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Leistungssteigerung städtischer Straßennetze - Improving the Performance of Urban Road Networks

Executive Summary

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Scope of the Study

Connected and automated driving can have a significant impact on the performance of future urban road networks. The aim of the project "Improving the Performance of Urban Road Networks", commissioned by the German Federal Ministry for Digital and Transport (BMDV) within the framework of the “Forschungsprogramm Stadtverkehr” (FoPS), is to investigate these possible changes in the performance of urban road infrastructure. To analyze possible impacts on network performance, microscopic traffic flow simulation is used as the primary tool. Based on the results and a survey of experts, recommendations will be developed for research and practice on how to address the impact of connected and automated vehicles (CAVs) on traffic flow in the future.

In detail, the project consists of three main steps:

1. In the course of a comprehensive literature review, existing national and international literature as well as results of completed research projects are analyzed. The review covers the characteristics and effects of CAVs in particular, including their modeling in traffic flow simulation programs. Based on the review, plausible future scenarios for urban road traffic will be defined.

2. In the next step, microscopic traffic flow simulations and traffic engineering calculations are performed to estimate the change in performance in an urban environment. For this purpose, the previously defined future scenarios are simulated and evaluated on representative routes. Subsequently, correction factors are calculated for characteristic parameters that occur in the guidelines of the German Road and Transportation Research Association (FGSV). In this way, a proposal is made as to how the observed effects can be incorporated into the regulations.

3. Finally, the results are interpreted and discussed with members of the FGSV committees. On the basis of some selected parameters, the possible transfer of the results into the regulations will be presented. Finally, recommendations will be developed for research and practice on how to address the impact of connected and automated driving on urban traffic networks in the future.

Methodology

In order to narrow down the range of possibilities and to present realistic developments, the present study carried out simulation-based investigations. For this purpose, three future scenarios with different levels of CAV penetration rates and traffic control measures were defined:

- *Conservative*: CAV penetration of 33% without specific traffic control measures,

- *Innovative*: CAV penetration of 66% with dedicated CAV lanes,

- *Visionary*: CAV penetration of 95% with traffic-adaptive, reinforcement learning-based traffic control.

Additionally, four representative road sections were selected, three of which are located in the city of Ingolstadt and one in the city of Munich. They contain a wide range of infrastructure elements (different intersection geometries and access types, single and multi-lane road segments, as well as signalized and non-signalized intersections) and thus represent typical urban road networks well. In the selection process, attention was paid not only to the frequency of occurrence of the infrastructure elements, but also to their share of the mileage in an urban road network. The routes selected in this way were modeled using the traffic flow simulation software SUMO (Simulation of Urban Mobility) (Lopez et al., 2018) and calibrated using real data. With regard to the driving behavior model, compliance with the manual for the design of road traffic facilities (HBS) (FGSV, 2015) was taken into account. Behavior models for CAVs were taken from the CoExist project (CoEXist Consortium, 2020).

Traffic flows and densities, their correlations, and saturation traffic volumes and queue lengths were evaluated as parameters. Each scenario was compared with a base scenario, which represents today's situation without CAVs, in order to examine the respective impact on the road section. The results of the simulation study were used to assign correction factors to the calculation methods used in the HBS and other guidelines that take the effects of CAVs into account.

In addition, recommendations for action were derived from the calculation results and additional expert interviews.

Results

Evaluation methodology

Based on the simulations, statements can be made about a large number of parameters. A good overview is provided by the fundamental diagram of traffic flow (correlation between average traffic volume and density), since it (i) is an input variable for the dimensioning in the HBS, (ii) provides information about the traffic conditions at different demand intensities, and (iii) can be used to read off the capacity as well as the extent of congestion. Exemplary results of the conservative scenario are shown in Figure 1.

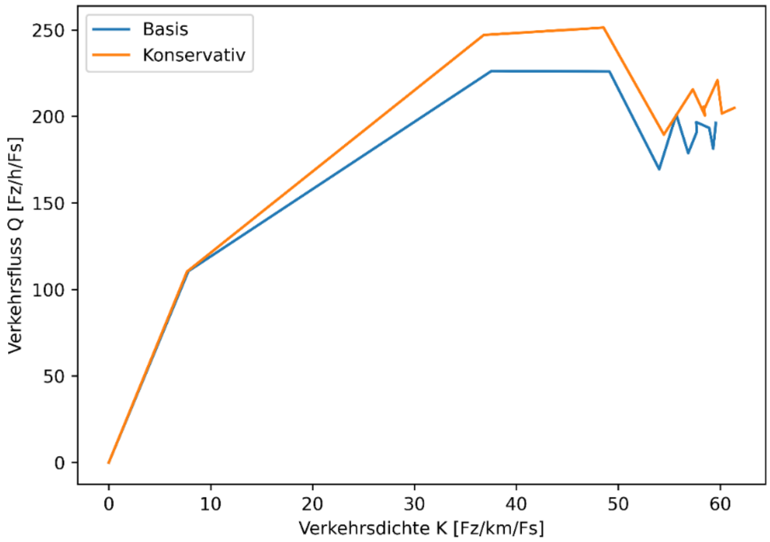

Figure 1: Fundamental diagram for the conservative scenario and the "Ingolstadt small" section. *[With: Q = traffic flow, F = traffic density.]*

Simulation of the Conservative Scenario

Overall, the positive impact of automation on capacity is significant. This is an expected result since the CAVs follow each other with shorter time intervals. However, the more constant driving seems to have little effect on the variance of the congested traffic conditions, as the unsteady curve shows. Thus, the general traffic pattern at high traffic densities still appears to be highly stochastic. For the conservative scenario, a correction factor of up to 1.15 was obtained for the capacity determined with the fundamental diagram compared to the base scenario on the four simulated road sections.

Simulation of the Innovative Scenario

In the innovative scenario, the additional implementation of a dedicated CAV lane did not have a positive impact on traffic flow on the investigated road sections compared to driving in mixed traffic of automated and conventional vehicles. This is mostly due to the increased number of conflicts and complex interactions on the intersection approaches, where traffic flows must cross each other to reach desired turning lanes. This means that such dedicated CAV lanes would have to be implemented based on other arguments. Simulated was a dedicated CAV lane design that was found to perform best in prior extensive simulation runs of an isolated intersection approach: The dedicated lanes were located on the left side of the road whenever possible, and no pre-signals (for sorting before intersections) are considered. CAVs are allowed to use bus lanes, if existing. Overall, the capacity correction factors for the road sections, again determined by using the fundamental diagram, lay between 0.9 and 1.4 compared to the base scenario.

Simulation of the Visionary Scenario

The results of the visionary scenario showed that a high penetration rate of CAVs combined with adaptive traffic control based on reinforcement learning has a comparatively strong positive impact on traffic flow. This is already the case at low traffic densities and is partly due to the high penetration rate of 95% and the low time gaps between CAVs as shown in the comparison scenarios. It should be noted, however, that the reinforcement learning control leads to a further significant increase in the effect of the short time gaps. I.e., the optimization of the signals based on the vehicle data can lead to enormous performance improvements, compared to traffic adaptive signal control. In the investigated case, capacity has at least doubled compared to the baseline scenario. Furthermore, the results show that a large variability of signal timings can also have a positive effect on traffic flow. This is an interesting result considering the general opinion that the effects of cooperative functions such as a Green Light Optimal Speed Advisory (GLOSA) can be utilized effectively with as little variability as possible. The visionary scenario resulted in a correction factor of the capacity determined with the fundamental diagram of about 2.5.

Expert Interviews

Finally, the simulation and calculation results were discussed in a total of nine interviews lasting between one and two hours. The focus of the interviews lay on the calculation of the correction factors as well as the foreseeable development of connected and automated driving and the representation of the corresponding effects in the FGSV guidelines. The interviews were conducted with representatives of the working groups (WG) 3.1 Telematics, WG 3.3 Traffic Management in Urban Areas, WG 3.10 Theoretical Principles of Road Traffic and WG 3.13 Quality of Traffic Flow. The main results of these discussions are presented in the next chapter.

Implications for Practice

Results of the study showed that higher capacities can be achieved with high CAV penetration rates, appropriate driving dynamics of automated vehicles, and an advanced adaptive traffic signal control. In the long term, this could make it possible to reallocate lanes currently reserved for motorized private transport and make them available to other road users or for other purposes. In the near future, however, further field tests and simulator studies should be conducted to update or verify the assumptions used in this study.

The experts interviewed agreed that the complex relationship between automation and performance is not yet fully understood and that the assumptions made in the parameterization of simulation models are likely to have a greater or lesser influence on the results. This is also applies to the present study. However, there is a consensus that the influence of CAVs on traffic flow parameters needs to be considered in future regulations. The effects of CAVs can be included as a correction factor in the HBS or described in a section on CAV modeling in the FGSV notes on microscopic traffic flow simulation (FGSV, 2006). In general, it was emphasized that the guidelines represent the current state of the art and that much more empirical CAV data are needed before recommendations on parameterization and correction factors for CAVs can be considered in an update of the guidelines.

Overall, the present study provides a solid basis for further investigation, as it shows which aspects need to be focused on (e.g., basic diagrams, empirical data, and control procedures). Furthermore, a closer cooperation between academia and the automotive industry (e.g. in future research projects) is strongly recommended in order to further improve the integrated models for CAVs.

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A detailed bibliography can be found in the final report on the research project.