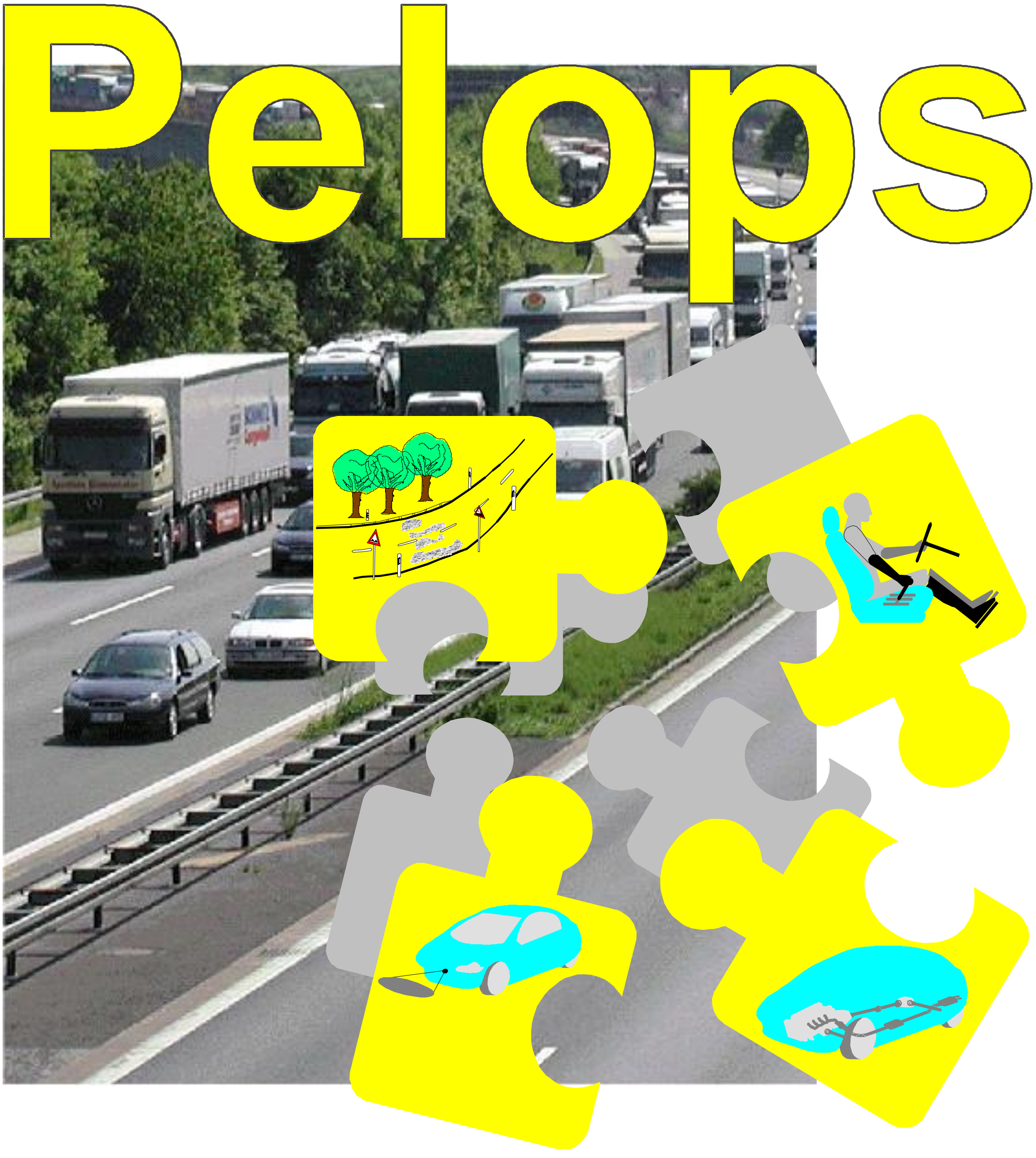
PELOPS
White Paper



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Contents

1 PELOPS

1.1 Introduction

The microscopic, vehicle-orientated traffic simulation program PELOPS (**P**rogram for the D**E**velopment of **LO**ngitudinal Traffic **P**rocesses in **S**ystem Relevant Environment) was developed by ika/fka in cooperation with the BMW AG [LUD89] [DIE95]. Today it is sold and maintained by fka.

PELOPS represents a combination of the models of detailed sub-microscopic vehicle model and microscopic traffic model. This allows for the analytical investigation of the vehicle longitudinal dynamic behaviour as well as the traffic flow. The advantage of this method is to consider all interactions that take place between the driver, vehicle and traffic.

Contrary to classical simulation tools in the automotive industry, which represent only a part system or single isolated vehicle, the core of PELOPS comprises the three significant elements of the traffic system – track/environment, driver and vehicle – and their interactions. These three elements are modelled in a modular program structure and defined by interfaces (Figure 1-1)

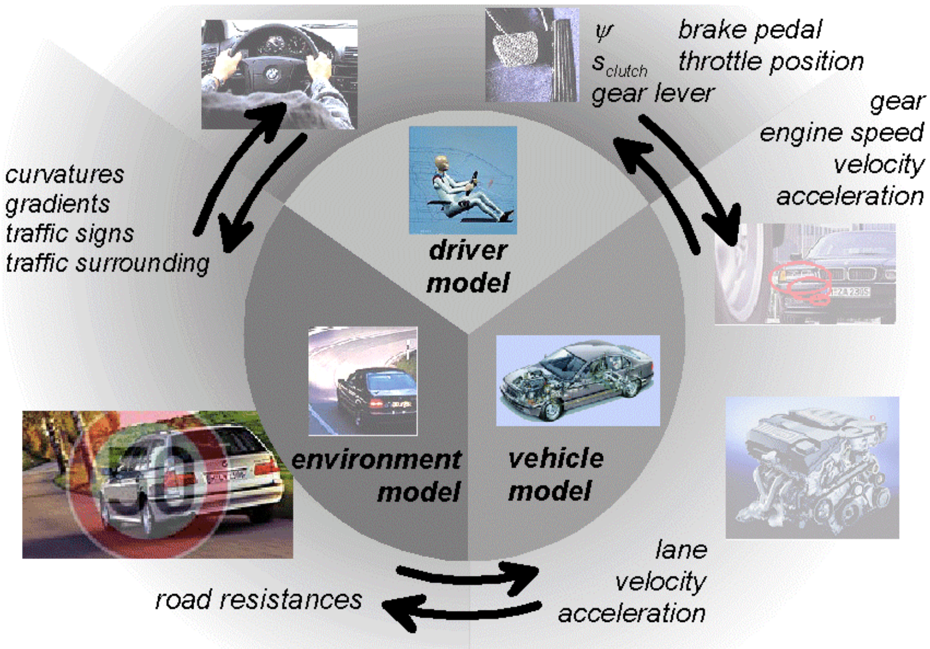

Figure 1-1: PELOPS structure

The influences of the traffic environment can be adequately represented by the environment model. The course of the road is described not only by radii and transitions in horizontal and vertical direction but also the number and width of lanes. In addition to this geometric information, the signposting and environmental parameters can also be simulated.

In the vehicle model, vehicle dynamic characteristics are calculated based on the actuating variables, such as pedal position and gear selection. Since the vehicle model is presented in a very detailed manner at the component level, parameters such as overall efficiency and fuel consumption can also be determined very precisely. The vehicle itself is modelled according to the cause-effect-principle [BEN01].

The connection between the vehicle and the traffic simulation is realised by the driver model. It is subdivided into a behaviour and an action model. In the behaviour model, the variables of the local driving strategy are determined according to the current driving status and the surrounding traffic situation. These variables consist of the desired acceleration, lane and gear choice. The action model converts the variables of driving strategy into actuating variables of the vehicle, such as pedal position, steering wheel angle, gearshift and the state of turning indicators [NEU03].

The behaviour model also consists of two parts; a Following, and a Lane Change model. The Following model describes the traffic in a single driving lane, in which it is not possible to overtake or change lanes. This Following model is based on the workings of Wiedemann [WIE74], and numerous aspects have been further developed by fka over the last ten years. The Lane Change model covers all traffic situations which appear on multi-lane roads, and in urban traffic. It contains not only the classic lane change situations (such as overtaking on multi-lane roads, avoiding obstacles, and lane changes in order to follow a route in a road network), but also tactical consideration such as using turn signals to obtain consent from other road users to enter a small gap [HOC01a]. The Driver and environment models together realise the generation of virtual traffic.

1.2 Vehicle model

The vehicle model is based on the cause-effect-principle, in which a calculation of the propulsion force is made by starting at the engine operating point through the clutch, gearbox and differential to the wheels. At this point the propulsion force is balanced with the driving resistances (Figure 1-2). The working point is changed by the variation of engine torque (cause). By considering the elements in the drive-train, the resultant acceleration, and the change of velocity, leads to a change of the engine speed (effect). Gearbox types implemented include conventional manual gearboxes as well as automatic gearboxes. Additionally, for utility vehicles, engine braking or retarder can be modelled in the drive-train. Using the cause-effect-principle, this detailed model of the vehicle allows for the analysis of automatic control devices e.g. ACC.

In addition to the described vehicle modelling method (which is called “real” vehicle in PELOPS), it is possible to work with a less complex vehicle model that demands less computing time to analyse traffic phenomena. Modelled vehicles are called as “synthetic” vehicles. They are described with a reduced dataset, which is composed of the following parameters: vehicle type, maximum engine power, maximum deceleration, overall weight, aerodynamic resistance and rolling resistance [WEI99].

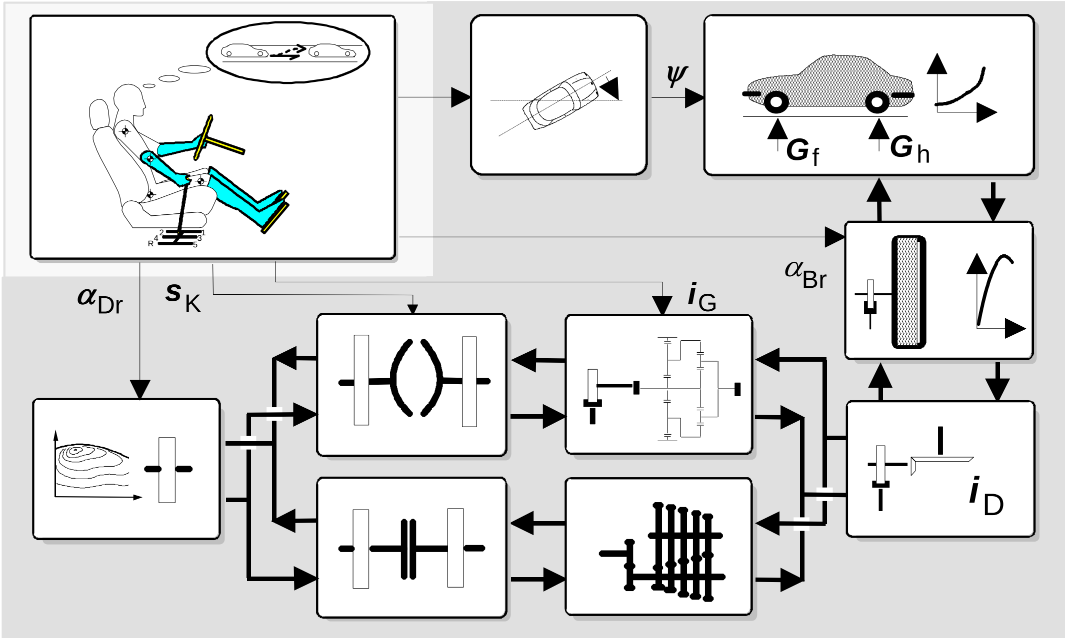

Figure 1-2: PELOPS vehicle model

In the vehicle model, the maximum velocity for each synthetic vehicle is first calculated according to the predefined maximum engine power. From the relation between the current and the maximum vehicle velocity, the current gear and the mass factor are determined with the help of a statistic method [DIE95]. Therefore the maximal possible acceleration in the current driving status can be calculated based on the balance of driving resistances of current and the maximal velocity under the simplified assumption of a linear engine map [BRE04].

In [BRE04] PELOPS, the vehicle model was expanded upon so that the vehicle lateral dynamic behaviour is also modelled. The difference between synthetic and real vehicles still lies in the computation of the lateral dynamics. Synthetic vehicles are simulated by means of a simplified single track vehicle model, in steady state circular driving. For real vehicles, the single track vehicle model with transient behaviour is used [WAL00].

1.2.1 Sensor model

The sensor module permits the user to position as many sensors as desired in arbitrary places on a vehicle. The sensor characteristics, such as opening angle, detection range and error rate can be given freely. The setting of the sensor data is determined by the so-called “sensor concept file” (Figure 1-3), which is selectable in the graphic interface of PELOPS. All the sensors, which are integrated in the vehicle, are summarised in this file. Each element in this concept defined sensor can have its own sampling rate.

```
PELOPS Version 4.0
*  Sensor concept example
   my_concept
*
*
*   NO. of Sensors
   2
*  Sensor No.    Position           Angle    Y-offset   X-offset   Update rate
*  [-]           1/-1 = front/rear  [°]      [m]        [m]        [s]
   3             1                  0        -.5        0          0.1
   4             1                  0        -.5        0          0.4
```

Figure 1-3: Sensor concept file, senso'x'.data[1]

There is an initialization file for each sensor specified in the sensor concept, in which the detection geometry, the detection error and the tracking are specified (Figure 1-4).

```
PELOPS Version 3.0
*  Sensor data
   Sensor_example
*
*
*  No. of sections     Occlusion          Noise             Ideal tracking
*  [-]                 0/1 = no/yes       0/1 = no/yes      0/1 = no/yes
   3                   1                  1                 1
*  Distance            Velocity           Ref. Centre       Edge
*  Max. error [m]      Max. error [m/s]   Max. error [m]    Max. error [m]
   5                   3                  0                 0
*  % error             % error            % error           % error
   10                  5                  0                 0
*  section length      Pol3               Pol2              Pol1
   50                  0                  0                 1
   70                  0                  1                 0
   80                  0                  0                 0.5
```

Figure 1-4: Sensor initialization file, sen'y'.data[2]

The parameters in these files are presented in the following. The keywords of the sensor definition are emphasised with *italic*.

1.2.1.1 Sensor position

Figure 1-5 shows the reference coordinates for sensors which are installed in the driving direction (*position* = 1) and opposite to the driving direction (*position* = -1). *Y-offset* [m] and

[1] x = Number of the sensor concepts

[2] y = Sensor number, according to the number in the sensor concept

X-offset [m] are specified according to these coordinates. The *angle* [°] refers to the axis of sensor (positive rotation direction = counter clockwise).

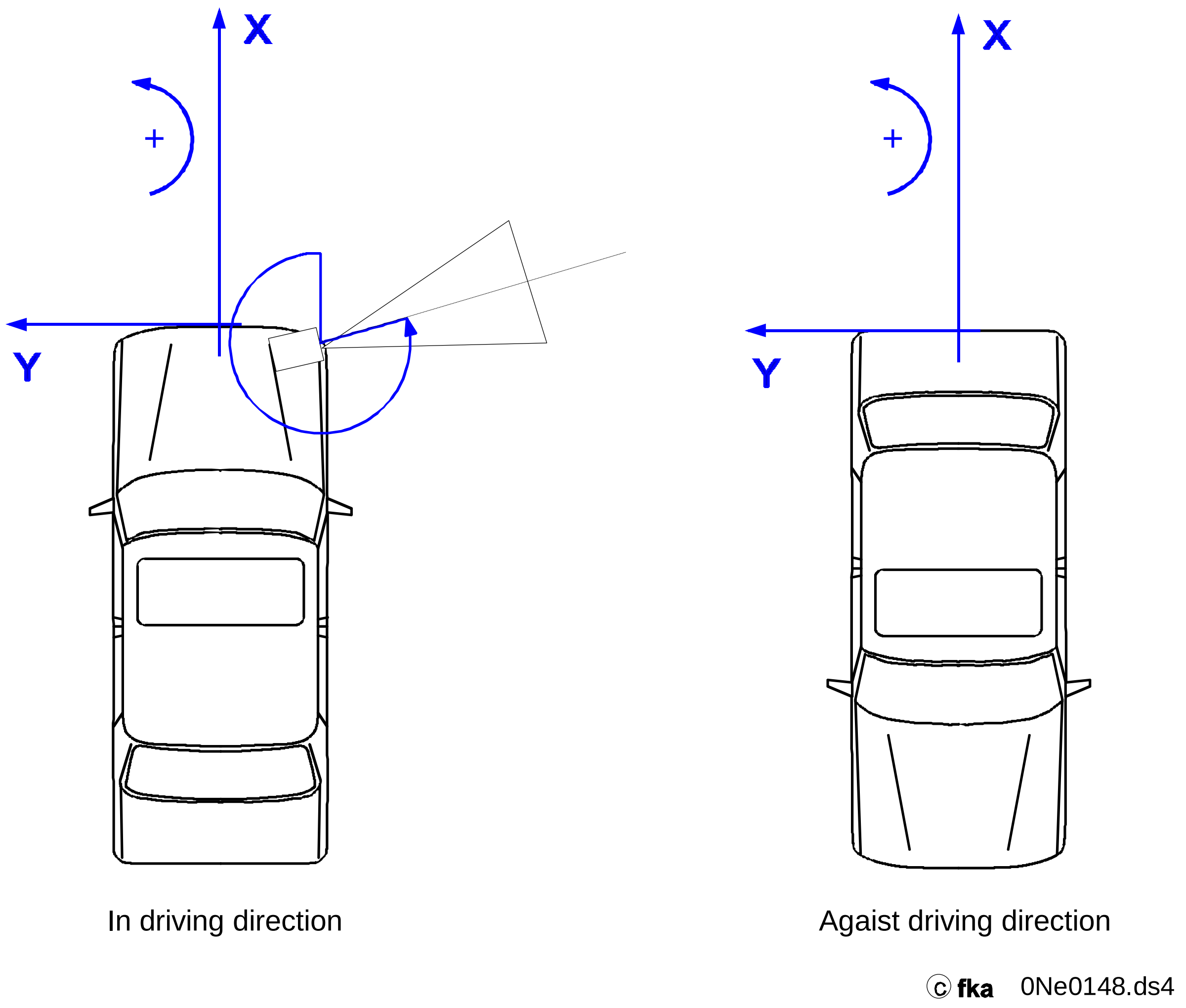

Figure 1-5: Definition of the sensor position

1.2.1.2 Detection geometry

The detection geometry of a sensor is defined *in sections* with the help of a 3rd order polynomial, which is valid on the left (positive sign) and on the right (negative sign) of the sensor axis.

$$\text{Detection\_boundary}_{left/right} = \pm(plo1 \cdot x + pol2 \cdot x^2 + pol3 \cdot x^3)\Big|_{1}^{No.\_of\_sections} \quad [m]$$

Sensor's detection boundary is specified in sections. This means that the x-coordinate for each sensor section is counted from 0 to its *absolute length*.

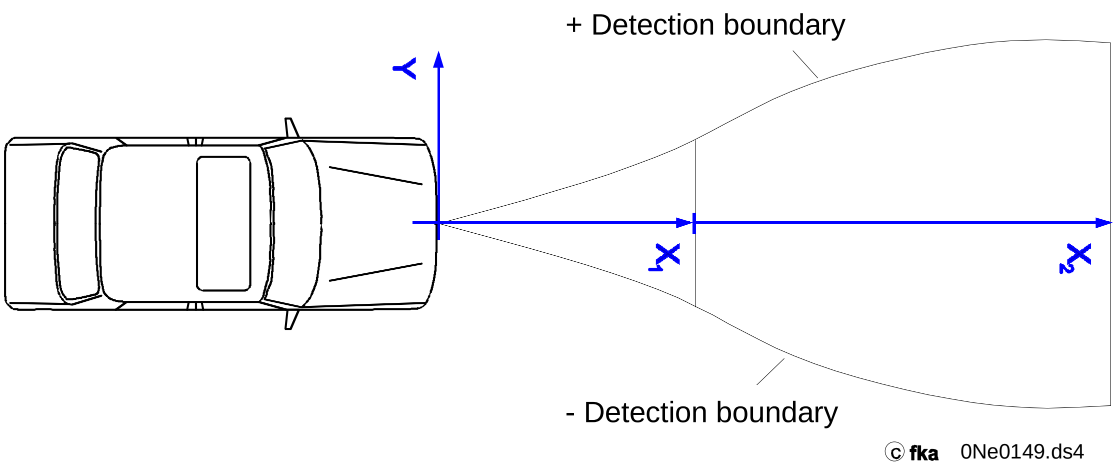

Figure 1-6: Definition of the detection geometry

Besides the detection geometry, it can also be specified whether the occlusion of a sensor's field of vision, which is caused by the edges of neighbouring objects, should be considered. For each occlusion, the shading angles are computed and evaluated.

1.2.1.3 Detection error

Detection by a sensor can take place error-free or with *noise* in the measuring data. If the *noise* option in the sensor initialization file is selected, the *maximum absolute* and *proportional detection error* for the variables:

- *distance* [m],
- *relative velocity* [m/s],
- lateral offset of the *reflection centre* on target object [m] and
- lateral offset of the closest contour (*edge*) on the target [m]

can be set separately.

The reflection centre is generated arbitrarily with a uniformly distributed random number on the rear of the vehicle. In each time step of the sensor, the *reflection centre* is generated again; it jumps back and forth on the rear of the vehicle. The characteristic *edge* represents the lateral distance to the closest outline of the target vehicle.

1.2.1.4 Tracking

Ideal tracking is activated by default. Alternatively a real tracking module can be integrated into the simulation environment.

1.3 Driver model

1.3.1 Following model

The model of the Following Behaviour is based on the psycho-physical approach of Wiedemann. Perception thresholds are defined based on driving velocity and driver-individual parameters; e.g. estimation abilities and safety need. Depending on the relative velocity and distance to the leading vehicle, these perception thresholds subdivide the driving into four parts: uninfluenced driving, approaching, following and braking. In Figure 1-7 the borders and ranges are schematically illustrated.

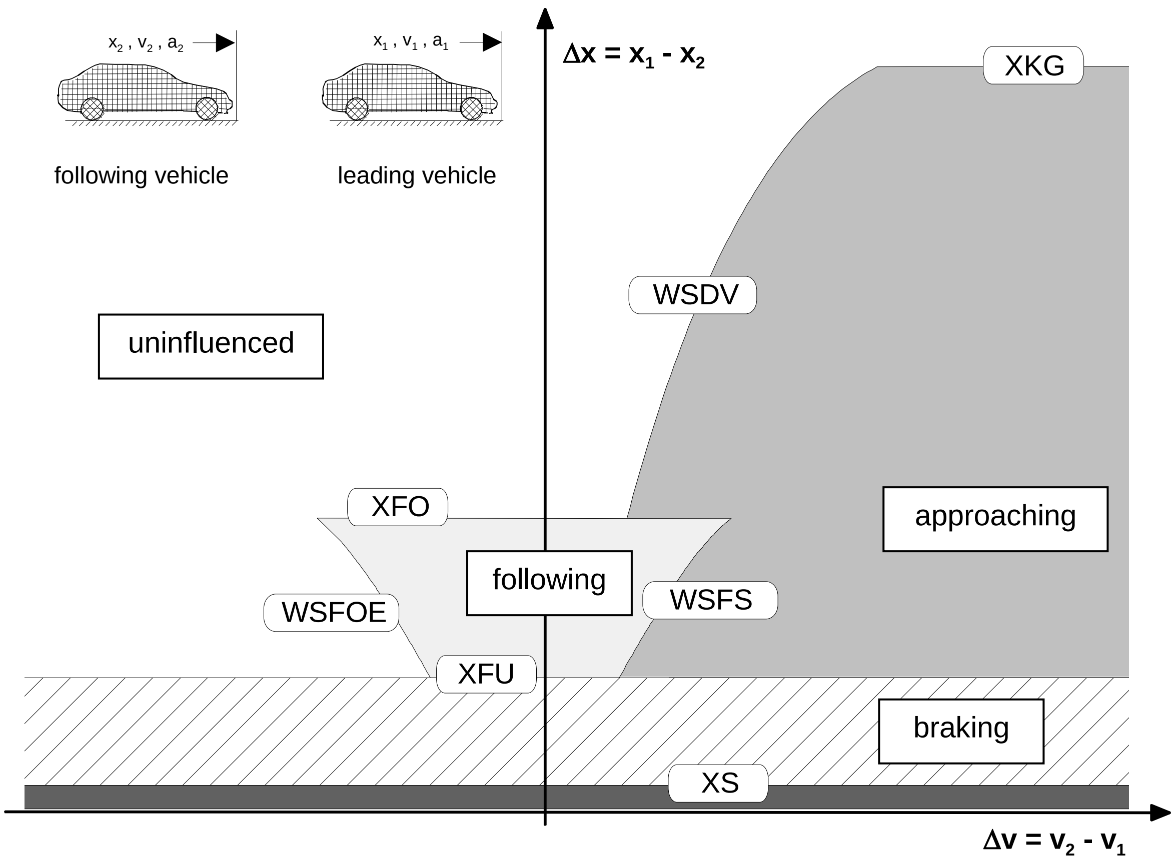

Figure 1-7: Perception model according to Wiedemann

The borders in the original model:

XS is the desired gross distance at standstill. It consists of the length of leading vehicle (according to Wiedemann 4.5 m [WIE74]) and a net distance depending on safety need.

XFU is the desired minimum distance while following. Besides the standstill distance (XS) another velocity-dependent distance is kept, which is influenced by safety needs. This velocity dependence is thereby parabolic.

XFO is the upper following distance. Depending on the driver it is in the range of 1.5 to 2.5 times the lower following distance, and is dependent on XS, XFU as well as estimation ability and daily variation.

WSDV is the perception threshold for relative velocity at a large distance. It depends on safety needs and estimation ability.

WSFS is the perception threshold for relative velocity at a small decreasing distance. It depends on the estimation ability, safety needs and daily variations.

WSFOE is the perception threshold for relative velocity at a small increasing distance. It is calculated using WSFS and the parameter for the daily variations. Together with WSFS, XFO and XFU, it limits the following range.

XKG is the boundary value for the perception of objects (other vehicles, signposts, etc.). The driver perceives only the objects, which locate within this boundary value.

Parameters such as estimation ability, safety needs and daily variation (which are necessary for the determination of the above mentioned variables), have a range between 0 and 1. These are standardised parameters, which are specified for the entire driver population and uniformly distributed around the average value of 0.5.

Four areas of differing behaviour are distinguished with the aid of the perception thresholds described above:

- Uninfluenced driving is characterised by no leading vehicle which the driver classifies as noteworthy. Within this area, the driver tries to hold or reach a desired velocity by acceleration.

- Within the area of consciously influenced driving, the drivers approach a perceived leading vehicle, which is slower. Therefore they try to keep an individual minimum distance and adapt the velocity to the leading vehicle.

- Following a leading vehicle with small relative velocity and small distance is represented by the area of unconsciously influenced driving. The drivers try to adapt their velocity to the leading vehicle, and keep the distance as constant as possible. However, the perception of velocity and distance, as well as the motor skills of drivers, are insufficient to adjust the acceleration via the pedal exactly. Thus the distance, as well as his velocity, varies.

- The last area is braking. If a critical distance is reached, the drivers brake, in order to avoid an accident.

For all areas, the treatment of the reaction time is the same. In the original model, the reaction time is represented by a computing step of one second. It is the range of human reaction time. By the actualisation of driver's wish in each time step the reaction time is fixed with one second.

As mentioned previously, the perception thresholds are velocity dependent; a typical approach process, which is characterised by variable velocities, can only be represented in a three-dimensional illustration. Figure 1-8 represents such a process for the approach to a constantly driving vehicle.

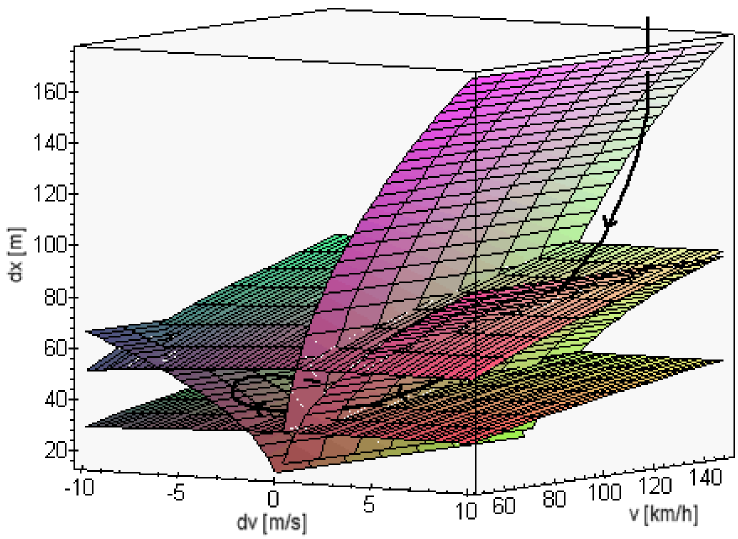

Figure 1-8: Approaching and Following

A noteworthy feature ofthis illustration is that the Following area can become very small, just like the braking area at low speed.

The Following model, according to Wiedemann, represents a very good basis for the description of the vehicle's longitudinal guidance in the traffic. However this model has limits, especially the exclusive consideration of highway traffic and fixed calculation step. These limits meant that a revision of the model was necessary [HOC01a].

By the adaptation of the driver model to the requirements of sub-microscopic simulation, [DIE05] the spectrum of possible behaviours was extended clearly. Thus, the model in PELOPS has amongst other abilities besides the reaction to the direct leading vehicle, the ability to consider foresighted the dominant traffic in front of it, to realistically execute the starting and stopping phases, particularly before traffic lights [LUD98], to show cooperative behaviour to other road users [BEN03a], and also to perform tactical lane changes [EHM02]. Beyond the modelling of normal behaviour, the model was extended by work in [MAA03] and [BEN03b] to represent the extreme behaviours. Different time steps in the consideration of driver assistance systems, as well as the modelling of nonlinear procedures in automatic transmissions, made it necessary to introduce an adjustable calculation step. Furthermore, the model was extended in such a way that different reaction times of the drivers can be considered. With its characteristics, the current version of the driver model can cover the relevant behaviours in the traffic situations on highways, country roads and in urban areas [BRE04].

1.3.2 Lane change model

Besides the Following model, the PELOPS driver model also contains a lane change model. The structures of all classical lane change models in the time-step-based simulation programs are always based on the same pattern. Firstly, it checks whether a lane change wish exists at all. Secondly, it will check whether a possibly existing lane change wish can be realized. After concluded assessment, the lane change is finally executed. This pattern (Figure 1-9) is the basis of all well-known lane change models (e.g. [GIP86], [HID99], [SPA78], [THE97]).

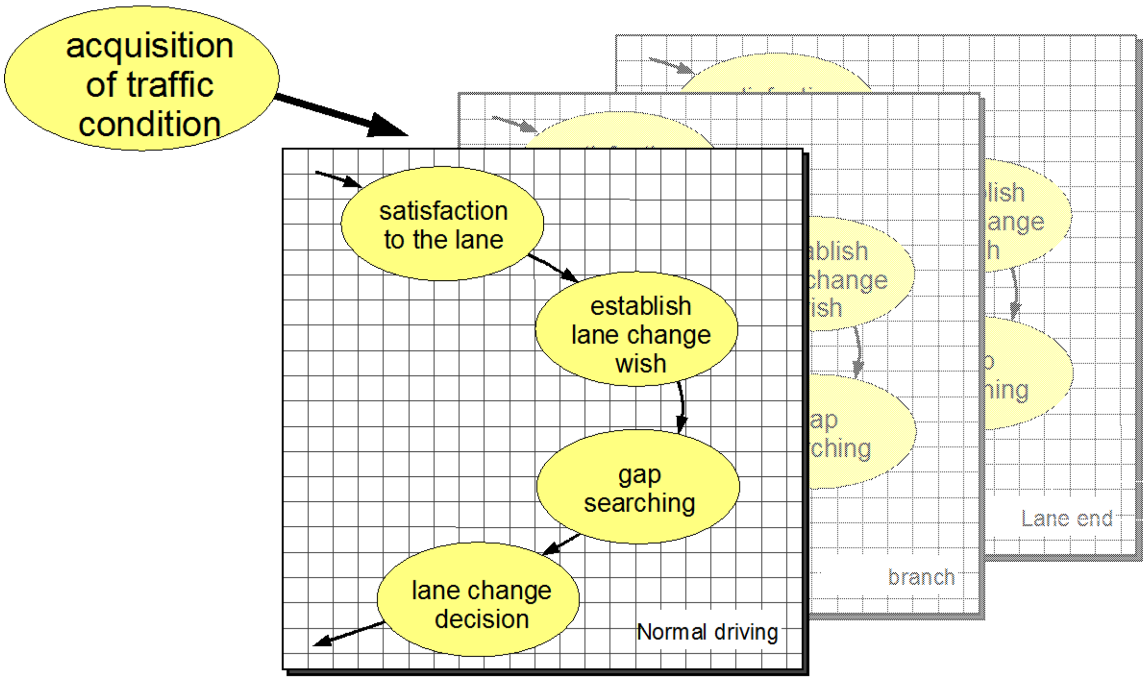

Figure 1-9: Structure of the lane change

There are many possible motivations for lane changing. Two common motivations are following a certain route and overtaking. Tactical considerations can also lead to a lane change. If a faster vehicle approaches from the rear, it could also motivate a lane change to the right lane. In order to keep the type and the number of distinguishable lane change motivations flexible, in PELOPS, a structure for the lane change model was selected, where all motivations are represented by a factor. Furthermore, different driver types should also be modelled in the lane change behaviour. The factor, which summarizes the lane change motivations, can be interpreted as satisfaction. In each time step this satisfaction is determined for each driver. Influencing factors include the driver-individual desired velocity in comparison with the current driving velocity, and the velocity on the neighbour lanes. The above mentioned faster vehicle, which approaches from the rear, reduces the satisfaction towards the current lane, whilst increasing the preference towards the right lane. The individual satisfactions are summarised by a value, which describes the overall situation. This satisfaction is driver dependent, since the desired velocity is a driver-dependent value.

The values of satisfaction are summed over time and weighted with a forgetting factor. This simulates a hypothetical process of forgetting, which can be assumed as compatible with the driver. As the time duration since a specific driving situation increases, so its influence on current behaviour decreases. The satisfaction values for the current lane and the two neighbour lanes are compared with each other. A hysteresis is considered, in order to avoid unstable lane change behaviour. Unstable lane change behaviour appears for example, if the traffic situations in all lanes are approximately identical. A marginal change in the neighbour lane would lead to a lane change. If hysteresis is introduced, the situation on the neighbour lane must be a better with regard to a predefined threshold, in order to trigger the driver's wish to change lanes. If the situation is slightly better during a longer period, summing the satisfaction leads to the exceeding of the hysteresis threshold after a certain time, and then to the driver's wish for a lane change. To convert the lane change wish, a multi-step acceleration behaviour for targeting a gap was realised. Thus, in addition to the lateral guidance, the longitudinal dynamics are also regarded. An acceleration phase is assigned to the lane change procedure before cut-out, either its purpose is to reach a suitable gap or to adjust the velocity to that of the relevant vehicles in the target lane. Altogether, the conventional consideration of the pure lane change procedure is extended by the tactical driver behaviour, described by the acceleration process [NEU03].

1.3.3 Driver-dependent influencing variables

Driver-dependent influencing variables in the behaviour model includes, for example, safety needs, or the estimation ability of distance and velocity. By these parameters it is already possible to model different driver characters (e.g. "sporty driver"). "Safety needs" is the most important parameter in the driver model: It affects all distance-dependent behaviours. A High safety need translates to a larger following distance. The size of the gap in the neighbour lane, which is necessary for overtaking or a lane change procedure, rises likewise with higher a safety need. Additionally, the choice of velocity is also affected by it. The parameters "estimation ability" and "pedal sensitivity" serve as model inputs for the description of inadequacies of the driver during the estimation of distance or relative speed, and the operation of vehicle variables like accelerator pedal, brake pedal and steering. Reaction time is classified with four categories: standard driving, reaction in a potentially dangerous braking manoeuvre, lane change, and starting of the leading vehicle. Additionally the driver model processes individual levels of compliance of overtaking prohibitions (e.g. right overtaking).

A sporty driver can be described in the simulation with PELOPS for example by a low safety need, good estimation ability and high pedal sensitivity. Low safety needs of a sporty driver translates to essentially lower following distances, and the gaps, which the driver uses for lane change, are significantly smaller than a normal driver. At the same time, the sporty driver is willing to accept small distances and gaps, which are presented to him by the surrounding traffic. Good estimation ability and high pedal sensitivity denote good control of his actions in this context. These two parameters have however only a small influence on the modelled driver behaviour, and are less important in comparison with the safety need. Furthermore the sporty driver is described by an appropriate parameterisation of the values “reaction time” and “level of compliance”. His reaction time is possibly low, likewise his level of compliance for speed limits (i.e. he drives much faster than permitted). Analogous to this example, other “driver types” (safety orientated, economical etc.) can be simulated by a suitable choice of the driver parameters. For the simulation, a validated set with hundreds of standard driver types is available in a statistic distribution. Here typical passenger car drivers are covered, as well as various types of truck driver [NEU03].

In the following, the individual driver parameters are described [HOC01b]:

- Desired velocity (0... ∞):
  The desired velocity describes the velocity which the driver would like to drive on a free road, by free driving without speed limit.

- Max. possible deceleration (0... ∞):
  The maximal possible deceleration is a limitation of the negative acceleration values. It is designated in m/s^2. The physically reasonable maximum value is not higher than that of gravity g (= $9{,}81 m/s^2$).

- Utilisation of vehicle acceleration (0...1):
  The utilisation of vehicle acceleration indicates what percentage of the maximum achievable acceleration will actually be used in a certain instance. If the value is zero, the vehicle will not accelerate at all. The designation is dimensionless.

- Safety need (0...1):
  Safety needs iare a complex driver parameter, whose influence is most significant in distance behaviour. The larger the safety need, the larger the distance is. A safety need of 0 describes an extremely risk-seeking driver, whereas a very careful driver is described by a value of 1. The designation is dimensionless. Wiedemann [WIE74] designates this parameter as normally distributed with an average value of 0.5 and a standard deviation of 0.15.

- Estimation ability (0...1):
  Estimation ability also has an influence on many values. An estimation ability of zero represents a very poor ability to estimate the position and movement of other vehicles; the value 1 describes a very accurate estimation of the actions of other vehicles. The designation is dimensionless. Wiedemann [WIE74] designates this parameter as normally distributed with an average value of 0.5 and a standard deviation of 0.15.

- Pedal sensitivity (0...1):
  A value of zero describes very poor control of the accelerator pedal, a value of one however means that the driver can accelerate very precisely. The designation is dimensionless. Wiedemann [WIE74] designates this parameter as normally distributed with an average value of 0.5 and a standard deviation of 0.15.

- Speed limit compliance (0...1):
  The grade of speed limit compliance represents how much the driver is willing to drive faster than the speed limit. A value of zero means that the driver does not follow the speed limit; he drives up to 1.5 times faster (for example up to 180 km/h with permitted 120 km/h). In contrast, a value of one describes the accurate compliance to all speed limits. The designation is dimensionless.

- Compliance with an overtaking prohibition (left overtaking, right overtaking, left/right overtaking, compliance of all):
  The compliance with an overtaking prohibition is to a large extent self-descriptive. “left overtaking” means that, despite the prohibition, the driver is willing to overtake on the left. “left/right overtaking” is thus equivalent to a driver, who does not follow the overtaking prohibitions at all. The designation is dimensionless.

- Max. foot braking force (0... ∞):
  This parameter is only considered for the simulation of real vehicles. The maximum foot braking force describes the force, which the driver can apply on the brake pedal. It is measured in Newtons. The maximum value of 500 can be assumed for the maximum foot braking force, since in the analysis, it has been found that in the scenarios without emergency braking, realistic results can already be obtained from 200 Newtons.

- Controller parameter k_p (0... ∞):
  This parameter is only considered for the simulation of real vehicles. The conversion of the driver’s acceleration wish to a pedal position is modelled by means of a PI-element. k_p indicates the proportional amplification. Simulations show that k_p may not take negative values, otherwise the behaviour becomes unstable. In order to remain close to the stability limit of zero, this value should not exceed 1.

- Controller parameter k_i (0... ∞):
  This parameter is only considered for the simulation of real vehicles. The controller parameter k_i describes the weighting of the integral part in the PI-element. Simulations show that k_i may not take negative values, otherwise the behaviour becomes unstable. In order to remain close to the stability limit of zero, this value should not exceed 1.

- Max. pedal adjusting speed (0... ∞):
  This parameter is only considered for the simulation of real vehicles. The maximum pedal adjusting speed describes the speed with which a jump response of acceleration, or a deceleration, can be executed. The value zero means that the pedals can not be ad-

justed at all. Changes in acceleration, and thus the speed, are also attributed to the driving torque. It is designated in 90°/s.

- Normal reaction time (0... ∞):
  The reaction time in PELOPS is realized as a ring buffer. As a reaction to the current traffic situation, the acceleration is calculated. This is written in the ring buffer, and kept therein until the reaction time run off. Only then is the acceleration read and converted to the position of the actuator in the action model. The reaction time does not change the driving behaviour, but it translates to latency in the reaction to the traffic situation. In this way, the reaction time indirectly generates another behaviour, because the traffic situation - casually formulated – has been changed in one second without doing anything. It is designated in seconds.

- Reaction time by braking (0... ∞):
  The reaction time by braking plays a role only if the driver is in the driving situation “braking”. The operating mode is the same as normal reaction time. It is designated in seconds.

- Reaction time by lane change (0... ∞):
  The reaction time by lane change plays a role only if the driver is in the driving situation “lane change”. The operating mode is the same as normal reaction time. It is designated in seconds.

- Reaction time by starting (0... ∞):
  The reaction time by starting plays a role only if the driver is in the driving situation “starting”. The operating mode is the same as normal reaction time. It is designated in seconds.

- Lane preference (0,1,2,3 ... ∞):
  Lane preference describes the favoured lane of the driver. Depending on the surrounding traffic situation, the driver also leaves this lane e.g. to overtake an extremely slow vehicle. He will return to his preferred lane after the overtaking manoeuvre. A value of 0 means that the driver does not have a preferential lane.

1.4 Environmental model

If necessary, the environmental model allows for a detailed description of the influences of the stationary traffic environment. This not only specifies the course of the road in the horizontal and vertical directions by radii, clothoids, gradients and vertical curve radii, but also the number, and the width of lanes. In addition to this geometrical data, road signposts, lane markings, as well as environmental condition can be predefined by parameters such as humidity, slipperiness, and range of vision. The current traffic conditions for a vehicle are determined by the number of surrounding vehicles, as well as their distance and velocity. In order to provoke certain behaviours in traffic, or reproduce the predefined driving cycles, certain movement profiles can be designated to single driver-vehicle-unit. The insertion of the vehicles at the beginning of the course can be realised on the basis of macroscopic (traffic volume, average velocity, and portion of truck in each lane) or microscopic (type, inserting time, velocity, and lane of each vehicle) traffic data. Furthermore, it is also possible to perform the simulation as an "endless loop", in which the end of the course is connected to its beginning.

1.5 Hardware-in-the-Loop – Software-in-the-Loop

Since [BRE04], it is possible to use PELOPS as a rapid prototyping tool for the development of assistance systems. Thus, it is no longer obligatory to merge the algorithms and functions directly in PELOPS as source code when simulating new system concepts. Both hardware components and software programs can be operated with PELOPS in a coupled simulation. In addition, PELOPS provides a network connection; a serial interface, which allows for example the coupling with dSpace hardware, and a CAN bus as interfaces.

The execution of hardware-in-the-loop (HiL) simulations requires generally a simulation in real time. This means that the time unit in simulation lasts the same length as in reality. This is necessary, because the tested components must be exposed to the same boundary conditions as their deployment in a completely real environment. Thus, it shows for example whether the processing speed of an examined controller is sufficient for its tasks, whether the used data transmission rate between individual components in a system is high enough, or whether mechanical control elements can be driven precisely enough, in sufficiently little time [BRE04].

In hardware-in-the-loop, the synchronisation of PELOPS is realised with a real-time reference value. This reference value can be made available either by the real-time quartz clock component, which is available in each PC, or by a component, which takes part in the simulation, and is equipped accordingly. With an external time reference, it must be guaranteed that the corresponding supplier is able to control its time basis, and detect any possible errors by itself, otherwise the entire simulation would run incorrectly, and the results would incorrect [BRE04].

If no component with external real time basis is available, the HiL variant of PELOPS uses the clock component in the PC. This component is autonomous and independent of the computing load of the processor, so a constant time basis can be assumed. The use of the clock component, as an internal time basis, becomes necessary during a HiL-simulation of PELOPS with a direct connection to the CAN bus. Since this data bus does not offer fixed time slots for each bus participant, it cannot be accepted as a reliable source for a time basis [BRE04].

In order to avoid incorrect results, generally the simulation is broken off immediately by real-time deviation; the user is informed about this circumstance. Since this scenario usually only occurs due to too high a computing load, the user can simplify his simulation scenario, as well as increase the performance of the corresponding component. With a PC, this can be achieved for example by stopping processes which are not currently necessary [BRE04].

Contrary to HiL simulation, a software in the loop simulation normally does not have to run in real-time, because the time basis of the software, which has to be supplied with data, does not run in real-time either. In order to ensure the consistency of the simulation data in this case, all programs involved must be synchronised. The necessary synchronisation of all participants is made at the interfaces for data exchange, as both PELOPS, and the coupled software, can wait arbitrarily long in the current time step for the data from other components. For the realisation of such a synchronisation, a common time step on both sides is necessary during the calculation or at the data interface [BRE04].

1.6 Operation

In the following section, an overview of the operation of PELOPS is given. Detailed explanations for operation can be found in the PELOPS training material.

The described models (driver model, vehicle model and environmental model) make up the computation core (“Solver”) of PELOPS. The computation runs without dialogue with the user, so that it can also take place in a batch processing. In order to compose a simulation in a simple manner, PELOPS contains a graphic interface which allows dialogue with the user (“Pre-process”). Since the Solver generates pure number columns as simulation results, which is not possible for the user to assess directly, additional programs (“Post-process”) are available for the transformation, illustration, and animation of the results. Figure 1-10 clarifies the structure of the program system.

In the Pre-process, the user can build up the driver-vehicle-units either from data separately, or resort to the standard data sets of individual components, or the complete units, which are contained in a library. The same is valid for the gradient, curvature and signposting of a course. In order to simplify the input of the driver vehicle units (DVU) for larger traffic scenarios, a DVU generator was developed, which distributes the single datum according to the statistic boundary conditions on the basis of a few parameters (e.g. number of DVU, truck portion, average velocity, etc.). With the help of a graphic output, the composed scenario can finally be examined. Besides the composition of the simulation scenario, the boundary conditions also have to be defined; for example the duration of simulation, the time step of computation as well as of the output. Furthermore, those data, which are important for the analysis, can be selected from the multitude of possible result data for the vehicle status, driving condition, or driver behaviour.

After the computation, it is possible to process the results statistically, graphically or as animation with different types of post-processing. The statistic processing provides the opportunity to create fundamental diagrams, or frequency distributions of the velocity and distance, for each measuring loop. Thus, a simple result comparison with real measuring loops in the traffic, becomes possible. The graphic processing provides arbitrary point or line illustrations of the results for each driver vehicle unit. In the animation “Bird's Eye” an observation on the traffic flow from above is available. Since [BRE04] it is possible to view a 3D-animation during the simulation from driver’s view in a reference vehicle, which has to be selected before the simulation starts.

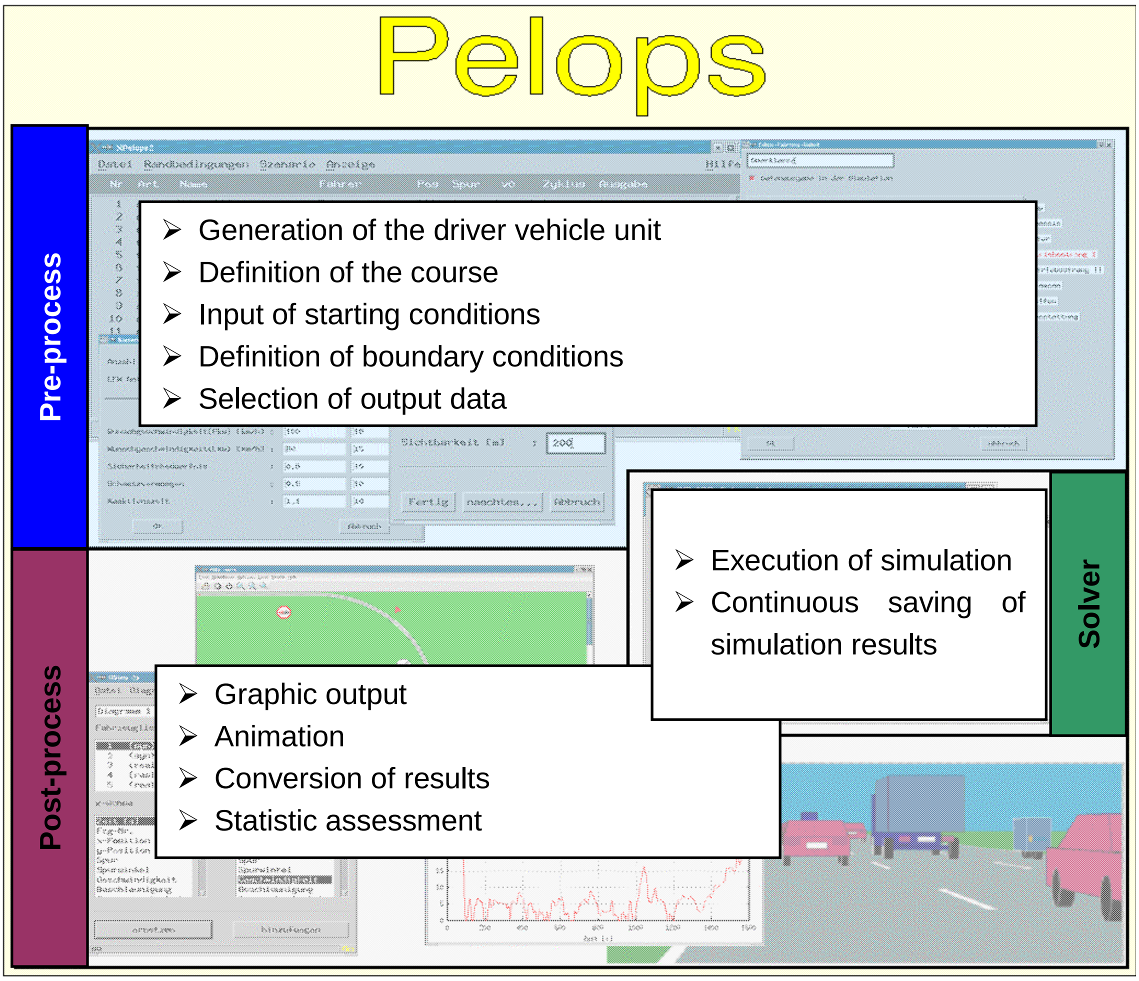

Figure 1-10: Structure of PELOPS’ program system

1.7 Output

For each vehicle-driver-unit (at user defined frequency, e.g. 1 Hz):

- road position [m]
- lateral position [m]
- lane [-]
- rel. lane angle [rad]
- velocity [m/s]
- acceleration [m/ss]

- abs. x-coordinate [m]
- abs. y-coordinate [m]
- abs. z-coordinate [m]
- abs. yaw angle [rad]
- odometer [m]
- distance to vehicle ahead [m]
- relative velocity to vehicle ahead [m/s]
- timegap [s]
- TTC [s]
- driving condition switch [-]
- lane change wish driver [-]
- turning indicator [-]
- desired acceleration driver [m/ss]
- driving resistance force [N]
- max. possible acceleration [m/ss]
- yaw rate [rad/s]
- width of lane [m]
- distance between middle of lane and right side [m]
- steering angle at wheel [rad]
- current slope [-]
- act. curvature in the middle of lane [1/m]
- pedal position [%] (only detailed vehicle model)
- pedal speed [90°/s] (only detailed vehicle model)
- clutch-pedal state [-] (only detailed vehicle model)
- engine speed [1/min] (only detailed vehicle model)
- engine torque [Nm] (only detailed vehicle model)
- engine power [W] (only detailed vehicle model)
- current fuel consumption [g/h] (only detailed vehicle model, only if included in engine map)
- total fuel consumption [l] (only detailed vehicle model, only if included in engine map)
- current CO emission [g/s] (only detailed vehicle model, only if included in engine map)
- current HC emission [g/s] (only detailed vehicle model, only if included in engine map)
- current NOx emission [g/s] (only detailed vehicle model, only if included in engine map)
- total CO emission [g] (only detailed vehicle model, only if included in engine map)
- total HC emission [g] (only detailed vehicle model, only if included in engine map)

- total NOx emission [g] (only detailed vehicle model, only if included in engine map)
- clutch torque [Nm] (only detailed vehicle model)
- current gear [-](only detailed vehicle model)
- brake force front [N] (only detailed vehicle model)
- brake force rear [N] (only detailed vehicle model)
- driving torque [Nm] (only detailed vehicle model)
- torque converter: torque multiplication (=1 if declutch) [-] (only detailed vehicle model)
- angular acceleration (automatic gearbox) [m/ss] (only detailed vehicle model)
- angular speed (automatic gearbox) [m/s] (only detailed vehicle model)
- lockup clutch (automatic gearbox) [-] (only detailed vehicle model)
- ACC status [-] (only detailed vehicle model)
- trailing throttle fuel cutoff [-] (only detailed vehicle model)
- retarder stage [-] (only detailed vehicle model)
- overrunning clutch state [-] (only detailed vehicle model)
- sideslip angle [rad] (only detailed vehicle model)
- sideslip angle rate [rad/s] (only detailed vehicle model)
- retarder torque [Nm] (only detailed vehicle model)

In addition, macroscopic data can be computed by means of virtual induction loops placed by the user.

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