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The Future of Public Transport in Rural Areas – A German Case Study on Ridesharing with Autonomous Vehicles

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Abstract

Conventional public transport is facing major difficulties in rural areas of Germany due to current social and demographical changes. In the dawn of autonomous driving, flexible, economically viable ridesharing options emerge, and the reduction of transit personnel can cut operation costs considerably. An agent-based software model of a rural area is established to simulate the implementation of transit system operating with autonomous ridesharing and investigate economic feasibility. The model is established in AnyLogic depicting the real mobility demand of one administrative district in Germany.

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Keywords: ride pooling; autonomous driving; shared vehicles; public transport, transit

1. INTRODUCTION

Conventional public transport in rural areas is facing major difficulties, especially in countries exhibiting demographic and societal changes. In rural areas in Germany demographic change and the accompanying decrease in population and pupil numbers endanger the already brittle financial situation of public transport.

Accordingly, in most rural areas only major links to and from cities are serviced by public transport. The offered services are mainly an extension to school bus services, adding only few additional trips to the schedule to assure a minimum of mobility for the public. Most of the mobility demand in rural areas is covered using private vehicles. Considering demographic change, more senior citizens will become dependent on mobility through private vehicles, who might not want to or should not drive anymore.

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This study explores the opportunities presented through the dawn of autonomous vehicles and their application in a new mode of public transport. This study is conducted exemplarily on a rural administrative district (AD) in Northern Bavaria in Germany. Using a mobility survey available from that district, the public transport demand is modelled as trip requests and serviced with a new transport mode utilising shared autonomous vehicles (SAV).

Conducting this study, major trends are taken into consideration to estimate public transport demand and supply for rural areas in Germany in the future.

This study delves into answering questions about feasibility, vehicle utilisation and accessibility through SAVs. A software model of a typical rural area in Germany is established to show the implementation of a SAV service. The focus of the model is not to represent all traffic in the rural area but only to investigate the new public transport mode SAV. The main results will be information about the number of vehicles needed to serve a certain demand level, overall vehicle kilometres driven daily, average billable trip-km per passenger (shortest origin-destination-connection in a distance based tariff), and average trip costs. This paper sets the focus on the first results applying 4-seated SAVs to cover a demand of about 30% in the underlying administrative district.

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2. BACKGROUND

Flexible mobility solutions, such as carpooling, have been tested repeatedly in Germany. However, they have never caught on and most public trials featured major financial problems. Today, most carpooling services supporting public transport are subsidized through local governments to a major extent. They are merely an addition to regular taxi services, and mostly confined to one municipality. In some areas, partially flexible bus services are gaining momentum. This is especially evident in rural areas with high tourism potential.

However, today, conventional carpooling is picking up momentum through a rise in the sharing economy. Services like Uber and Lyft are in successful operation in urban areas in the United States, and car sharing schemes are gaining attention in German cities, as well [Shaheen, Mallery, and Kingsley 2012; Shaheen et. al. 2016].

With the example of Lisbon, it has already been shown that shared taxi services could reduce the number of cars in large cities by up to 80% substituting private vehicles altogether [ITF 2015]. Similar studies have been conducted in Hamburg [Huß 2016] and Stuttgart [Friedrich and Hartl 2017].

This study, however, will focus on sharing rides in rural areas, where there are different conditions compared to inner city mobility. Average trip distance is longer, and there are potentially fewer people that could share a ride [Statistisches Bundesamt 2016].

In the dawn of autonomous driving, flexible mobility solutions surface again. New economically viable options for carpooling are appearing. On the supply side, reducing driver costs through autonomous vehicles is hoped to be linked to reduced operation costs and reduced fares. In Germany, personnel costs in public transport make up about 1/3 of all operational costs (reduction from 55 % of operational costs down to 22 % are reasonable) [Resch 2015, Loos 2016; Bundestag 2016]. In rural areas with generally fewer passengers per transit vehicle the share of personnel costs is even higher.

Definition and Characteristics of Rural Areas in Germany

Defining rural areas in Germany, one can resort to the BBSR (Bundesinstitut für Bau-, Stadt- und Raumforschung) which distinguishes between four different spatial settlement structures [BBSR 2014].

- City: A City has more than 100,000 inhabitants.
- Urban districts: Districts with at least a 50 % share of the population living in a density of at least 150 people/km² or districts with a density (without cities) of at least 150 people/km².
- Rural districts with agglomeration tendencies: Districts with a 50 % share of the population in cities under 150 people/km² and districts with an average density of 100 people/km².
- Scarcely populated rural districts: Districts with a population share in cities under 50 % and average densities lower than 100 people/km².

Even though people are moving to cities at an increasing rate [Statistisches Bundesamt 2016; SHELL 2014; Chilla, Morhart, and Braun 2008], in Germany, about 50 % of the population are living in rural areas. This part of the population could face major difficulties with declining public transport services. On the other hand, an increase in service quality could improve an individuals' quality of life and reduce their dependency on private car ownership.

Autonomous Driving

This study takes for granted the ubiquity of safely functioning autonomous vehicles in a few years. Additionally, this study opts for the implementation of fully electric vehicles. However, with this option, the consideration of battery capacity, charging time and location of chargers are not considered.

Trends on transport demand and supply

Public transport in Germany is a public service and supposed to facilitate mobility for everybody. However, due to cost constraints, public transport in rural areas is often merely an absolute minimum service, relaying on school bus service to obtain a certain economic feasibility. Implementing a public transport built on autonomous shared vehicles might be the major step to an affordable, flexible, good quality service that might even be cost effective over time.

Conventional public transport is in peril in rural areas. Several societal trends are affecting people's lives and the public transport customer base, as well. The following figure depicts societal mega trends and their effects on demand and supply of mobility. These trends feed into changes in transport operation form, transport operation model, and vehicle concepts.

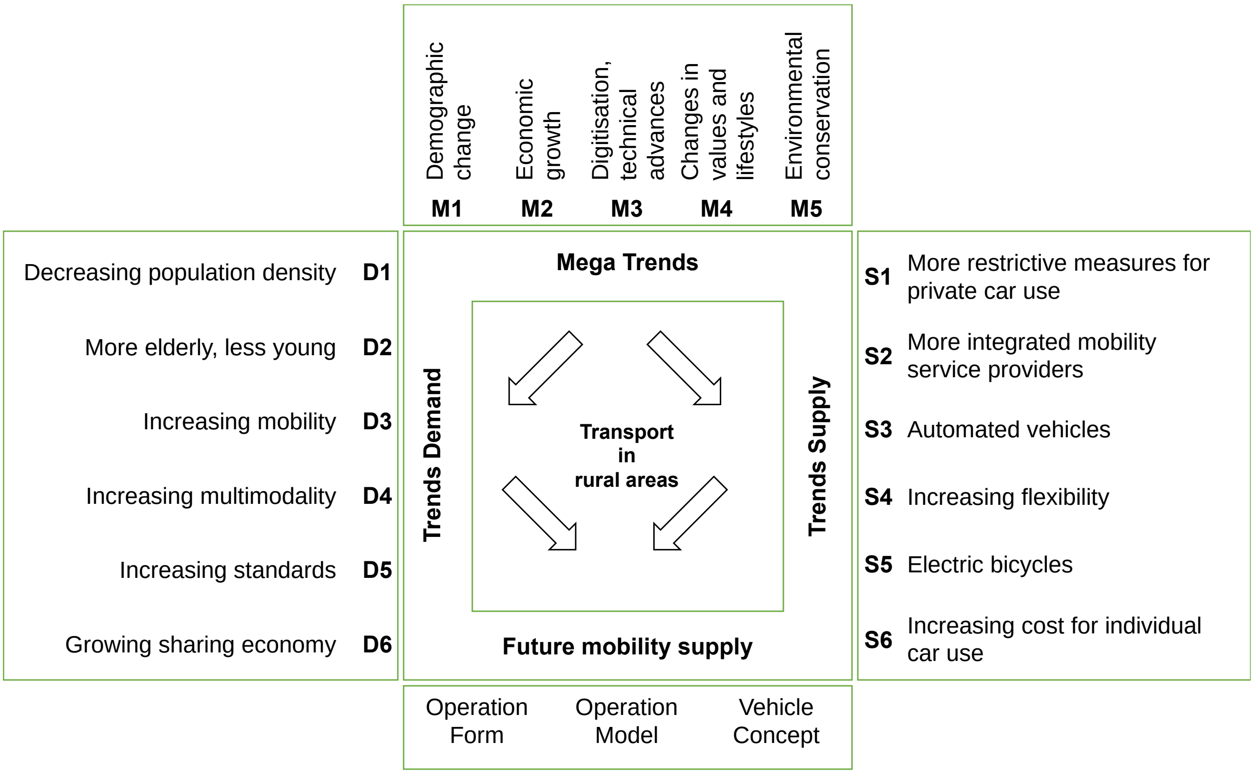

Fig. 1. Trends affecting rural districts in Germany [MÖRNER 2018].

From these trends on transport demand and supply the following?? were identified as key factors for implementing a sound software model for autonomous ridesharing in rural areas:

- D1 decreasing population density:
  → Extrapolation of population counts to 2030 timeline.
- D2 more elderly, less young:
  → Estimation that 60-year olds today show a similar demand on mobility as 60-year olds in 2030.
- D3 Increasing mobility:
  → Simulation with different demand levels.
- D4 Increasing multi-modality:
  → New mobility concepts will not be mono-modal and will feature connections to other means of mobility.
  → Simulation with different demand levels.
- D5 Increasing standards:

  Punctuality and spontaneous trip requests.

  → Implementation of a low detour factor for passengers in ridesharing.
  → Flexible service through many stops with a small catchment area, that comes close to door-to-door service.
  → Checking the efficiency of the proposed system with short time duration between trip request and requested departure.
- D6 Growing sharing economy:
  → Higher willingness to share vehicles.
  → Focus on ridesharing with different demand levels.
- S2 More integrated mobility service providers:

  → Comfortable door-to-door solutions.
  → Trip requests through a single entity.
  → No need for the user to compare different providers.
- S3 Automated vehicles:
  Focus on a simulation utilising autonomous vehicles.
  → No need to incorporate breaks for drivers.
- S4 Increasing Flexibility:
  Very flexible ridesharing with small vehicles.
  → Implementation of small vehicles with 4 to 8 seats.
  → Testing system efficiency with short duration between trip request and requested departure.

3. MODEL SCOPE AND STRUCTURE

The major scope of the model built for this research is to demonstrate the functionality and to investigate the efficiency of a public transport service using SAV in a rural area. The microscopic model simulates single vehicles operating in one coherent SAV fleet serving all requested trips over a full day. Heart of the model is the dispatcher (see chapter 4) that links the search for a fitting vehicle for each trip request and pooling rides to obtain a high vehicle occupancy (a detailed model description can be found in [MÖRNER, 2018]).

The model is written in AnyLogic 8 (anylogic.com). AnyLogic 8 is a java based multi method simulation environment. The simulation created for this research is an agent-based model, representing a realistic simplification of a public transport operation using SAVs. As program modules, the following agents were created for building the model:

- Stops
- Passengers (demand)
- Dispatcher
- Vehicles - SAV (supply)

Furthermore, the model accounts for the following specifications:

- Model duration 24+ hours (model run time from 20:00 day before till 03:00 day after)
- Simulation of only the new means of transport
- No complete traffic simulation (no delay, no traffic jams, no difference in travel times due to congestion)
- Travel times and driving speeds are obtained from OpenStreetMap (OSM osm.org)
- Dispatcher tries to gain high vehicle occupancy rate
- Maximum detour coefficient per passenger
  (actual travel time / shortest origin-destination connection time per passenger)
- Demand – all share of all trips except trips with a duration < 5 minutes as these trips are most likely conducted on foot or by bike (duration < 1 minute for seniors)

Details on the programming of the model are included in the doctoral thesis *Sammelverkehr mit autonomen Fahrzeugen im ländlichen Raum* [MÖRNER 2018].

4. DATA UTILISED

Stops

Theoretically, door-to-door service is possible using autonomous vehicles. However, for this model, a less dense stop distribution is chosen. Under the assumption that almost everybody can bear a small offset between door and nearest stop, stops with a 100 m catchment area were placed covering most of the settlements in the district excluding single houses and farms. The model incorporates 1,588 stops (a detail of the map is shown in Figure 2). However, in a real-world implementation a change to door-to-door service should hardly impact efficiency. All stops are assigned a unique ID to be addressed in the model.

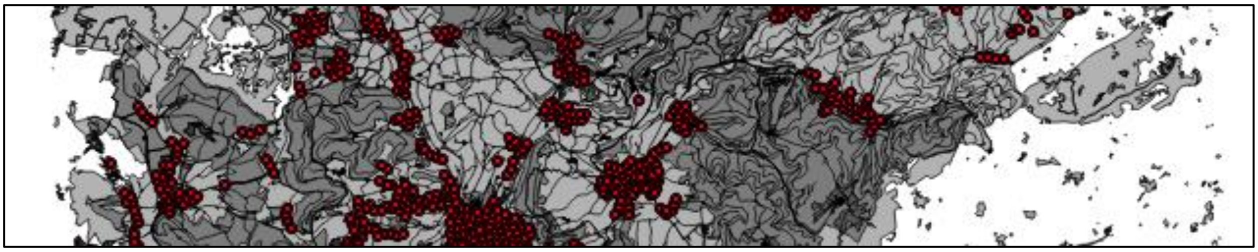

Fig. 2. Map showing stops in red covering the settlement areas (100 m catchment area). map data OSM/Geofabrik.de July 2017.

Demand

Demand is extrapolated from a mobility household survey conducted in an administrative district (AD) in Bavaria, Germany, from 2014. The household survey showed an overall return rate of around 14 %, which is unusually high for such a survey conducted in Germany. Students showed some over-representation due to the survey being promoted in schools. The extrapolation and normalisation were done utilising demographic information (prognosis) for the administrative district for 2030 [BERTELSMANN STIFTUNG 2017]. Thus, leading to around 95,000 trips were conducted on a typical Tuesday.

The trips requested in the model do not represent the whole extrapolated mobility demand. Different modal splits for SAV usage can be implemented through a uniformly distributed variable “transit marker” (shown in Table 1). “Trip requests” depict the time difference between booking of the trip and actual requested departure time. “Flexibility” depicts the time interval in which the trip can begin (here +/- 30 minutes from requested departure time).

Table 1. Example of trip demand data utilised in the model.

Passenger type	Origin ID [-]	Age	Trip reason	Destination ID [-]	Trip request [hours]	Flexibility [min]	Requested departure [hh:mm]	transit marker [1-100]	Min. trip [min]
working	450307	58	work	9901100	-2	30	06:45	62	5
student	350307	8	school	350110	-2	30	06:00	84	5
other	150801	29	supply	123201	-2	30	08:10	13	5
senior	450307	73	supply	9901100	-2	30	09:10	45	1

Supply

On the supply side, the focus lies on smaller vehicles as opposed to average public transport vehicles. This maximises flexibility for individual users. This model incorporates vehicles with 4 and/or 8 seats. The vehicle fleet size can vary with the goal of servicing all trip requests. In an iterative process, the fleet size for each scenario was determined in steps of 25 vehicles with the goal of serving the whole demand.

Routing

Routing is done via the street network available through OSM-Maps [© OpenStreetMap Creative Commons BY-SA 2.0]. The maps are obtained through Geofabrik GmbH. Fastest routes in between all stops are then determined utilising speed limits for driving speed. These driving durations are used in an O-D-Matrix covering roughly 2.5 million trip combinations. This O-D-Matrix is utilised in the Agent Dispatcher for the determination of a good travel time for each trip request.

Dispatcher

The dispatcher handles trip requests when they are placed. It runs through every vehicle in the fleet to find a good fit. This fit is defined through a dispatching strategy that aims for high efficiency in fleet utilisation. Goals are a highly utilised capacity in vehicles and short empty trips or detours for vehicles preventing the detour factor reaching a predefined level (here 1.4 x shortest origin-destination-connection).

5. MODEL RESULTS

The model results are clearly showing that ridesharing is a viable alternative for line-based public transport services in rural areas. Even with rather low demand levels (today's public transport share of 12 %) a flexible and reliable service can be implemented. Results of various demand levels with corresponding fleet size are shown in Table 2.

The scenario shown in the following examples depicts a demand of 75 % and an adapted fleet size of 1,575 4-seated vehicles.

As shown in Table 2 and Figure 3, through pooling the number of passenger trip kilometres far exceeds the real vehicle kilometres travelled. The share of vehicles riding empty stays at around 17 %. Assuming a distance-based pricing scheme, where only the shortest origin-destination connection is charged to passengers, this would mean that in the example with 35 % demand, 145 % of the vehicle kilometres travelled could be charged to passengers (billable km). These thoughts lead an end-user cost estimations following in chapter 6.

Vehicle utilisation (Figure 4) shows a typical daily demand curve with highest trip demand and vehicle utilisation in the early morning and late afternoon. The mid-day peak around 14:00 is due to pupils returning home from school. Even in high demand peaks only about 20 % of all vehicles drive empty to their next passenger pick-up. In low demand hours, these empty vehicles driving to the next passenger drop below 10 %. The higher share of empty trips might be due to strong direction based transport demand into the major cities (morning) and out of these (afternoon).

Table 2. Model results comparing different demand levels with adjusted fleet sizes (4-seated vehicles) adapted from [MÖRNER 2018].

Scenarios				
SAV Share in Demand	**~ 12 %**	**~ 20 %**	~ 35 %	**~75 %**
trip requests				
number of trip requests [-]	12,191	19,106	33,766	74,540
trip requests served [-]	12,191	19,106	33,766	74,540
trip requests not served [-]	0	0	0	0
reached modal split	**12%**	**19%**	**34%**	**75%**
share of trip requests not served	0%	0%	0%	0%
transport performance (overall)				
vehicle km (occupied and empty) [km]	128,970	195,925	328,341	660,921
vehicle km (occupied) [km]	107,260	162,446	270,568	551,522
passenger km [km]	167,159	270,343	476,977	1,051,202
vehicle km (empty) [km]	21,709	33,478	57,773	109,399
share vehicle km (empty)	**16.83%**	**17.09%**	**17.60%**	**16.55%**
share passenger km *	**129.61%**	**137.98%**	**145.27%**	**159.05%**
Vehicles				
fleet size [-]	**350**	**475**	**750**	**1,575**
max. number simultaneously in operation [-]	284	447	749	1,541
max. number with passengers [-]	250	372	594	1,281
average kilometres travelled [km]	368	412	438	420
kilometres travelled per vehicle and day				
min [km]	58	86	66	119
max [km]	796	871	948	951
average [km]	367	412	437	443
billable distance per vehicle [km]	478	569	636	667
operation time per vehicle and day				
min [hh:mm]	1:08	1:43	1:20	2:24
max [hh:mm]	16:00	17:30	19:01	19:14
average [hh:mm]	7:22	8:15	8:46	8:53
passenger per vehicle and day				
min [passengers]	3	5	4	6
max [passengers]	83	101	109	117
average [passengers]	35	40	45	50
distance per trip request				
Covered distance per trip request [km]	**10.58**	**10.25**	**9.72**	**8.87**
Billable distance per trip request [km] **	**13.71**	**14.15**	**14.13**	**14.10**

* based on vehicle kilometres (occupied and empty) sum of the shortest O-D-connections for each trip request

** accounts for occupancy greater than 1 passenger

The average occupancy rate (Figure 5) ranges between 2 - 2.5 passengers per vehicle. This occupancy rate is remarkably high, whereas private cars usually feature average occupation rates from 1.2-1.4 passengers per vehicle in Germany [INFAS AND DLR 2010].

Vehicle occupancy (Figure 6) shows a highly utilised vehicle capacity in peak hours only when many pupils are on their way to and from school. Comparing this figure to vehicle occupancy in Figure 7 it can be seen that larger vehicles alone do not necessarily lead to an increase in efficiency. 8-seated vehicles show an occupancy larger than 4 passengers in peak hours, only. Even more striking, this is merely true for about 20 % of all vehicles. Thus, leading to the conclusion, that a mix of vehicles in the fleet is necessary and that larger vehicles should be focused on high demand corridors or for pupil transport.

Distances covered by each vehicle range from 150 km/day to 900 km/day (Figure 8). However, the average is around 440 km/day. This broad range is caused by the high utilisation of vehicles in peak hours, whereas in low demand times only half of all vehicles are transporting passengers. The distribution of operating hours features similar results. With a broad range from 2 to 20 operating hours per day and an average of 9 operating hours per day.

Some of this discrepancy could be overcome through optimisation of the dispatcher. However daily demand curves will most likely stay the same, thus always leading to a somewhat broader range of utilisation.

The range in vehicle utilisation could be used to implement maintenance breaks for vehicles with low utilisation at this day. Additionally, vehicles serving low and high demand could be switched every other day, averaging out the discrepancy in mileage and operating hours.

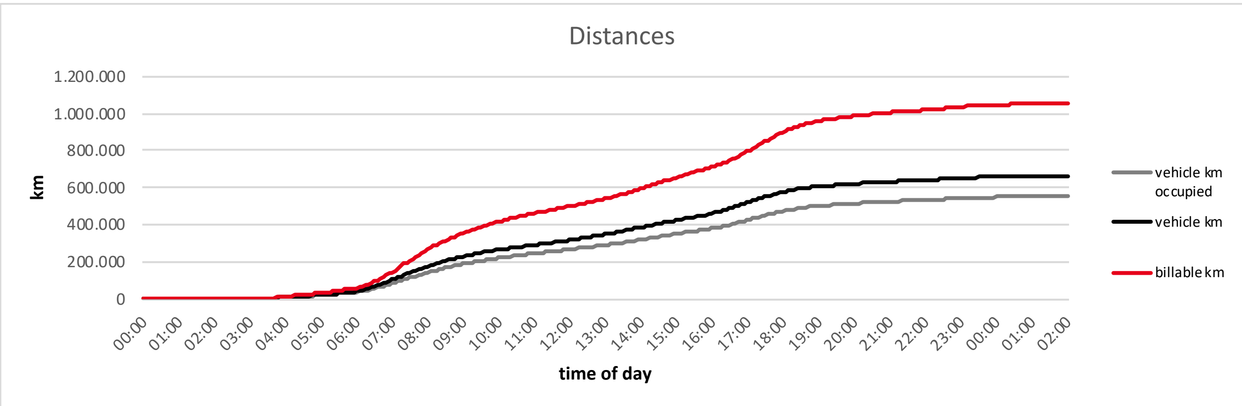

Fig 3. Sum of all veh-km and billable trip kilometres (demand ~ 75 %, 1,575 4-seated vehicles

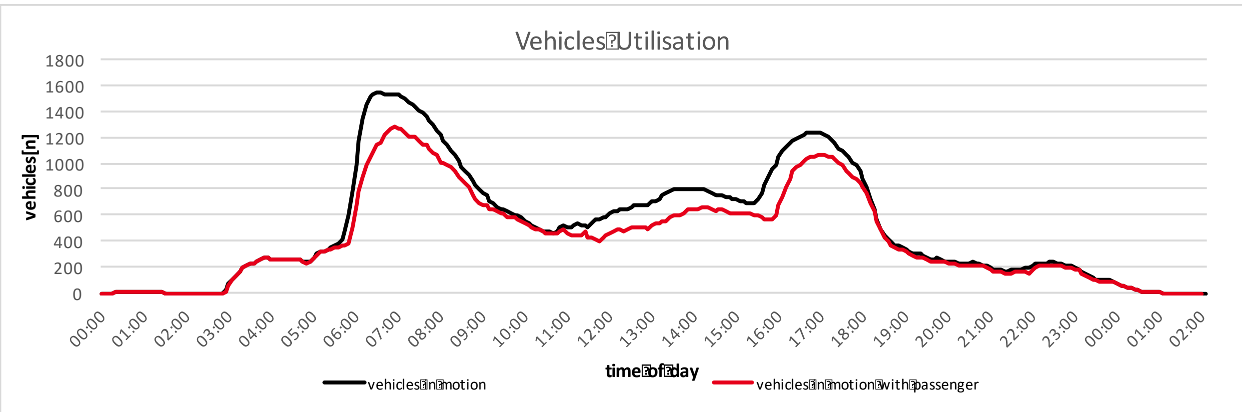

Fig 4. Vehicle utilisation (demand ~ 75 %, 1,575 4-seated vehicles)

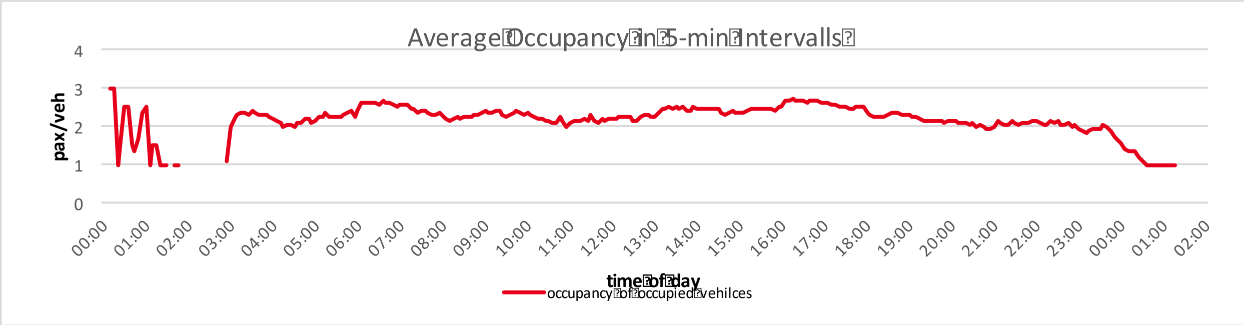

Fig. 5. Average vehicle occupancy (demand ~ 75 %, 1,575 4-seated vehicles)

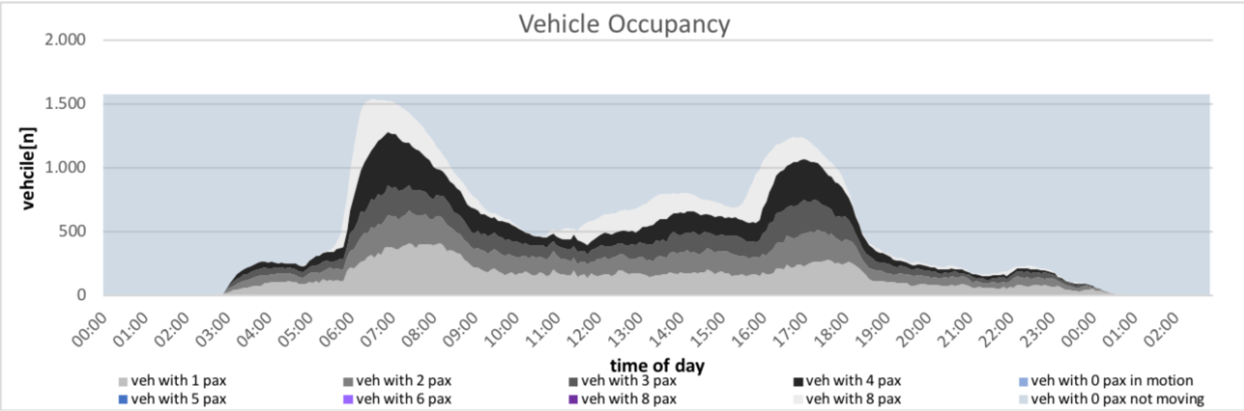

Fig. 6. Vehicle occupancy of 4-seated vehicles (demand ~ 75 %, 1,575 4-seated vehicles)

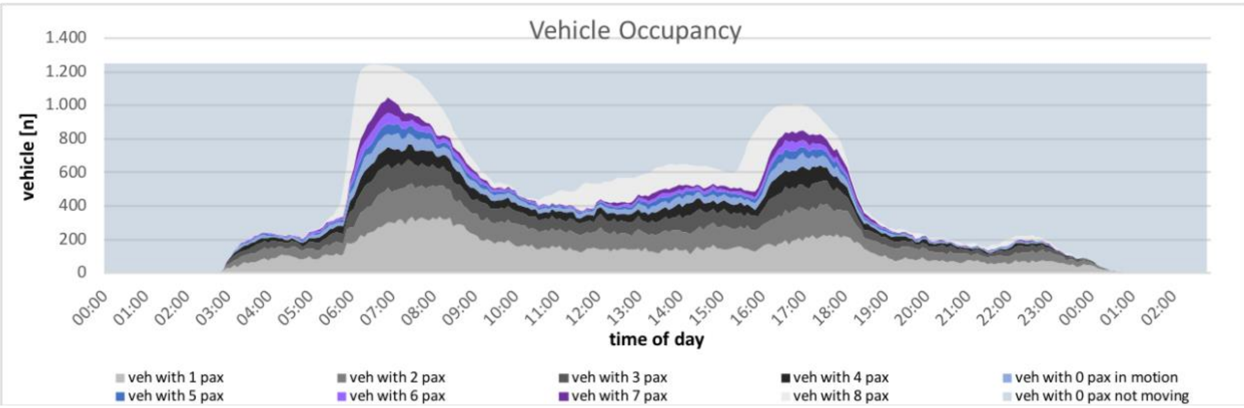

Fig. 7. Vehicle occupancy of 8-seated vehicles (demand ~ 75 %, 1,225 8-seated vehicles)

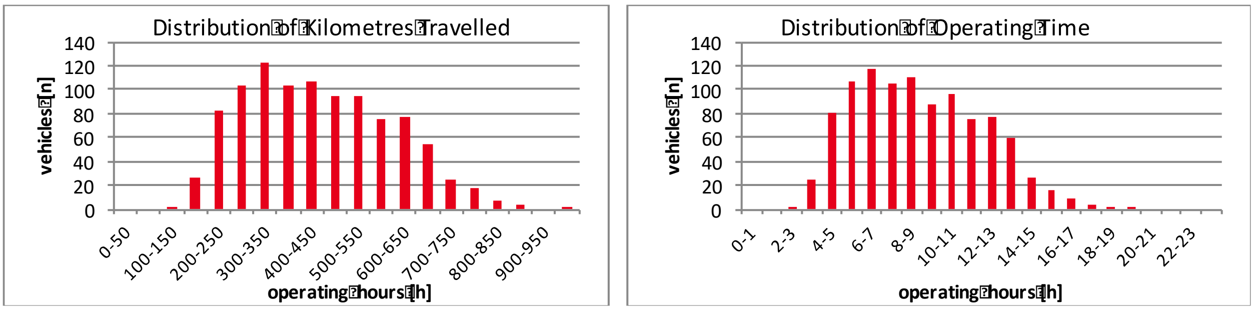

Fig. 8. Distribution of kilometres travelled (left) and distribution of operating time (right) (demand ~ 75 %, 1,575 4-seated vehicles

6. END-USER COST ESTIMATION

Transport in shared autonomous vehicles can be conducted with reasonable end-user costs. Real-market acquisition costs for autonomous vehicles are unknown today.

However, to estimate trip costs for passengers, an estimation by Sinner et al. from 2017 is consulted. The total cost of ownership (TCO) for a midi-bus in service for three years is estimated (including deductions, interest, material, tires, fuel, service, insurance, building deduction, operation centre, troubleshooting, depot, administration and others [SINNER, BRAWAND, WEIDEMANN 2017]):

- 190,000 CHF for a midi-bus
  corresponds to ca. 160,000 € (1 € = 1.172 CHF Deutsche Bank 09.02.18)
- 3 years lifetime
- yearly kilometre travelled 60,000 km – 70,000 km

Assuming a TCO of 160,000€ for three years and taking into consideration passenger kilometres, end-user prices could end up between 0.21 € and 0.37 € per kilometre (Table 3). These end-user costs are estimated without any subsidies, while public transport in Germany usually is subsidised. These estimated end-user prices are validated through similar results in cost estimations conducted by Friedrich and Hartl [FRIEDRICH AND HARTL 2017].

However, as the 160,000 € are the estimated price for a midi-bus, in the rural area smaller vehicles should be deployed. Thus, a reduced cost calculation with 120,000 € TCO for three years is assumed. Unsubsidised end-user prices could range between 0.16 € and 0.28 € per kilometre. Exceeding the yearly mileage used in the referenced estimation is not taken into consideration in this cost estimation.

The range of kilometre prices is shown in Table 3 where different demand levels and fleets consisting of 100 % 4- and 8-seated vehicles are compared.

Table 3: End-user costs per kilometre and average trip

	End-user costs per kilometre and average trip							
demand	~ 12%		~ 20%		~ 35%		~ 75%	
number of seats	4	8	4	8	4	8	4	8
number of vehicles	350	325	475	400	750	675	1550	1250
average km per veh and day]	365	379	412	456	438	439	425	452
average billable km per vehicle and day	478	514	569	676	639	707	678	841
yearly mileage (factor 300) [km]	109,500	113,700	123,600	136,800	131,400	131,700	127,500	135,600
billable kilometre/year (factor 300) [km]	143,400	154,200	170,700	202,800	191,700	212,100	203,400	252,300
simplified km-price for passengers (160,000 € TCO)	**0.372 €**	**0.346 €**	**0.312 €**	**0.263 €**	**0.278 €**	**0.251 €**	**0.262 €**	**0.211 €**
simplified km-price for passengers (120,000 € TCO)	**0.279 €**	**0.259 €**	**0.234 €**	**0.197 €**	**0.209 €**	**0.189 €**	**0.197 €**	**0.159 €**
average billable distance [km]	13.71	13.71	14.15	14.15	14.13	14.13	14.10	14.10
average trip cost (160,000 € TCO)	**5.10 €**	**4.74 €**	**4.42 €**	**3.72 €**	**3.93 €**	**3.55 €**	**3.70 €**	**2.98 €**
average trip cost (120,000 € TCO)	**3.82 €**	**3.56 €**	**3.32 €**	**2.79 €**	**2.95 €**	**2.66 €**	**2.77 €**	**2.24 €**

7. FINAL REMARKS

Ridesharing as a new means of public transport is a feasible alternative to line-based public transport. Combining ridesharing with autonomous driving can represent a new dawn in ubiquitous mobility options in rural areas. Autonomous ridesharing is not only an option for cities and urban areas as shown in other studies, but it is also a chance to alter rural mobility in the long run. One can only imagine what streets without parked cars will look like and how these areas will be used differently.

The model results are showing that vehicle fleets should consist of differently sized vehicle. Mostly small vehicles (here 4-seaters) should be implemented in rural areas when high flexibility is a major goal. Additionally, about 20 % of 8-seated vehicles can be put to good use on high demand corridors, where pooling is achieved more easily. School commutes should be organised in larger vehicles, as well. For one, these trips all end at the same place at the same time (in the morning), the other reason is the sheer number of cars, necessary to transport all students. If these influences can be reduced, it would create a safer environment.

The average range of the modelled vehicles exceeds the abilities of today’s battery electric vehicles (BEV). However, with stops outfitted for battery charging, the fleet could be implemented at least partially with BEV. With this paper, focusing on the time horizon 2030, BEV might already feature a larger range and therefore charging should hardly impact operations.

Estimated end-user costs are far below taxi prices but still exceed today’s public transport prices in Germany. However, today's public transport prices in Germany are subsidised, in contrast to the estimated end-user costs calculated shown in Table 3. Hence, it is conceivable that ridesharing as a means of public transport could be subsidised, as well. More so, vehicle prices will most likely drop with increasing production capacities, leading to even lower end-user prices. With a reliable, punctual service this transport mode can become an alternative to own a personal vehicle. The prices can be reduced, so it will be cheaper for individuals to use ridesharing than owning a car, which could also reduce the number of vehicles drastically.

As this paper solemnly focuses on the feasibility of ridesharing in rural areas, further research is needed to clarify details. How such a service can react to traffic jams, late passengers and no-shows need to be considered. Additionally, the implementation of battery charging, servicing and maintenance breaks should be implemented in an operation model.

On a more strategic level, it needs to be investigated how such fleets of SAV can be best combined with fixed-scheduled fixed-route services. In such cases, for example, the SAV fleet may be operated as a feeder service to express bus lines. Modelling such feeder services might also go further into demand modelling, using an econometric modelling approach [DAS, MAITRA, BOLTZE 2009]. It is obvious, already, that an integrated operation of remaining bus services and SAV fleets bears significant benefits regarding efficiency and quality of service.

In the long run, research also needs to be conducted on the adaption rate modal shift towards ridesharing, and how to convert former parking spaces and transport infrastructure. Autonomous ridesharing can be a great solution to overcome challenges in covering mobility needs in rural areas.

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