DATA ACQUISITION CONCEPT FOR SIMULATIVE ANALYSES OF TRAFFIC FLOW OPTIMIZING ADAS

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ABSTRACT

In recent years initial proposals have been presented for advanced driver assistance systems (ADAS) which are to optimize traffic flow globally by means of the interaction of autonomous vehicles. This kind of ADAS is hereinafter referred to as traffic assistance system (TAS). For the design, optimization and evaluation of these TAS investigative simulations are necessary. These investigations hold their own set of particular requirements, including the simultaneous consideration of microscopic and macroscopic behavior. Therefore, in this paper a two-level approach for calibration and validation of traffic simulations is presented. Previous calibration and validation methods utilized either microscopic or macroscopic measurement data. Therefore, this contribution presents a new measurement concept that is needed to gather the required data for the suggested two-level approach for calibration and validation. This concept advocates simultaneous data acquisition sourced in both a vehicle (microscopic) and an overall traffic (macroscopic) perspective. First microscopic measurement results obtained by an equipped vehicle are presented. Compared to the current state of the art, the application of the two-level approach for calibration and validation with the gathered microscopic and macroscopic measurement data will enhance the possibilities to investigate the efficiency of TAS and yield results which are characterized by a higher degree of confidence.

Keywords: driver behavior, simulation, ADAS, traffic flow, optimization, data acquisition

1 INTRODUCTION

The current procedures for influencing traffic on highways as implemented at traffic control centers only affect limited sections of highways due to deployed infrastructure resulting from sensor and actuator related reasons. Advanced driver assistance systems (ADAS), which themselves use their measurements to continuously influence traffic flow by means of local interactions, could be used to remedy this deficiency. The primary objective for driver assistance systems so far is to increase driving safety or driving comfort. As enhancement, in recent years initial proposals have been presented for ADAS which are to optimize traffic flow globally by means of the interaction of autonomous vehicles, and independent of a traffic center [1, 2]. These systems control the longitudinal vehicle behavior in order to optimize traffic flow and therefore can be considered as traffic assistance systems (TAS). For the design, optimization and evaluation of these systems, simulative investigations have to be carried out.

Models employed for traffic simulations have been examined for more than fifty years. However, the investigations associated with TAS make new requirements essential which have not been considered over the last several decades ever since those simulation investigations were designed with different objectives in mind. Section 2 of this paper will show that for the investigation of these TAS the simulation model has to be valid on both the microscopic and macroscopic level. In order to reach this goal, it is necessary to perform a calibration (adaptation of simulation parameters to increase the simulation's faithfulness to reality) and validation (confirmation of the simulations faithfulness to reality) of the simulation model in use. Section 3 describes two typical simulation investigation cases, and presents a two-level approach for calibration and validation which is based on this knowledge. Section 4 presents a data acquisition concept to obtain the necessary measurement data for fulfilling the determined requirements. First results from a self-equipped vehicle are presented in Section 5. The paper closes with a conclusion and an outlook for further research.

2 REQUIREMENTS FOR INVESTIGATION OF TAS

The use case to dimension and evaluate TAS originates new challenges which require a methodical approach. The following requirements have to be met by the tools as well as the methodical approach in use. With this knowledge in Section 3 the state of the art of simulation investigations is reflected and a new approach is derived.

2.1 Necessity for simulative investigations

It is desirable to investigate the impact TAS-equipped vehicles would have on real-life traffic. Because of the high number of vehicles on highways, for investigation purpose it seems impossible to have enough equipped vehicles to reach an acceptable penetration rate. Therefore, the confirmation of effectiveness of TAS is only possible with simulation investigations. Advantages are time and cost savings as well as the possibility to investigate more variants.

The modeling of traffic reaches back to the middle of the 20th century when mainly physicists began to describe the phenomena of traffic by differential equations. Fundamentally different model structures are existent that may be classified in agreement with e.g. [3-6]. However, not all of them are suitable for the considered application case.

Nanoscopic traffic models contain a detailed model of both the vehicle behavior and the driver behavior. Considering vehicle behavior for example, the details of the engine and the tires are included in the model. The driver model describes the way the control variables of the vehicles are influenced to perform car-following and lane-changing.

Microscopic traffic models simulate the behavior of the vehicle and the driver in a combined driver-vehicle-unit. The models describe the interactions of the driver-vehicle-units by rule-bases that specify acceleration or velocity. Generally the dynamics are based on local variables like distance or relative speed to the front or rear vehicle.

Mesoscopic traffic models combine the properties of microscopic and macroscopic traffic models. Single vehicles are simulated, but instead of considering vehicle-vehicle interactions macroscopic relationships are used to determine vehicle behavior.

Macroscopic traffic models neglect individual vehicles. They are devoted to aggregate state variables such as traffic density and traffic flow for representing the collective behavior of vehicles. The equations are derived from the laws of nature and are often structurally similar to fluid mechanics.

For traffic simulations different traffic tools are available on the market, whose models are based on one or more than one of the above mentioned model structures. The most popular tools are VISSIM, PARAMICS and AIMSUN, which all use microscopic traffic models for simulation. In addition to a traffic model to describe the interaction between the driver-vehicle units these tools also offer an advanced visualization as well as interfaces for data exchange.

2.2 Necessity to consider two systemic levels

For the investigation of TAS it is necessary to model the differences between longitudinal control performed by a human driver compared to that performed by the TAS. In fact, the nanoscopic approach seems attractive for the investigation of TAS due to the possibility to model the differences between a human driver, the TAS and the vehicle in detail. Considering nanoscopic traffic models, this approach is applied rather seldom. One reason may be that the simulation of nanoscopic traffic models requires a great amount of computing power, especially in the case of considering large traffic networks and a lot of vehicles. Since the investigation of TAS makes it necessary to simulate a lot of vehicles, this approach is characterized by a significant demand for computing power. Therefore, in this paper this approach is not considered.

Macroscopic simulation models neglect individual vehicles and are therefore not adequate for reproducing the difference between human and TAS behavior. Although mesoscopic models simulate individual vehicles they are not suitable, because they do not model the interaction between one vehicle and another. Modeling the interaction between the vehicles is absolutely necessary to adequately model TAS behavior and the difference to human behavior. Therefore only the microscopic approach seems reasonable for an investigation of TAS.

The goal of the TAS is the optimization of traffic flow i.e. reducing congestion or shortening overall travel time. Still, the traffic flow behavior depends on the behavior of the individual vehicles as part of the traffic flow. Therefore, the simulation tools using a microscopic traffic model must be able to reproduce a valid behavior on the microscopic and macroscopic levels [7]. Subsection 3.1 presents an evaluation of the suitability of previous use cases of microscopic simulation models.

2.3 Necessity of calibration and validation

The behavior of the driver-vehicle units is generally determined by the models in use, the interactions of the sub-models and especially by the parameters for the models. In order to obtain reliable simulation results, it is necessary to prove the validity of the selected parameters for each individual application [5].

Therefore, it is necessary to perform a *calibration*, i.e. adjusting the model parameters so that the simulation is sufficiently accurate when compared to actual behavior, as well as a *validation*, i.e. proving the parameters with simulation results which are compared to a second measurement data set.

For *calibration* it is necessary that a comparable set of actual measurement data for the selected route or network section is available. The goal is to minimize the deviation between the model result and the recorded, actual measurement data. For this, one needs to select an application adapted measured variable, such as measurement of travel times, velocities, time gaps or waiting periods.

The *validation* of model parameters immediately follows the calibration. For this process, an additional set of data measurements is required. Calibration and validation data sets should also be collected under comparable conditions and "the core problem should be directly or indirectly described" [5]. For validation purposes, the simulation parameters must not be changed beyond this point. The simulation results are to be compared to the second measurement data set. The model gives valid results when the previously determined error measurement bound is not exceeded. Quantitative statements can only be made from a sufficiently validated model. The authors of [5] say that the "Validation […] therefore serves for a determination of the reliability of attainable statements in the particular application case" and "The calibration and validation step is of crucial importance for the reliability of reachable statements in every application case."

However, “in practical experiences calibration and validation are often neglected” [5]. One of the reasons is that recent simulation tools offer an advanced visualization of moving vehicles, pedestrians and the environment which seem to have a realistic behavior even without calibration and validation.

3 PROCESS MODEL FOR CALIBRATION AND VALIDATION OF TRAFFIC MODELS

This section presents the state of the art of calibration and validation of microscopic traffic simulation models. Based on this knowledge the new two-level approach is presented, which is suitable for the investigation of TAS.

3.1 State of the art of calibration and validation

The previous section classified microscopic models as suitable models for the investigation of TAS. Therefore in this subsection only these kinds of models are considered. For the calibration and validation of microscopic simulation models, microscopic or macroscopic empirical data can be used. Therefore two different approaches can be identified:

- The first possibility is the calibration and validation of a *microscopic simulation model* with *empirical microscopic data* [8]. In this approach only isolated driver-vehicle units are considered. Therefore, the validation applies only to the microscopic level of the simulation. This approach does not explain the impact of the individual driver-vehicle unit behavior on the macroscopic variables (traffic flow, traffic density). That is the reason why this approach does not fulfill the requirements for the investigation of TAS.
- The second possibility is the calibration and validation of a *microscopic simulation model* with *empirical macroscopic data* [9]. Performing the validation only on the macroscopic level does not automatically result in a validation of the microscopic sub models. It may be possible that different combinations of microscopic behavior lead to the same macroscopic behavior. This approach does not guarantee the validity of the difference between human and TAS behavior. Therefore, this approach is not appropriate for the investigation of TAS.

3.2 Two-level approach for calibration and validation

A view on the current state of research shows that the microscopic and macroscopic levels of simulation currently co-exist and are not interwoven. Current research does not take into account that for the optimization of TAS the interrelations of both levels of simulation need to be reflected. For this reason a two-level approach for calibration and validation is stipulated in this paper. It is to calibrate and validate a traffic simulation on both the microscopic and macroscopic level. The microscopic simulation model simulates every vehicle individually. Each vehicle behavior in the simulation has to be valid with special focus on the crucial input factors for the TAS. Improving the macroscopic traffic flow with the TAS, the simulation has to be validated on the macroscopic level, too.

The new proposed two-level approach is shown in Figure 1. *Calibration* can be seen as a closed loop which involves the iterative execution of the following steps: At first a microscopic simulation run is performed. In the second step the microscopic data - empirically observed in the field - are compared against a first set of data resulting from the simulation. The deviation is compared against a predefined threshold. In cases when the deviation between empirical results and simulation results is above the threshold, a thorough analysis of the underlying causes in a third step is needed. This is the crucial step in the calibration process. In order to properly identify the reasons of the deviation, a deep knowledge of the qualitative correlations of the model parameters is required. Especially for the causal analysis, a good understanding of the traffic simulation model is necessary. The fourth step is that of model adjustment. As soon as the cause has been identified the simulation can be adjusted. This can either be an adjustment of the parameters (parameter variation), or a change in the underlying mathematical functions relating the parameters to each other (structural variation). After having adjusted the model we have to start with step one again and perform a new simulation run.

In case the deviation during calibration is below the threshold, the *validation* of microscopic model parameters immediately follows the calibration. Calibration and validation are closely related to each other. The calibrated model is transferred into a new, but comparable situation. For this situation an additional set of measured (microscopic) data is required. For this new situation a simulation run is performed. The microscopic simulation results are to be compared to the second set of measurement data. The simulation run should deliver sufficiently accurate results for the new situation as well. In case the previously defined threshold is exceeded, a re-calibration is necessary, thus the causal analysis is the subsequent step. The model gives valid results on the considered microscopic level when the previously determined error measurement bound is not exceeded.

Once microscopic parameters have been successfully validated a validation of macroscopic variables (e.g. traffic flow, traffic density, mean speed) is possible. Again, this can be done by running through the following steps. First a microscopic simulation run is performed. This time the behavior of the sum of all individual driver-vehicle units in the simulation is measured. This simulation run yields the macroscopic variables previously identified. In a second step the simulation results are compared against empirical data observed in the field. In case the results stay within the permissible range, the calibration and validation on the microscopic and macroscopic levels have been successful. Otherwise a re-calibration on microscopic level becomes necessary.

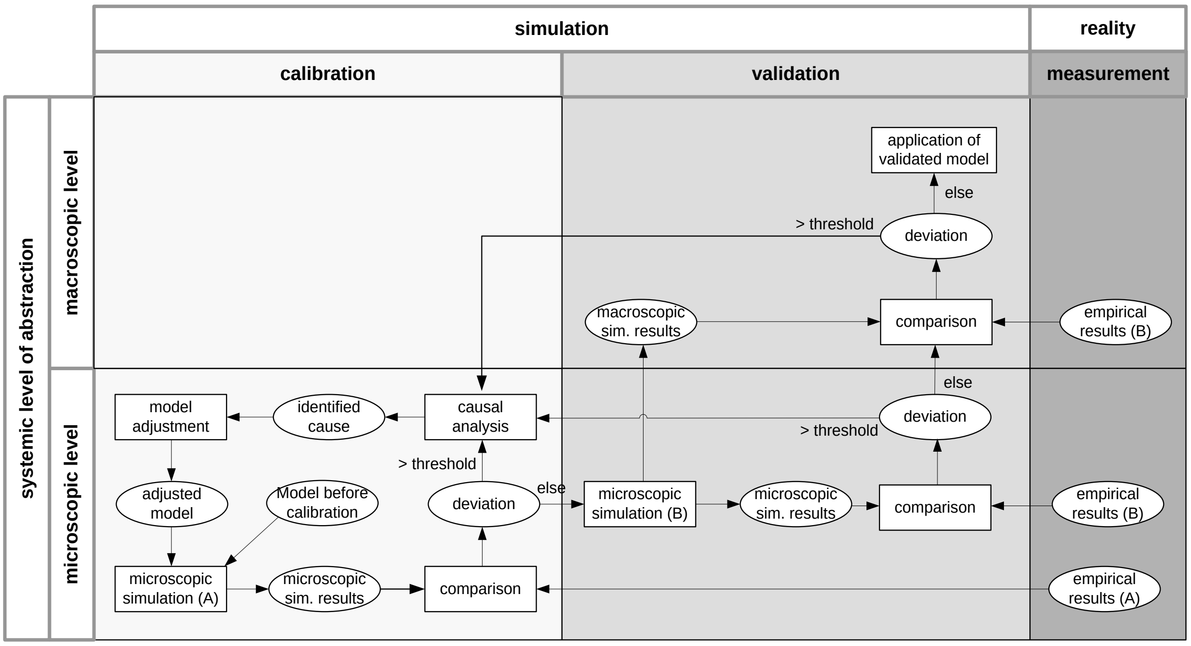

Figure 1: Calibration and validation of a microscopic simulation model on microscopic and macroscopic levels

4 DATA ACQUISITION CONCEPT

The approach shown in the previous section requires both the macroscopic and microscopic empirical measurement data in such a manner that they share the same time and geographical reference. Additionally the equivalent microscopic and macroscopic simulation results are required. A plausible data acquisition concept is proposed in this section. This data allows for a calibration and validation of traffic simulation models on microscopic and macroscopic levels.

4.1 Empirical data acquisition on macroscopic level

The knowledge about the traffic flow within the considered section of the highway is necessary in order to run the simulation. Measurement data for the inflow at the beginning of the section, the inflow for all on-ramps and outflow for all off-ramps should be available. In cases where the measurement data has to be fed into the simulation manually, an aggregation of several minutes seems sensible. The simulation tools allow for a choice between different arrival distributions in order to generate the vehicle arrival based on these aggregated measurements. But under ideal conditions this measurement data is not aggregated and includes each single vehicle. E.g. the application interface of the simulation tool AIMSUN allows for importing this measurement data set and realizing vehicle arrival based on this data.

Recent sensor systems are able to classify between two and eight different vehicle classes. The sensor systems installed at the German highway A2 store data measurement of two vehicle classes, namely “passenger cars” and “trucks”. The data is stored in 1-minute intervals. In order to use this sensor system in a first approach, only these two vehicle classes are distinguished. The behavior of these two vehicle classes can be modeled in a different way.

Most of the on- and off-ramps are not equipped with any sensor system. To acquire the required measurement data, these ramps have to be equipped with a temporally sensor system. For measuring traffic variables, different systems can be applied, such as inductive loop sensors, radar sensors, video or floating car data.

Suitable sensor systems should be equipped with a stand-alone power supply and a data storage unit which are able to work 24 hours a day for at least one week. The most important measurement variable is the traffic flow categorized in the vehicle classes mentioned before. A comparison of different sensor systems [10] showed that for installation nearby the track the radar sensor as well as the passive infrared sensor are suitable. For installation on the track the magnetic field sensor, pneumatic sensor or piezo sensor are appropriate. Although the last sensor systems are less expensive (partially less than 1000 Euro) in comparison to the sensors for installation nearby the track (about 3000 Euro), taking into account the aspect of traffic safety the last sensor systems have to be refused. Considering the layout of the on-ramp (curved ascending or descending slope) the installation on the track can be dangerous especially for motorcyclists. For the installation nearby the track it is useful to place the sensor system away from the main section to ensure that only vehicles on the ramps are considered. Therefore, the vehicle speed on the ramps, which depends strongly on local conditions (e.g. curve radii), will not be considered during calibration.

All the above mentioned data is necessary as basic input data to perform the simulation. This data describes the traffic volume, the turning percentages at off-ramps as well as the percentages of passenger cars and trucks. This data does not describe the individual microscopic behavior. An exception is constituted by the free flow speed, which can be estimated in the case of low traffic flow by the sensor systems used at the German highway A2. However, for a more detailed description of the microscopic behavior, empirical data on the microscopic level is necessary (see section 4.2).

To reach the aim of properly evaluating TAS, suitable measurement variables have to be selected. Considering observations on a larger scale, that is sampling data on longer segments and for longer time intervals, the traffic flow seems to be a suitable variable. Also the mean speed per lane can be used for evaluation. Especially in the case of congestion in the section these two variables seem to be suitable to evaluate the benefit of the TAS. Both variables are already available by the sensor systems used at the German highway A2.

For the individual driver the reduction of travel times is one important evaluation aspect. Recent sensor systems are not able to recognize vehicles on the track reliably when determining travel time. Therefore, this aspect can only be measured by individual vehicles (see Section 4.2).

4.2 Empirical data acquisition on microscopic level

To describe the individual driver behavior, empirical data acquisition on microscopic level is necessary. The interaction between the individual vehicles results in the macroscopic behavior. Car-following behavior and lane-changing behavior describe this interaction.

To determine this behavior a Volkswagen Passat was equipped with a suitable sensor system. For an investigation of the car-following behavior the radar sensor of the vehicle's existing ACC system is used. This sensor provides the distance and relative speed to the preceding vehicle. This measurement data describes the car-following behavior of the test driver steering the equipped vehicle. Because the driver knows that he takes part in an investigation, this data may be affected by this knowledge. This reactivity is also known as the so called "Hawthorne effect". Therefore, the distance and relative speed to the following vehicle is also measured by a lidar sensor at the rear end of the equipped vehicle. The advantage of this approach is that the drivers of the following vehicles cannot influence the measured distance as they do not know that they are observed. There may still be a remaining effect of the test driver's driving behavior on that of the following vehicle's driver. Therefore, considering calibration and validation the measurement data observing the following vehicle has to be preferred. A MicroAutobox from dSpace stores additional information about the equipped vehicle. These measurement variables are for example vehicle speed and the steering angle. At the moment the Institute of Traffic Safety and Automation Engineering investigates the possibility of using the same measurement data for the investigation of lane-changing behavior. Since the sensor systems do not only measure the preceding and following vehicle, but also the vehicles in the neighboring lanes, it seems possible to determine the gaps used for lane changing. Considering the progress in time, the benefit for the driver (speed difference) on the new lane also seems to be measurable. A Global Positioning System (GPS) device delivers the vehicle position and GPS time information. In this first stage only one vehicle was equipped. This vehicle can be used to show that it is possible to measure the necessary required variables. The goal is to equip several vehicles with this sensor system in order to perform measurements with these vehicles on a predetermined section at the same time. For all equipped vehicles the GPS time stamp will be used as coherent reference time. The macroscopic information has to be gathered at the same time and for the same section. The GPS position information allows for an assignment of microscopic data to macroscopic data. One another advantages results from the use of several equipped vehicles: the effect of the test driver's driving behavior on that of the following vehicle's driver mentioned before can be determined and taken into account for calibration and validation.

For validation purposes, the travel times of the several equipped vehicles can be compared with the travel times of the vehicles in the simulation.

4.3 Simulation data acquisition on microscopic and macroscopic levels

In general, simulation can be performed by different simulation tools. At the moment the comparison is implemented for the simulation tool AIMSUN. This simulation offers an established microscopic car-following and lane-changing model as well as a detailed description of these models. In addition, this tool offers an application interface to realize user specialized functions.

In a first step the preparation of network layout as a prerequisite for all simulations has to be realized. Therefore a detailed knowledge about the considered section of the German highway A2 is necessary. It is essential to ensure the consistency between the simulated track and the track in reality. A lot of stationary properties have to be edited in the network editor: the detailed layout of the traffic routing, the number of lanes, road markings, existing mandatory signs (e.g. speed limits) and prohibition signs (e.g. no passing for trucks) as well as the locations of on- and off-ramps including those to and from rest stops. The traffic routing is available on maps from the internet for free or against payment. An alternative is the electronic map from the government agency in Lower Saxony for ground measuring (LGN). AIMSUN allows for an import of the map in Drawing Interchange Format (DXF) available from LGN. Missing information (number of lanes, road marking, speed limits) can be extracted from video recordings and GPS position information from a test drive on the route. Some of this information can also be extracted from Open Street Map, a project that provides free geographic data.

After finishing the network layout, in a second step the traffic flow at the beginning of the section, the inflow for all on-ramps and outflow for all off-ramps, measured by the sensor systems introduced in Section 4.1, can be assigned to the network.

After finishing the second step it is possible to run a simulation. But for calibration and validation of the simulation model it is necessary to measure microscopic and macroscopic values during the simulation run. The measurement of macroscopic data (e.g. traffic flow and mean speed per lane) is by default possible with the simulation tool. The user can place virtual detector systems anywhere in the network. The measurement data can be visualized or extracted in a file for each simulation run. This data can be compared to the macroscopic empirical data sets (see Section 4.1).

The measurement of microscopic data is not possible with the standard simulation tool. Hence, the application interface of AIMSUN is used to extend the functionality and to obtain microscopic measurement data from individual vehicles wich can be compared to the empirically observed behavior (see Section 4.2). Single simulated vehicles are "equipped" with virtual sensor systems to measure distance and relative speed to the preceding as well as the following vehicle. Hereby it is possible to compare the empirical data sets with the simulation data sets. The next step is to extend the functionality by observing lane-changing behavior in the simulation. This corresponds to extend the investigation of the microscopic measurement concept to lane changing behavior (see Section 4.2).

5 RESULTS

The implementation of the entire measurement concept is currently under construction. In a first step, the captured data of the first test vehicle for the German highway A2 between

Hanover and Braunschweig was compared with simulation results of the simulation tool AIMSUN when using the default parameters for car-following and lane-changing behavior. The evaluation is currently limited to human car-following behavior at constant distance as one of several factors to ensure the valid reproduction of human behavior.

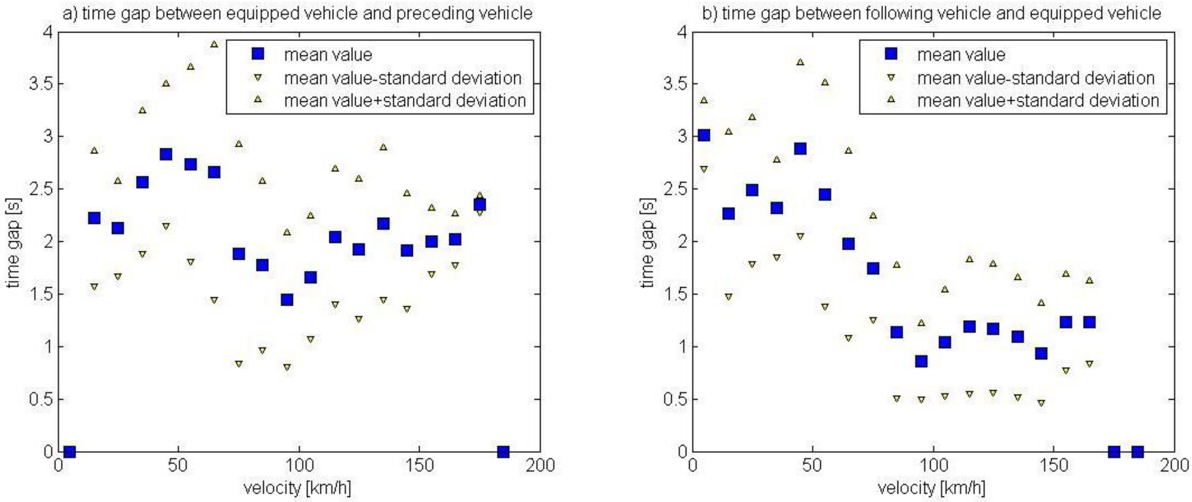

Figure 2: Time gaps from empirical data sets (at mean value=0 no data for this speed range was available)

Figure 2a shows an aggregated representation of the distance behavior of the driver steering the test vehicle for the route Braunschweig-Hanover. The data was gathered during trips on different days and describes trailing vehicles only, excluding the acceleration phases or stages of the approach to overtake. In comparison, Figure 2b shows an aggregated representation of the distance behavior of the vehicles following the experimental vehicle. Most journeys took place at speeds between 90 km/h and 140 km/h, so that the readings for the other speed ranges are partly based on a few records only. Comparing the two images it can clearly be seen that the test driver kept much larger distances compared to the following vehicles. This is possibly due to the aforementioned Hawthorne effect implying that the test driver of our equipped vehicle was extra careful on the road.

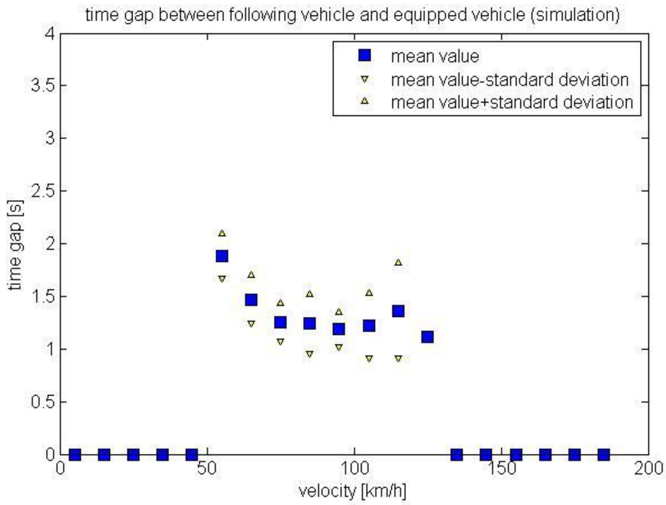

Figure 3: Time gaps from simulation (at mean value=0 no data for this speed range was available)

Figure 3 shows the distance values of the following vehicles for simulated equipped vehicles. Since no traffic congestions were generated in the simulation no measurements of the speed range of 0-50 km/h are available. What is more, vehicles driving faster than 130 km/h do not occur in the simulation. The time gaps shown in the figure for the speed range from 50 to 130 km/h differ for both, the mean value as well as for the standard deviation from the empirical data. The simulation was carried out with varying traffic volumes. The distance behavior of the vehicles in the used model at a certain speed is independent of the traffic volume, only the driven speeds were lower with increasing traffic volume. These first results already demonstrate the need to calibrate and validate the simulation model. The evaluated data states the suitability of the test vehicle for determining the distance and relative speed of the preceding and following vehicles.

6 CONCLUSION

This paper presented a data acquisition method which is necessary for calibration and validation of microscopic simulation models in order to investigate TAS. The method is based upon the two-level approach for calibration and validation. This approach requires empirical data sets from microscopic and macroscopic levels, which originate from the same time span und same road network. For an applicable comparison of empirical data with simulation results, the same road network has to be used by the simulation tool. The paper presented the possibilities to obtain the required input data. To obtain the empirical microscopic data a vehicle was equipped with the necessary measurement instruments. Using the application interface of the simulation tool the necessary simulation results on microscopic and macroscopic levels can be obtained. With the two-level approach it will be possible to investigate the efficiency of these TAS with a higher degree of confidence. The next steps are the refinement of the two-level approach and the verification that the measurement concept using several individual vehicles is a suitable solution for obtaining the measurement data.

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