# A Comprehensive Driver Model with Application to Traffic Simulation and Driving Simulators

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**Summary**

This paper presents a comprehensive driver model developed as a component of the microscopic traffic flow simulation package PELOPS. The model is capable of simulating driver behavior and actions including control and decision processes. It is well suited for use within a complex and dynamic traffic context ranging from one-lane roads to multi-lane highways, including lane-changing maneuvers. Detailed simulation of these processes is essential for realistic incorporation of microscopic simulation into a driving simulation environment.

Application of the model for traffic flow simulation is briefly summarized. Adaptation of the model to the BMW driving simulator is presented here, and in particular the portable interface of the driver model to the driving simulation environment by means of “environment views” is described.

## 1 Introduction

Models describing human driving behavior have been available for several decades in the area of traffic simulation. They are more or less detailed, depending on the simulation task. The main goal of these models is to create a realistic picture of traffic with regard to physical characteristics such as time gaps, distances and velocities. The idea of using such a model in a driving simulator to control the surrounding vehicles is a new challenge requiring some adaptations. The driving behavior of the simulated vehicles must convey a realistic impression to the person in the driving simulator. Additionally linking the model to the driving simulator requires a well-defined interface for the exchange of data.

## 2 The Driver Model

The driver model is divided into two modules: the behavior module and the handling module. An environment and a vehicle module complete the traffic simulation. Information exchange between these modules is summarized in Figure 1. Within the

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behavior module, a driving intention is determined based on the driving conditions and the traffic environment, which are both part of the environment module. This intention consists of an acceleration wish and the choice of a lane ($a_{require}$ and lane in Fig. 1). The behavior module consists of two models for lateral and longitudinal control, the car-following model (see Section 2.1) and the lane-changing model (see Section 2.2).

At the action stage, the intention of the driver resulting from the behavior model is used within the handling module to compute the appropriate positions of control elements ($\Psi$, $\alpha_{br}$, $\alpha_{thr}$, gear, clutch in Fig. 1). Conceptually, the accelerator and brake pedal are united into one “drive pedal” in the vehicle module. The drive pedal is controlled by a PI-control algorithm, and its behavior is limited by the driver’s abilities. A change of gear depends on engine speed, current acceleration, and pedal position. For each driver, individual times to execute a gear change as well as clutch handling are considered.

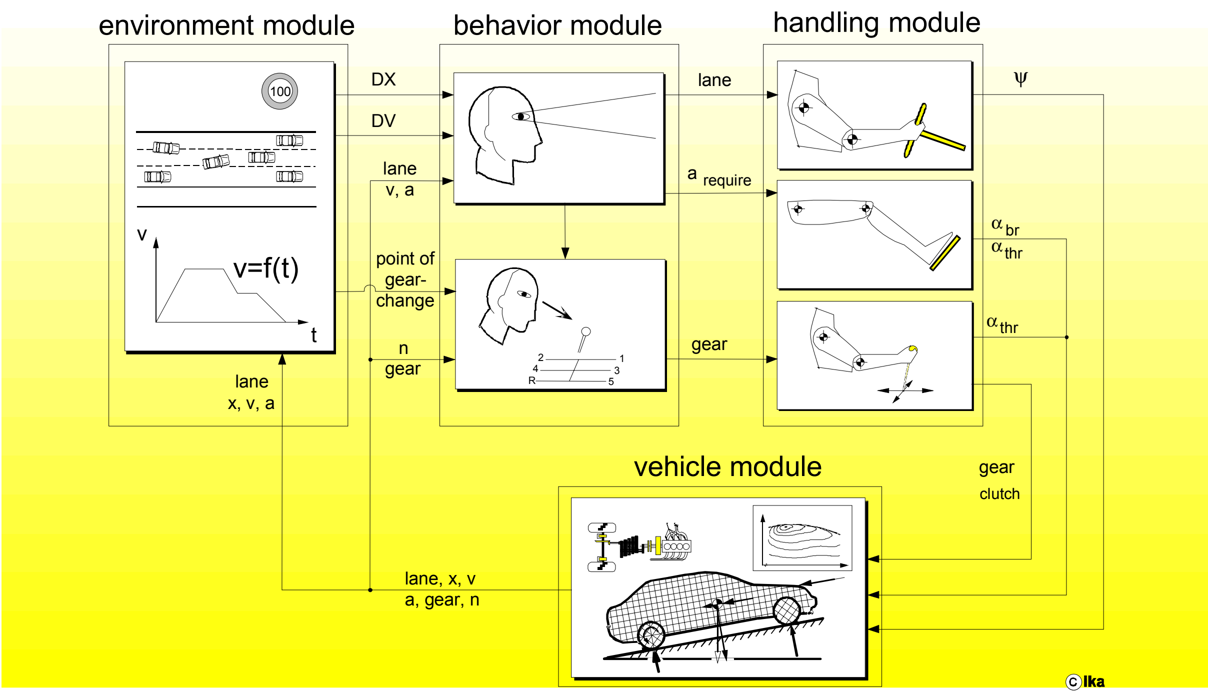


Fig. 1: Information flow within main traffic simulation modules

## 2.1 Follow the leader model

The car-following model is based on the psycho-physical distance model of Wiedemann [17], which separates different ranges of the driver’s behavior by means of perception thresholds. The model was developed further and extended substantially for use in the traffic simulation program PELOPS [1], [5], [6], [10], [13], [16]. The driver’s individual behavior is described by typical parameters such as reaction time, level of perception, level of attention, need for safety etc. Furthermore the model used in PELOPS distinguishes between different driving situations depending on the surrounding traffic situation and the environment. The parameters

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of the driver model are adapted to four different driving situations in which drivers behave significantly differently: *uninfluenced driving, approaching, braking in emergency situations* and *following*. Depending on differential speed dv and relative distance dx to the preceding vehicle and the current vehicle speed v, the PELOPS driver model calculates the driver's desire for acceleration or deceleration.

In Figure 2, these four different driving situations are shown in a 3-D plot. The axes designate the three main input parameters: relative velocity dv, relative distance dx and current vehicle speed v. The boundaries between the situations are shown as planes. A vehicle is in an *uninfluenced* situation when it is not yet reacting to the vehicle far ahead. It will react and decelerate in the *approaching* situation. When relative distance falls below some lower limit, the so-called "minimum following distance" which is to be maintained for safe driving, the *braking* situation has been reached. As soon as an acceptable individually desired following distance has been reached, the driver model switches to *following* mode and will accelerate again when relative distance and relative velocity exceed appropriate perception thresholds. Limitations on control of the acceleration pedal, e.g. due to a lack of concentration or driver errors in gap estimation, lead to distance variations between the minimum and the maximum following distance (see Fig. 2, $\Delta x_{min}/\Delta x_{max}$). The planes separating the different situations are driver specific and depend -- in addition to the main input parameters mentioned above -- on the driver's level of perception.

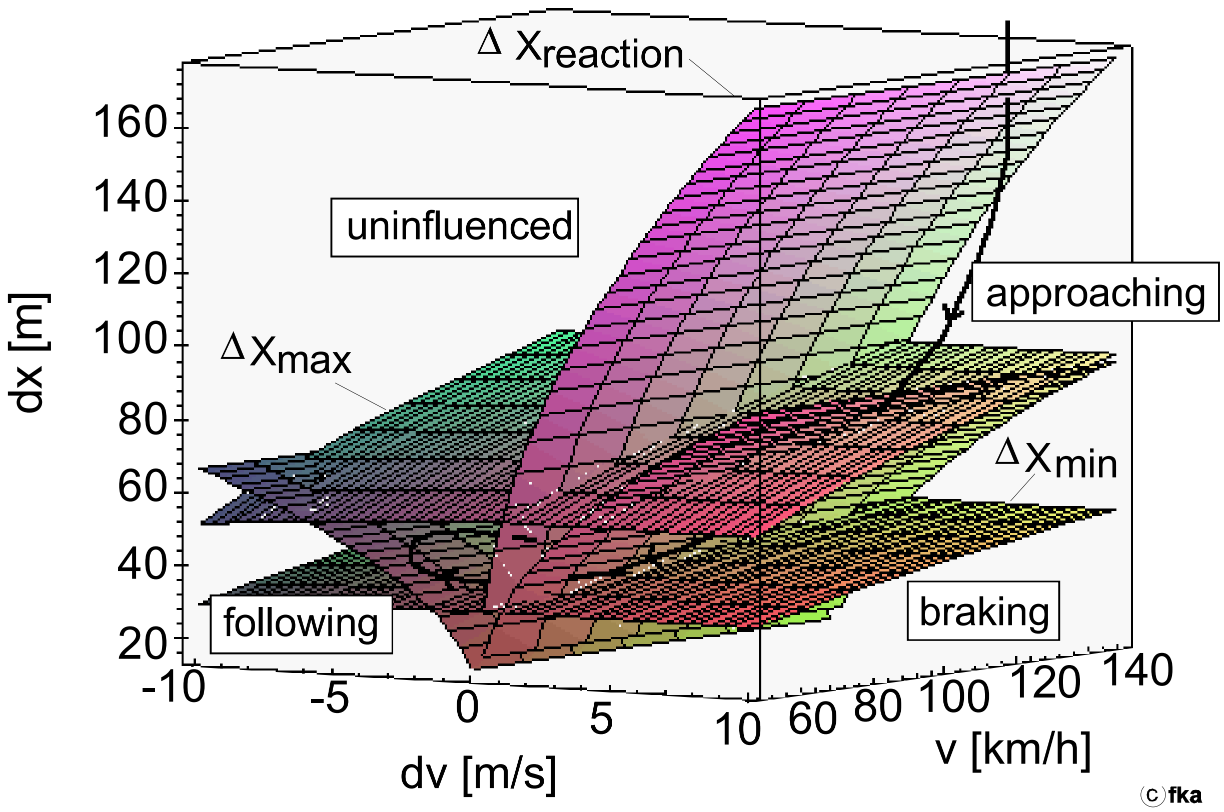


Fig. 2: Driving situations and levels of perception (see also [17])

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The PELOPS model of the driver's behavior described above is used during "standard driving situations" on a one-lane road. For modeling the traffic on multi-lane roads and for modeling the driver's reaction to the road's topology (e.g. approaching intersections or ending of a lane), the driving model has to be extended by a lane-changing model.

## 2.2 Lane-changing model

When describing lane-changing behavior, the formation of the desire to change lanes has to be distinguished from assessing the feasibility and finally from the feasibility itself.

Different motivations can lead to a desire to change lanes. The most frequent motivations involve following the chosen route and moving faster by a passing maneuver. But other tactical considerations can also motivate a lane change. For example, another reason for changing over to the right is being badgered from behind. In order to handle these different situations properly, a structure for the lane-changing model has to be developed which considers all the main relevant factors for forming the desire to change lanes. It should not depend on a simplistic, static assessment of the traffic situation, as for example in the Sparmann model [14].

In order to realize this flexible structure, a measure of "momentary contentedness" was introduced and is assigned to each lane for each driver. This new measure characteristically depends on one's own speed $v_i$, the speed of the preceding vehicles $v_p$, as well as the speed of *their* predecessors ahead $v_{pp}$. These velocities are considered in relation to the acceleration of the respective vehicles $a_i, a_p, a_{pp}$ and the desired speed $v_{desired}$ of the driver under consideration. Further external influences affect the contentedness measure. For example, a vehicle exerting pressure from behind may reduce the contentedness in the current lane under certain circumstances. Weighted by a so-called forgetting factor λ (see the equation below), the contributions of the contentedness parameter $a_i$ are iterated over a period of time as follows

$$c_n = \lambda \cdot c_{n-1} + a_i \quad \Rightarrow \quad c_n = \sum_{n=1}^{\infty} \lambda^{n-1} \cdot a_i \quad \Rightarrow \quad \lim_{n \to \infty} c_n = \frac{a_i}{1-\lambda} \qquad 0 \le \lambda \le 1$$

with: $a_i = f(v_i, a_i.v_p, a_p, v_{pp}, a_{pp}, v_{desired}, \ldots)$ "momentary contentedness"

$c_n$ = *see above* "contentedness with respect to the past"

The resulting "contentedness with respect to the past" reflects human behavior, since past driving situations are forgotten more and more. By computing a weighted average of the contentedness values, a memory of driving history is simulated so that a driver's lane-changing motivation due to previously experienced situations can be considered.

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Figure 3 shows the structure of the lane change model. The contentedness based on the equation described above is calculated for every available lane. The contentedness in the current lane is compared with the potential contentedness in the neighboring lanes. Higher values in neighboring lanes exceeding a “difference threshold” consequently provoke the desire to change lanes. This corresponds to “determine my lane-change desire” in Fig. 3. A hysteresis has been introduced for the difference threshold, which is dynamically controlled in order to avoid unstable lane-changing behavior (changing back and forth between the lanes).

Based on the position and movement data of the cars on the neighboring lanes, the “calculation of gap” (in Fig. 3) can be performed. If the safety margin to potentially conflicting vehicles on the target lane is large enough and the intended lane change appears to be “feasible”, the driver model will initiate a lane change. The smallest accepted gap depends on the differential speed between the vehicles, the driver’s individual need for safety, and the speed level. The driver who is changing to a faster lane estimates the deceleration he enforces on the new following vehicle. As his desire to change lanes increases, he will accept higher deceleration values for the new following vehicle. Analogously a driver estimates his own deceleration required when changing to a slower lane (i.e. because he has to follow a route). The closer he approaches the intersection, the more sharply is he willing to decelerate. This procedure is denoted “lane-change decision” in Fig. 3.

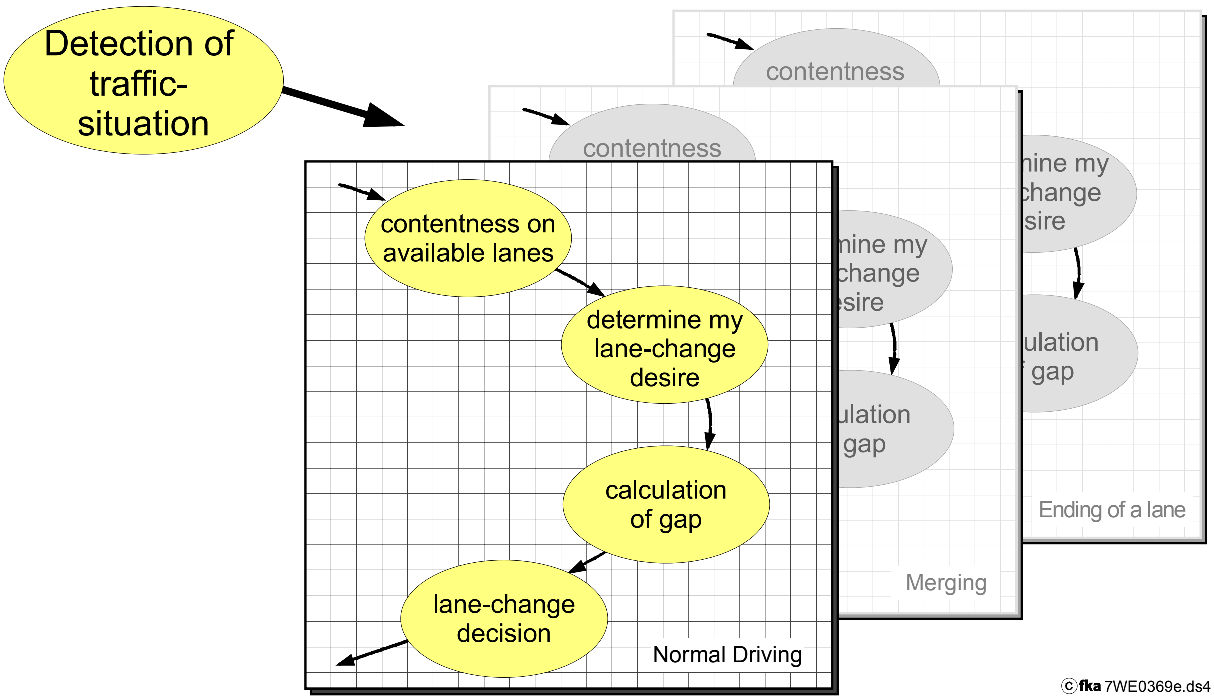


Fig. 3: Lane-change decision

While changing lanes, a continuous check is performed whether the gap the driver is heading for has changed so that he cannot continue changing lanes. In this case he breaks off the lane change in order to avoid an accident.

During a lane change, the lateral dynamics is adapted to the progress of the maneuver. The vehicle moves along a sinusoidal curve from one lane to the other. The length required for the lane change depends on the kind of lane change, which is again individually calculated for a driver in this specific situation. For a detailed description of the lane-change model, see also [2].

## 3 Application of the driver model to traffic simulation

Convincing and reliable traffic simulation is only possible if vehicles move realistically. Therefore a model is needed that reflects human driving behavior in a sufficiently realistic manner. The above described driver model has been used inside the traffic simulation program PELOPS for several years. Detailed investigations have been published describing the simulation tool PELOPS [5], its validation [6], its applications [16], and results achieved with it [3]. In particular, these investigations show that PELOPS provides reliable results with respect to characteristic traffic parameters (see [11]). The term "complexity" in Figure 4 denotes the number of model parameters and therewith also the handling efforts for the model. The $T^3$ model has the disadvantage that the model parameters are derived by a parameter identification procedure and do not correspond to physical parameters.

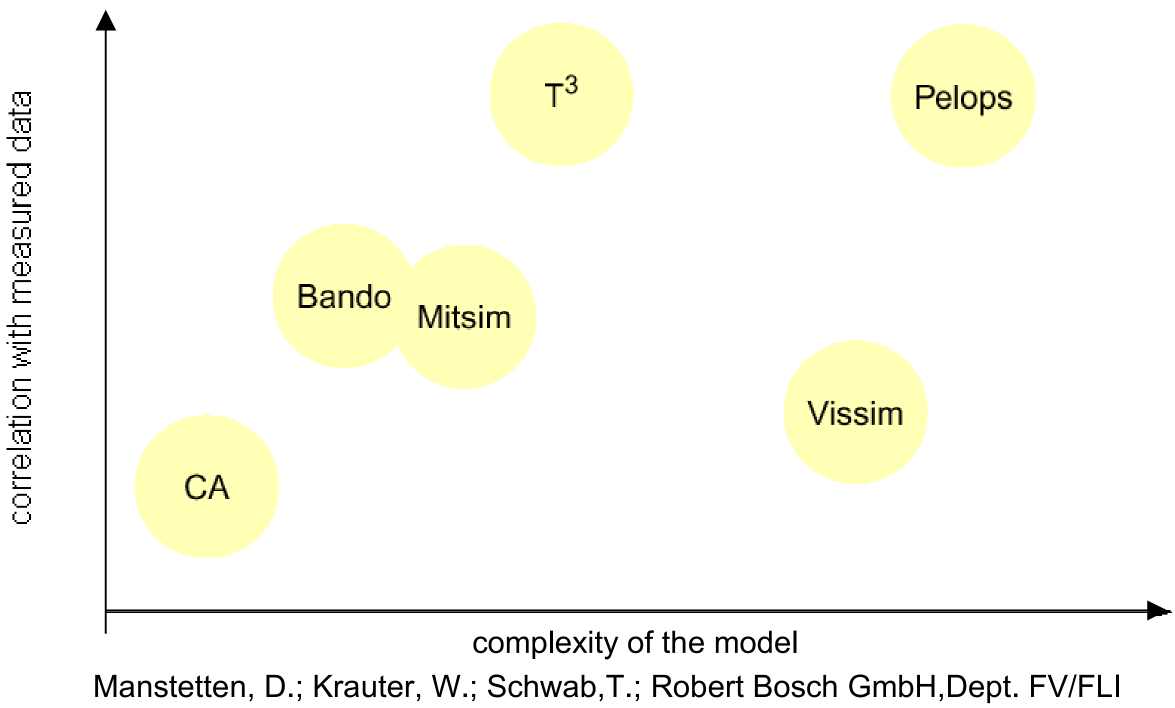


Fig. 4: Comparison of different microscopic traffic simulation models

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## 4 Application of the driver model in the driving simulator

### 4.1 Tasks in the driving simulator

Classic driving simulators play a very important role in research and development. With a comparably small investment, one can achieve a first evaluation of e.g. the quality of a human-machine interface. In simple driving simulators, the surrounding vehicles follow fixed cycles, i.e. they do not react to the driving maneuvers of the person in the simulator. Thus it is possible for example to drive right through other cars in the simulator. The advantage of these simulators is the reproducibility of scenarios and hence the comparability of results. Unfortunately this kind of comparability implies the price of largely eliminating the effective variability of “real” traffic.

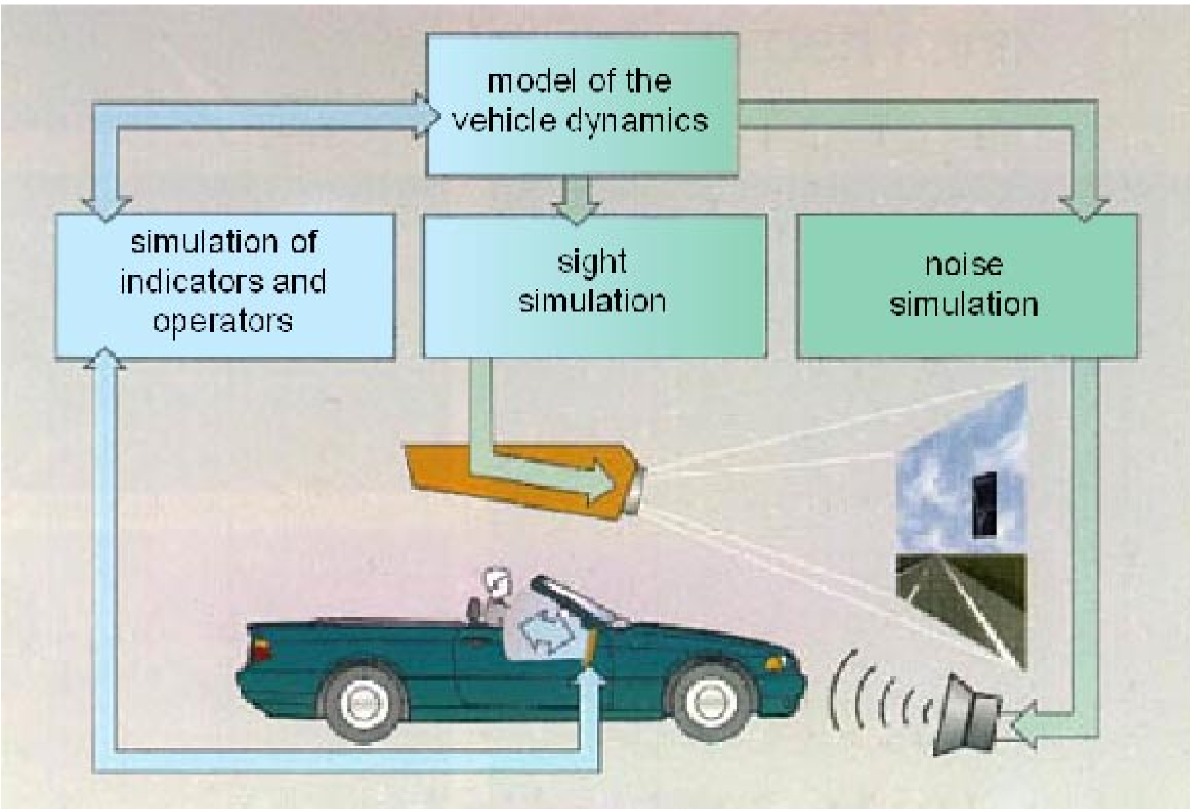


Fig. 5: functionality blocks of the driving simulator

During the development phase of a new vehicle, test driving in a real traffic environment is important. This leads to the idea of simulating a realistic traffic environment in the driving simulator. The neighboring vehicles should react to the driving maneuvers of the person in the simulator in a manner similar to that of human drivers. Thus, the range of investigations that can be performed in the driving simulator can be expanded by two major aspects: the influence of the driver’s behavior on the surrounding traffic can be evaluated (i.e. with respect to safety considerations), and the test person in the simulator experiences a real driving situation with a realistic work load of driving the car and observing traffic.

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Psychological aspects such as distraction, stress, etc. when using assistance systems can be assessed as well as their influence on driving behavior and safety.

This intelligent driving simulator can only be realized if the surrounding vehicles are controlled by a model of the human driving behavior. The simulation of realistic reactions of surrounding drivers to the test person's driving behavior requires a data exchange between the simulator itself and the model. Two aspects must be considered: which parameters the simulator provides, and which parameters the model on the other side requires.

### 4.2 Conditions in the BMW driving simulator

The idea of an intelligent driving simulator has been pursued from the beginning in the BMW simulator (Fig. 5 and 6).

Fig. 6: Vehicle mock-up from behind

An independently developed driver model was implemented which allowed the modeling of even moderately complex intersections.

However, it was not yet based on a generally used car-following model, and for performance reasons it was closely interlinked with the specific simulation environment of the driving simulator. Therefore it could not be used in other applications without adaptations.

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In the context of developing and investigating new driver assistance systems, such as lane-changing assistance within the German MoTiV[1] project [4], the need to create a flexible and realistic simulation of dense motorway traffic arose. A major requirement was that the surrounding vehicles should react to any lane-changing maneuver in a realistic way.

Since the task of developing a powerful driver model for the simulator is very similar to the task of developing one for traffic simulation, the idea of developing and maintaining only one common model, which can be used in both applications, was born. In this way, both applications will benefit from future enhancements.

### 4.3 Adaptation of the driver model and new concepts

Similar to traffic simulation, the driver model needs a linkage to one or several vehicle models and to an environment model. In addition to physical and geometrical parameters, both the vehicle and the environment model include numerous parameters describing the optical qualities and the graphical presentation of the environment and of neighboring vehicles.

To be able to use the driver model in both applications (traffic simulation and driving simulator), it is necessary to isolate it from specific vehicle and environment models. Therefore the driver model, which was originally written for simulation in Fortran, was encapsulated and rewritten in C++. Additionally the following new concepts were realized.

#### 4.3.1 The “model-view” concept

During the translation of the driver model from Fortran to C++ within the context of an object-oriented approach, a “model-view” concept was chosen:

The access to the required data about vehicles and environment is realized by means of “views”. These views are updated for every driver at each time step. The views contain all parameters that are relevant for driving behavior (e.g. road information, traffic signs, distances and differential speeds) in a representation that is independent of the specific application.

Views are generated by an “adapter”, which extracts -- in a separate data set for each driver -- his own personal view of the environment from the application-specific environment. The information about the neighboring vehicles is treated in an analogous manner. The adapter reads the relevant information out of the (application

[1] Motiv was a joint research project of German car manufacturers funded by the German „Bundesministerium für Bildung und Forschung “ (ministry for education and research) from 1996 - 2000.

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specific) data structures describing vehicles and converts them into “ego-vehicle-centered” views of each neighboring vehicle.

Based on the current view at time $t_n$ and the driving state at time $t_{n-1}$, an update of the driving state for the current time $t_n$ is performed. The calculated parameters of the behavior module and the actuators’ positions (the output of the handling module) are delivered in an output data structure of the driver model and are available for further use in the respective application.

#### 4.3.2 Parallel processes

In order to support simulations of at least 60-100 vehicles in the driving simulator in real time, the computational load must be allocated to several processors. This applies to graphical presentation as well as to real-time computation of driver and vehicle models.

Typically, for every processor, at least one system process will be started which will simulate a subset of vehicles, including the respective driver and vehicle models. Since the vehicles assigned to one process must also be visible for cars belonging to other processes, the views are communicated via a communication-backend to the involved processes.

It is important that the data exchange is performed via the defined communication-backend only. Other “bypass” methods (i.e. via global variables) would not operate in a multi-process environment.

The mechanisms for debugging and logging are designed to operate locally on each driver’s software implementation and therefore do not require interprocess communication.

#### 4.3.3 Performance optimization

To be able to simulate as many vehicles as possible in real time, optimization of performance is very important. Among others, the following improvements were introduced:

- Instead of multiple calculations of behavior-determining parameters (e.g. time gaps, ttc’s), those parameters are computed once per time step, saved in memory and reused in subsequent assessments of other situation aspects.
- Fast data access methods were implemented by means of class hierarchies, pointer structures, and the use of lookup and hash techniques.
- Indices are generated once to sort the neighboring vehicles according to their position, and vehicles thus can be quickly accessed by specifying their position numbers.

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Of course, decoupling of the driver model from the vehicle and environment models implies some performance costs, because data has to be copied into the view-structures, and result data has to be read out again. These additional costs were more than compensated by the optimization measures. Other possibilities for increasing performance are still available.

### 4.3.4 New lateral guiding concept

Traffic simulation applications generally simplify matters by assuming that drivers remain exactly in the very middle of a lane, except when they are changing lanes. This simplification seems to be justified because results such as speed, time gaps, distances etc. remain unchanged by neglecting the lateral position of the car on the lane. The motion trajectory from one lane to another is idealized as a sine wave, which is planned once at the beginning of the lane change and will then be followed during the execution of the lane change.

The test person in the driving simulator will of course not achieve this behavior. A small deviation from the ideal middle position may therefore not be interpreted as a beginning lane change by other drivers controlled by the driver model. This means that the intention to change lanes must be identified by other – more human like – criteria. The movement from the middle of the lane to one side of the lane must already have persisted for some time, and it must be noticeable to the following vehicles. During this time, the car is still situated within the initial lane. Meanwhile the situation may have changed in a way that the lane change is no longer possible or safe. For this situation the driver model must include a break-off of the lane change. As lane-changing maneuvers take several seconds, re-planning of the lane change trajectory must also be an option. Particularly in a situation where the velocity has changed significantly since the start of the lane change, the trajectory must be re-calculated and be adapted to the new speed.

Therefore a new lateral guiding concept was established, which fulfils the following criteria:

- Permanent adaptation of the lane change trajectory to current velocity.
- Continuous verification of the feasibility of the lane change. If necessary a break off maneuver and a calculation of a trajectory to change back to the starting lane is triggered.
- Integration of a state controller for steering, which adjusts for the difference between the desired trajectory and the currently driven trajectory by controlling the steering wheel angle.

Thus, it is possible to include the influences of non-ideal steering behavior and disturbances in the lateral dynamics (e.g. crosswind) on the driver-vehicle-system in a realistic way within in the simulation.

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#### 4.3.5 Concept for external control

In some test scenarios, not only the flexible and realistic reaction of the neighboring vehicles to the test persons driving behavior is important, but also the possibility of externally influencing the traffic situation in order to enable the test manager to generate certain driving situations (Fig. 7). Unfortunately, the idea of enforcing specific driving situations conflicts with the general lack of control of the test driver’s behavior.

Fig. 7: Control center of the driving simulator

Therefore the interface to the driver model was extended in order to transmit also certain external requirements (e.g. to stick to a preferred lane). These specifications will not be followed absolutely, but will influence the internal assessments in the driver model. E.g. a preferred lane will increase the driver´s contentedness on this lane and decrease the potential contentedness on neighboring lanes. In order to avoid an accident, the driver will nevertheless depart from the externally imposed requirements whenever necessary.

Thus it is possible for example to set up the situation of short distance cut-in maneuvers in front of the test driver. Despite distances falling below the normal internal security margins of the driver model, the “computer driver” who is cutting in will still avoid accidents with the test vehicle.

### 4.4 The interfaces of the driver model

The input interface to the driver model is established by the following views:

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- View of the own vehicle
- View of the neighboring vehicles
- View of the environment

These views will be described shortly in the following sections. All views are used for input only and not modified; newly computed resulting actuator positions are part of the output data of the model.

#### 4.4.1 The view of the own vehicle

This view includes all the relevant information which the driver can perceive about his own vehicle and which he needs for vehicle guidance:

- Vehicle geometry, length and width
- Kind of vehicle like passenger car, truck or motorcycle and the maximum possible acceleration at the current vehicle state
- Current motion state of the vehicle, longitudinal and lateral position on the road, velocity, acceleration and the yaw angle
- Current positions of the actuators (steering wheel, pedals, indicators, light, horn)

#### 4.4.2 The view of the neighboring vehicles

The view of the neighboring vehicles comprises all relevant information that a driver is able to perceive about neighboring cars:

- Distance and relative speed
- Acceleration and lateral velocity
- Relative lane number of the neighbor car and lateral position on this lane
- State of indicators and lights

#### 4.4.3 The view of the environment

The view of the environment contains all the relevant information about the driving environment:

- The “curvature view” including distance and position of the maximum curve
- The “gradient view” of the vertical profile of the road

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- The perception of environment and weather conditions
- The view of all lanes including their width and a list of obstacles for each lane
- The view of traffic signs which includes all perceivable signs and traffic lights

### 4.4.4 The output data of the behavior module

The following parameters are provided by the behavior module as output data and are passed to the handling module:

- Current desired acceleration or deceleration
- Current desired steering wheel angle
- Current desired velocity (the maximum desired velocity adapted to the current surrounding conditions)
- Current driver's visibility range and other dynamic parameters of the driver model adjusted to the current situation (e.g. following distance, perception threshold)
- Desired indicators, light, and horn operation

### 4.4.5 The output data of the handling module

The output parameters of the drivers handling module are the actuator positions, which are forwarded to the vehicle model:

- Position of gas and brake pedals, gear selection
- Position of the steering wheel
- Position of the light switches (indicators, headlights, brake lights) and horn usage

### 4.4.6 Processing of the output parameters

The application using the driver model must forward the resulting actuator positions to the vehicle model. On the basis of the current gear selection and the gas/brake pedal position, the resulting acceleration of the car is calculated. Initial position, speed, acceleration and steering angle are integrated over time to provide the current velocity and position on the road.

After updating each vehicle model for a time step, the traffic situation of the next time step is known. Also all dynamical changes of the environment during this time step (i.e. traffic lights) must be taken into account. On the basis of updated vehicle

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positions and environment data, the views for the driver model are refilled for the following time step.

## 5 Results

### 5.1 The application "lane-changing assistance"

The integrated driver model was applied within the German project MoTiV to investigate different lane-changing assistance concepts in the BMW driving simulator [12]. Numerous evaluation tests were performed, about 100 hours with 30 test persons within controlled experiments and additionally about 200 hours in the preparation phase.

With a cycle time of 10 ms, about 80 cars could be simulated in real time. These cars were put into the scenario in a distance out of the sight of the test person and were taken out again when they drove out of sight [15]. In this way the impression of a trip in continuous to heavy traffic could be presented to the test person.

The driving behavior of the neighboring vehicles provided a subjectively realistic impression to the test subjects, even the horn and the headlamp flasher were operated by the driver model when it did "complain" about small headways and small time gaps.

Fig. 8: Lane-change assistance warning (red light on the outside mirror)

During the preparation phase, the lane-changing behavior model was extended, and additional relevant parameters for the formulation of contentedness on a lane were introduced.

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Vehicle parameters and average traffic density in the test scenarios were configured within the mostly used three lane motorway scenario as follows: the cars on the right lane had an average desired speed of 70 km/h, on the middle lane 130 km/h and on the left lane 170 km/h. By means of slight differences in desired velocities, different sets of driver parameters and externally controlled decelerations of single vehicles, the desired variety of the generated traffic was achieved. The setup provided a vivid traffic scenario with varying distances between the cars to allow for different lane-changing situations.
Lane changing of the neighboring vehicles could be suppressed on demand; it could be permitted only in front of the simulator vehicle or in front of and behind the simulator vehicle. The test manager could influence collective following traffic (when lane changing was prohibited behind the simulator), or could select the car following on the left behind and accelerate or decelerate it. Hence, it was possible to provoke critical lane-changing situations.

This scenario enabled a risk free and detailed examination of driving behavior and driving safety even in critical lane-changing situations within a realistic traffic environment.

### 5.2 Improvement in traffic simulation

Because of the ample visualization of the neighboring vehicles in real time, the test driver in the simulator can quickly compare the observed behavior of neighboring vehicles with his own driving experience and expectations. Limitations of the driver model become immediately apparent and lead to new hypotheses and suggestions for extensions of the driver model.

In this way, revisions and extensions of the model were triggered and their effects on the traffic could immediately be assessed. Due to the common external interface of the model, every extension was and will be available for both the traffic simulation and the driving simulator.

### 5.3 Basis for additional integrations

The decoupling of the driver model is the basis for using this universal model for applications in addition to the traffic simulation program PELOPS and the BMW driving simulator. The availability of a clearly defined external interface enables integration of the model into every application without having to know its internal details or even the source code. Only the view structures need to be filled by the application program.

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## 6 Outlook

Up to now, the driver model can simulate human driving behavior on multi-lane motorways. Any number of lanes can begin or end.

First efforts have been undertaken to extend the application range of the model to country and urban roads as well. Especially at intersections, the realistic guidance of vehicles forms a major challenge. While appropriate reactions to traffic lights have already been implemented within PELOPS, methods to integrate information about the intended route into the driving behavior are currently ported to the model from the BMW driving simulator (triggering i.e. appropriate lane changes towards navigation lanes). Extended data structures to provide all necessary information about crossing traffic have been developed; appropriate techniques are being integrated from the driving simulator and will be further developed.

Another extension of the driver model that is currently being implemented in a first version is a new “active lane gap search” as a substantial component of tactical driving behavior. A driver who wants to change lanes indicates his wish to the surrounding cars by activating the turn signal. He himself tries to fulfill his wish by adjusting his speed and “aiming” towards some gap on the target lane. The surrounding vehicles behave cooperatively by enlarging the gap when their “costs” i.e. in terms of necessary deceleration are not “too high”. The “acceptable costs” are modulated by the current driving situation. A model of the principal factors determining these acceptable costs has been established that allows for an even more realistic lane change behavior [2]. This tactical model will be integrated into future more advanced tactical driving behavior (e.g. changing lanes while approaching an intersection).

Generally tactical driving behavior is an important component of traffic dynamics. Therefore it should play an increasingly important role in traffic modeling as well. Advanced maneuvers such as overtaking with opposing traffic can only be described by means of a driver model considering tactical behavior.

Another important influence on human driving behavior is the non-rational reaction to traffic situations. At present, aggressive driving behavior is an object of research at the fka together with the IZVW (Interdisziplinäres Zentrum für Verkehrswissenschaft, Würzburg). In general the development of efficient psychophysical and psychological models for the main mental processes that influence driving behavior will become increasingly useful.

## 7 References

[1] Ehmanns, D.: "Modellierung des Fahrerverhaltens bei verschiedenen Verkehrszuständen zur Analyse von Fahrerassistenzsystemen". Diplomarbeit am ika der RWTH Aachen, 1996.

[2] Ehmanns, D.; Hochstädter, A.: "Driver-Model of Lane Change Manoeuvres". 7th World Congress on Intelligent Transport Systems, Turin, 2000.

[3] Ehmanns, D.; Ludmann, J.: "Investigation of the Traffic Flow in a Tunnel by Means of the Simulation Program PELOPS". In: Proceedings of IEEE International Conference on Intelligent Vehicles, Stuttgart 1998.

[4] Fastenmeier W.; Gstalter, H.; Zahn, P.: "Prospektive Risikopotentialabschätzung am Beispiel der Spurwechselassistenz", VDI-Berichte Nr. 1613, VDI-Verlag, Düsseldorf, 2001.

[5] Hochstädter, A.; Ehmanns, D.; Neunzig, D.: "PELOPS as a Tool for Development and Configuration" EUROmotor Telematic/Vehicle and Environment 1999: Adaptive Cruise Control, Series Introduction and Future Development, Aachen, 8-9 February 1999.

[6] Hochstädter, A.; Neunzig, D.: "Simulating Macroscopic Traffic Phenomena with a Microscopic Traffic Simulation Program" 1998 IEEE International Conference on Intelligent Vehicles, Stuttgart, 28-30 October 1998.

[7] Hochstädter, A.; Zahn, P.; Breuer, K.: "Ein universelles Fahrermodell mit den Einsatzbeispielen Verkehrssimulation und Fahrsimulator". 9. Aachener Kolloquium, Aachen, 5-6 October 2000.

[8] Lerner, G.; Hochstädter, A.; Kates, R.; Demir, C.; Meier, J.; Poschinger, A.: "The Interplay of Multiple Scales in Traffic Flow: Coupling of Microscopic and macroscopic Simulation". 7th World Congress on Intelligent Transport Systems, 6.-9.11.2000, Turin 2000.

[9] Lerner, G.; Hochstädter, A.; Meier, J.; Poschinger, A.: "Kopplung von Verkehrsflussmodellen unterschiedlichen Detaillierungsgrades - Realisierung und Anwendungen". 7. Aachener Kolloquium, 5.-7.10.1998, Aachen 1998.

[10] Ludmann, J.; Neunzig, D.; Weilkes, M.: "Traffic Simulation with Consideration of Driver Models, Theory and Examples". Vehicle System Dynamics, Vol. 27, 5-6, pp. 491-516, 1997.

[11] Manstetten, D.; Krautter, W.; Schwab, T.: "Traffic Simulation Supporting Urban Control Development". 4th World Congress on Intelligent Transport Systems, Berlin, 1997.

[12] MoTiV-ASA: Kurzdarstellung, "Zusammenfassung der Ergebnisse des Projekts ASA als ergänzende Information zur MoTiV Broschüre", information flyer, WES-Office, Kirchheim, May 2000.

[13] Neunzig, D.; Weilkes, M.; Hochstädter, A.; Ludmann, J.: “Assessment of Advanced Vehicle Control Systems with the Vehicle Oriented Traffic Simulation Tool PELOPS”. 1998 SAE Future Transportation Technology Conference, Costa Mesa, CA, 11-13 August 1998 (SAE-Paper 981890).

[14] Sparmann, U.: “Spurwechselvorgänge auf zweispurigen BAB-Richtungsfahrbahnen“. Forschung Straßenbau und Straßenverkehrstechnik, Heft 263, Bonn, 1978.

[15] Strobl M.; Löwenau J.; Bernasch J.; “Generation of Complex Traffic Scenarios in the BMW Driving Simulator“, Driving Simulation Conference 2000, Paris, France, 2000.

[16] Weilkes, M.; Hochstädter, A.: “Analyse neuer ACC-Strategien mit dem Verkehrssimulationstool PELOPS”. 7. Aachener Kolloquium, Aachen, 5-7 October 1998.

[17] Wiedemann, R.: “Simulation des Straßenverkehrsflusses“. Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe, Heft 8, 1974.

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