The impact of automated vehicles on long-distance travel in Germany

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Introduction

Automated vehicles (AV) might soon become reality, considering the rapid development of vehicle technologies and data processing in the past years. Following the technological pathway and the complexity of driving tasks, the highway pilot might be one of the first use cases of autonomous driving, since it requires a lower level of automation (ERTRAC, 2017). According to experts, automated driving might change personal mobility and mode choice decisions, as the driver being able to pursue other activities during the trip increases the comfort of travelling (Anderson et al., 2014, Fraedrich et al., 2016). This is especially the case on long-distance trips, in which driving is often seen as an exhausting and monotonous task (Trommer et al., 2016). Such trips are particularly relevant due to a number of reasons. They are mostly rare events but amount to a large proportion of the overall vehicle miles travelled (VMT), private car is dominating the modal split, and the total mileage traveled on long-distance trips has continuously increased in past years, even though daily mobility remains constant (Kuhnimhof et al., 2014). The share of the total VMT by car in Germany on highways is 28% (Bäumer et al., 2017). These facts also indicate the high impact that long-distance car trips have on the environment in general (Goeverden et al., 2016). It is therefore necessary to ascertain whether autonomous driving – even with vehicles having lower automation (e.g. Level 3) – will impact on car VMT in the near future in order to provide decision makers information for planning the transport system in accordance to the future challenges posed by automation.

As highway pilots will likely be the first automated driving functions and drivers could benefit the most on long journeys, the context of long-distance travel on highways in Germany was chosen in this study. We defined long-distance travel as trips longer than 100 kilometer for all analysis steps. The time horizon of the study is the year 2030, when the market ramp-up of AVs with mostly lower automation functions is expected to occur (Trommer et al., 2018). With respect to the classification of automation (SAE, 2014) we defined that vehicles with high automation (Level 4 or 5) can drive fully automated on highways at any time. In contrast, vehicles with conditional automation (Level 3) need to be monitored by the driver in the automated driving mode. The driver might be required to take over control of the vehicle in certain unforeseen situations, e.g. uncharted roadworks or difficult light or weather conditions. The more often such take-over requests occur, the less will drivers benefit from the additional comfort of automated driving. Finally, partial or non-automated vehicles (Level 0-2) cannot drive autonomously, so drivers have to continuously concentrate on the driving task.

The aim of the paper is to quantify the perceived comfort improvements brought by vehicle automation to car users, implement it into a travel demand model and estimate its impact on car travel demand for long-distance trips in Germany in terms of VMT.

Methodology

In order to provide insights into the impact of autonomous driving on long-distance travel we combined four analysis tools: An online survey including a stated preference experiment towards autonomous driving and mode choice to estimate changes in the value of travel time savings (VTTS) when autonomous driving is available (1), a technology diffusion model to determine the future fleet of privately owned vehicles and the share of AVs within this fleet (2), a transport demand model to simulate mode and destination choices and thus changes in VMT for each mode of transport (3), and finally a car traffic assignment model in which vehicles are differentiated by their level of automation (4). The contribution of our study is to present a comprehensive approach on the impact of vehicle automation on long-distance travel taking into account changes in user behavior, the diffusion of different levels of AVs and its usage.

(1) <u>Stated Preference Experiments on autonomous driving</u>

As already mentioned, when driving autonomously the driver do not longer have to follow the driving task and can instead engage other activities. This might lead to a change in the perception of time during the trip and finally in a change of VTTS. For this reason we conducted an empirical study on the change in VTTS as an online survey with a representative sample of approximately 500 participants in Germany. The study design was a combination of Revealed Preference (RP) and Stated Preference (SP) methods with two stated Preference experiments. In the first one, the participant had to choose between current available modes of transport: private car, train, bus and airplane. In the second one, a future mode choice decision was created by presenting a private car with autonomous driving function instead of the private car. According to the study design, the automated private car could be either driven manually or autonomously. All SP experiments were created on the information provided by the first part of the survey, in which the respondents reported detailed information about their last long-distance trip, such as trip duration and length. The attributes of each alternative in the SP experiments were the in-vehicle time, the arrival and departure time, the waiting time, travel/flight costs and the total travel time.

A joint Mixed Logit, including both SP experiments with the current and the future choice set, was estimated with the survey data using the software PythonBiogeme (Bierlaire, 2016). Based on the estimation results and its time and cost parameters, different VTTS could be determined for each mode of transport. Due to the possibility for the participant to choose between an autonomous or manual driving mode in the private car, different VTTS could be calculated for driving a car manually or autonomously. The survey and study design, as well as methodological approach including model estimation and calculation of the VTTS is described in details by Kolarova and Steck (2019).

(2) <u>Diffusion Model</u>

The diffusion of AVs in the overall passenger car fleet is a crucial factor when analyzing the impact of autonomous driving on the transport system. We adapted an existing technology diffusion model (Trommer et al., 2018) in order to forecast the share and the number of AVs in the German passenger car fleet in 2030. We differentiated the car fleet by automation level, age and segment in the following way:

- 3 automation levels: no automation (Level 0-2), conditional automation (Level 3) and full automation (Level 4 or Level 5)
- 3 age categories: up to 3 years, 4 to 7 years and 8 years or older
- 4 vehicle segments: XS, S, M and L (an adapted version of the German Federal Motor Transport Authority classification (KBA, 2018))

The diffusion rate of each automation level and each vehicle segment was calculated using a Gompertz function (Gompertz, 1825). The year of introduction and the initial market penetration rate differs for each vehicle segment and automation level, thus resulting in different overall diffusion levels. We derived the years of introductions from a Roadmap towards autonomous driving (VDA, 2015).

For calculating the size of the German privately owned passenger car fleet in 2030 we considered the current number of new passenger car registrations for each vehicle segment (KBA, 2018) and kept it constant for future years. On the other hand, we implemented a dynamic rate of abolishment for privately owned vehicles, based on the age distribution of the vehicle fleet in 2017. The result of this model is the total car fleet size differentiated by automation level, age and vehicle segment for each year, beginning from 2018 and up to 2030.

(3) Transport Demand Model

A multimodal, Germany-wide transport model (DEMO) was used to determine the effects of autonomous driving on long-distance traffic throughout Germany (Winkler and Mocanu, 2017). DEMO consists of several modules covering passenger and freight transport demand. For this study, only the long-distance passenger transport module was employed. In this module, the destination and mode choice for trips with distances of over 100 km are modelled using a nested logit model. The utility function and the preference parameters towards travel times and costs are derived from a German value of travel time study (Axhausen et al., 2014).

Travel demand for 2030 is based on the results of the Reference scenario from the DLR project "Transport and the Environment" (Winkler and Mocanu, 2017). The Reference scenario foresees a business-as-usual development of the transport system in terms of infrastructure, network quality, income growth, user costs etc. and does not consider the effects of vehicle automation on travel demand. The scenarios presented in this paper differ from the Reference scenario only by the explicit consideration of privately owned AVs.

In order to model the impact of automation on long-distance travel demand we used insights from the stated preference experiment on autonomous driving (Kolarova et al., 2019) and implemented the VTTS reduction into the car utility function. As only Level 3 (to some extent), Level 4 and Level 5 vehicles will benefit from this VTTS reduction we based the travel demand calculation on a fictional car serving as weighted "average" over all automation levels. The weights are given by the respective automation level shares in the vehicle fleet, as estimated by the Diffusion Model. Furthermore, this VTTS reduction only applies on those journey segments where autonomous driving is enabled, i.e. according to the scenario considered here on highways. The thus modified utility affects both destination and mode choice in the Transport Demand Model. OD matrices and total VMT by mode are the results of this model step.

As the benefit of automation by Level 3 depends on the frequency of users having to take-over control of the vehicle during a trip, we set up a recent review on the number of take-over control on highways. Since no verified numbers were found, a sensitivity analysis was done by varying the reduction of VTTS for different automation levels. In the Reference Scenario ("No Benefit") for all levels of automation no reduction of VTTS is assumed. In Scenario 2 ("Partial Benefit") the reduction of the VTTS is considered by 50% for Level 3, indicating that with a higher number of take-overs the benefit of automation decrease. However, Level 4 or higher generates the full benefit of automation. In Scenario 3 ("Full Benefit") Level 3 also benefit by the total reduction of VTTS by automation just as Level 4 and 5.

(4) Differentiated Car Assignment Model

The scenarios presented in this paper investigate the effects of enabling autonomous driving on highways only, and assuming manual driving for all other road types. Therefore, a route choice model is required in order to determine the proportion of travel time on AV-enabled roads, i.e. highways, for each OD pair. Furthermore, as driving on highways becomes more attractive for users of AVs, this might also lead to different routes being chosen compared to drivers of non-autonomous vehicles.

A multi-class assignment based on the DEMO network model (Winkler and Mocanu, 2017) was set up, with each automation level representing an individual vehicle class. As the car trip matrices resulting from the Transport Demand Model are not differentiated by automation levels, they were split up according to the procedure proposed by Mocanu (2018) factoring in the vehicle fleet shares, the trip purpose and trip distance. Results from the assignment model, i.e. impedance matrices for travel times (on highways only and overall) and distance were fed back into the transport demand model to ensure consistency between the two model steps.

Results

The combination of different analysis tools gives us the opportunity to investigate the impact of AV on the transport system and address some specific questions. Crucial inputs for our transport demand model is VTTS for each mode of transport as well as the composition of the private vehicle fleet. The model estimation on the mode choice experiment including autonomous driving shows that participants perceive the in-vehicle time less negatively if they rode a private car autonomously than participants driving their private car manually. The results from the stated preference experiment indicate a reduction of the VTTS by 22 % for people riding their private car autonomously instead of driving it manually. In more detail, the calculated VTTS of participants with middle income is 16.20 €/h for riding a private car autonomously and 20.80 €/h for driving a private car manually and is almost similar to the VTTS of using the train (15.60 €/h) (Kolarova and Steck, 2019).

This VTTS reduction is relevant only for cars having automation level 3 or higher. In 2030 the share of AVs in the German privately owned car fleet is 17 %, whereby primarily vehicles of the segment M or L are automated. In total the modelled car fleet consists of 45.46 million vehicles with 5.16 million and 2.46 million vehicles

having automation level 3 and 4 respectively. The latter ones are capable of driving fully automated on highways, so the full reduction of VTTS by 22 % can be assumed for the travel time on these road segments.
The VTTS reduction leads to an increase in car travel demand, both in terms of mode shares and trip distances. To sum this up, the impact of automation on long-distance travel demand in Germany is evaluated by means of the total car VMT. In the Reference scenario (“No Benefit”), this amounts to 167 billion VMT per year. The figure increases by 2.8 % in Scenario 2 (“Partial Benefit”) and 4.2 % in Scenario 3 (“Full Benefit”), highlighting the impact that the uncertainty regarding the functionality of Level 3 automation has on the results. These preliminary results indicate that, while automation will not radically change long-distance travel demand, it will nevertheless lead to a noteworthy increase in car traffic.
Finally, the assignment model results show that, already in the Reference scenario, 87 % of the car VMT from long-distance trips will occur on highways. This indicates that the German highway network is sufficiently dense and accessible to attract the overwhelming majority of long-distance travel. The percentage increases slightly to 88 % in the automation scenarios. As expected, highways will attract a comparatively larger amount of additional traffic, though this effect seems to be rather limited due to the already high levels in the Reference scenario. The resulting overall VMT increase on highways will be of 5.1 % in Scenario 3.

Conclusions

The combination of the four analysis tools shows that even in the near future a partial automated vehicle fleet with a low level of automation can influence the transport system significantly. The individual benefits for the users by automation might lead to an increasing usage of the private car and consequently to more VMT by car. On the one hand, users choose the private car instead of other modes of transports automation. On the other hand, automation also induces additional transport. These negative effects on the transport system as well as on the environment have to be investigated further on.

References

Anderson, J. M., Nidhi, K., Stanley, K. D., Sorensen, P., Samaras, C., and Oluwatola, O. A. (2014). Autonomous vehicle technology: A guide for policymakers. Rand Corporation.

Axhausen, K., Ehreke, I., Glemser, A., Hess, S., Jödden, C., Nagel, K., Sauer, A. and Weis, C. (2014) Ermittlung von Bewertungsansätzen für Reisezeiten und Zuverlässigkeit auf der Basis eines Modells für modale Verlagerungen im nicht-gewerblichen und gewerblichen Personenverkehr für die Bundesverkehrswegeplanung. FE-Projekt-Nr. 96.996/2011, BMVBS, Berlin.

Bäumer, M., Hautzinger, H., Pfeiffer, M., Stock, W., Lenz, B., Kuhnimhof, T., and Köhler, K. (2017). Fahrleistungserhebung 2014 – Inlandsfahrleistung und Unfallrisiko. Ed.: Bundesanstalt für Straßenwesen, Bergisch Gladbach, Germany.

Bierlaire, M. (2016) PythonBiogeme: a short introduction. Report TRANSP-OR 160706, Series on Biogeme. Transport and Mobility Laboratory, School of Architecture, Civil and Environmental Engineering, Ecole Polytechnique Fédérale de Lausanne, Switzerland.

European Road Transport Research Advisory Council (ERTRAC) (2017). Automated Driving Roadmap.

Fraedrich, E., Cyganski, R., Wolf, I., and Lenz, B. (2016). User perspectives on autonomous driving. A use-case-driven study in Germany. Geographisches Institut, Humboldt-Universität zu Berlin, Arbeitsbericht 187.

Gompertz B. (1825). On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. Philosophical Transactions of the Royal Society of London B: Biological Sciences.

KBA, 2018. Bestand an Personenkraftwagen nach Segmenten und Modellreihen am 1 . Januar 2018 gegenüber 1. Januar 2017 (FZ 12). Hrsg.: Kraftfahrt-Bundesamt. Abrufbar unter: https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Segmente/segmente_node.html (last acces: 2018-12-21).

Kolarova, V., and Steck, F. (2019). Estimating impact of autonomous driving on value of travel time savings for long-distance trips using revealed and stated preference methods. In: Mapping the Travel Behavior Genome. The Role of disruptive technologies, automation, and experimentation. Ed. Goulias, K. and Davis, A. (in press).

Kuhnimhof, T., Frick, R., Grimm, B., and Phleps, P. (2014). Long distance mobility in central Europe: Status quo and current trends. In: European Transport Conference 2014, Frankfurt, Germany.

Mocanu, T. (2018). What Types of Cars Will We Be Driving? Methods of Forecasting Car Travel Demand by Vehicle Type. Transportation Research Record.

Trommer, S., Kolarova, V., Fraedrich, E., Kröger, L., Kickhöfer, B., Kuhnimhof, T., Lenz, B. and Phleps, P. (2016). Autonomous driving: the impact of vehicle automation on mobility behaviour.

Trommer, S., Kröger, L., and Kuhnimhof, T. (2017). Potential Fleet Size of Private Autonomous Vehicles in Germany and the US. In: Road Vehicle Automation 4, Berlin, Germany. Edt. Meyer, G. and Beiker, S.

van Goeverden, K., van Arem, B., and van Nes, R. (2016). Volume and GHG emissions of long-distance travelling by Western Europeans. Transportation Research Part D: Transportation and Environment, 45, 28-47.

VDA (2015). Automatisierung - Vom Fahrassistenzsystemen zum automatisierten Fahren. VDA, Berlin.

Winkler, C., and Mocanu, T. (2017). Methodology and Application of a German National Passenger Transport Model for Future Transport Scenarios. In: Proceedings of the 45th European Transport Conference, Barcelona, Spain.