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Microscopic simulation of automated and connected vehicles in the Test Field Hamburg

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Abstract

What effect does the automation of road traffic have on traffic and the environment? To answer this question, a microscopic simulation (SUMO - Simulation of Urban Mobility) was used to model the test bed for automated and connected driving in Hamburg, which was then used as the basis for examining two scenarios. In the first scenario, the traffic was replaced by automated and connected vehicles. For the second scenario, the model infrastructure was upgraded to provide the GLOSA service to connected vehicles at selected intersections, which is intended to optimize the approach of vehicles to a traffic light. This paper presents how travel time, time loss, and average speed, as well as CO_2 and PM_x emissions change when traffic demand is replaced by automated and connected vehicles. In the second scenario, we examined how the waiting time and CO_2 and PM_x emissions change as a result of the GLOSA service.

Keywords:

Simulation & Modelling, Connected Automated Vehicles

Introduction

The implementation of automated and connected driving requires the technical equipment of vehicles and the corresponding infrastructure. The aim is to realize potentials such as more efficient, safer and more environmentally friendly traffic and - in particular through communication between vehicles and with the infrastructure - to use new forms of services. A test field for automated and connected driving is being operated in the city center of Hamburg, where various services and functions can be tested. In the context of a study for the LSBG Hamburg[1], supplementary studies were carried out on a simulation

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[1] Landesbetrieb Straßen, Brücken und Gewässer der Freien und Hansestadt Hamburg

model. This article explains the procedure for the simulative study and presents the results on the basis of two selected aspects (automated driving as such in comparison with conventional vehicles and the GLOSA service with a speed recommendation for optimized traffic flow at light-signal systems).

Use cases of automated road transport

In the following, the two use cases are described in detail.

Automated and connected driving

Connected automated vehicles (CAV) behave differently in traffic than manually controlled vehicles. In the simulation described here, the vehicle behavior was adapted so that, on the one hand, it behaves in accordance with the traffic rules (e.g. adherence to the maximum permissible speed, distances between vehicles) and that it reacts more quickly (e.g. when accelerating). With these assumptions, it was investigated which differences arise for different penetration rates of automated vehicles in mixed traffic with regard to traffic flow and emissions. The reference was traffic with conventionally parameterized vehicle behavior. The hypothesis to be tested was that with the appearance of automated vehicles in mixed traffic, the traffic flow initially deteriorates at low penetration rates due to the stronger rule conformity, and that with increasing penetration with automated vehicles, this effect is cancelled out when the stronger homogeneous driving has an efficiency-increasing effect. In addition, it was assumed that the use of CAV has an impact on environmental emissions. Therefore, for the different simulation runs, the focus was on parameters like trip duration, time loss, mean speed and the emission of CO_2, NO_x and PM_x.

Green light optimal speed advisory

Green light optimal speed advisory (GLOSA [2]) enables a capable vehicle to optimally approach and pass a traffic signal system via Infrastructure-2-Vehicle (I2V) communication. For this purpose, the traffic signal system sends real-time information about the current traffic light status and the remaining time (signal phase and timing - SPaT). In order to make use of the SPaT information, it is useful to link SPaT with GLOSA, which uses the position of the vehicle to give a speed recommendation. Within the scope of this study, three traffic intersections within the test field were equipped with GLOSA. The following effects can be assumed: Due to the availability of information about the remaining time of the current phase, a more homogeneous traffic flow should result from behavioral adaptation with an increasing share of connected vehicles, thus resulting in a reduction of waiting times. More homogeneous driving is also expected to reduce CO_2 and NO_x emissions. Likewise, this change in driving behavior may lead to less brake abrasion and thus reduce PM_x emissions.

Modelling and microscopic simulation

The following sections describe how the use cases were implemented in the SUMO simulation [1].

Infrastructure and traffic demand

The basis of the simulation scenario is the traffic network, which represents the Hamburger test field as realistically as possible (Fig. 1). Site plans, aerial photographs and circuit diagrams of traffic signals were used for this purpose.

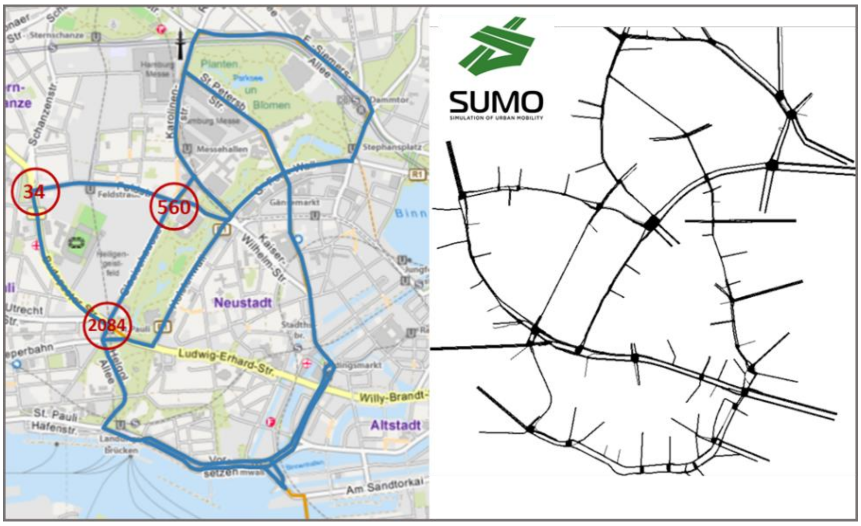

Figure 1 – Test field for automated and connected driving in Hamburg (left) modelled as network in SUMO (right); the marked intersections are equipped with GLOSA

The traffic demand is based on traffic counts of the city of Hamburg. For the studies of the two use cases, the modelled traffic demand was step-by-step replaced by an increasing share of augmented vehicles: In the use case CAV, vehicles were introduced that are automated and interconnected between vehicles. In the use case GLOSA, the vehicles differ from the conventional ones only in that they are connected with the infrastructure. Only these vehicles can make use of the GLOSA service. The incremental replacement of the demand with augmented vehicles is used to investigate the effect of mixed traffic.

Parameterization of automated and connected vehicles

The consideration of the differences between conventional vehicles and CAV in the model is done via the vehicle following model, which, in this case, differ in six parameters. The following table compares the different parameterization of the vehicle types “human driver” and “CAV”. It shows the properties and the value ranges of the parameters, the default values which are implemented in SUMO for the conventional vehicles and the assumptions made regarding the adaptation of the conventional and automated vehicles in this study. All default values are determined by the standard vehicle succession model according to Krauß [3].

Table 1 - Parametrization of the Car-Following Model based on [4]

Attribute Name	**speedFactor**	**Sigma**	**tau**	**minGap**	**lcCooperative**	**lcAssertive**
Description	The vehicles expected multiplicator for lane speed limits and the deviation from this value. Optionally minimum and maximum values for the speed can be set.	The driver`s imperfection (0 = perfect driving)	The driver's desired (minimum) time headway. It is based on the net space between leader back and follower front)	Minimum Gap when standing (m)	The willingness for performing cooperative lane changing. Lower values result in reduced cooperation.	The willingness to accept lower front and rear gaps on the target lane. The required gap is divided by this value.
Range	≥ 0	[0,1]	≥ 0	≥ 0	[0,1]	positive reals
Default in SUMO	speedFactor 1.0, speedDev 0.1	0.5	1.0	2.5	1.0	1.0
Human driver (and connected Vehicle)	(1.1,0.1,0.8,1.4)	0.5	1.0	2.0	0.8	1.2
CAV	(1.0, 0.0)	0.0	1.0	2.5	1.0	1.0

The starting point for the parameterization were the default values. These were adapted for both vehicle types with the aim of creating the most realistic vehicle behavior possible. The *speedFactor* used in the Krauss model specifies by how much the vehicles exceed and fall below the prescribed maximum speed. Each vehicle initially selects its own *speedFactor*, which does not change during a simulation run. The *speedFactor* values of all vehicles are drawn from a normal distribution with the mean *speedFactor* (default value 1.1) and the corresponding standard deviation (*speedDev* default value here: 0.1). In the four-parameter variant, the minimum and maximum values of the *speedFactor* can also be set. Thus, conventional vehicles can both under- and exceed the given speed specification, as is common in reality. The automated vehicle should basically differ from the conventional vehicle in its rule-compliant, homogeneous driving behavior. Thus, its speed choice is limited to 100% compliance of the specified speed limit (*speedFactor*=1, *speedDeviation*=0). The parameter *sigma* represents human inaccuracies in driving. Conventional vehicles reduce the optimal acceleration (acc) by the factor *sigma* und a random value. For automatic vehicles *sigma* is set to zero in this study. Both types of vehicles equally adhere to the specified time gap (*tau*) when driving. When coming to a hold, the conventional vehicle approaches closer to the vehicle ahead than the CAV, which is represented by the parameter *minGap*. The automated vehicle maintains a *minGap* of 2.5m from the vehicle in front, whereas the conventional one keeps 2m distance. When changing lanes, the automated vehicle cooperates with involved road users (*lcCooperative*) and also accurately maintains the required gap in the passing lane (*lcAssertive*). The conventional vehicle, on the other hand, less often considers other participants (0.8 out of 1) and also accepts a smaller gap for an overtaking maneuver (1.2 instead of 1, the required gap is divided by the chosen value). The assumptions chosen here to describe the behavior of an automated vehicle were tested using sensitivity analyses and verified by traffic experts. For further discussion of the parameterization of the vehicle following model for automated and manually controlled vehicles in SUMO, the publications of Li and Wagner [5] and Wagner [6], for example, can be consulted.

GLOSA

Three intersections of the test field are equipped with the GLOSA service. They are marked in Fig. 1 as intersections 34, 560 and 8024. As soon as a connected vehicle is detected 200m from the intersection, the target speed at which the vehicle would reach the green traffic light can be calculated from the vehicle's position, its speed and the upcoming phase change. In this process, an increase of the current speed is not permissible, as the vehicles always try to drive at their possible maximum speed. GLOSA intervention in this case means reducing or maintaining the current speed, while maintaining a minimum speed of 3 m/s. If these measures do not result in a timely arrival at the green traffic light, an attempt is made to optimize the approach to the traffic light by slowing down or to allow for an early approach after the traffic light turns green.

Results

The results of the simulations are presented below. These are averaged values from 10 simulations with different starting values for random route calculations.

Indicators

The indicators analyzed here serve to describe the influence of automated and connected driving on traffic flow and the environment. The analysis for the use case CAV takes into account the entire network. The decisive indicators here are speed, travel time and time loss which are presented here as average values (avg.) per vehicle. The indicator time loss represents the difference between the theoretically permitted and technically achievable shortest travel time and the actual travel time required (including stops at traffic lights, congestion, etc.). The effects on CO_2 and PM_x (cumulated across all vehicles) also refer here to the entire network. In the use case GLOSA, on the other hand, a detailed evaluation of the vicinity of the equipped intersections is carried out in order to capture the local effects. Here, the effect of the GLOSA service is determined by the waiting time[2] of the vehicles and the influences on CO_2 and PM_x emissions (all values as sum across all vehicles in the vicinity of the intersection).

Effects of CAV

The first parameters analyzed with regards to traffic flow were the average travel times and time losses (Fig. 2).

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[2] Waiting time is here defined in Sumo as the time during which the vehicle travels at less than 0.36 km/h

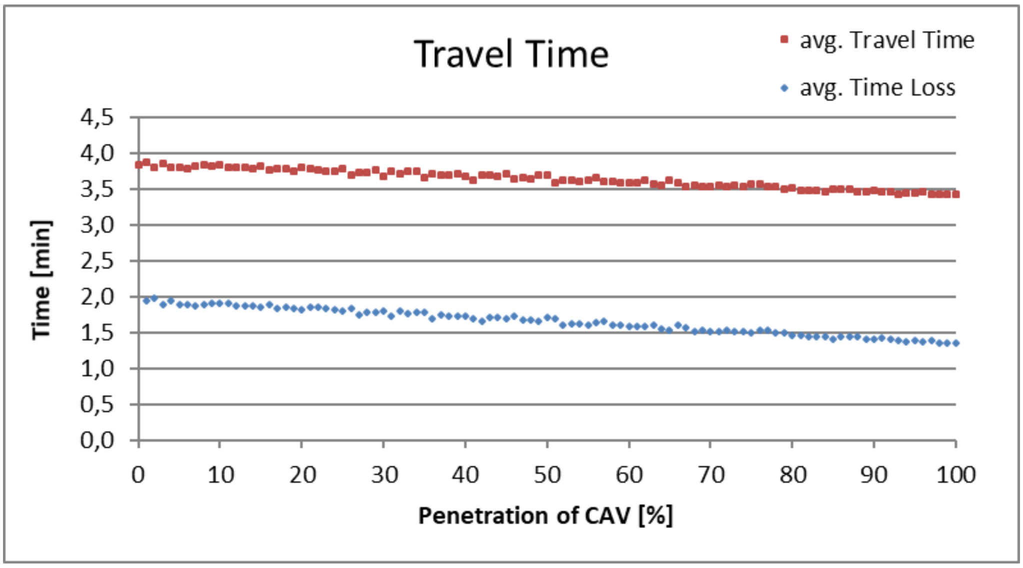

Figure 2 – Average travel time and time loss per vehicle in use case CAV

With increasing penetration of the traffic with automated and connected vehicles, the average travel times and, in parallel, the average time loss are continuously decreasing (-30 %). This corresponds to the analysis of the travel speed (-11 %) (Fig. 3):

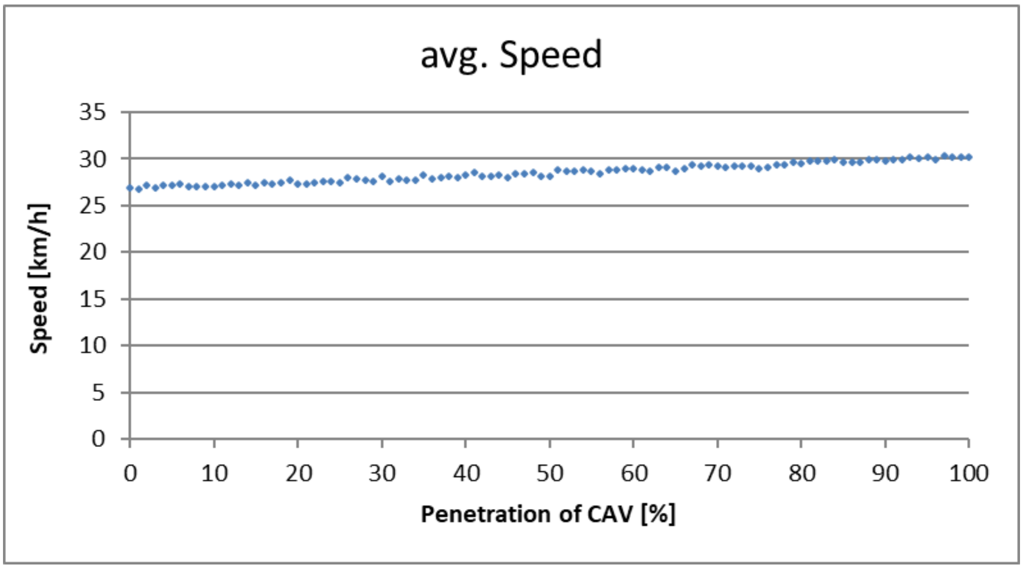

Figure 3 – Average speed of per vehicle in use case CAV

The average travel speed increases with the automation rate. With the automation of all vehicles, an increase of approx. 12 %is measurable. The following effects of automated and connected driving lead to an increase in average speed, which in turn is an indicator of improved traffic flow:

- The vehicles react more quickly after a stop. This contributes directly to higher average speeds.
- The vehicles adjust their speed almost simultaneously (homogeneous acceleration and braking possible due to connection).
- The vehicles always cooperate when a vehicle announces a lane change; less severe braking maneuvers are necessary and thus less severe disruptions occur.

The travel speed is more homogeneous overall, since automated vehicles always try to maintain the speed prescribed by law. As a result, there are fewer overtaking maneuvers and lane changes and this leads to fewer disturbance. The implementation of automated and connected driving is associated with a reduction in traffic-related environmental emissions. However, this could not be confirmed in this study. The change in vehicle type from conventional to automated does not show any significant changes in the environmental parameters studied (Fig. 4 and 5). The slight fluctuations in both figures are stochastic.

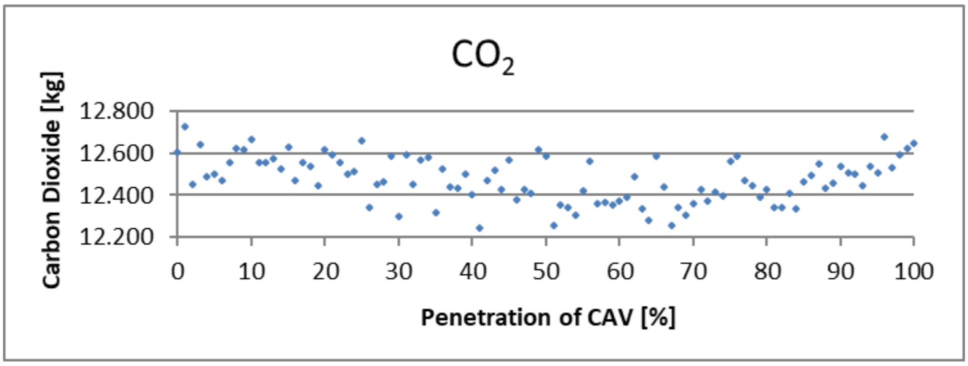

Figure 4 - Carbon Dioxide emissions in use case CAV

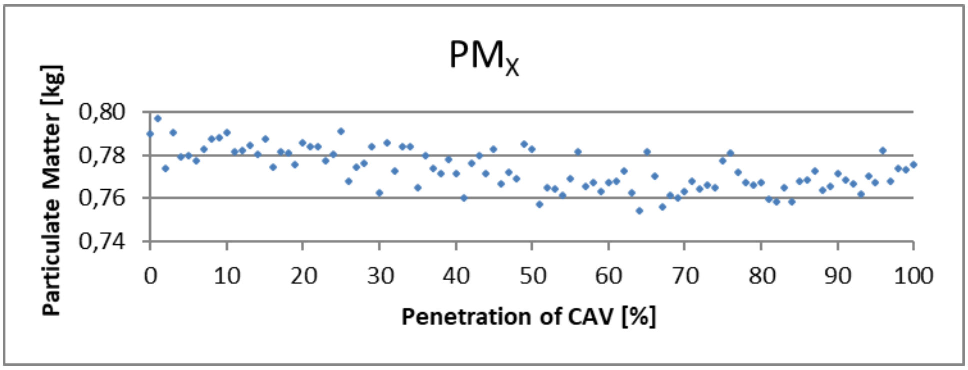

Figure 5 - Particulate matter emissions in use case CAV

This could be due to the fact that the higher average speed leads to higher emissions, which practically cancels out the effect of decreasing emissions due to reduced travel times and travel time losses. The reduced travel times on the network would have to lead to a reduction in fuel demand and thus in carbon dioxide and nitrogen oxide emissions. The increase in average speed, in turn, would have to increase fuel demand. These opposing effects seem to cancel each other out in this case. The emission of particulate matters depends not only on speed (tire abrasion) but also on acceleration and braking maneuvers (tire and brake abrasion). Reducing braking and acceleration maneuvers can lead to a slight decrease in particulate matter emissions. But here, too, higher average speeds increase tire wear.

Effects of GLOSA

The scope of the GLOSA service and thus the evaluation is locally limited to the vicinity of the intersection. Significant effects can be observed with regard to the waiting times of the vehicles at the equipped traffic lights (Fig. 6).

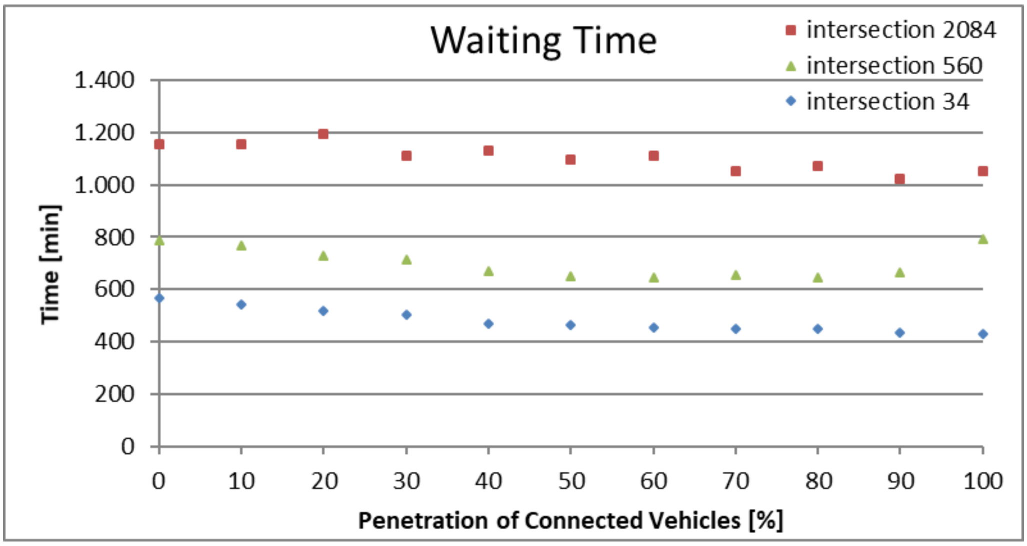

Figure 6 - Total waiting time at the intersections equipped with GLOSA

With increasing penetration of connected vehicles, waiting times decrease by up to 24% at intersection 34 and by up to 9% at intersection 2084. A reduction in waiting time is also observed at intersection 560. This reaches its optimum at a penetration of 60 % with -18 % less waiting time, but increases again significantly from 90 % to 100 % penetration and almost reaches the original level (< 1%). The abrupt increase starting at a rate of 90% connected vehicles seems implausible and requires a specific investigation. It can be concluded that vehicle waiting times can be reduced directly at intersections equipped with GLOSA. Investigating impacts on adjacent intersections is reasonable, but was not conducted in this project. The simulated environmental emissions were less significant (Fig. 7).

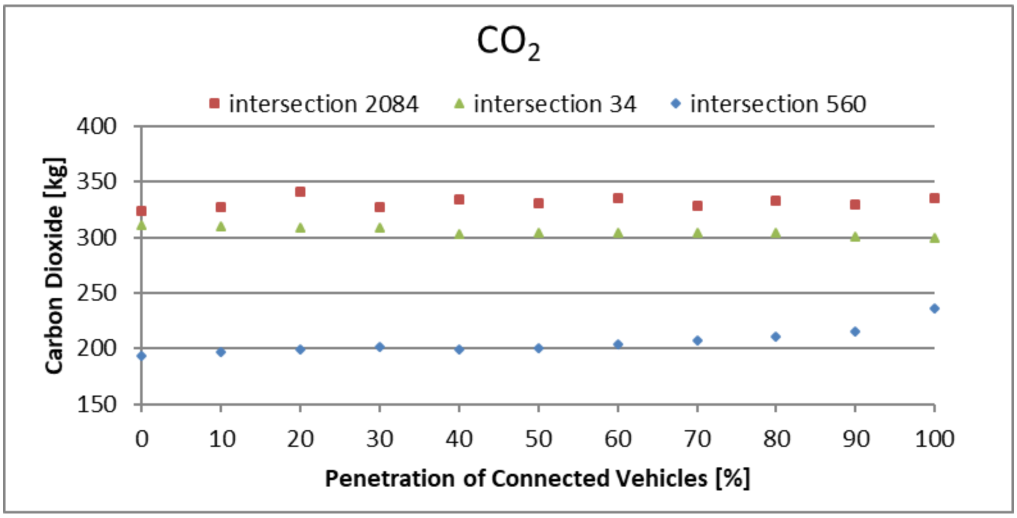

Figure 7 - Carbon dioxide emissions at the intersections equipped with GLOSA

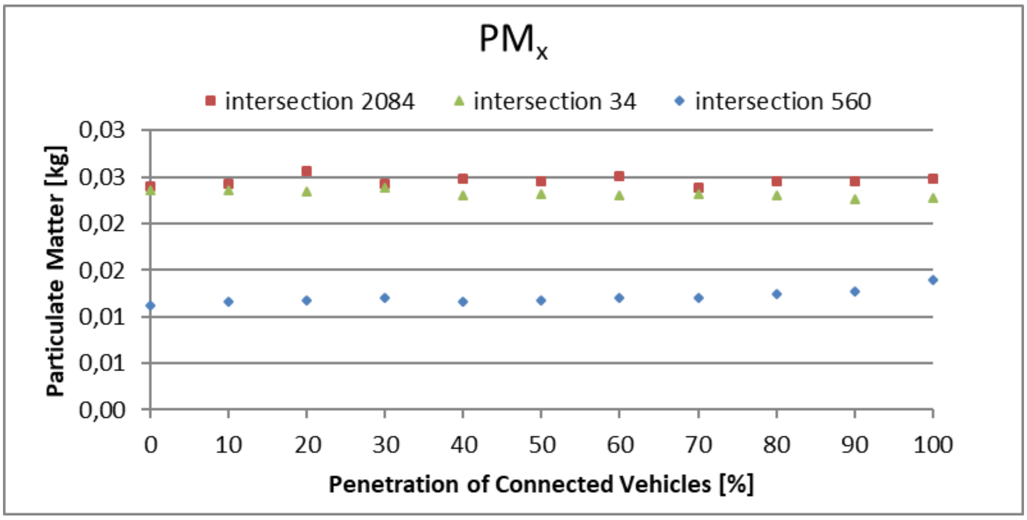

Figure 8 - Particulate matter emissions at junctions with GLOSA

At intersection 34, all types of emission decrease by about 4%. At intersection 2084, CO_2 and PM_x increase by 3%, whereas at intersection 560 they increase by 22% (CO_2) and 25% (PM_x). In order to clarify the increasing emissions at intersection 560 and 2084, further investigations would have to be performed.

Conclusion

This study has shown that the use of automated and connected vehicles as well as a connection of vehicles with traffic lights can have an efficiency-increasing effect on the traffic flow. Due to more reactive driving (low *sigma*), similar acceleration (same *speedfactor*) and full cooperation during overtaking, a more homogeneous traffic flow is achieved with increasing penetration of CAV. It is assumed that the higher average speed and shorter travel times relativize the positive effect on CO_2 and PM_x emissions. Thus, it can be assumed that by reducing the speed (e.g., by reducing the permitted speed), a reduction of emissions can be achieved. The expected initial deterioration of traffic flow at low percentages of CAVs in mixed traffic was not observed in this study. The connection of vehicles with infrastructure using GLOSA can reduce waiting times locally at an equipped traffic light. This effect is strongly dependent on the local conditions of the intersection (e.g., distance to the next intersection) and also only affects the vicinity of the traffic light. The same applies for effects on emissions. Therefore, it is worthwhile to examine in a further study to what extent the effect can be increased by equipping all traffic lights on the test route.

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