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Shared Autonomous Vehicles in rural public transportation systems

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JEL classification: H400, R410, R480

Keywords: Shared Autonomous Vehicles; Regulation; Rural; Regional Public Transportation; Future Scenarios; Switzerland

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ABSTRACT

This article focuses on the economic potential and the consequences on the regulatory context of Shared Autonomous Vehicles (SAV) used in a regional public transportation system. Based on an experimental case study two on-demand scenarios were developed for the Swiss rural area of the Töss Valley. Scenario 1 replaces the current public transportation by SAVs; scenario 2 operates with a SAV fleet instead of buses and integrates the regional railway. Data sources are an overall traffic model and the current business figures of the public transportation. The results suggest that scenario 2 is, out of an economic and traffic system view, an attractive solution compared to line-bound traditional bus and train systems. In both scenarios, a cost-covering service may be possible due to an increase in productivity and demand. Regarding the present regulatory context of the Swiss public transportation system, we propose to change the system of call for tenders for single public transportation lines towards a call for tender for entire regions. This paper contributes to the scholarship discussion on the role of the final provider of new services and which adaptions of current regulations have to be targeted in the future.

1. Introduction

Autonomous vehicles may help to reduce traffic congestion as well as accidents and may influence travel behaviour (Fagnant & Kockelman, 2015). Fully autonomous vehicles (level 5[1] after the taxonomy of: SAE J3016, 2016) are expected to be cheaper (Bösch, Ciari, & Axhausen, 2016) and more sustainable (Brown, Gonder, & Repac, 2014) than traditional transportation modes. At the same time, the increase in comfort and the possibility to use the travel time as productive time could inverse the positive aspects of the autonomous vehicles into negative effects: the higher comfort may lead to an increase in the vehicle usage and the vehicle kilometres travelled (Fagnant & Kockelman, 2015). Those different views on possible impacts of autonomous vehicles show that transportation planning should take into consideration different scenarios of the usage of autonomous vehicles in order to provide a sustainable public and private transportation system in the future.

According to the authors' reading of literature, studies on the implementation of autonomous vehicles in the public and private transportation system show a high concentration on urban areas (e.g. Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2015; ITF, 2015; Spieser et al., 2014) and are often calculated on agent-based simulations (e.g. Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2015; Heilig, Hilgert, Mallig, Kagerbauer, & Vortisch, 2017; Hörl, 2017; Hyland & Mahmassani, 2018). At the same time, a study conducted by Meyer, Becker, Bösch and Axhausen (2017) predicts that rural public transportation can profit more from Shared Autonomous Vehicles (SAV) than urban areas. The reason can be found in the high public transportation coverage in urban areas whereas in rural areas public transportation can only be provided on minimal scale

[1] Definition of level 5 of driving automation: "The sustained and unconditional (i.e., not ODD-specific [operational design domain]) performance by an ADS [automated driving system] of the entire DDT [dynamic driving task] and DDT fallback without any expectation that a user will respond to a request to intervene." (SAE J3016, 2016).

due to low population density and low demand. At the moment, there is a difference in the reliance and the attitude of the population in urban and rural areas regarding the public transportation system (Gray, Farrington, & Kagermeier, 2008).

During the last few years, new on-demand mobility services based on smart-phone apps like Uber, DidiChuxing or Lime experienced a rapid growth. However, ridehailing services were implemented faster than the regulator could respond to the market entry. In order to protect the local taxi market, some regulators prohibited the provision of ridehailing services, whereas in other regions their market entry was facilitated. The regulation of ridehailing services shows that the entry of new players in the mobility sector can depend on the regulators' view on the implications of a new service on the entire transportation system (Deighton-Smith, 2018). For instance, a study conducted by Hörl, Becker, Dubernet and Axhausen (2019) in an urban context shows the importance in regulating the usage of privately owned autonomous vehicles as they could lead to an increase of 40% in the total vehicle kilometres travelled. Another scenario with the service provision by autonomous and pooled taxis shows in lower increase of 25% in the total vehicle kilometres travelled.

In this current paper, we will concentrate on the discussion on the regulation of the usage of SAVs in a public transportation system in the rural context of the Töss Valley region in Switzerland. We will present the current regulatory context and then make first predictions on how the regulation of different SAV scenarios could look like in the future. The paper will focus on a public transportation system in a Swiss rural area. By defining two different scenarios of changes in the public transportation system with the entry of autonomous vehicles, we simulate the possible effects of an on-demand and door-to-door SAV service on the public transportation system in the research perimeter of the Töss Valley. Assessing the different possible scenarios then helps to discuss the regulatory context of the proposed services. The authors want to open up the discussion on how the regulator may react on the usage of SAVs in the public transportation system, operating on-demand. Different from many agent-based simulations, we focus on the overall system of the public transportation.

The remainder of this paper is organized as follows: Section 2 introduces the current regulation context of the public transportation in Switzerland. Section 3 discusses the research context, the methods of the simulation as well as the assumptions behind the two scenarios. The results are presented in Section 4, followed by the discussion for future implications of the regulatory context of SAV services in the public transportation system in Section 5.

2. Regulation in the current Swiss public transportation

In order to understand different SAV services in public transportation and their regulatory needs, the present context of regulations in public transportation in Switzerland will be presented hereafter (BAV, 2019).

The Swiss public transportation system is divided in four subsystems:

- Long-distance traffic
- Regional traffic
- Local traffic
- Touristic traffic

All those subsystems pursue different goals and are regulated in different ways. Our simulation of new SAV scenarios concentrated on the context of the regional public transportation, therefore the regulatory context will focus on this subsystem.

2.1 Regulation of the regional public transportation

The Swiss law describes regional public transportation as the transportation provided by buses or trains within and between adjoining regions as well as the rough allotment of local communities. Two conditions have to be fulfilled for declaring a line to be part of the regional public transportation. First, bus or rail lines need to make local communities with more than hundred inhabitants accessible. Second, there has to be at least at one end of the line a connection to the superordinate public transportation system, and they have to make at least one local community accessible. If a line fulfils these conditions, the Swiss Confederation as well as the cantons order the line and subsidize uncovered costs (BAV, 2019). The subsidisation of the public transportation is considered as a public service (UVEK, 2016).

In order to provide the most cost-efficient service, there is a process of tender offers. The invitation for tenders is necessary, if

a) there is a new line for the regional public transportation planned and a concession is necessary. If the anticipated uncovered costs of the line are under CHF 230,000 per year, there is no need for the tender offer process.
b) a concession is renewed and the canton has defined in the first tendering process that the line has to be put out for tender again after the concession has expired.
c) the transportation provider was not able to fulfil the predefined obligations during the concession.

If a new line is planned to become part of an existing regional network of public transportation lines provided by the same operator, the process of the tender offers is not necessary. The reason behind this exclusion is, that matching the new line with the existing lines can increase the synergy potential of the transportation provider (BAV, 2019).

New lines are put out for tender if the regulator sees uncovered demand in a region, but further needs of different stakeholders must be considered in the assignment process of each service too:

- the service has to provide an adequate basis exploitation of the area;
- the service is a request of the regional politic, especially for fulfilling the needs of economic development of peripheral and mountainous regions;
- the service has to be conform with the land use planning;
- the service has to be conform with environmental protection;
- the service has to consider the needs of handicapped persons (Schweizerische Eidgenossenschaft, 2010).

There is the possibility of objections, if one of the listed stakeholder’s needs is not considered in the planning of the new line service. Therefore, the most relevant stakeholders in this case are representatives and politicians of peripheral/mountainous regions, land use planner, environmental activists and handicapped persons.

By winning the tendering, the transport operator has to fulfil several obligations on the provided transportation lines, the most important obligations include:

- Paying customers must be transported (transport obligatory).
- The transport operator is obligated to provide timetables for the lines and to provide the service during the defined operation hours.
- The transport operator defines tariffs for the transportation service, which are adjusted to the frequency, the quality and the cost of the service.
- Services in the regional public transportation system must be integrated in the subordinate public transportation system. There are subordinate tariff systems that have to be adopted and tickets have to be provided over the boundaries of their own service area (BAV, 2019).

2.2 Summary of the present regulatory situation

New lines in the Regional Public Transportation are generally given to operators that can fulfil the different criteria described above. Each line is granted a single concession in order to bundle all the demand on one provider of a line. If there would be no monopoly in the line, the competition may lead to lower cost-efficiencies and higher substitutes that are necessary. Currently, there are 114 transportation operators providing 1,425 lines in the Swiss regional public transportation system. The Swiss Confederation subsidies them annually with around one billion Swiss francs (BAV, 2019).

3. Empirical context

3.1 Research perimeter

The Töss Valley is located in the upper-east of Switzerland (see Figure 1) and is the study site of this current study. The research area consists of ten villages with around 35,000 inhabitants in total (Federal Statistical Office, 2018). The passenger railway line S26 is crossing the whole region and the research area. The entire area is located in the canton of Zurich, the most populated Swiss canton. We chose the Töss Valley because of its location and availability of high quality traffic data and business figures of current public transportation. The valley is located southeast of and close to Winterthur, Switzerland's sixth biggest city and a second-tier city. Winterthur attracts most outbound trips with public transportation from the research area, followed by Zurich, the biggest city in Switzerland. Today, the trip to Winterthur from remote villages takes around 30 to 45 minutes, and the trip to Zurich takes 45 to 55 minutes. From villages near the S-train S26, the trip with the railway takes between 13 to 36 minutes, and around 45 minutes to Zurich.

3.2 Status quo and two SAV scenarios

The current public transportation system (see Figure 1), here called status quo, builds upon two main transportation modes. First, the S-train S26 traverses the research area of the Töss Valley, starting from Winterthur in the north. In the south, the S-train is separating in the south side of the perimeter in two lines. The S-train S26 operates two times an hour: to the half hour only until the end and to the full hour further south of the research perimeter. The second main transportation mode are several fixed route bus lines operating to and from the S-train stations of the S26 line. Several of the bus lines operate between the S-train stations of the S26 and the S3 south of the research perimeter; additionally, numerous short bus lines connect settlements and municipalities with the S-train stations. Depending on the line, the buses operate mostly hourly or each half hour. The overall traffic model indicates around 8,800 person trips with public transportation on an average weekday in and out of the research area. One transportation enterprise provides the entire regional public transportation system, the "Zürcher Verkehrsverbund" (ZVV). The motorized individual transportation, in contrast, generates nearly 82,000 trips on an average during weekday, showing that there is a lower demand for public transportation in the research area, valued from the Swiss perspective.

Scenario 1 (see Figure 1) builds on the entire replacement of the public transportation inside the research area by a SAV fleet, which means no bus or S-train operates anymore. Two different trip modes are possible in this concept. First, all trips to other villages inside the research perimeter are provided by door-to-door SAV trips. Second, for trips outside the research area, SAVs transport the users from their home to an S-train-hub outside the research area. In this scenario, the S-train S26 does not operate inside the research area anymore but operates autonomously between the hub “Sennhof-Kyburg” and Winterthur as well as from “Steg” to the south.

Scenario 2 (see Figure 1**Error! Reference source not found.**) combines the SAV service with the existing S-train S26 line passing through the research area. Therefore, we only substitute the current bus system by on-demand SAVs. The train operates autonomous in this concept, too. Seven existing train stations along the S26 supplement the hub concept. The two sorts of trips in scenario 1 are complemented by two additional possibilities of transportation. First, SAVs bring users from their home to a train station where they change to the S-train. Second, users living near the train station are able to walk to the station and then take the S-train. We assumed a walking distance of five minutes as reasonable.

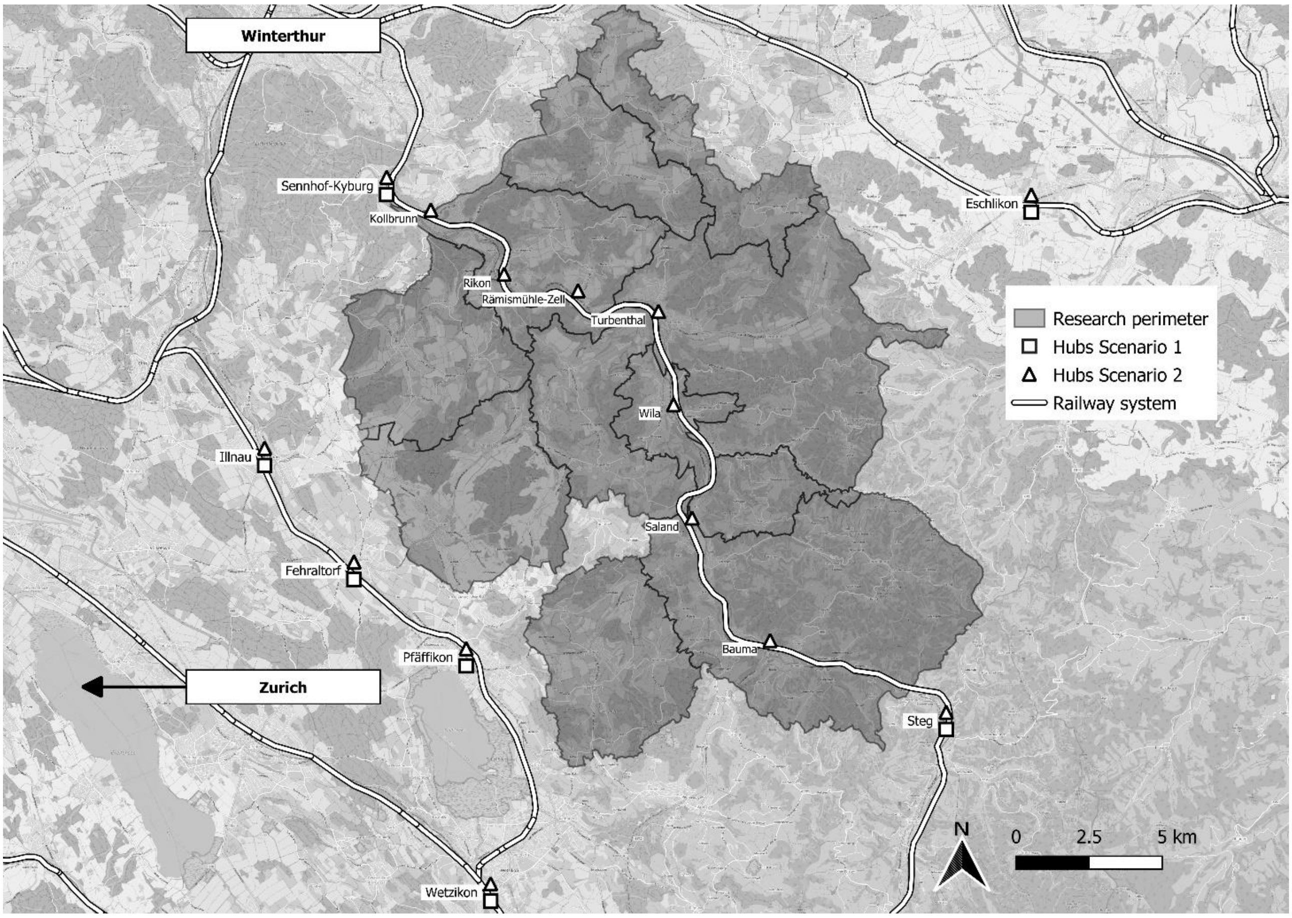

Figure 1. Empirical context and scenario 1 and 2

3.3 Data sources and assumptions

For realistic estimations of the business figures of both new scenarios, we used and analyzed two main data sets. First, the overall traffic model of the canton of Zurich was source of the top ten origin-destination-relations for each village in the research area. This means, that either the origin or the destination, or both, of a trip is registered in one of the ten villages in the research area. The relations are then aggregated on the level of the village, where we always used the village center for further analysis. The overall traffic model (Volkswirtschaftsdirektion Kanton Zürich, 2011) focuses on passenger traffic inside the canton of Zurich as well as the connections from and to the neighbouring cantons. The model differentiates between motorized individual and public transportation traffic as well as human powered (by foot and bike) mobility. Included are all traffic networks, being for public transportation the stops, points of transportation mode changes, hours of service and intervals of each line. The data is available for an average working day as well as for peak hours in the morning and in the evening and for the traffic between 11 and 12 o'clock. The origin-destination-relations are the base of estimating the changes in demand due to improvements in travel time, interchanges of the transportation mode and changes in the interval frequency. Second data set are business figures of the current (situation 2013) railway and bus system for estimating the cost-efficiency of the new scenarios, based on the concept specific demand.

The research is based on data of the anticipated costs and revenue of SAVs and the change in demand due to changes in the travel time and the service interval. Bösch et al. (2018) show that the costs of a 8-seat SAV used in regional circumstances, similar to our research area, will be at

0.55 CHF per km per vehicle. The costs calculation of Bösch et al. (2018) include on one hand the variable costs like depreciation, cleaning costs of the vehicle and abrasion of the tires. On the other hand, fixed costs (e.g. insurance, tax and parking costs) of the vehicle are included as well. For the S-train, costs of 11.26 CHF per kilometre were calculated, based on the available data of the business figures of the current public transportation in the research area. The revenue side builds upon scientific data on the perceived costs of operating SAVs as well as own calculations on the ticket-based costs. Each public transportation user in both scenarios pays 1.70 CHF (based on own calculations that are based on the current public transportation system) as ticket base for the entire trip and 0.16 CHF per travelled kilometre, regardless of the transportation mode.

For the average degree of utilization of the SAVs with eight seats, Bösch et al. (2018) spatially differentiates between suburban and rural areas and temporally between off-peak and peak hours. Four of the villages in our research perimeter were classified as rural, six villages as suburban areas. For the suburban area, the degree of utilization during off-peak hours is assumed as 2.5, rising to 3 persons per trip during peak hour. In rural areas, the degree of utilization is lower with 1.5 persons per trip during off-peak hours and 2 persons per trip during peak-hour.

Further, the level of productivity of the SAVs must be included in the cost-efficiency analysis. During peak-hour, the SAVs can operate during 60 percent of the operation time with the transportation of guests. Distributed over the day the level is little lower at 50 percent. The productivity level results from the calculation of 100 percent minus the charging time, waiting time and transfer time (Bösch et al., 2016 in Bösch et al. 2018).

We used following elasticities (Vrtic & Fröhlich, 2006) to anticipate the change in demand:

- For change in the travel time an elasticity of 0.598
- For the service interval an elasticity of -0.191

The change in travel time was based on Google Maps trips, which was then compared to the current travel time of the bus and S-train services. For the service interval, we calculated an interval of 10 minutes for the SAVs, but the S-train remained on two services per hour. As this paper wants to open up the discussion the topic of regulating future SAV services, we forbear to go more into detail of the calculation steps of each key performance indicator presented in the results.

3.4 Limitations and discussion of the simulation

The estimations in this paper as well as in other studies on the impact of (S)AVs on the transport systems are based on numerous assumptions (Soteropoulos, Berger, & Ciari, 2019). In this paper, the estimations of the model-specific demand are built upon today’s customer trips with public transport in the research area. It was not focus of the research to assess the possible shift away or towards the usage of privately owned vehicles.

The simulation is limited to current transport data and prospective usage scenarios for autonomous vehicles in public transport systems. All trip costs are based upon today’s figures, broken down to the costs per kilometre. The different SAV scenarios will lead to different trip lengths for the same origin-destination relation: in scenario 1, trip routes are more direct than in scenario 2. Consequently, kilometrage, revenues and costs differ between the scenarios.

Further, both scenarios end at the research border or at hubs in neighbouring areas. The present study scenarios manipulated the public transport services originating or ending singly within the research area. Adjacent and connected public transport areas may influence the outcome in the study area, depending on their own usage of autonomous vehicles in public transport.

The chosen simulation can be considered as a new approach to test possible business models with real data on the current usage of public transport. We differ from frequently used agent-based models by focussing only on the available data and by looking more into business model aspects of replacing parts of the public transport offering with SAVs rather than the consequences of such a replacement on the entire traffic system from a transport planning standpoint.

4. Results and Discussion

The different assumptions and consulted scientific cost-analysis lead to the following business figures.

			Scenario	
Figures (annually)		Status quo	1	2
Costs	in millions of CHF	16.22	11.80	14.00
Revenue	in millions of CHF	8.30	13.09	15.17
Gains	in millions of CHF	-7.9	1.28	1.17
Cost-efficiency		51%	111%	108%
Total Vehicle Kilometers Bus	in millions of km	1.18	-	-
Total Vehicle Kilometers SAV	in millions of km	-	16.39	9.73
Total Vehicle Kilometers S-train	in millions of km	0.68	0.21	0.77
Passenger trips (bus or SAV)	in millions of trips	2.90 (bus)	3.83 (SAV)	3.02 (SAV)
Passenger trips (S-train S26)	in millions of trips	1.12	1.59	1.78
Trips by foot to railway S26	in millions of trips	unknown	-	0.72
Total passenger trips	in millions of trips	2.90	3.83	3.74

Table 1 Annual business figures, per scenario

4.1 Forecasts of the different scenarios

4.1.1 Change in demand

Both scenarios show (see Table 1) an increase in the total passenger trips. In the present system, there are nearly 2.9 million passenger trips with the bus. The passenger trips with the S-train are on 1.1 million. In scenario 1, we see an increase of the demand in the form of the passenger trips of around one million additional trips, for scenario 2 the passenger trips rise by 0.9 million. The reason for the high increase in both concepts can be seen in the direct trips of the SAVs inside the research area as well to the hubs with a calculated changing time of only five minutes to the S-train. In addition, the trips include only maximum one changing process, reducing the overall travel time.

The increase in demand is higher in scenario 2 due to more direct trips especially to the hub "Sennhof-Kyburg" (see Figure 1), where the most trips are leading to. They are more direct, as the SAVs operate mostly diagonal towards this hub; in scenario 2 the SAVs operate to the hubs inside the research area, leading to less direct trips compared to Scenario One and therefore to slightly longer trip lengths. The trips are less direct, as the SAV trip to the hubs lead to a slight detour compared to the diagonal trips toward "Sennhof-Kyburg".

4.1.2 Cost-efficiency

In the status quo, the entire system can only be provided due to subsidies, as only 51% of the revenues cover the costs. The estimations of the two scenarios show a high gain in efficiency of the entire system. In scenario 1, we see an increase of the gains per year. By replacing the entire public transportation system by SAV, this ratio jumps over the hurdle of 100%. The revenues are 11% higher than the total costs. The explanation behind this efficiency increase can be manifold. At first, the omission of the driver's task lowers the costs of the system. This is only possible when SAVs can drive without any driver being present in the vehicle, being the above-mentioned level 5. A further aspect of the increase in efficiency is the attractiveness of the door-to-door service. This can increase the demand for public transportation as well as the bundling effects. The demand is increasing due to lower travel time and direct trips without changes of the line or the vehicle.

Compared to scenario 1, scenario 2 shows still a higher revenue side than the system should cost, but it is with 108% slightly lower than seen in replacing the entire public transportation by SAVs. The usage of S-train in this system leads to the highest costs of all three scenarios. As the driver's task in trains is responsible for only about 15% of all the costs (bus: around 50%), the system sees slightly lower gains in the end. However, due to attractive direct trips towards the different S-train hubs, the system remains attractive and attracts more passengers than the current system.

4.1.3 Effects on the traffic situation

In the current system, buses in the research perimeter are responsible for 1.18 million vehicle kilometres travelled per year. In both new scenarios, we can see a high increase of the total vehicle kilometres travelled. In scenario 1, SAVs travel 16.39 million kilometres. This increase of the total vehicle kilometres travelled by a factor of nearly 14 compared to the current situation may put a high pressure on the entire road system within the research perimeter. By integrating the S-train in the system, the pressure can be lowered, nevertheless SAVs are still responsible for around 9.72 million vehicle kilometres in the research perimeter (factor of 8.2 more vehicle kilometres travelled compared to today).

Beside the overall increase of vehicle kilometres, it is important to consider local consequences on the traffic situation, too. We did that by assessing all trips to a hub in both scenarios for the peak-hour traffic. In Figure 2, we depict the frequency of trips to and from each individual hub in both scenarios.

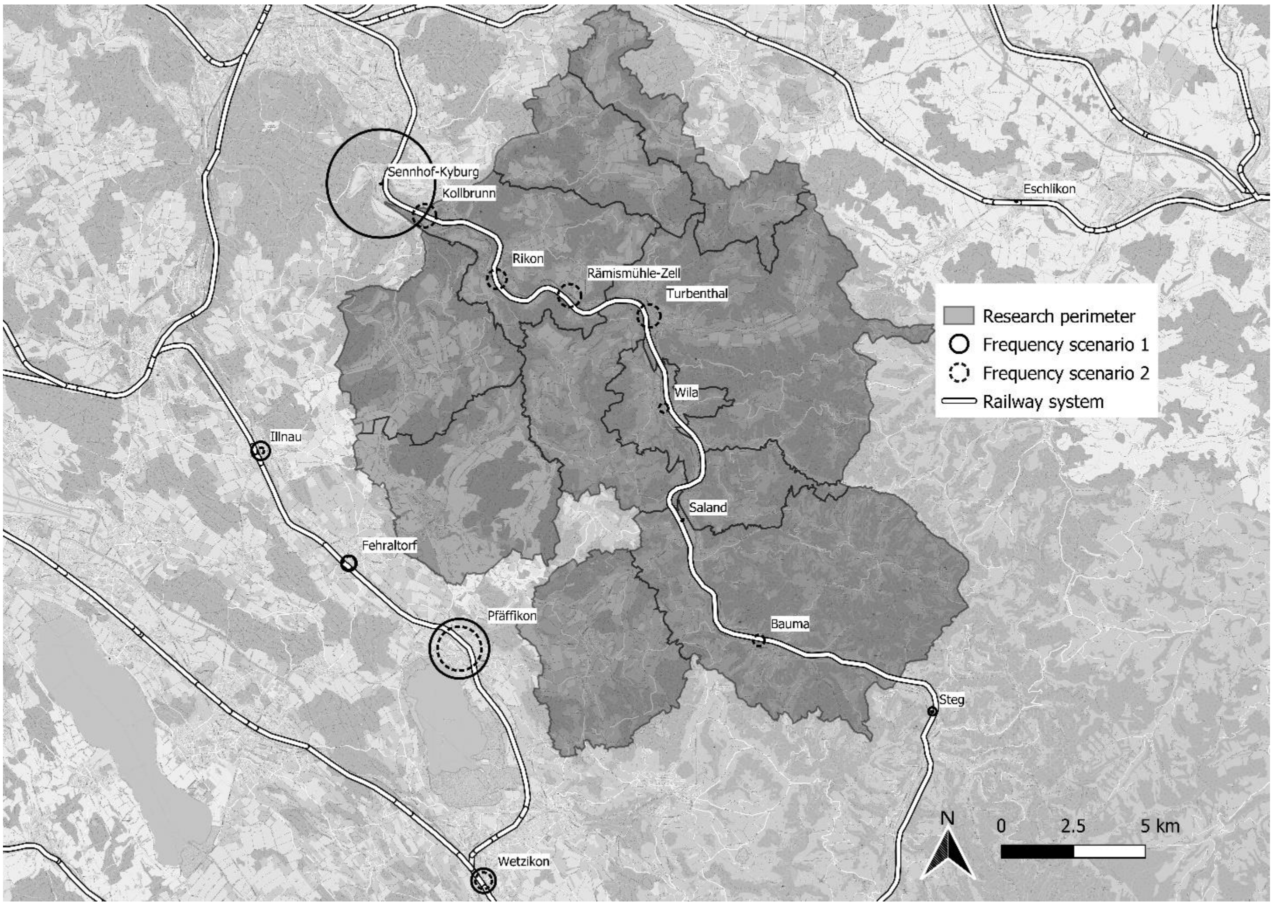

Figure 2. Frequency of trips to and from each hub in scenario 1 and 2 during peak-hour

Due to the proximity of the Töss Valley to the city of Winterthur, most of the trips are going towards the north-west of the research perimeter. The hubs situated northeast, in Pfäffikon, Fehraltorf and Illnau, register a high number of trips, too, as the passengers have the possibility to change to the train in direction of Zurich. There are only few trips going north or south, due to less workplaces or points of interest in these regions.

In scenario 1, the placement of all hubs outside the research perimeter has the consequence, that the nearest hub to Winterthur, Sennhof-Kyburg, registers the highest frequency. This high frequency during peak-time may lead to congestion problems, as all SAVs are planned to arrive at the hub a short time before the departure of the S-train towards Winterthur. Two anticipated problems are overloads of the access roads to the hub station and parking problems at the station. By re-integrating the S-train system in scenario 2 as well as respecting footpaths to the hub stations, this punctual congestion problem can be dissolved and distributed over the entire S-train-line. The hub with the highest frequency in scenario 2 can be found southwest of the research perimeter in Pfäffikon with the connection possibility towards Zurich.

5. Discussion on the regulatory needs in the future

In this current study, we attempted to develop two future scenarios of SAVs used in a regional public transportation system. By analysing their implications on the economic and traffic system, we anticipate that a system entirely built upon SAVs shows the best economic gains but has high implications on the traffic system. Impacts can be seen in a huge increase in the total vehicle kilometres travelled by the SAVs as well as punctual concentrations of traffic at single hubs. Consequences may be an overload of the entire road system and local congestion problems at the access roads to the hubs.
Scenario 2, combining the SAV service with the existing S-train line, showed lower gains than scenario 1 did, but there would be no subsidies needed as the system is self-feeding, too. In addition, having an S-train crossing through the research perimeter helps to reduce a certain number of trips with SAVs, to bundle demand in big vehicle sizes and to prevent the hubs from a high frequency during peak-hour. Even when the traffic impact is increasing in scenario 2 compared to the status quo, the local overload of a single hub are avoidable and the entire traffic system is less afflicted than in scenario 1.

We showed in section 2 the present situation of the regulation of the regional public transportation. With our two scenarios, we tried to maintain the current level of service and the goal and condition of the public service in the research perimeter. Nevertheless, both scenarios would need adaptions of the regulatory context. Today, for every new single line in the Swiss regional public transportation, a call for tender is necessary. An exception of this principle is given when a line can be integrated in an existing network of public transportation lines provided by one enterprise (BAV, 2019). From our point of view, there are adaptions necessary to this regulation. First, the call for tender for single lines in a regional SAV service as presented in both scenarios would make no sense, as the service is not line-bound anymore. In contrast, the SAV service would be flexible and on demand, operating on order with direct trips to the hubs or to the destination inside the research area. We therefore propose to open the line-bound regulation towards a call for tender for entire regions, in which the SAVs have the allowance to operate freely. It would be necessary to specify the perimeter in detail and if there are areas, where the SAV cannot operate, for example in pedestrian zones.

The change from a line-bound to a highly flexible service would have further implications: an on-demand door-to-door service does not need any timetable anymore if the passengers can order their trips per app (or other technological solution). A possible service each ten minutes like in our estimations seems to improve the accessibility enormously in a rural area, where currently buses operate sometimes only hourly or less frequently. However, in order to maintain the current service quality, there have to be some restrictions. Especially the connection guarantee at the hubs from one transportation mode to another has to be ensured in order to provide a fast, easy and comfortable service to the passengers. Here, the regulator has to provide standard guidelines for the transportation operators how the connection between transportation modes has to be organized. A door-to-door service has also implications on the access of different passengers, especially handicapped persons. The entrance and exit of a vehicle needs to be suitable for handicapped persons and there has to be enough space for wheelchairs and other aids. In our estimations, we excluded the needs of handicapped persons as there are many uncertainties how the vehicles will be organized and if handicapped persons even are able to use the same SAVs as unhandicapped persons. A possibility would be to obligate the provider of a regional SAV service concept to provide parallel services for handicapped persons to the same conditions of economic and service aspects. Further, the system has to prevent the exclusion of people that are not able to book services on an app or other technological solutions. Today, services like some ridesharing or traditional public transportation provide hotlines for ticket booking and obtaining information. In both aspects the regulator does not need to adapt the present regulatory context, as these stakeholder's needs, like the access of handicapped people to public transport or the guarantee of public transport services in peripheral and mountainous regions, are represented in the current law for the provision of public transportation in general. This will be the task of the service provider.

In the present situation, the Swiss Confederation and the cantons subsidize unprofitable lines in the regional public transportation. Our estimations show that subsidies for a combined concept with SAVs and S-train used in regional public transportation would be obsolete if one enterprise provides both transportation modes. Today, S-train services cannot be provided with gains and therefore need subsidies. By taking away the driver's task in S-trains, the cost-efficiency can be slightly increased, but not to a break-even. The cross sourcing between SAV and S-train service is one solution seen in this research to relieve the Swiss Confederation and the cantons from subsidizing regional public transportation services. The resulting gains then open up the question of the usage of the gains: will it be possible to cross-subsidize different serviced regions of one single transport enterprise or are the transport enterprises forced to pay their gains in a national project fund. A project fund could have for example the goal to help the Swiss confederation and the cantons in the funding of national and cantonal public transportation infrastructure projects. Political institution need to solve these questions in the next years, in favour of ensuring attractive public transportation services in rural areas.

With this paper, we showed how the regulator might react to new SAV services, with different open points. The state and the cantons as regulator will have the duty to regulate SAV services in the way that the population has the optimal benefit and a high quality service. From today's point of view, we cannot suggest who will be the provider of a proposed regional SAV service network including the S-train infrastructure. Nevertheless, transportation operators would need to establish new knowledge on on-demand public transportation in order to be ready to compete with new upcoming players that already have this knowledge. Yet new players may have the difficulty to receive the same support from the population in a region, which established transport operators have built up over time.

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Declarations of interest

Declarations of interest: none.

CRediT author statement

Sebastian Imhof: Writing – Original Draft, Writing – Review & Editing, Investigation, Visualization; **Jonas Frölicher:** Conceptualization, Methodology, Investigation, Data Curation, Visualization; **Widar von Arx:** Funding acquisition, Supervision, Conceptualization.