Two-Level Validation and Data Acquisition for Microscopic Traffic Simulation Models

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***Abstract*—Advanced driver assistance systems can have consequential effects on traffic flow. For the design, optimization and evaluation of these systems investigative simulations are necessary. Previous calibration and validation methods for these simulations utilized either microscopic or macroscopic measurement data. This paper's purpose is to argue that the formerly held calibration and validation perspectives with regard to traffic simulations are incomplete. Moreover, these assistance systems have their own set of particular requirements, and require the simultaneous consideration of microscopic and macroscopic system behavior. Therefore, this paper presents a new measurement concept that is needed to gain the required data necessary for proper calibration and validation. This concept advocates simultaneous measurements sourced in both a vehicle (microscopic) and overall traffic (macroscopic) perspective. Microscopic measurement results obtained by an equipped vehicle are presented.**

***Index Terms*—Traffic simulation; validation; calibration; microscopic and macroscopic perception, equipped vehicle**

I. Introduction

In this paper we extend our previous work [1][2]. The extensions and new contributions are as follows: the simulation requirements for investigation of recent developed advanced driver assistance systems (ADAS) are presented in a more structural method, therefore the difference between the previous and the new calibration and validation method becomes more clear. The measurement concept is presented in more detail and first empirical results from own test drives with an equipped vehicle are presented.

To date, exclusively the driver and the physical behavior of the vehicle have determined the overall driving behavior. More and more, it is becoming the trend to have assistance systems take over functions in areas of longitudinal and lateral dynamics of the vehicle. An already established system in the field of longitudinal guidance is the Adaptive Cruise Control (ACC) system. Using ACC, the driver chooses a target speed, and depending upon traffic conditions, the system automatically accelerates the vehicle to this target speed. If there is a preceding vehicle the vehicle decelerates and follows the preceding vehicle at a safe distance. Radar or laser sensor systems are used for distance and speed measurement. The driver assistance system uses distance or relative speed to the preceding vehicle as input variable. The combined vehicles' behavior as a system determines the macroscopic traffic characteristic, e.g. traffic flow or mean-speed. Therefore, the driver

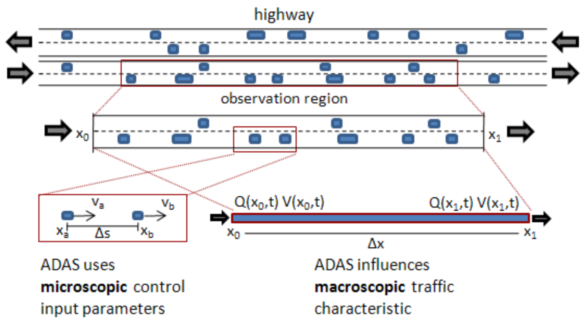

Fig. 1. Driver assistance system perception at the microscopic and macroscopic levels

assistance system also influences these characteristics (see Fig. 1). Since the introduction of these systems to the market, there have been many simulation investigations concerning the influences of ACC on traffic flow. For an overview of the past work considering the effect of conventional ACC systems on traffic flow see [3][4].

In recent years, initial proposals have been presented for advanced ACC systems which recognize the current traffic state and adapt system parameters to optimize traffic flow [5]. Simulation investigations are carried out for design, optimization and evaluation, and are essential for the improvement of the system. Models employed for traffic simulations have been examined for over fifty years. However, the investigations associated with the advanced driver assistance systems, make new requirements essential which have not been considered over the last several decades since those simulation investigations were designed with different objectives in mind. This paper investigates these new requirements and proposes a measurement concept to fulfill these requirements.

This paper is structured as follows. In Section 2 an overview of current simulation models and tools is presented, which are most popular for examination of recently developed ADAS. In order to obtain quantitative results, a calibration and validation of the simulation model is mandatory, and this significance is presented in Section 3. Subsequently, Section 4 describes three typical simulation investigation cases, and based on this knowledge identifies the new requirements for simulation investigations for this kind of assistance system which have not yet been considered. Section 5 presents a new measurement concept to fulfill the determined requirements. First results from an own equipped vehicle are presented.

II. Traffic Flow Modeling

In this section the most common traffic stream features are explained and different model structures are classified. Concluding the most widely-used simulation tools are presented.

A. Measures for Traffic Stream Features

One makes a distinction in general between microscopic and macroscopic measured variables. When considering the microscopic driving condition it is necessary to have: the position on the street s, the speed v as well as the acceleration (positive values) or deceleration (negative values) a of the vehicle as a function of time. In the case of the consideration of two successive vehicles, the distance Δs as well the relative speed Δv are also considered.

When considering the macroscopic traffic state, the traffic flow, sometimes also referred to as ”traffic volume”, density, as well as space-mean speed are essential. The dimensions are defined in detail as follows:

The number of vehicles N_q observed at a fixed location during a time interval Δt is the traffic flow Q (veh/h) for this interval:

$$Q = \frac{N_q}{\Delta t} \tag{1}$$

The traffic density k (veh/km) is the instantaneous number of vehicles N_k for a given road segment with the length Δx :

$$k = \frac{N_k}{\Delta x} \tag{2}$$

k and Q yield the space-mean speed v (km/h):

$$v = \frac{Q}{k} \tag{3}$$

For a detailed discussion about traffic variables see e.g. [6][7][8].

B. Traffic Simulation Models and Tools

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. There exist fundamentally different model structures that may be classified in agreement with e.g. [6][8][9]:

1) Microscopic traffic models
2) Macroscopic traffic models
3) Hybrid traffic models
4) Mesoscopic traffic models

Microscopic traffic models simulate the behavior of single vehicle-driver-units and describe their interactions 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.

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

Hybrid traffic models are a combination of macroscopic and microscopic approaches. Regions of the traffic network are modeled either in a macroscopic or microscopic manner, depending on which manner is more reasonable. For example at on and off ramps it may be interesting to regard the microscopic interactions of cars entering or leaving the highway, whereas traffic dynamics on the highway between ramps is sufficiently modeled by a macroscopic approach.

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.

Traffic simulation tools offer a network model for storing the data for the relevant traffic route properties as well as a traffic demand model for determining the amount of vehicles depending on time and day. The movement of the vehicles is determined by the behavior model. The behavior model itself consists of sub-models. In microscopic traffic models these are models for car-following, lane changing and route choice behavior.

The most well-known car-following models include Gazis Herman, Gipps, Wiedemann, IDM as well as the Cellular Automata ([10][11][12][13][14]). Popular lane changing algorithms have been presented by Sparmann, Gipps and for Cellular Automata ([15][16][17]). An integrated approach including car-following and lane changing behavior is investigated by [18].

At this time, the commercially most successful traffic simulation tools like VISSIM, PARAMICS and AIMSUN use the microscopic approach for the behavior model. Some of them also offer a macroscopic approach. Additionally, there are simulation tools, such as PELOPS, which have not been widely marketed, which use a more detailed description of human and vehicle behavior than in other microscopic models, therefore this type is called nanoscopic model.

III. Calibration and Validation of Traffic Models

The behavior of the driver-vehicle units is determined generally by the model behavior and especially by the parameters for the individual models. In order to obtain reliable simulation results, it is necessary to prove the validity of the selected parameters for each individual application [19].

Calibration involves adjusting the model parameters so that the simulation is sufficiently accurate when compared to actual behavior. It is necessary that a comparable set of actual measurement data for the selected route or network section is available for calibration. The goal is that the deviation is minimized between the model result and the recorded, actual measurement data. For this, an application adapted measured variable needs to be selected, such as measurement of travel times, velocities, time gaps or waiting periods. In general the measurement data, which originates from the varying behavior of the individual vehicles, illustrate the traffic behavior in an aggregated form. A calibration according to non-aggregated, real comparative data (such as car-following or lane change behavior) seldom takes place, if at all, since this data often is not available. As shown below, a representation of the actual behavior on both microscopic and macroscopic levels is difficult to achieve.

The validation of model parameters immediately follows the calibration. Therefore, an additional set of data measurements is necessary. Calibration and validation data sets should also be collected under comparable conditions and "the core problem should be directly or indirectly described" [9]. 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 account described above is based on information from [9]. The American equivalent is [20]. The makeup of both documents is very similar. A large difference originates from the validation evaluation of the traffic model. While [20] "presumes that the software developer has already completed this validation of the software and its underlying algorithms in a number of research and practical applications", [9] says that the "Validation [. . .] therefore serves for 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."

IV. Simulation Requirements for Investigation of Recent Developed ADAS

Although the models employed for traffic simulations have been examined for over fifty years, previous research completed on simulation models consider either the microscopic or the macroscopic level during calibration and validation. In general four different approaches can be identified:

- The approach of calibrating a *macroscopic simulation* with empirical *microscopic data* is not possible as macroscopic simulations do not model the details of the microscopic level. Therefore this approach will not be discussed in the following.
- Approach I deals with the calibration and validation of a *microscopic simulation* with empirical *microscopical data* (c.f. Subsection IV-A)
- Approach II deals with the calibration and validation of a *macroscopic simulation* with empirical *macroscopic data* (c.f. Subsection IV-B)
- Approach III deals with the calibration and validation of a *microscopic simulation* with empirical *macroscopic data* (c.f. Subsection IV-C)

The existing approaches are discussed in the following section along with their specific pros and cons. With this knowledge the new two-level approach is explained in Subsection IV-D.

A. Calibration and validation following approach I

There are a lot of investigations considering car-following behavior. Calibration and validation is performed for one or several car-following models and the differences between measuring data and simulation results are evaluated. The investigation of lane changing behavior seldom takes place.

Figure 2 shows the approach for calibration and validation on microscopic level. This investigation is only possible with microscopic simulation models, since macroscopic models neglect the details of the microscopic level. Calibration can be seen as a closed loop which involves the iterative execution of the following steps: First a microscopic simulation run is performed. In the second step the microscopic parameters empirically observed in the field are compared against the set of data resulting from the simulation. As stated before the investigation on the microscopic level is often restricted to the investigation of car-following behavior. Depending on the use case it may also be necessary to consider lane changing behavior. The deviation is compared against a predefined threshold.

In case the deviation between empirical results and simulation results is above the threshold in a third step, a thorough analysis of the underlying causes 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 the 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 the 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 necessary. For this new situation a simulation run is performed. The microscopic simulation results are to be compared to the second measurement data set. 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 needed, 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.

Macroscopic measurement data is not considered in this approach. Therefore a validation on macroscopic level is lacking. The validation is achieved only for one single driver-vehicle unit. In the case of considering only car-following behavior the validation is only achieved for one single function

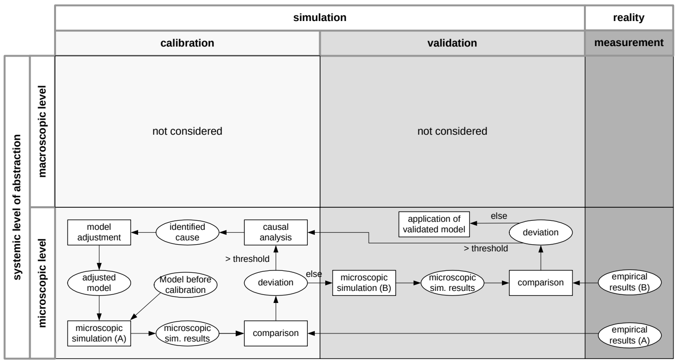

Fig. 2. Calibration and validation of a microscopic simulation model on microscopic level

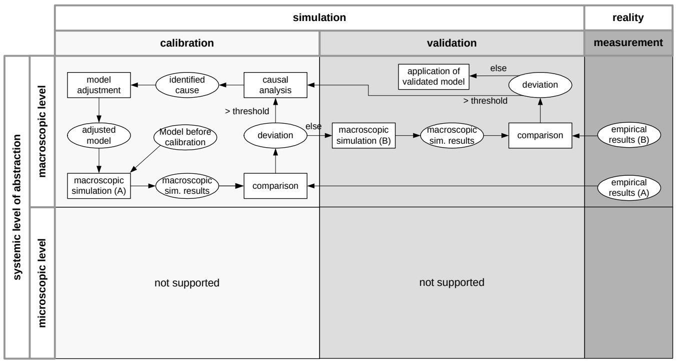

Fig. 3. Calibration and validation of a macroscopic simulation model on macroscopic level

of the driver-vehicle unit. The validation of one function as a subsystem of the complex simulation model does not result in a validation of a higher level of the model.

This conclusion is confirmed by the work of [21]. The authors of [21] present a multi-stage calibration and validation procedure. The microscopic calibration of headway behavior is one of the first steps. After completing the parameter fine-tuning to reconstruct traffic variations, the parameter values for the Mean Target Headway are raised by almost 25%, in comparison to values after headway behavior calibration. The reaction time is even raised by 59% in comparison to the previously determined value. With [21] it was therefore necessary to make an adjustment of the microscopic headway behavior in order to model the measured values from the macroscopic behavior. The question naturally arises whether or not it is advantageous to conduct a microscopic calibration and validation, and afterwards evaluate the macroscopic simulation results. As a restriction, it must be pointed out that in the investigation mentioned above the authors used measurement data from different traffic sites and different days.

In conclusion it can be stated that the validation of the simulation model does not walk hand in hand with the validation of separate sub-models.

Another crucial point is, that for the acquisition of the measurement data used for calibration and validation of car-following behavior many simplifications are used: the tracks in use are often single lane roads, sometimes the data is obtained on special test tracks or only consider inner city driving. Nevertheless these measurement data or the parameters determined by these measurement data is used for investigating traffic behavior on motorways. For example [22] found as a result of their car-following investigations that calibration with measurement data from urban rides cause strong deviations between the calculated parameters in comparision to suburban rides.

Many investigations also consider only a very small amount of car-following rides. For example [5] uses only three following-rides to determine the parameters of the model in use. When attempting to use only a very small amount of car-following rides, it does not seem possible to distinguish the behavior of different drivers (inter-driver variability) and the variation of the behavior of a single driver in the course of time (intra-driver variability).

B. Calibration and validation following approach II

Often the primary focus is not on the detailed analysis of the behavior of individual vehicles. Instead the major interest lays on the aggregated macroscopic traffic behavior. Examples for this can be found in traffic planing where the effects changes in the control of traffic light signals or modified traffic routings can be evaluated. For those analyses both microscopic and macroscopic traffic simulation models are applied. In the following Section we elaborate on how the calibration and validation of a macroscopic traffic simulation model based on macroscopic data can be performed. In the next Section we describe how a microscopic traffic simulation can be calibrated and validated taking into consideration macroscopic simulation results.

Figure 3 shows the procedure of calibrating and validating a macroscopic traffic simulation on the macroscopic level. This procedure is comparable to the the procedure of calibration and validation on microscopic level. In contrast to this only the macroscopic level is considered in this case. As the first step a macroscopic simulation is performed with standard parameters and during calibration and validation the results of the macroscopic simulation are compared to the macroscopic empirical data. Again the adjustment of the parameters of the macroscopic simulation requires a thorough and deep understanding of the model as the model's parameters often do not have an explicit relation to empirically observable parameters. Validation follows the succesful calibration. In the validation phase macroscopic simulation results are compared with a second data set of macroscopic empirical data. It should be stressed, that the macroscopic simulation does not simulate individual driver-vehicle-units and thus does not allow an analysis on the microscopic level.

However, for design and evaluation of advanced driver assistance systems optimizing traffic flow it is required that the model is valid and explains the differences of the microscopic behavior of the driver and the macroscopic behavior at the system level. This will become obvious in different driving

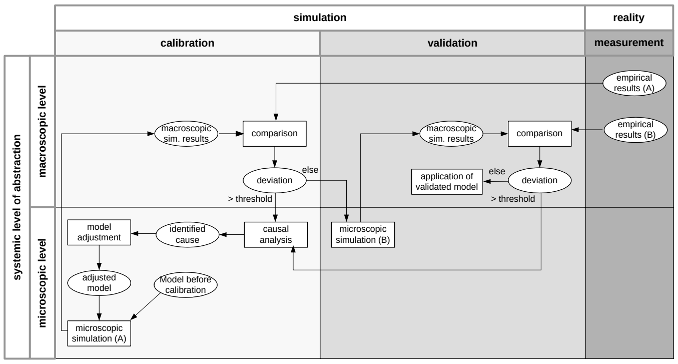

Fig. 4. Calibration and validation of a microscopic simulation model on macroscopic level

situations, where for example a following vehicle approaches the preceding vehicle, follows a preceding vehicle, brakes due to the decelaration of the preceding vehicle or accelerates to the level of the previously entered desired value as soon as no other vehicle is in front of the own vehicle. In order to show the differences of the vehicles' longitudinal dynamics performed by a human driver compared to an assistance system it is necessary to simulate the behavior of indvidual vehicles. The design of advanced driver assistance systems brings about requirements macroscopic simulations can never meet due to these principal considerations.

C. Calibration and validation following approach III

For the same investigations as mentioned in IV-B also microscopic simulation models are used. But in these cases the detailed microscopic behavior is not considered. Instead, the microscopic simulation is used only with regards to macroscopic results.

Figure 4 shows the approach for calibration and validation on macroscopic level. The calibration is comparable to the calibration process in subsection IV-A. During calibration almost the same steps have to be performed. Only the second step differs. As unlike before not the microscopic empirical results and microscopic simulation results are considered, but the macrosopic empirical results are compared to the macroscopic simulation results. For validation also a second macroscopic measurement data set is necessary. Finally in this case the model offers valid results on the considered macroscopic level when the previously determined error measurement bound is not exceeded.

Microscopic measurement data is not considered in this approach and therefore a validation on microscopic level is lacking. The validation on the macroscopic level of the simulation model does not result in a validation of the sub-models. It is possible that different combinations of the microscopic sub-models result in the same macroscopic behavior.

D. Two-level approach for calibration and validation

The review of currently available research shows that the microscopic and macroscopic levels of simulation currently co-exist and are not interwoven. Current research did not reflect that for the optimization of advanced driver assistance systems 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 both on microscopic and macroscopic level. The microscopic simulation model simulates each vehicle individually. Each vehicle behavior in the simulation has to be valid especially concerning the crucial input factors for the advanced driver assistance system. Improving the macroscopic traffic flow with the advanced driver assistance system, the simulation has to be validated on a macroscopic level too.

Taking the ACC system as an example, the system changes the following behavior of the vehicle to its preceding vehicle. Therefore it is absolutely necessary to use a microscopic traffic model for testing such a system which includes the headway behavior of the human driver as well as the ACC system. The ACC equipped vehicles exhibit different vehicle headway behavior than those vehicles driven by humans. It must be particularly assured that human following behavior is modeled precisely as long as no 100% system equipment is considered, since the interaction between system headway behavior and human headway behavior can be of particular importance.

It seems reasonable to conduct both a microscopic calibration and validation of the vehicle headway behavior for human and ACC system behavior in the first step. This step is the same as described in subsection IV-A. Subsequently, it is possible to estimate the accuracy and reliability of the simulated vehicle headway behavior of humans and the system.

As stated in Section I the previously mentioned ACC system will influence traffic flow behavior. In recently developed ADASs the individual vehicle will even optimize traffic flow [5]. The microscopic behavior is thus changed in order to optimize the macroscopic behavior. Subsection IV-A stated that a valid model on microsopic level does not have to be valid on macroscopic level. However, for evaluating system efficiency macroscopic variables, e.g. traffic flow or travel times are used as a measurement variable. Therefore after calibrating and validating the simulation model only on microscopic level the simulation seems not yet suitable for investigation of these ADAS. Therefore a microscopic calibration and validation of the individual models and a concluding macroscopic validation appear to be meaningful. This is the reason for proposing a two-level approach of traffic simulation models.

The basic idea of a microscopic calibration and a macroscopic validation has been already described in [23] in the explanation of calibration and validation.

> "This should ideally be undertaken at both a macroscopic scale (validation) to ensure the overall behavior of the model matches that readily observable, but also at a microscopic scale, with regard to individual vehicle-vehicle interactions (the calibration, and "tuning" of the many behavioral parameters comprising the decision making processes)."

One of the first research using this approach can be seen

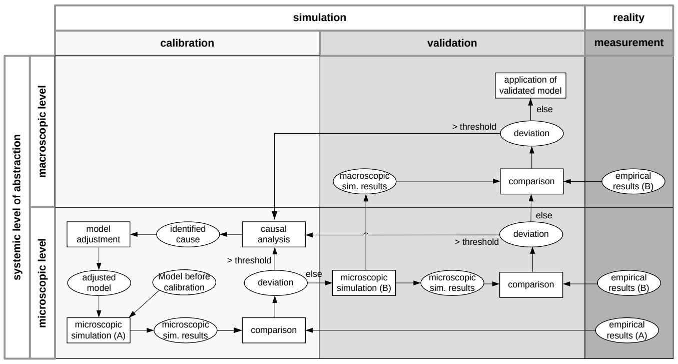

Fig. 5. Calibration and validation of a microscopic simulation model on microscopic and macroscopic level

in [24]. Witte, the author of [24], carried out a microscopic calibration and afterwards a macroscopic validation. Unfortunately, this validation is limited to a purely qualitative consideration. Moreover the validation is carried out with the help of an single-lane roundabout, therefore overtaking and merging are not considered. Witte comments that he observes relatively high traffic flows and traffic densities from the simulation. He attributes these results to the absence of trucks and the measuring data used for calibration.

The new proposed two-level approach is shown in Fig. 5. The first steps for calibrating and validating the model on microscopic level is the same procedure as in subsection IV-A. As soon as 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 doing 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 microscopic and macroscopic level has been successful. Otherwise a re-calibration on microscopic level becomes necessary. Now it becomes obvious that calibration is only possible on the microscopic level, as well as the fact that the microscopic variables are independent variables whereas the macroscopic variables can be considered as dependent variables.

The next step is to gather both the macroscopic and microscopic real-traffic variables in such a manner that they share the same time and geographical reference. A plausible measurement concept is proposed in the next Section.

V. Measurement Concept

In general three different approaches for the acquisition of measurement data can be identified:

- The approach of acquisition of *macroscopic data* (c.f. Subsection V-A)
- The approach of acquisition of *microscopic data* (c.f. Subsection V-B)

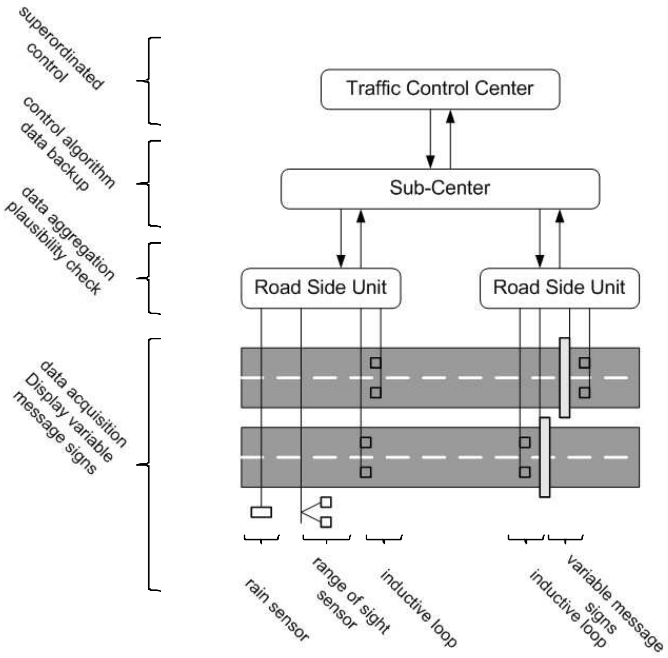

Fig. 6. System layout of a traffic control center

- The approach of acquisition of *both macroscopic and microscopic data* (c.f. Subsection V-C)

Based on the knowledge of the previous measurement concepts a new approach for acquisition of both macroscopic and microscopic data is presented. First empirical results regarding the measurement of microscopic variables are shown.

A. Acquisition of macroscopic data

Primarily, the calibration and validation of simulation models is done with macroscopic measurement data. This measurement data is often obtained by traffic centers which typically store aggregated measurement data. The general system layout of a traffic control center is shown in Fig. 6. Traffic Control Center often consists of sub-Centers and the road-side-units near the highway. The main sensor in use is the inductive loop sensor to measure traffic flow and vehicle speed, and to differ between different vehicle classes. Variable message signs are used to influence driver and traffic flow behavior. The data from the sensors is aggregated in the road side units - often is used a time span of 1 minute or more. The typical distance between the sensor systems is one or several kilometers.

B. Acquisition of microscopic data

To obtain microscopic measurement data different methods are used. This can either be a terrestrial or an aerial perspective.

Following the terrestrial perspective, test vehicles are in most cases equipped with an appropriate sensor system. The test vehicle speed, distance and the relative velocity to the vehicle driving ahead are measured by the system. Usually it is well-known by test drivers that they are being observed while driving, and in some cases they are given special driving tasks.

It is accepted that the drivers in these special test conditions do not react as they might under normal conditions. Such an investigation was conducted for example in [25]. In this investigation the suitability of 10 traffic flow models of vehicle headway behavior was tested for emulating measured data.

Another terrestrial perspective is the equipment of several test vehicles with a GPS system. The test vehicles have to drive behind each other. Therefore these kind of investigation is often performed on special test tracks. Using the GPS position data of the individual vehicles the speed, acceleration and distance information is calculated.

Following the aerial perspective, traffic observations are carried out from a helicopter. Initial investigations already have been conducted as found in [26]. The latest investigations with a video camera installed under a helicopter come from [27]. This approach has the advantage that the observed drivers remain uninfluenced as much as possible. The disadvantage exists that a great effort is needed to collect data, and inaccuracies occur when determining the distance and velocity of the observed vehicles from the video material. This inaccuracy directly influences the calibration of the traffic model.

C. Acquisition of both macroscopic and microscopic data

Presently, there are empirical investigations acquiring either macroscopic traffic data or microscopic traffic data. As previously discussed, it would make sense to simultaneously measure data from microscopic vehicle headway data and lane change data from several vehicles as well as macroscopic measurement data for the same section and the same time span.

One approach already exists for the collection of such data. In the NGSIM project [28] vehicle positions are extracted from video material obtained by several cameras and translated into vehicle tracking data. Additionally, for the road segment observed by the video macroscopic data can be calculated. In NGSIM project loop detector and weather data also have been recorded.

The data sets originate exclusively from the USA and indicate the road network layout that is typical there, as well as drivers' behavior. It is otherwise undetermined whether or not this data can universally be applied to driving scenarios in Europe or Germany. A comparable European project does not exist. Another problem with the NGSIM project exists as a result of the camera technology used. For this data only relatively short road segments a maximum of 640 m were considered. In current databases there exist two data sets from freeways, the sides measuring 500 m and 640 m, respectively. The mean-speed of the vehicles is less than 50 km/h and therefore each car is tracked for about a maximum of 50 seconds. Additionally, estimating vehicle trajectories from video data leads to measurement errors that cannot be neglected. These errors have to be taken into consideration using the data for calibration and validation [29].

D. A new approach towards the acquisition of macroscopic and microscopic data

A new approach towards the acquisition of microscopic data is the continuous and entire movement data acquisition of single vehicles on longer road segments and for greater time periods in combination with the acquisition of the macroscopic data from traffic centers. Without influencing the traffic behavior extensive data sets can be collected from the equipment of the measuring vehicles participating in the real flow of traffic. By means of suitable sensor facilities (radar, lidar), the measuring vehicles are able to capture the behavior of several surrounding vehicles precisely and pursue them continuously for a longer period.

At the same time a traffic center provides aggregate data for this road segment. This data, among other things, represents the traffic flow, truck percentage and mean vehicle speed. To simulate the real traffic flow, it is at least necessary to know the amount of vehicles entering the section under observation, and the amount of vehicles entering or leaving this section by on- or off-ramp. Figure 8 shows a road segment with the necessary inductive loop sensors as well as several equipped vehicles and observed vehicles.

Up to now test vehicles were equipped with sensor systems measuring the vehicles in front of the test vehicle. With this approach the behavior of the test driver and the test vehicle itself can be monitored, especially regarding the movement of the preceding vehicle. The test driver can be monitored for a longer time period, therefore intra-driver variability can be investigated. The disadvantage of this application is that the test driver knows that he is observed personally.

In addition to the sensors monitoring the activity ahead of the vehicle, sensors should also be mounted on the vehicle's rear in order to observe the following traffic, including the following driver's behavior. As soon as the following vehicle changes with another vehicle, the next following vehicle can be observed. This procedure has the advantage that within a short time frame the behavior of multiple drivers can be examined without the examined drivers' awareness. Therefore, the following driver's influence on the measurement can be neglected. Hence with this data the calibration of the vehicle subsequent model of the traffic simulation can be carried out. Due to the large number of observed drivers, where behavior can vary from driver to driver, the so-called inter-driver variability is determined and can be applied to the traffic simulation.

The Institute for Traffic Safety and Automation Engineering equipped a Volkswagen Passat with a radar sensor in the front and a lidar senor in the back to monitor the preceding and following vehicles. In addition a lot of measurement data from the own vehicle (speed, steering angle, actuation of throttle and brake, ...) is recorded. For verification of the measurement data a video system is recording the view to the front and back. Figure 7 shows the general system layout.

Up to now only one vehicle was equipped with the sensor system. The goal is to equip several vehicles with this system.

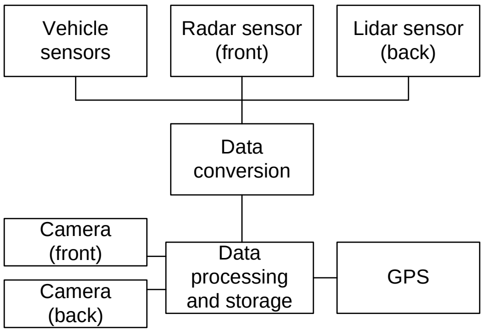

Fig. 7. General layout of the in-vehicle measurement system

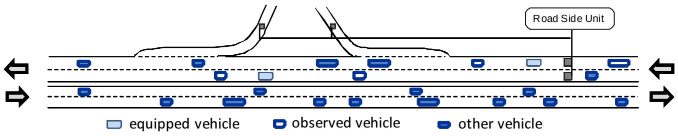

Fig. 8. Measurement concept with several cars

In this case the GPS device is an important component for the measurement concept with several cars. Of course on the one hand the GPS device allows the measurement of the position of the vehicles. On the other hand it is much more important that the GPS device delivers a unique time base. This unique time base is absolutely necessary to merge the measurement data of several vehicles. The GPS time base is available almost everywhere. The advantage of this approach is that the vehicles don't have to exchange any data between each other to synchronize the measurement time.

E. Empirical results

Our equipped vehicle was tested and gathered data from trips with more than one thousand kilometers. The measurement data shows, that our measurement system is excellent for observing the own vehicle, the preceding vehicle and the following vehicle. Due to the developments in sensor technology over the past several years, testing on microscopic level is feasible with significantly lower technical effort in comparison to a few years ago.

Figure 9 shows a small section of our measurement data. The figure shows the trajectory of the movement of our equiped vehicle and the trajectory of the following and preceding vehicle in a typical stop-and-go situation on the Autobahn A2 near Hannover, Germany. In this measurement data we can identify the driving situations mentioned in Subsection IV-B. In phase A the vehicles follow with almost constant speed of about 70 km/h. In phase B the equipped vehicle and the following vehicle brake due to the deceleration of the preceding vehicle. The vehicles comes almost to standstill. In phase C the vehicles accelerate very slowly up to a speed of almost 80 km/h before starting to decelerate in phase D again. Finally the vehicles drive at almost constant speed in phase E of about 40 km/h.

With this measurement data the car-follwing behavior of our test driver and our equipped vehicle as well as the car-

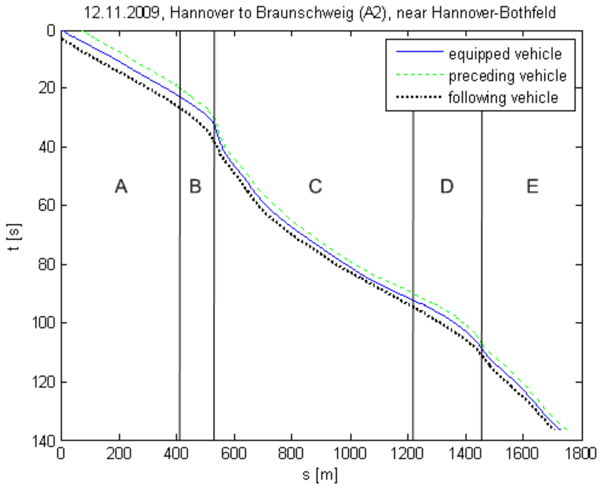

Fig. 9. Different driving situations observed by an equipped vehicle

following behavior of the following driver and vehicle can be investigated.

VI. Conclusion and Future Work

For future investigations of ADAS it is necessary to validate the simulation at the microscopic and the macroscopic level. As a result, it has been deemed necessary to simultaneously obtain both microscopic and macroscopic data.

After verifying the qualification of our measurement system to observe car-following, the next step is to extend our analysis to lane changing behavior. With the knowledge of the preceding and following vehicle and some additional information it should also be possible to observe lane changing behavior. Afterwards several vehicles can be equipped with this measurement system. It is noteworthy that fortunately a large number of institutes and research facilities already own one or several such measuring vehicles. It is possible to use GPS signals as a uniform time and local reference. Therefore, only the coordination of a uniform data format is necessary in order to enable these vehicles to examine together traffic behavior together. With such common measurements, a new data base can be achieved for the first time.

The final goal is to coordinate the measuring vehicles on a predetermined road segment where for the same time span a traffic center provides macroscopic data for this road segment. Therefore the details for this measurement have to be developed together with experts from traffic centers and institutes, and research facilities interested in participating in such an investigation with their own test vehicles.

If video data of the segment is available it can be used as a reference. For example in Germany on the Autobahn A7, a long stretch is equipped with such a video camera system. Because the videos are used only as a supplement, a clearly larger road segment, as opposed to the NGSIM project, can be considered.

This approach makes it possible to connect the microscopic and macroscopic view. Using the evaluation of the data of all measuring vehicles and the data from traffic centers the current traffic behavior of a large road segment can be developed. A calibration and validation on microscopic and macroscopic scale can then also be achieved.

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