factor of 1. Available work places represent the major future development potential for an area and are therefore used here as substitutes for the overall opportunities of a location.

Profitability is calculated by multiplying the total passenger kilometers of the AV service with the passenger price and comparing this to the cost per VKT multiplied with the total VKT of the service.

TRANSPORT MODEL

MATSim

The transport model used here is a MATSim model. MATSim, an agent-based transport model *(21)*, is chosen for its suitability for the evaluation of transport policies targeting individuals and their traveling decisions and because of its computational performance.
MATSim uses a co-evolutionary, iterative optimization process to identify the user equilibrium of a transport system. A population of agents with daily plans, listing activities to be executed and routes and modes to get from one activity location to the next, represents transport demand. Each iteration, a random sample of agents can mutate their plans (change modes, routes, or departure times). Then the transport simulation simulates a full day with all agents executing their daily plan. A queue model is used to simulate traffic *(27)*. After the simulation, each agent scores his plan with a scoring function. It rewards activity time and punishes travel time and cost. During the iterative process, plans with good scores are kept, while plans with bad scores are discarded.

The MATSim functionality which is particularly important for this study, is the simulation of AVs *(14, 28)*. In the basic configuration used here, it simulates AV-based taxi services organized by a central dispatcher. Agents, which would like to use a taxi, place a request at the central dispatcher, which looks for the closest free taxi and assigns it to the agent. The taxi serves the agent and waits at the agent's destination for the next assignment. Relocation is not

included. The taxis are initially placed based on population density.
Additionally, it also allows for the simulation of ride-sharing *(28)*. With ride-sharing, as long as no customer's trip becomes 10% longer than without ride-sharing, the dispatcher can assign detours to serve several customers concurrently.

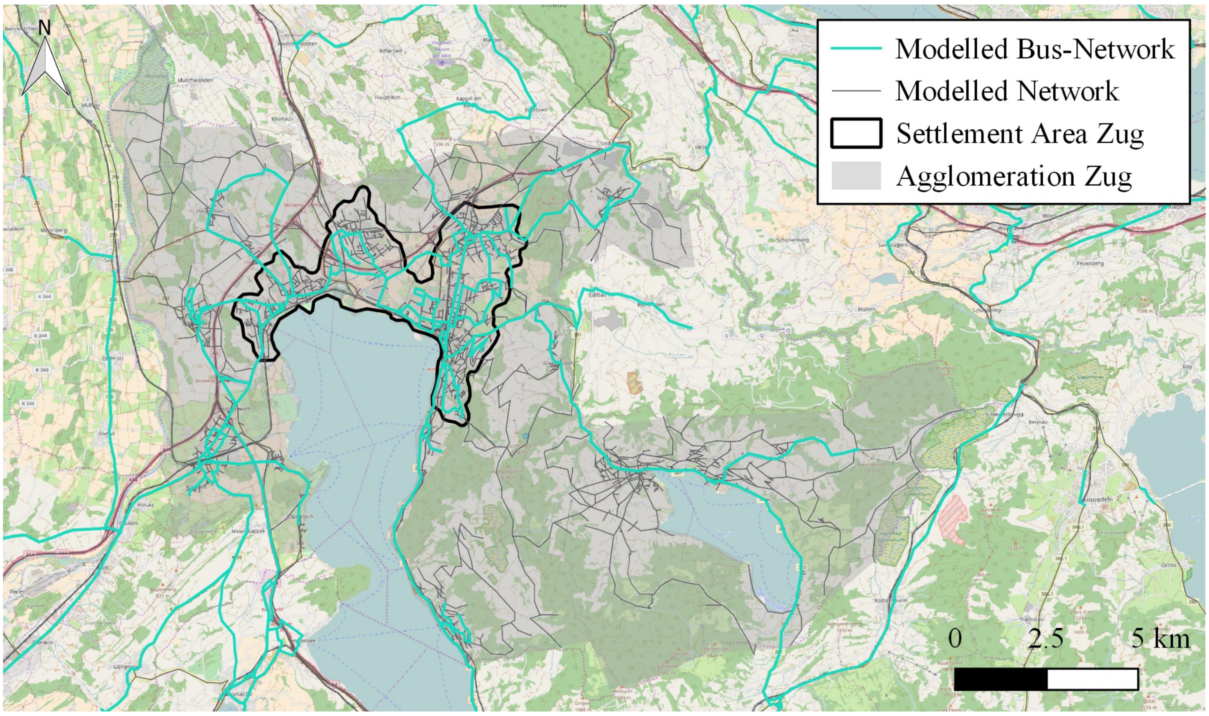
Region of Zug

The city of Zug is a mid-size town located about halfway between Zurich and Lucerne. It has 29'000 inhabitants and is the capital of the canton of Zug with 120'000 inhabitants *(25)*. The canton approximately represents the agglomeration of Zug *(29)*.
From a simulation point of view, Zug is very suitable for this study as it is a large enough town to have its own agglomeration and its own public transport system *(30)* densely covering the main settlement area (Figure 1), but also small enough to allow for quick computation times even if the full population is represented by agents. This representation is required to get realistic results on the usage of public transport and taxi services *(31)*.
Additionally, Zug attracts increasing attention for transport experiments in Switzerland. It was selected for an AV shuttle experiment by the Federal Swiss Railways *(32)*. Starting summer 2017, an AV shuttle will connect Zug main train station with a nearby research campus. Recently, the canton of Zug was also selected by the Swiss Federal Government for a study on the potentials and the possible effects of mobility pricing *(33)*. A study on future transport systems and suitable transport policies for Zug is therefore a good fit with these events.

MATSim Model of Zug

The MATSim model of Zug used for this study is cut from a recently developed 2015 MATSim model for Switzerland (see *(34)* for a detailed description). The model covers all agents having their home within the area, that is the agglomeration of Zug (Figure 1), and all agents of the full Switzerland scenario which have an activity in the area or pass through the area. Within the area, the modelled infrastructure (street network, public transport, facilities) is fully detailed as described in *(34)*. Outside of the area, the street network is modelled on the level of arterial roads (capacity min. 1'000 veh./h) and public transport is only modelled if used by an agent included. AV services are restricted to trips within the area.

The scenario represents the full population, which means that every agent in the simulation represents one real person (assuming no error in the available statistics). In 2015, the population of canton Zug consisted of 117'695 persons *(25)*. Analysis of the simulations however, are focused only on the agents which have their home location in the densely populated main settlement area of Zug (*(35)*, outlined in Figure 1), that is 55'378 agents.
In the baseline scenario, the trip-based modalsplit of these agents is 14% PT, 42% MIT, and 44% SM. Compared to the official statistics (14% PT, 37% MIT, 48% SM, *(36)*), there is a slightly higher use of MIV at the expense of SM. This is balanced however, by the average distance travelled per agent per day with 8km/d PT, 21km/d MIT, and 3.1km/d SM compared to the official 7km/d PT, 26.6km/d MIT and 3.5km/d SM *(37)*. This leads to the conclusion that the model fits well and that the deviations are likely due to the different sampling processes. This is further supported by the reasonably fitting average speeds (Model: 17.3km/h PT, 48.7km/h MIV, 2.6km/h SM; *(37)*: 20.2km/h PT, 46.9km/h MIV, 5.9km/h SM).



Source: background from openstreetmap.org

FIGURE 1 Zug area.

RESULTS

In total 72 scenarios were simulated. Each simulation was run for 100 iterations, which is a low number for MATSim. This somewhat unusual stop criterion is justified by the large number of scenarios and the fact that the two key outputs, average accessibility and total VKT, stabilized already after a very low number of iterations.

Organizational Forms of Future Modes

This subsection compares all scenarios. It focuses on the performance of the different organizational forms of the AV based services. For each scenario, Figure 2 presents the average accessibility versus the total VKT, differentiating the scenarios based on the organizational form of the AV based service.
Figure 2 shows that all policy configurations without any AV based services performed substantially better (ca. 2% higher accessibility with ca. 10% less VKT) than any with such a service - independent of the organizational form of the service. The increase in VKT is most likely the reason for the lower accessibilities due to the congestion caused by the empty kilometers.
Of the policy configurations with AV services, monopoly aTaxi services perform better than the other organizational forms, almost independently of other policies. The RS monopoly and the oligopoly perform both similarly, with scenario differences being due to the combination of other policies.

Non-AV Policy Comparisons

Table 2 presents a comparison of all scenarios without any AV based service. It shows that the price of aPT has the strongest effect on the system performance. A cheaper aPT leads to higher

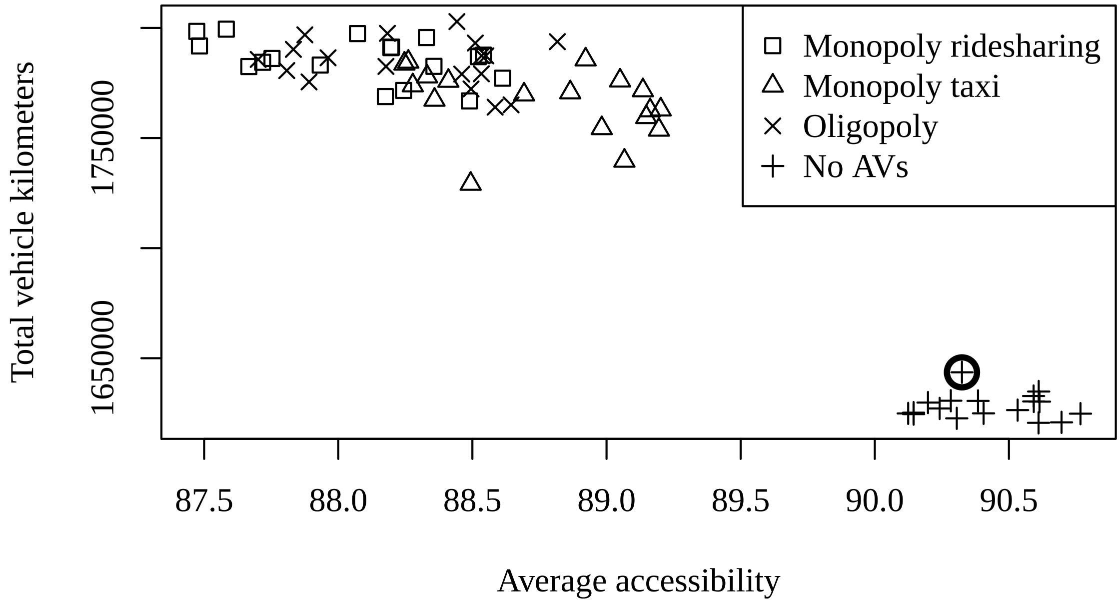


FIGURE 2 VKT accessibility trade-off by market configuration (reference scenario highlighted with a circle).

accessibility at lower VKT. The proposed reason is that the cheaper aPT, the more agents chose it, which leads to fewer cars on the road and thus to faster travel times and less VKT in the system.

In contrast, the strong increase (25%) of the price of aMIT seems to have no effect, which is surprising. Apparently, the attractiveness of aMIT would - political debates aside - sustain such an increase, reminding of the observation that the recent rise of the oil price did also not substantially reduce the modal split of MIT.

The different assumptions on the future perception of travel time (VOT aMIT) have an effect, but only in second order to the price of aPT. Within the same level of price of aPT, a better perception of travel time leads to a higher accessibility. As an explanation for this observation, it is assumed that a reduction in perceived travel time cost increases the modal split of aMIT, which is usually faster than aPT.

Compared to the baseline scenario, the best policy combinations (free aPT and aMIT more comfortable than PT) achieve an increase in average accessibility of 0.5%, while reducing the total VKT by 1%.

Monopolist AV-Taxi Policy Comparisons

This third part focuses on the best performing organizational form of AV service, which is an aTaxi monopoly (Figure 2). Among these scenarios, the pricing of aPT and aMIT, as well as the perceived VOT of aMIT, have comparable effects as described for the scenarios without any AV based service, leading to a similar ranking and thus confirming the respective conclusions.

In none of these simulations, the aTaxi monopolist was able to operate profitably: The average

TABLE 2 Accessibility VMT trade-off for the non-AV scenarios (reference scenario bold).

Price aPT	Price aMIT	VOT aMIT	Average accessibility	Vehicle kilometer
0.00	1.00	pt_plus	90.77	1624811.71
0.00	1.25	pt_plus	90.70	1620876.23
0.00	1.25	pt	90.61	1630282.40
0.00	1.00	pt	90.61	1634877.35
0.50	1.25	pt_plus	90.61	1620651.38
0.00	1.25	car	90.59	1630374.02
0.50	1.00	pt	90.59	1632827.93
0.50	1.00	pt_plus	90.53	1626430.31
0.50	1.25	pt	90.41	1624969.74
0.50	1.00	car	90.39	1630616.51
1.00	**1.00**	**car**	**90.33**	**1643612.24**
0.50	1.25	car	90.31	1622705.01
1.00	1.00	pt	90.28	1630686.73
0.00	1.00	car	90.24	1627178.92
1.00	1.25	car	90.20	1629857.45
1.00	1.25	pt	90.14	1624598.04
1.00	1.00	pt_plus	90.14	1625275.06
1.00	1.25	pt_plus	90.12	1624933.15

Source: In the ”VOT aMIT” column, ”car” means no change to today, ”pt” means the same level as PT, and ”pt_plus” means 25% better than PT.

passenger trip with an aTaxi was 2.038km long. To serve this trip, the average pick-up distance (driving distance from the closest free aTaxi to the passenger) was 2.855km, leading to a productive to total VKT ration of 42%.

DISCUSSION

The results presented in this paper surprise in the sense that the literature (e.g. *(9, 11)*) usually assumes - more or less explicitly - that shared AV fleets improve the transportation system. Here, comparing different possible systems with shared AVs and especially, comparing them with the case without such services, reveals that such an improvement is not necessarily happening.

Before developing this argument further however, the methodology and the simulations should be discussed. The methodology to find optimal transport strategies applied here is based on *(15)*, but simplified as temporal aspects of the policies have been neglected. Given the uncertainty about the arrival of AVs in the consumer market however, this simplification appears justified.

The transport model scenario, on the other hand, should be discussed in more detail. The region of Zug, despite many advantages, has also some important implications for the interpretation of the results. Zug was chosen explicitly for its small area to ensure simulation performance, allowing comparing many different scenarios. For the interpretation of the observation that none of the services was profitable however, this small area indicates that for towns of the size of

Zug, either the service would have to be extended to cover larger distances and to include bigger markets, for example the neighboring areas Zurich or Lucerne, or it would have to be subsidized by the community.
The topic of subsidies raises the question, if within smaller towns (with short trip lengths) and for dense settlements areas in general (often city centers, where today a good coverage with a mass transit system is often already in place), a combination of aPT and of an aTaxi system might really be reasonable. The results suggest that in the long term, one would have to invest in the one or the other.

The baseline model reproduces the existing transport situation well, as shown above. This is further supported by the result that cheaper aPT services without (medium to long term) service reduction lead to a better system performance being common sense.

This brings the discussion back to AV services reducing system performance. The example of Uber in Manhattan *(38)* indicates that this is indeed a valid observation. There, additional empty miles by Uber taxis combined with more customers using car based services, led to an increase of VKT in a system already operating at its limits and thus to a substantial worsening of the overall situation.
Nevertheless, the design of the offered AV based services indicates future work. The fleet sizes were estimated to fully serve 25% of the people in the area. No optimization of the fleet sizes was conducted. This is certainly part of future work. The same applies for the chosen level of prices. Although based on a detailed estimation *(2)*, the assumptions leading to the estimated prices did not fully apply to the scenario at hand. Again, a detailed calculation and optimization of the prices will be part of future work. The simulation of the AV fleets themselves is - up to now - also rather simple. Relocation to minimize pick-up distances and more complex assignment algorithms are in development and might be applied to future studies.

Despite the limitations mentioned in this section, the results represent valuable indications that the introduction of services based on shared AVs, especially if compared against the development of existing services (e.g. lowering PT prices), might not always necessarily mean an improvement for existing transport systems. Having systematically reached this conclusion certainly adds to the present discussion on possible AV based services.

CONCLUSION

In this paper, different policy measures for future transport systems were investigated. They included different levels of subsidies for aPT, of pricing of aMIT, and different organizational frameworks (monopoly vs. oligopoly) for AV based services (Table 1). This was complemented with different assumptions on the future VOT of aMIT, which means how comfortable private AVs will be.
Following *(15)*, different possible combinations of these policies and assumptions were simulated in a scenario of the agglomeration of Zug, Switzerland, using MATSim *(21)*. Zug is small enough to allow simulating the large number of scenarios, but large enough to produce relevant outcomes.
The results of these simulations showed that scenarios including AV services, independent of their organizational form, performed worse than any combination without them (Figure 2). They all lowered the average accessibility in the area while increasing total VKT. Lower accessibilities means more effort for the people to reach the same number of activity opportunities. As

mass transit PT had constant VKT here, more VKT means more externalities, more intense infrastructure usage, and a less SM friendly environment.
Focusing on the scenarios without AV services, lower prices for aPT (assuming constant service levels) led to the best results, while higher prices for private vehicles (aMIT) seemed to have no effect (Table 2).
In scenarios with AV services, monopolistic aTaxi services fare better than monopolistic RS services or oligopolies of different services (Figure 2).

In terms of policy recommendations, these results suggest to be careful with new AV based services. Policy makers are well advised to be critical about promises of such new services and to evaluate in detail how they fit into their particular transport system. The results suggest that, especially for smaller areas and areas with already well-developed PT systems, the role of these new services should be critically questioned. They might increase traffic, including its generalized costs, while at the same time reducing the quality of the overall transport system by e.g. causing more traffic jams, additional waiting times for customers, and reducing the number of free parking spots. A real life example for this is what happened with Uber in Manhattan *(38)*. In this sense, the results also suggest policy makers and society to prepare for an "it will get worse before it gets better".
Small-scale experiments with AVs and the development of new services are to be encouraged as long as it does not cause too much additional traffic and does not disturb the existing system. When the day for large-scale introduction comes, the results of this study suggest that, at least for smaller areas, one should support one aTaxi monopoly. Of the organizational forms tested in this study, it performed best.
Until this day comes however, policy makers are suggested to use the benefits of automation for the improvement of the existing system. The results show that if the cost savings possible with automation of public transport are reinvested in the transport system in the sense that subsidies to public transport are not or only partially reduced, the overall performance of the transport system can be increased and costs reduced - a finding also supported by other recent studies (*(26, 39)*).

To conclude, it might not be as clear that services based on shared AVs will actually improve the overall performance of the system as often suggested. The existing system has grown and evolved during the past century. It is about 100 years, since affordable private cars came on the market, and thus the last major "game changer" in transport was introduced. Since then the system has been improved and a good balance between externalities, affordability and accessibility has been found which has supported the economic growth experienced in the recent decades. If empty rides of private autonomous cars can be prevented or at least kept within reasonable limits, the results of this study suggest that the existing balance between mass transit and private transport is very suited to serve the current society and its spatial distribution. New services might lead to new spatial distributions leading to new requirements, which they will be more suitable to serve, but until then, one needs to be careful with what is to lose, before thinking about what could be won.

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