Autonomous car- and ride-sharing systems: A simulation-based analysis of impacts on travel demand in urban, suburban and rural German regions

Lars Kröger, Benjamin Kickhöfer, Tobias Kuhnimhof
Institute of Transport Research, German Aerospace Center (DLR)
Rutherfordstraße 2, 12489 Berlin, Germany
Correspondence address: Lars.Kroeger@dlr.de

March 15, 2017

Keywords: *autonomous vehicles, car sharing, ride sharing, transport system analysis, spatial analysis*

Extended Abstract

Motivation

The introduction of autonomous or driverless vehicles (AVs) is expected in the upcoming decades. In contrast to their appearance as private vehicles only, AV-based car- and ride-sharing systems might have a disruptive potential since the automation possibly lifts sharing systems from a niche to a mainstream market, establishing a new mode of transport. Autonomous sharing systems are likely to combine the benefits of a short-term rental service with the characteristics of a driverless taxi (Fagnant et al., 2015), potentially offering a fast and reliable travel alternative. From the operator‘s point of view, these vehicles could reach a substantially higher usage rate compared to conventional car sharing vehicles. This might lead to user price levels, which are comparable to conventional public transport services (Burns et al., 2013).

However, before a new transport mode is introduced, there are several questions that need to be answered. Potential operators might ask under which conditions the service turns out to be profitable. Public authorities might wonder what impacts the new mode will have on the usage of other transport modes (in terms of modal shift and vehicle-kilometers traveled), how to avoid the emergence of a monopolistic provider, and whether or not to subsidize the new service in certain areas in order to provide a cost-efficient travel alternative to private cars or underused conventional public transport. Against this background, the present paper uses a simulation-based approach to evaluate the impacts of Autonomous Car Sharing (ACS) and Autonomous Ride Sharing (ARS) systems on travel demand in urban, suburban, and rural German regions.

Model

The transport model covers the first three steps of a classical four-step model (trip generation, destination choice, mode choice). For flexibility reasons, it explicitly omits the traffic assignment step and is therefore rather suited for sketch planning and first estimations. However, the travel demand is captured in great detail as the model uses all trips reported in the German national travel survey (DLR and Infas, 2008).

The autonomous sharing systems are introduced into a scenario for Germany of the year 2035, where autonomous private cars are already present in the vehicle fleet, representing the reference case (Kröger et al., 2016; Trommer et al. 2016). The ACS system allows only one party in the same vehicle at the same time. The AP system, in contrast, allows more than one party in the same vehicle, i.e. offers a sharing of trips and costs. However, passengers have to expect detours for waiting for, picking up and dropping off others, leading to longer in-vehicle times. Operator costs include a mileage-dependent depreciation of vehicles, fixed costs per vehicle per year, variable costs per vehicle (e.g. personnel costs, considering scale effects for larger fleets), and fuel costs for empty trips and trips with passengers.

This study focuses on the impacts on travel demand with emphasis on the comparison between urban, suburban and rural areas. It uses a parametric grid search approach, systematically varying the supply parameters of fleet size and user price per kilometer. For any combination of these parameters the model computes various indicators such as operator profit, capacity utilization of the vehicles, and modal share of the new systems.

Results

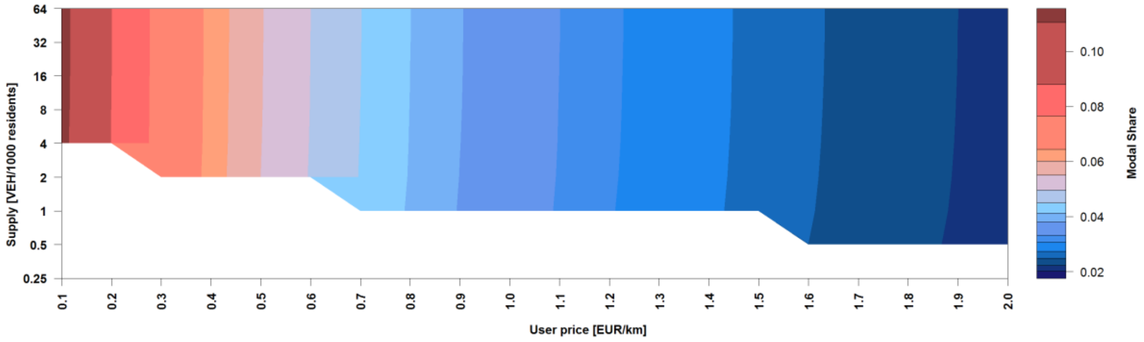
The preliminary results indicate that – under the current assumptions – urban areas reach the highest modal shares for automated sharing systems. A situation in which (1) the operator is breaking even, (2) the capacity utilization of the vehicles is in a realistic range and (3) the user prices are lowest (emulating competition in the market) appears to be most realistic and is therefore of specific interest. For this situation, the model indicates higher modal shares for the ACS than for the AP system and stronger differences between the area types for the AP than for the ACS case:

- urban regions: 12% (ACS), 11% (AP)
- suburban regions: 10% (ACS), 6% (AP)
- rural regions: 9% (ACS), 5% (AP)

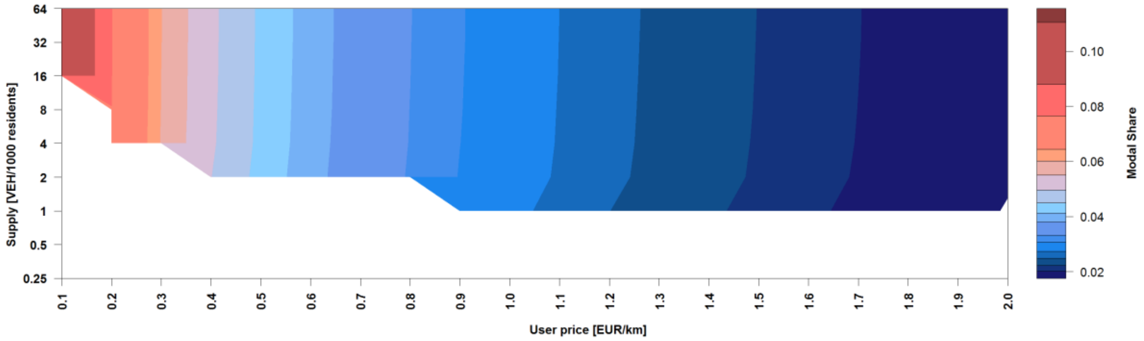
The corresponding combinations of user prices and fleet sizes are 0.30-0.35 EUR/km and 3.0-4.5 vehicles per 1,000 residents in the ACS case, and 0.11-0.38 EUR/km and 2.5-4.0 in the AP case, respectively. In both cases, the lowest user prices and the highest fleet density occur in urban areas, whereas the highest user prices and the lowest fleet density occur in the rural areas. This is due to the fact that private car ownership rates are lowest in urban areas making systems very attractive for former non-car users. Furthermore, in urban areas the systems can operate more efficiently because of higher population and infrastructure density giving rise to shorter waiting times and lower user prices. For the AP case, trip matching is much more important in urban areas and almost not existent in rural areas. However, the model captures a dependency between waiting time and detour factors, which are acceptable for the passengers, and the trip matching rate. That is, by relaxing the assumptions on the corresponding passenger preferences, the trip matching rate can be increased.

Fig. 1a and Fig. 1b show the mode share of the AP system in urban and rural areas, respectively, as a function of user price (in EUR/km) and fleet size (in vehicles/1,000 inhabitants). White areas indicate a capacity utilization of the vehicles above 0.5 (the car is on the move for more than 12 hours per day). Against the background of a high concentration of demand in peak hours which the shared vehicle fleet would have to be scaled for, such scenarios do not seem to be realistic and are therefore not considered further. Red areas indicate a high mode share; blue areas indicate a low mode share of the system. It can be seen that the modal shares at a given user price/fleet size combination are generally higher in urban areas. For the system state described above the modal share in urban areas is even more than twice as high than in rural areas due to the fact that lower user prices at a larger fleet density are still operationally profitable. This corresponds to the described shift of the point of operation to the upper left in the illustrated diagram.

The full paper will (i) investigate the shifts between the different transport modes together with performance indicators of the system, and (ii) present sensitivity analyses for different input parameters related to waiting time calculations, mode specific constants of the choice model, or operator costs assumptions.



(a) urban regions



(b) rural regions

Figure 1: Modal share of the AP system as a function of user price (EUR/km) and fleet density (vehicles/1,000 inhabitants) for urban and rural areas in Germany.

References

Burns, L. D., W. C. Jordan, and B. A. Scarborough (2013). *Transforming Personal Mobility*. Earth Island Institute, Columbia University, Tech. rep.

DLR and Infas (2008). *Mobilität in Deutschland (MiD) 2008*. Tech. rep. Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für angewandte Sozialwissenschaft GmbH.

Fagnant, D. J. and K. M. Kockelman (2015). “Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations”. In: *Transportation Research Part A: Policy and Practice* 77, pp. 167-181.

Fagnant, D. J., K. M. Kockelman, and P. Bansal (2015). “Operations of shared autonomous vehicle Fleet for Austin, Texas, market”. In: *Transportation Research Record* 2536, pp. 98-106.

Gruel, W. and J. M. Stanford (2016). “Assessing the long-term effects of autonomous vehicles: a speculative approach”. In: *Transportation Research Procedia* 13, pp. 18-29.

Kröger, L., T. Kuhnimhof, and S. Trommer (2016). „Modelling the Impact of Automated Driving. Private AV Scenarios for Germany and the US”. In: *Proceedings of the European Transport Conference* (ETC).

Litman, T. (2014). *Autonomous vehicle implementation predictions*. Tech. rep.

Tampère, C. M., S. P. Hoogendoorn, and B. Van Arem (2009). “Continuous traffic flow modelling of driver support systems in multiclass traffic with intervehicle communication and drivers in the loop”. In: *IEEE transactions on intelligent transportation systems* 10.4, pp. 649-657.

Trommer, S., V. Kolarova, E. Fraedrich, L. Kröger, B. Kickhöfer, T. Kuhnimhof, B. Lenz, and P. Phleps (2016). *Autonomous Driving – The Impact of Vehicle Automation on Mobility Behaviour*. Tech. rep. ifmo – Institut für Mobilitätsforschung.