Estimation of Passenger Car Equivalents for New Forms of Mobility

Investigating the effect of automated vehicles on the saturation flow of urban intersections

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Abstract

Automated vehicles promise to change traffic patterns by improving traffic flow and increasing traffic safety. More and more road authorities are interested to know the effects of such new technologies in order to account for them when planning for the future transportation systems. In guidelines for the design and dimensioning of road infrastructure, transformation factors are used to account for vehicles with differing dimensions and dynamic behaviors. These differences are expressed by the so-called Passenger Car Equivalents. The paper investigates which properties of automated vehicles lead to changes in traffic performance. Based on that, we propose a factor model to be incorporated into the guidelines to account for future changes in vehicle technology and compute adapted values for the mixed traffic between conventional and automated vehicles in traffic.

Keywords: *automated and connected vehicles, traffic performance, transportation planning*

Introduction

The mobility industry is in a time of change, as new drive technologies and service forms are introduced. Particularly, the progressive automation of road traffic induces major changes. New vehicles are able to take over more and more driving tasks automatically, while at the same time, the diversity of the composition of road users is increasing. The mixed traffic of road users with different automation and communication skills represents one of the great challenges of the near future.

The automated driving technology is expected to improve traffic performance and safety. Current research in transportation is focusing on investigating these effects. For future transport planning, new forms of mobility like automated vehicles need to be considered when it comes to designing new road infrastructure or implementing traffic control measures. In contrast to human-driven vehicles, automated vehicles will show a fundamentally different driving behavior, as human inherent factors, such as reaction times and imperfect car-following behavior, will not be present in the driving patterns of these vehicles.

Current tools used by transportation scientists and engineers to analyze traffic, aim at replicating the human driving behavior. For example, in traffic simulation tools, the aforementioned factors are modelled. Current guidelines for the calculation of road dimensioning or performance evaluation also consider the human behavior. New forms of mobility, such as automated vehicles, will soon come into market and might change today's traffic flow patterns. Therefore, new metrics and models become necessary to account for these changes when planning for the future transportation systems.

This paper investigates the effects that automated vehicles have on the saturation flow of urban intersections and proposes new values for passenger car equivalents for these vehicles. Passenger car equivalents are used to account for different road users with distinct dimensions and dynamic characteristics in a traffic stream. Guidelines for road dimensioning contain transformation values for different vehicle types such as heavy goods vehicles (accounting for 2.3 passenger cars according to [1]) or motorcycles (accounting for 0.4 passenger cars according to [1]). The results of this work can be used for consideration in future guidelines accounting for automated vehicles on the roads. Additionally, some simulation tools working on a mesoscopic or macroscopic level also need this type of input parameters for estimating the impacts of these new forms of mobility on the network.

Research Needs and Methodology

The research aims at identifying the effect of automated vehicles on the saturation flow of urban intersections to account for mixed traffic scenarios. As passenger car equivalents (PCEs) are used in many transportation engineering tasks. The effect of automated vehicles shall be quantified and compared to the values for human drivers, so that new PCEs for automated and communicating vehicles can be calculated. The work is based on assumptions for the behavior of automated vehicles, as this technology is still under development. Previous research activities investigated the impacts of automated vehicles on traffic flow patterns and give insights into the effects, which are due to different driving behaviors. Therefore, the assumptions were retrieved through a systematic literature review considering both simulation-based and theoretical approaches. This allows for the calculation of different PCEs according to the technology. In this paper, a factor model is proposed to account for the different components having an effect on the change in PCE values.

The currently used PCE values are retrieved from official international guidelines not considering any vehicle automation or communication. As of today, vehicles with a level of automation up to level 2 according to the SAE nomenclature [2] are already present on the streets.

The saturation flows reached with automated vehicles are compared to those reached by human-driven vehicles. As a result, PCEs for automated vehicles on urban intersections are calculated and new factors for the calculation of saturation flows for future traffic compositions with automated vehicles are proposed. Figure 1 depicts the methodological approach of this paper. The red arrows show the output of the research, which might be used as an input for simulations and new guidelines.

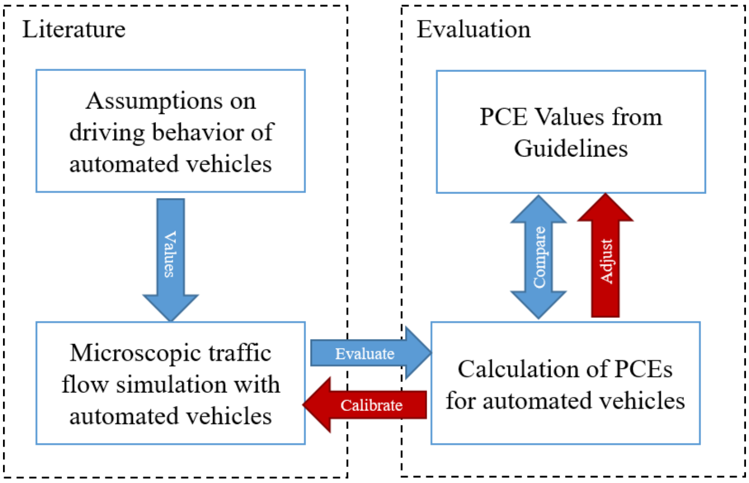

Figure 1: Methodological approach

Related Work

The transformation of vehicle counts into PCE values is used to account for differing driving behaviors and vehicle dimensions when evaluating the traffic performance at intersections or other parts of the road infrastructure used by various road users [3]. In the guidelines for the calculation of capacity and quality of service of infrastructure facilities, standard values are given for the transformation of vehicle counts into PCEs. For the calculation of the saturation flow on urban signalized intersections, factors are used that account for heavy goods vehicles (HGV). In the German Highway Capacity Manual, the HGVs are differentiated into trucks and busses, for which a factor of 1.75 is used, and trucks with trailers, for which a factor of 2.5 is used [3]. If this differentiation was not made in the vehicle counts, a combined factor of 1.9 is applied. In their paper, [4] present several methodologies for an even more exact calculation of PCEs. In [5], lagging headways are computed for the estimation of PCEs and a differentiation between truck classes is made.

According to the standards used in Germany, the time a passenger car needs to leave an intersection is 1.8s. The saturation flow is the amount of vehicles that can theoretically leave an intersection from one approach during one hour of green time. Under standard conditions, this value sums up to 2000 vehicles per hour [3]. The value, though, depends on the traffic composition. A factor is multiplied with the required time of 1.8s depending on the share of HGVs. Additional factors account for reductions in the time due to the turning radius, the width of the lane and the inclination. In the US American guidelines, additional adjustment factors account for the existence of parking lanes or bus stops that might have a blocking effect on the stream when stopping in the area of the intersection. Factors for the lane utilization, right or left turning vehicles in the vehicle stream as well as conflicting pedestrian and bicycle flow adjustment factors, additionally reduce the saturation flow of the lane group under consideration [6]. Many studies suggest that the factors considered in the guidelines are not enough to estimate PCEs. In [7] the effect HGVs on traffic are proven to be different depending on the traffic conditions. The effect was quantified for two locations, an entrance ramp merge area, and a construction zone. Also [8] examined traffic flow in differing traffic conditions for a basic freeway segment and found that the PCE values were estimated to be higher in congested conditions.

Many current research activities focus on the evaluation of the effects that automated vehicles have on traffic flow. Studies reveal that the capacity of road infrastructure might change due to the differing driving behaviors of automated compared to conventional human-driven vehicles. The effects, though, depend on the share of automated vehicles and the parametrization of these [9], [10]. For urban intersections, according to [11], a capacity increase of 40% could be achieved, if only autonomous vehicles were present.

Preliminary Results

For the study of the effects of different automated vehicle functionalities, the relevant literature was analyzed in detail. The following aspects are considered when developing the factor model for automated vehicles:

- Level and functionalities of the vehicle automation (A)
- Communication capabilities (C)
- Penetration rate of the technology in the fleet (PA – penetration of automation technology, PC – penetration of communication technology)

The automation functionalities mainly describe which tasks the vehicle is able to perform automatically and which effect this has on the traffic system’s performance. A longitudinal controller for the vehicle may be set to keep a specified time gap to the preceding vehicle and has negligible reaction time in comparison to human drivers. Communication capabilities might help in the prediction of other driver’s behaviors and can change the performance since some information might be available to the vehicle control at an earlier stage in comparison to vehicles, which are controlled only based on signals detected by the on-board sensors. Communication with the infrastructure might additionally provide useful information for the vehicle control. Furthermore, considerations with regard to the penetration rate of the technology in the fleet need to be made since equipped vehicles might not be able to show their full potential if conventional vehicles influence the others.

According to the German Highway Capacity Manual, the saturation flow is the maximum possible number of vehicles leaving an approach of a signalized intersection. As mentioned above, this value is 2000 veh/h under standard conditions, which means that there are no trucks, there is no longitudinal inclination of the road and the lane width is a standard size. Therefore, the required time (t_r) for a conventional vehicle to leave an intersection under these conditions is 1.8s.

In order to adjust this value to the present conditions with trucks, and differing road designs the following formula is used to calculate the adapted t_r, where the factors f_1 and f_2 account for the influence of the turning radius, the longitudinal inclination of the road and the lane width:

$$t_r = f_{HGV} * f_1 * f_2 * 1.8$$

The following formula introduces the factors into the calculation of the required time for a vehicle to leave an approach of the intersection (t_r), where f stands for the factors accounting for the aforementioned effects of automated and communicating vehicles and X for the original part of the calculation, which remains the same. The communication effect can be split into the communication between vehicles (V2V) and the communication between vehicles and the infrastructure (V2I). We assume that a higher share of communicating vehicles and communicating infrastructure elements leads to a greater influence on traffic performance.

$$t_r = (f_A * PA) * (f_C * PC) * X$$

The factor, which accounts for vehicle automation (f_A) considers the following aspects:

- Changes in reaction time
- Changes in time headways between vehicles
- Changes in acceleration behavior

We assume that the reaction time can be set close to zero, since it is only due to latency in wired signal processing. Furthermore, the time headway between vehicles may be set between the legal recommendation of 2s and the minimum allowed value of 0.9s [12]. The acceleration behavior is assumed to be optimized due to smoother acceleration procedures. However, we estimate the impact to be lower than the other two in terms of traffic flow. To account for the three effects, the factor f_A needs to be split into the portions of the total influence I.

$$I_{Total} = I_{Reaction} + I_{Headway} + I_{Acceleration} = 1$$

$$f_A = f_{Reaction} * I_{Reaction} + f_{Headway} * I_{Headway} + f_{Acceleration} * I_{Acceleration}$$

The factor accounting for communication (f_C) includes:

- Changes in reaction times towards the traffic signal (V2I) and towards the preceding vehicle (V2V)
- Changes in time headways between communicating vehicles (V2V)
- Changes in approaching behavior

The procedure for the calculation of the factor f_C is similar to the calculation of f_A explained above. Again, the reaction time is reduced to the latency in signal processing. A value of 10 ms can be assumed if G5 technology is present [13]. This corresponds to a reduction of about 90% and can be applied to V2V and V2I communication. In this case, we estimate the headway to have the biggest influence as communicating vehicles might form platoons that might be allowed to have lower time gaps and therefore significantly increase the throughput of an intersection. The adapted approaching behavior might lead to fewer acceleration and deceleration processes and therefore slightly increase traffic throughput.

The factors for the penetration rates (PA and PC in percent for automation and communication, respectively) account for the fact, that not all vehicles in the traffic stream have the same capabilities in terms of communication and automation. This way, mixed traffic conditions, of different forms of automation and conventional vehicles can be replicated. In order to validate the model, it is necessary to obtain real data from traffic. Since automated vehicles are not yet present on the roads, the verification cannot be carried out with real data. As mentioned before, many studies estimated the behavior of these vehicles and used then in microscopic traffic flow simulation software. This could also be an approach to verify the approach prior to the presence of automated vehicles on the roads.

Conclusions

This paper investigates the effect that automated vehicles with differing capabilities have on the saturation flow of urban intersections. We propose a model to calculate passenger car equivalents for these vehicles based on their dynamic characteristics. This can be used as an input for traffic flow simulations as well as new considerations for capacities of roads with automated vehicles deployed.

The introduction of new factors to adapt the passenger car equivalents to different automation and communication capabilities seems to be a suitable approach to directly map the effects in mixed traffic scenarios. The verification remains an open topic since good models of these vehicles or actual observations from traffic with this type of vehicles are needed. Nevertheless, the approach promises a smooth transition from current to future traffic planning, without neglecting the effects of mixed traffic and can thus help to introduce new technologies.

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