1 Simulation framework for testing ADAS in Chinese traffic situations

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1.1 Abstract

This paper describes a new simulation framework assisting the development of ADAS optimized for Chinese traffic. The framework couples the traffic simulators SUMO and VTD to combine different scales and fidelities. SUMO focuses on traditional European and American traffic, making it necessary to implement, calibrate and validate new traffic models. To this end, two driver studies conducted in China are described first. It is stated which characteristics in the driving behavior can be found and how they are reproduced in the simulation. Subsequently, the development and the implementation of the simulation framework are presented and test results are discussed. The focus on Chinese traffic demands a sophisticated combination of classic microscopic traffic simulations and more detailed considerations of the ego vehicle surroundings which are both integrated in the presented framework.

Keywords: Heterogeneous traffic, Driver Model, Testing ADAS

1.2 Introduction

Recently a new field of application for traffic simulation and driver modelling is arising, namely testing and developing advanced driver assistant systems (ADAS). When developing new ADAS or improving existing ones, a lot of real driving tests are carried out, since they deliver the highest degree of precision. With rising complexity this becomes not only more and more expensive but is also extremely time consuming. Consequently, time restrictions often render comprehensive real world tests cumbersome, which is why simulations are indispensable.
So far traffic simulations have mainly been used to evaluate traffic measures and new technologies concerning traffic flow. For this purpose even the most detailed traffic simulations, the microscopic simulations, have a reduced number of parameters, which minimize the effort of calibration and still fulfill the requirements of the stated use cases: traffic measures and new technologies concerning traffic flow [9]. The emulation of vehicle dynamics and the interactions between vehicles in the direct surroundings is necessary for testing and developing ADAS, since those systems are not able to work without this information. This kind of simulation is named sub microscopic simulation [8]. Up to now sub-microscopic simulations are mostly used for scenario based testing. This kind of simulation is quite common in the development process of driver assistant systems [10]. Schiller et al. states, that the current emphasis is primarily on the simulation of individual vehicles at a very

detailed level [2]. Additionally sub microscopic simulators like Virtual Test Drive (VTD) are able to reproduce the same scenarios several times in the exact same way [11]. This approach has one major disadvantage: It is limited to few situations and there is no real interaction of the surrounding vehicles with the ADAS controlled vehicle. This may be acceptable for safety validation of ADAS but for improvement and development a closed loop simulation with consideration of real traffic is needed.
To the best of our knowledge there is no work focusing on the coupling of a traffic simulation developed and calibrated for Chinese traffic with a sub-microscopic simulation that aims for testing ADAS. This issue becomes even more relevant when considering other traffic situations than typical domestic market scenarios. When developing ADAS optimized for local conditions in different countries the effort of real driving tests rises significantly, which makes the manual definition of relevant scenarios nearly impossible, at least for foreigners. To prove this point and give a comprehensive example, this paper describes two driver studies, which were carried out in China. Afterwards, characteristics of the examined driver behavior are described. These characteristics represent the basic knowledge for the design of the simulation framework. Subsequently the implementation of the framework is described and extensions of the used simulation tools are realized. Calibration and test of the framework will complete section 1.4. Section 1.5 concludes the paper, by discussing limitations of the developed framework and giving an outlook on future work.

1.3 Chinese traffic

It is necessary to find and analyze characteristics in Chinese traffic to evaluate the usability of existing simulation tools and models. Thus, situations and scenarios that differ from the European market which are relevant for (future) ADAS are investigated. Then, necessary model improvements and extensions are derived.

1.3.1 Studies

To figure out which situations differ from the European market a combination of a survey and driving test in real traffic was carried out. Since little background knowledge on this kind of studies was available before, we chose to conduct two consecutive studies. Before these two studies are described, results from the ADAS study that was carried out by Audi in 2013 but analyzed by the author in 2014 [12] are introduced. The focus group study explained in subsection 1.3.1 took place in 2014 and was executed in cooperation with Volkswagen AG and Volkswagen Group Research China. Its purpose was to point out critical situations typical for Chinese traffic which require assistance. The last study described in subsection 1.3.1, was planned and executed in 2015 in cooperation with Audi AG and Audi Group China and is used to analyze and describe the situations, found in the previous studies.

ADAS Study

The ADAS study is a large-scaled study with the aim to investigate existing driver assistant systems (DAS) on the Chinese Market, respectively in Chinese traffic. The focus is the evaluation of availability und usability of DAS (including the recording of sensor data) as well as the subjective opinions of the participants. Therefore, it is possible to derive situations in Chinese traffic which cannot be handled by state-of-the-art DAS but assistance was demanded by the test persons. To get representative results the study was carried out with 40 Chinese drivers that where selected due to the typical Chinese driver distribution, concerning age, driving experience and gender. The surveys in this study took part in several phases of the test. The drivers were interviewed before, during and after the driving tests. Additionally, sensor data and data of the vehicle were recorded to make the analysis of the occurring situations possible. The study showed that all tested DAS exhibited save behaviors. The biggest limitation was the availability during normal traffic conditions in Chinese traffic. For example the adaptive cruise control is working well in free flow and medium dense traffic but the availability is getting poor in dense traffic and congested situations. This effect is known from German traffic, too. However, these situations are more common in China and the availability of the system is therefore relatively poor. Moreover, the complexity in congested situations is much higher in China. Details on this point will be shown in the following sections. In summary it can be stated that the availability of existing driver assistance is low in congested traffic situations. Since these situations are quite common in China and drivers would like to have assistance in these situations they will be described in detail in the following sections. [12]

Focus Group Study

Since the ADAS study explicitly asked the participants about existing DAS, a subsidiary one, without this (possible) interference, was planned. For this study 24 participants have been selected. Similar to the selection in the ADAS study the typical Chinese driver distribution was the guideline for the selection. The participants were asked nine different questions about their driving experience, habits while driving and dangerous situations they experienced. For the purpose of this paper two questions are relevant:

1. What was the most dangerous situation you ever met?

2. Are there any boring situations on our trip?

The first question aims to find situations which are not for German drivers and considered as critical by Chinese drivers. The second one is useful to find out in which situations drivers may be inattentive and therefore need assistance. After the questionnaires have been completed a camera was installed on the front passenger seat of 8 participants to observe the drivers action in the car as well as the view through the front window and the mirrors. The collected videos were analyzed to extract situations addressed by the questions. Following this, the videos were shown to focus groups of six participants to collect insights out of the discussions, about the shown situations, within the focus groups. In summary, lane changes where named as the most dangerous situations. The insights gained out of the focus group discussion are that these dangerous lane changes happen everywhere. Heavy traffic was named as the main reason, sometimes in combination with trucks getting stuck in the fast lane. Interestingly, traffic jams are named as the most boring situations. Thus, we concluded that heavy traffic situations and traffic jams are not only a reason for dangerous driving behavior but also situations with need for assistance. Moreover, this outcome coincides with the knowledge gained in subsection 1.3.1 For this reason these traffic situations will be investigated in detail in subsection 1.3.2.

Traffic Situation Study

After china specific situations as well as the demand for assistance have been identified it is necessary to objectively analyze them. To this end, a study was planned in cooperation with Audi AG and Audi Group China. During the study that was carried out in November 2015, 24 participants drove in Shanghai during rush hour. Again the participants were selected with respect to the real Chinese driver distribution. They were neither told what the study is about nor to behave in a certain way. The purpose was to collect data in the focused traffic situations without any prior charge of the participants. This data will be used to complement the data collected in the ADAS study. The resulting data basis will be used to characterize lane changing in dense Chinese traffic.

1.3.2 Lane change characteristics in dense Chinese traffic

Real sensor data from the ADAS study and the traffic situation study is used to gain knowledge about the characteristics of lane changing in Chinese traffic. The data basis contains around 150 hour of driving tests in real Chinese traffic. In general the data analysis shows that the lane changing behavior strongly depends on the traffic conditions and on the level of driving experience. The difference between novice and expert driver increases with rising complexity of the traffic situations. As a result it is necessary to distinguish between driver types and traffic conditions. Thus, the simulated models must be capable to handle both.
Traffic conditions in China are not always determined by the road type. Therefore the differentiation between highway, country roads and city roads is not used here. Moreover there are a lot more road types occurring in Chinese traffic that do not fit into these standard categories. Due to these circumstances it is distinguished between free flow traffic, dense traffic, congested traffic and traffic jam. Motivation for lane changes in general can be divided into [1]:

1. Tactical: lane changes to gain speed
2. Strategic: lane changes to follow the route
3. Cooperative: lane changes for cooperative behavior
4. Obligatory: to follow the keep right rule

The analysis regarding the motivations for lane changes in different traffic conditions is summarized in Table 1.1. The total amount of lane changes under the different traffic conditions is given in brackets and the rows give the amount of the specified lane change type under the give traffic conditions.

Table 1.1: Motivation for lane changes dependent on the traffic situation

Traffic condition / **lane change type**	Free flow traffic (79.5%)	Dense traffic (17%)	Congested traffic (2.5%)	Traffic jam (1%)
Tactical left	38%	55%	33%	0%
Tactical right	37%	30%	66%	0%
Strategic	23%	10%	0%	100%
Cooperative	1%	5%	0%	0%
Obligatory	1%	0%	0%	0%

The table also proves the strong dependency on traffic conditions. The most obvious fact is that there are nearly no lane changes observed in traffic jam. The only type of lane change that occurs in traffic jam is the strategic lane change, whereas tactical lane changes are much more common in dense and free flow traffic. This has two major reasons. In traffic jams the possible speed gain is usually lower than in dense traffic situations and the possibilities for lane changes are also relatively rare. Thus, the motivation for changing the lane is not big enough to perform tactical lane changes. This is different for lane changes in congested traffic. Here, the observed drivers only performed tactical lane changes. This behavior is also known from German traffic, where drivers want to get on the (apparently) faster lane in congested traffic. Consequently, this has to be treated by the simulation model. Moreover, it is obvious that there is no difference between tactical overtaking on

the left and the right side in free flow traffic. Therefore, the lane changing models have to consider this characteristic and evaluate both neighbor lanes in view of tactical advantages. Surprisingly speeding is not common in the observed situations; vehicles mostly stick to the speed limit or exceed it just little. This has to be considered, when the tactical advantages of lane changes are evaluated. In dense and congested traffic the amount of lane changes to the left and the right is not equal. Anyway lane changes to the left and the right are performed frequently. In dense traffic more tactical lane changes to the left are performed. One possible reason is an average speed gain on the left lane. In contrast this seems to prove wrong for congested traffic.
Strategic lane changes should be similar under most circumstances but in the observed situations it often happens that drivers obviously miss to observe their route for some time and therefore have to change lanes quickly to follow the original route. Due to this characteristic a lot of critical lane changes occurred. It depends on the traffic conditions how critical such lane changes are. Thus, this has to be considered in the simulation of strategic lane changes. Driving between lanes is another special characteristic. In a lot of situations there are more lanes in reality than painted as road marks.

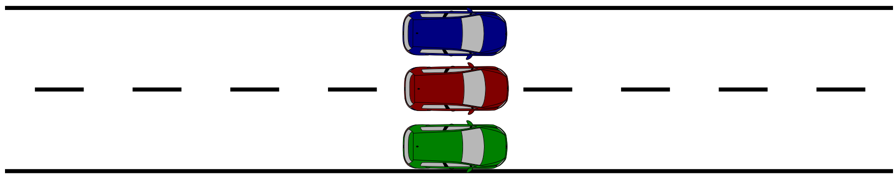

Figure 1.1: driving between lanes

For a better understanding Figure 1.1 shows such situation. It can be seen that the cars do not stick to the marked lanes. As long as they fit next to each other they just create their own lanes (the reason for this behavior is not visualized in the picture). This manner determines an extension in the lane changing logic, which is described in subsection 1.4.2.
There are only few cooperative lane changes in the observed data, mostly the cooperative changes are forced by other drivers that are very impatient. In these cases the cooperation is limited to the level to just prevent a collision. This behavior is one major reason for driving between lanes.
The last class of lane changes is the obligatory one which means clearing the left lane to obey the keep right rule. In the observed data this lane change motivation was quite rare. Usually this kind of lane change is caused by fast vehicles approaching from behind. Vehicles that still do not clear the left lane may also be one reason for overtaking on the right side.

1.4 Framework

To the best of our knowledge, no existing framework is able to fulfill all the acquired needs of the use case treated here. To meet the presented requirements for testing ADAS in Chinese traffic a co-simulation has been designed and implemented. This co-simulation has to deal with traffic flow simulation and driver assistant system simulations. Therefore, the proposed design combines a classic traffic simulation with a scenario based simulation tool. Moreover, a new instance is introduced for both controlling the simulation and implementing the ADAS.

1.4.1 Design

For microscopic traffic simulation SUMO (Simulation of Urban MObility) was chosen for its power and flexibility. SUMO already includes a set of different driver models and makes it relatively easy

to include additional models. This compares favorably to commercial alternatives such as VISSIM which only includes a single (albeit configurable) model and does not allow modifications of its models.
The sub-microscopic simulation software VTD is widely used for testing ADAS in the automotive industry and will therefore be integrated, too. Schiller et al. did some fundamental work in this area by introducing a multi-resolution simulation [10]. In contrast, in the framework presented here VTD is not coupled directly as an equally ranked simulator. To construct a multi-resolution simulation a central control component for the simulation framework is implemented in C++ and executed in ADTF (Automotive Data and Time triggered Framework). This so called simulation master is responsible for the time synchronization, data exchange and the integration of additional components. The described approach has several advantages as the paper focuses on realistic traffic simulation executed by SUMO. As there is no handover of the simulation control between the used tools it is easier to ensure the compatibility of vehicle and driver control. This is in fact an issue, since the drivers in SUMO always follow routes, whereas VTD is not necessarily based on routes. Due to the central simulation master this can be tackled accordingly and it is still possible to modify the behavior of drivers.
VTD is responsible for the visualization and the vehicle dynamics is used to convert the control quantities of coupled ADAS or driver models (like steering angle and acceleration) into new state variables (like position and speed). Moreover, the data of the surroundings of the ego vehicle are transmitted from VTD to the tested ADAS.
The central component has two more benefits. Both, SUMO and VTD do not require any special implementation and thus the usability with all (including future) versions of SUMO and VTD is made sure. Moreover, the implementation of the simulation master described in subsection 1.4.2 ensures the usability with OMNeT++, too. Hence, it is easy to either extend the framework or to change the focus from testing ADAS in traffic to testing ADAS with respect to V2X technologies.
Aside from the design of the presented framework it is necessary to guarantee the compatibility of the maps. The most important issue is to ensure the consistency of the coordinates in both maps. The OpenDrive standard is employed in VTD, which is widely used when it comes to testing of ADAS. In contrast, SUMO requires an individual xml based map format. The existing SUMO map converter netconvert allows back-and-forth transformations between SUMO maps and OpenDrive maps. For this project it was improved and extended to ensure a high level of geometrical accuracy when transforming between these formats. It is important to generate maps base on these transformations because independent generation would make it quite hard to ensure consistency of the coordinates.
Finally it is indispensable to ensure that the requirements defined by the characteristics of Chinese traffic are met. Therefor an enhancement of the traffic simulation software itself is necessary. The steps to implement the developed design are described in subsection 1.4.2.

1.4.2 Implementation

Simulation Master

The simulation master is the central instance of the presented framework. It controls the simulation framework and it realizes the coupling of the tested ADAS. To meet the requirements of most ADAS a step size of 40 ms has to be realized. This is by far more than classic traffic simulations like SUMO are able to realize. Consequently, a simulation step size of 200 ms is chosen for SUMO. This value seems reasonable since it corresponds to the average reaction time of humans [13]. To meet the requirement of tested ADAS the simulated measurement data is taken out of VTD. Nevertheless, VTD is not taking control of the vehicles. The basic assumption is that the driver behavior is not changing within 200 ms because this would be below the reaction time to even notice a change in conditions. The schematic sequence of the simulation is illustrated in Figure 1.2. One can easily see that there is data exchange between VTD and the ADAS every 40 ms whereas the data exchange with SUMO is triggered every 200 ms. Moreover, the data exchange is visualized. The first frame is

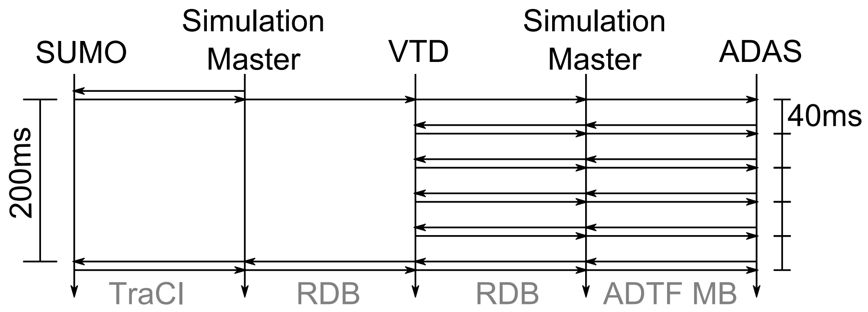

Figure 1.2: schematic sequence of the simulation

requested by the Simulation Master over the Traffic Control Interface (TraCI). The same interface is used by SUMO to send the requested data. The Simulation Master sends this data via the Runtime Data Bus (RDB) to VTD and via the ADTF Message Bus (ADTF MB) to the tested ADAS. Before the next frame of SUMO is requested after 200 ms the environment data is provided by VTD. It is send to the Simulation Master via RDB and forwarded via the ADTF MB to the ADAS.

Driver Models

Before the extensions of driver models are described a brief discussion of the available car following and lane change models is given.
The car following behavior in Chinese traffic is relevant for the lane changing decision and process too, since a vehicle may only change lanes if it can follow the leading traffic in its target lane "safely". The car following model is responsible for defining this safety criterion. Likewise, the following traffic in the target lane must be able to follow the ego vehicle safely. The safety criteria in this case might differ considerably between "Western" and Chinese drivers. The general principle of lane changing is shown in Figure 1.3.
The dependency between longitudinal and lateral movement is also the reason why researchers like

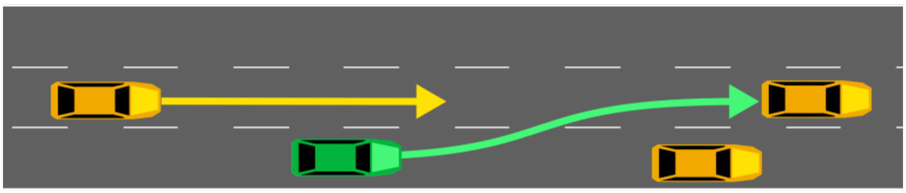

Figure 1.3: lane changing process

Gipps and Kesting et al. developed integrated lane change models [3, 4].
Gipps was the first who developed an integrated lane change model in 1986. His model is derived from the Nagel Schreckenberg model, which is based on the principle of Cellular Automaton [7]. In contrast to the Nagel Schreckenberg model the model of Gipps is continuous in spatial resolution. Therefore, it is better suited to a space-continuous microscopic simulation such as SUMO. The integrated lane change model presented by Kesting et al. is named MOBIL (Minimizing Overall Braking Induced by Lane Change) and is based on the IDM (intelligent driver model) which is described in [5].
Due to the fact that Cellular Automaton Models are limited to their spatial resolution they are not suitable for the adaption to Chinese traffic situations. All the described models, which are continuous in spatial resolution, share similar opportunities for adaption. Typically acceleration and deceleration

capabilities of the vehicles are important factors. Additionally, the gap acceptance of drivers has significant influence on the drivers behavior. Besides these factors the reaction time of the drivers is considered when calculating the drivers actions. None of the mentioned models includes a driver perception. Even though there are models that include a basic perception this will not be considered here, since the focus is on dense traffic and the perception limits concerning the distance to other vehicles has minor influence.
SUMO uses the car-following model of Stefan Krauß [6] by default. This model is quite similar to the Gipps model in limiting the driver to those velocities that still allow safe stopping if the leader vehicle comes to a full stop. For this paper a modified version of the Krauß model and an integrated lane change model is used. The reason is the good capability of this model in all the mentioned traffic conditions along with its simplicity [6].

Sub-lane model in SUMO

To meet the requirements of Chinese traffic it is necessary to adapt the fixed concept of lanes in the simulation tool. SUMO has focused primarily on European and American traffic where vehicles have a high rate of lane-following compliance and furthermore, the fraction of "narrow" two-wheeled road users is low. Thus, SUMO vehicles occupy exactly one lane in the lateral direction. To allow for

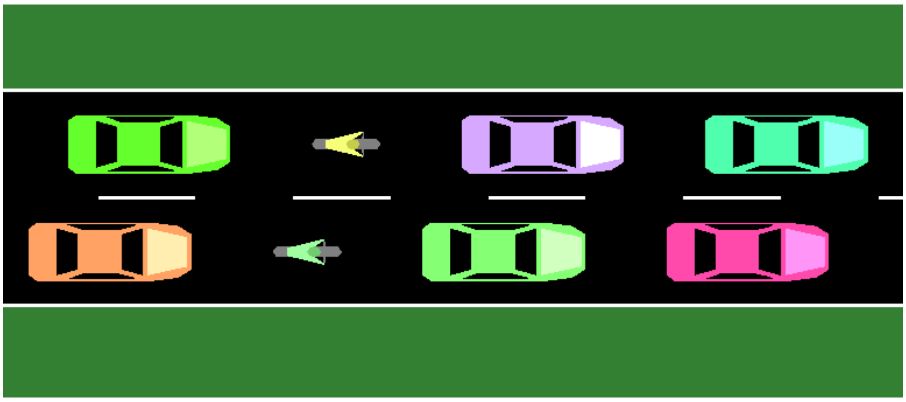

Figure 1.4: standard lane model in SUMO

Chinese traffic dynamics, it is deemed necessary to break up this fixed relationship and allow multiple vehicles on the same lane as well as vehicles which occupy more than one lane. This has benefits for modelling European traffic as well, since it allows a better representation of car-bicycle interactions. In the remainder of this section we describe the extensions to SUMO that were developed to meet these requirements.
Traditional lanes are divided laterally into a number of so-called *sublanes*. Each vehicle occupies a number of sublanes according to its lateral position and width. To maintain the concept of collision free traffic two vehicles may not occupy the same sublane when driving side by side. This necessitates further model changes for longitudinal movement (car-following) as well as lateral movement (lane-changing). Previously each vehicle had at most one immediate leader vehicle. With the introduction of sublanes a vehicle may have multiple immediate leaders (i.e. multiple motorcycles driving side by side on the same lane). Consequently, the car-following model is applied to all leader vehicles and uses the minimum safe speed to ensure safe driving.
It is expected that the existing car-following models can be calibrated to cover the behavior of Chinese drivers. If this assumption proves false, a new model may be necessary here as well.
A novel lane-changing model is required to make use of the sublanes. This model extends the lane-changing model described in [1].

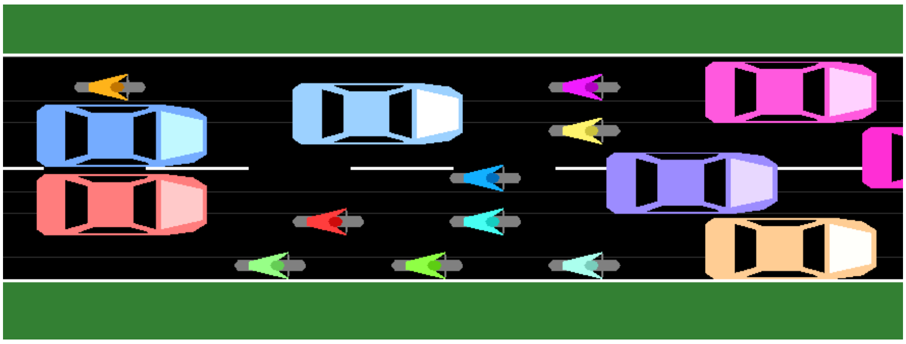

Figure 1.5: sub-lane model in SUMO

The most important changes are:

- The number of possible maneuvers that have to be considered is increased from the number of neighboring lanes (at most 2) to the number of neighboring sublanes (10-100 depending on the configured sublane resolution)
- The larger number of choices requires novel trade-offs to be made: (i.e. should a vehicle attempt to find a gap in the right sublane to increase its speed or should it move immediately to the left sublane where speed is also higher but not as high as to the right)
- When traversing multiple sublanes in a single maneuver, each of the intermediate sublanes must be checked to avoid collisions
- Lane changing motivations are no longer mutually exclusive: A strategic change to the right lane does not preclude sublane-changes within that target lane to optimize for travel speed

In addition to the existing lane-changing motivations, we introduce a new motivation for achieving a desired lateral position within a lane in the absence of more urgent motivations. The behavior is user configurable and includes such behaviors as

- Stay in the center or to a particular side of a lane
- Compact alignment to neighboring vehicles to maximize capacity

Another new aspect that needs to be modelled is lateral distance keeping. This scenario requires safety and speed considerations comparable to challenges of the traditional adaptive cruise control.

1.4.3 Calibration

This section describes the calibration of the driver models running in SUMO with real world data. To this end, the information gathered from the real world measurement data analyzed in subsection 1.3.2 is used. As the focus is on lane changing processes, the lane change motivation is considered first. As stated in section 1.3.2 there are four types of lane changes. Tactical lane changes are carried out to gain speed. The first thing to calibrate is the proportion of left and right overtaking for all speeds. Moreover, it is necessary to adopt the threshold values for the possible speed gain over a certain time. In Chinese traffic these values depend on the traffic situation. For example, there are only few tactical lane changes in traffic jam but a lot in dense traffic situations. The speed gain value already depends on the velocity. In contrast to the mentioned relation the value is rising when the absolute speed is low. This behavior is implemented to model the observed tactical lane changes in congested traffic. Therefore, this relation is reasonable. Nevertheless the number of lane changes in congested traffic is low. The reason is the dense traffic itself: Since the gaps are

relatively small it is complicated for the driver to change the lane. In this context the impatience of a driver is an important factor. The impatience is not constant but changing due to various conditions. Drivers waiting for merging into a lane several times will be more impatient than drivers who were able to merge without problems. Rising impatience causes a more aggressive driver behavior. This concept of impatience is also responsible for lane changes that force strong reactions from surrounding traffic, since drivers can reach a level of impatience that justifies this behavior. One more influence that mainly affects free flow traffic is the possibility of speeding. For this reason there is a factor, multiplied with the speed limit, which varies from driver to driver and the distribution of these factors has to be calibrated as well.
For strategic lane changes the foresight distance is the determining factor, it defines which distance ahead a driver knows his route. This factor is normally constant but for a more realistic simulation the attention of the driver is taken into account, whereby the foresight distance varies from driver to driver. To realize this, a varying factor must be introduced and calibrated. A short foresight distance can result in very egoistic and potentially dangerous lane changes because the lane change must be executed quickly to follow the route. In this case the urgency is not rising continuously but jumping up at the time the driver notices the situation. The very special characteristic of cooperative lane changes in Chinese traffic makes it quite complicated to model them. The way this forced cooperation is recognized here is strongly linked to the sub lane model: The lateral orientation of vehicles within a lane is normally defined by a factor that either causes the vehicle to stay in the center or a particular side of a marked lane or to drive as compact as possible to maximize capacity. This factor is now used to model the forced cooperation. To do so the factor is set to maximize capacity when other vehicles try to force a lane change. This causes vehicles to drive parallel instead of causing strong breaking reactions to avoid a collision. After ten seconds, the factor is set back to its original value and the vehicles start merging into the original lanes again. For the calibration of obligatory lane changes the probability for obligatory lane changes is reduced and the time the right lane has to be empty before drivers consider an obligatory lane change is raised.
Clearing the way for fast follower vehicles is not currently represented in SUMO. It can be considered as a form of cooperative lane change that can be triggered based on speed difference between ego and follower vehicle in relation to the inconvenience of performing the lane change. This new behavior will have to be calibrated as well. Besides the lane change motivation the viability of the lane change has to be considered. Like most lane change models an integrated car following model is used here. The model allows the calibration of acceleration and deceleration limits and the adoption of the desired gap.
In SUMO these parameters are attributes of each vehicle. To meet the characteristic driver distribution in Chinese traffic which comprises novice drivers, normal drivers and experts in a representative distribution of parameters will be calibrated.

1.5 Conclusion and future work

The previous sections have shown that it is possible to combine a simulation of Chinese traffic with the possibility of testing ADAS. For this purpose, the calibrated simulation framework is used for prototypic testing of the autopilot functions in Chinese highway traffic. The design and implementation of the framework for a closed loop traffic-ADAS simulation is described in subsection 1.4.2. This framework enables us to simulate realistic interactions between surrounding vehicles and the ego vehicle, without predefining a specific scenario. The simulated drivers are calibrated on the basis of real world measurement data. Future work will focus on model validation as well as evaluation of the framework. Additionally the framework will be extended by a more detailed driver model with consideration of driver perception in future.

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