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Intelligent Monitoring and Adaptive Competence Assignment for Driver and Vehicle

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Abstract— **This paper presents a concept for achieving higher safety in road traffic by addressing long and short term reduced capability of the driver in regard to his driving task. Pivot point of the proposed concept is the continuous monitoring of the driver and the vehicle's state and their competence assignment. For this purpose, the driver and vehicle will be treated as one system and regarded under cybernetic aspects. For estimation of the driver's condition or capability respectively, an approach is suggested, which combines data of the vehicle sensory equipment with methods for monitoring drivers.**

I. INTRODUCTION

Modern vehicles enable individual mobility for the users. In most industrialized countries the life expectancy has grown and is likely to rise in the future also. In addition the change in family structures to smaller, individualized and separate holds, brings the necessity to enable individual mobility in a longer period of life and/or for an extended circle of acquaintances (e.g. for those individuals with illness-caused limitation of the driving ability) than so far.

Elderly people have mostly more experience in driving motor vehicles than younger ones. On the other hand, there are some individual changes that occur with increasing age, which can lead to dangerous traffic situations. These include chronic or acute illnesses exactly the same as restrictions in the perception of the environment and/or the speed of decision making and execution[1]. Hereby, it should be considered that this circumstance is usually recognized too late by the concerned.

Due to these problems, a concept by which it's possible to achieve the goals specified here, will be presented in the following. The suggested solution is not limited in its applicability to the employment by individuals in late life phase. Fatigue symptoms or obstructions are fundamental problems, which can lead to dangerous situations. With the developed concept, an increased safety in traffic can be achieved by purposefully addressing special, suddenly or durably arising restrictions in the abilities of the vehicle and/or driver. In addition there is a need for monitoring drivers to detect alcohol or drug misuse as well as fatigue since these drivers must not participate in road traffic for lack of cognitive fitness. That's because now and in the mid-term future the driver will remain the responsible part for all actions of the system driver - vehicle, despite the increasing add by driver assistence systems.

II. CYBERNETIC ASPECTS

Systems which integrate humans, which are led by humans and/or which have effects on humans should be realized in the form of decision making support due to legal and moral reasons [1][2].

At the Institute of Information and Data Processing (IITB) Karlsruhe of the Fraunhofer Gesellschaft, several projects regarding autonomously driving systems have been accomplished in co-operation with universities and industrial partners [3][4]. These show inevitably that an introduction of automatic vehicles in the road system of Europe cannot be realized with ease in the near future.

This critical evaluation results in the following requirements for the further views:

1) Acting humans remain the legally responsible part of the overall system.
2) Only if the responsible person does no longer possess the necessary minimum driving capability, an automatic emergency system secures the driver and the vehicle.
3) Due to situation- and task-dependent changes of the condition/capability of the responsible person, technical systems (assistance systems) support him both in the reduction and in the observance of barriers.

These conditions represent the basis for the design of a cybernetic concept and strategies for the state-dependent determination of condition and assignment of competence to driver and vehicle.

The cybernetic decision structure for the guidance of mobile systems/vehicles is based on the 3-level hierarchical structure consisting of the levels autopilot, maneuver- and mission management. The task distribution between the human and the vehicle within the levels is situation and task dependent and has changed drastically in the last years.

The levels of the decision structure are outlined closely in the following:

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[1]Restrictions in the human/driver actuators can be relatively compensated by technical systems.

Level 1, the autopilot is responsible for all control tasks in the vehicle.

The maneuver management (level 2) comprises among other things the tasks for starting, driving, track switching, overtaking, parking, stopping, etc.. For these tasks, assistance systems for the driver have been successfully developed. With help of the suggestions proposed by the assistance system, the driver can realize the desired or necessary maneuver.

In level 3, the mission management, the planning, control and re-planning of a mission (course, way in 2D) are processed. These tasks take the target given by human as input. Planning, control and possible re-planning are done in a computer-aided way.

The distribution and competence assignment to the human and the vehicle has undergone an enormous change in the last century. In the beginning of vehicle development (approx. 1910) the driver solved several tasks of level 1 and all tasks of levels 2 and 3, where as today the driver already experience a great relief in the levels of the maneuver and mission management. Today, many tasks of the autopilot are taken over by an automated system.

The authors assume that this development of automation and assistance systems will continue, but humans must and will further have the responsibility in the levels of mission and maneuver management.

III. STRATEGIES FOR DETERMINING DRIVER CONDITION AND CAPACITY

Driver fatigue or hypo-vigilance have been identified as major cause for road accidents since years [12][13]. Because this, extensive research has been made in the past and is conducted presently to develop systems which detect fatigue and therefore are able to warn the driver. These systems can be categorized concerning the sensors used. In regard of real-time on-board approaches, these can be divided in those which use vehicle-based sensory data [14] and those which use driver-related sensory data [15]. In respect to the second group only non-intrusive methods should be regarded here, which mostly rely on vision-based systems in the manner of eye-movement or gaze detection for example [15]. The problem related to this methods is, that they are not able to be applied to the whole spectrum of drivers. Also they are often related to a need of high computing power. However driver fatigue is one form of unawareness, which is mainly characterized by a relatively slow change in driving parameters. In general it can be stated, that driving behaviour is not only different from driver to driver, but also differs for one driver in an individual range, for reasons of personal change over time. Newer developments of driver monitoring systems do also combine both strategies stated before and do use multi-sensory approaches [15]. Though this seems also promising to the authors of this contribution, in general this way will be considered here, while taking into account practical aspects in choosing the sensory data used for driver monitoring. In any case within the approach explained here, not a specific form of unawareness is considered, but by use of intelligent methods of driver monitoring, the current driver condition and capacity in relation to his driving task shall being estimated. Moreover through an innovative competence assignment strategy to driver and vehicle, short- but also long-term reduced capabilities of the driver should be faced in a manner that safe travel for all traffic members can be guaranteed at a best possible way. However it's also an important task of driver monitoring to detect drivers with insufficient cognitive fitness i.e. through alcohol or drug misuse, since these drivers must not participate in road traffic. Initial point for further development is the goal that the overall system (driver and vehicle) solves all problems situation- and task-oriented sufficiently. Due to the aim of monitoring the driver not only in regard to specific fatigue symptoms and to warn him respectively, but also to make an estimation for his driving capability and condition, an adequate system description is necessary. Therefore the concept proposed here relies on models for the driver and the vehicle. In addition the effects of driver assistance systems offered by the vehicle are integrated into the model of the driver. This will allow addressing reduced driver capabilities in a purposeful way later on.

A. *Model of the driver*

The behaviour of the driver is a nonlinear dynamic multi-variable system with n-sensory organs as inputs and j-actors/motoric organs and can be expressed in form of the laplacian transfer function for the j^{th} actor [16]:

$$G_{D,j}(s) = \sum_{i=1}^{n} g_{j,i} e^{-s\tau_{j,i}} \tag{1}$$

In this description $g_{j,i}$ is the sensitivity factor/amplification and $\tau_{j,i}$ the delay/deadtime of the driver.

In this contribution a general strategy will be presented to model changing driver behaviour over time. With this it will not only be possible to incorporate fatigue and hypo-vigilance, but moreover it integrates a much broader set of changing driver parameters. This will be achieved by ascribing changing driver behaviour in the manner of condition or capacity to the main parameters discussed before, namely driver sensitivity and delay. Due to overexertion, aging, illness, medicines, drugs etc. the parameters of the behaviour of the driver are not constant and thus time-variant. Therefore the parameters driver sensitivity and delay have to be considered as time-variant functions $g_{j,i}(t)$ and $\tau_{j,i}(t)$. To integrate the variety of driver assistance systems available today, they are also included by their effect on both parameters driver sensitivity and delay. Assistance systems can compensate the temporary or the long-term change of the parameters in the behavioural model of humans substantially. Thus already today the parameter sensitivity $g_{j,i}(t)$ is realized by load amplifiers with the gain g_F in brake and steering devices in the form

$$g^*_{j,i}(t) = g_{j,i}(t) \cdot g_F \tag{2}$$

The increasing response time i.e. due to aging can be substantially reduced by a combination of sensors in the form of cameras, lasers, radar, etc. and warning signals [6]. Therefore,

$$\tau^*_{j,i}(t) = \tau_{j,i}(t) - \tau_F \tag{3}$$

with τ_F as a warning time of the assistance systems of the vehicle.

As a new universal model of the driver, which includes the assistance systems for the sensoric and motoric of humans the following is suggested:

$$G^*_{D,j}(s) = \sum_{i=1}^{n} g^*_{j,i} \cdot e^{-s\tau^*_{j,i}} \tag{4}$$

B. Vehicle model

Beside the driver model in equation 4, the strategy of competence estimation does also need an appropriate vehicle model. It has to describe the respective motor vehicle type and adapt the dynamics sufficiently. Generally, these vehicle models consist of submodels for the longitudinal dynamics and the lateral dynamics.

In the submodel for the longitudinal dynamics, the engine moment $M_E(t)$, the brake cylinder pressure $P_{Br}(t)$ as well as acceleration in longitudinal direction $a_O(t)$ are used among other things as substantial measured variables. For the vehicle lateral dynamics the inputs are the curvature of the road C_{St}, the inclination of the road $I_{St}(t)$ and the front wheel steering angle ϕ_s while the lateral deviation acceleration $a_A(t)$ is the output. The universal model of the vehicle consists of the submodels for the longitudinal and lateral dynamics resulting in the structural schema shown in Figure 1.

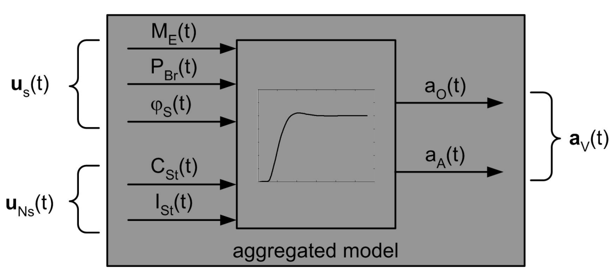

Fig. 1. Structure of model of the vehicle dynamics

For the model-based on-line component estimation by the driver, it is substantial that the inputs, engine moment, brake pressure and guidance angles are measurable and controllable (vector u_s), the curvature and inclination of the road are measurable. However, they are not controllable by the driver and therefore aggregated to the vector u_{Ns}.

The represented model structures were successfully applied among other things for the design of driver assistance systems for traffic congestion situation by the Volkswagen AG [7]. Moreover the vehicle model does include the essential parts of the environment. To estimate the driver's condition and for competence assignment the individual models explained before have to put together within a cybernetic structure. The resulting system description for further analysis is therefore depicted in Figure 2.

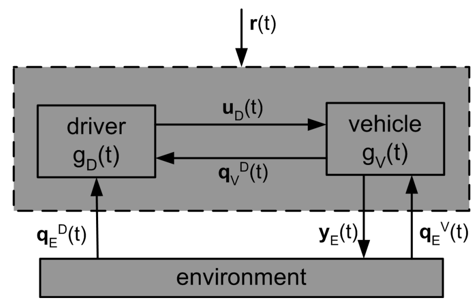

Fig. 2. Cybernetic system driver, vehicle and environment

$g_D(t)$ and $g_V(t)$ are the weighting functions according to the laplacian transfer functions of driver and vehicle $G_D(s)$ and $G_V(s)$. u_D is the control vector of the driver with respect to the vehicle and y_E is the output vector regarding the effect of the vehicle on the environment. Here q^D_V and q^D_E are the state vectors of the vehicle and of the environment as seen by the driver, whereas q^V_E is the state vector of the environment as seen by the vehicle systems. In general both the driver and the vehicle (in the sense of ADAS - Advanced Driver Assistance Systems - also) act together in a specific way towards the environment. Moreover both rely on different environmental awareness and actuator possibilities. Also their conditions and driving capabilities may change over time. Therefore in the author's opinion a general way of monitoring their condition and capabilities plus competence assignment is needed, which will be explained in the next chapter.

IV. COMPETENCE ASSIGNMENT STRATEGIES FOR DRIVER AND VEHICLE

The competence assignment module's task is to ensure, that the abilities of the overall system are not allowed to fall below a minimum and therefore the loss of one of the two subsystems requires a separate security management system. The strategies for the condition determination and assignment are based on the structure in Figure 3. Whereby q^{CAP}_D, q^{CAP}_V and q^{CAP}_E are the state vectors of the driver, the vehicle as well as the environment, respectively. They are as seen by the driver monitoring and competence assignment system (CAP). The output $y^T_c = [y_{cD}, y_{cV}]$ is the vector of the competence assignment. The underlying principle of this structure has already been successfully tested in context of the development of an onboard maintenance system for vehicles by the DaimlerChrysler AG [5]. Within this contribution this principle structure is for the first time extended for the application of estimating the driver's condition.

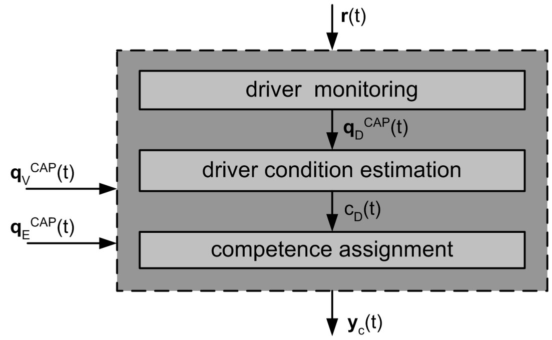

Fig. 3. Structure of driver condition estimation and competence assignment to driver and vehicle

A. Driver monitoring and driver condition estimation

Using the models for the driver, the vehicle and the recording of substantial states of the environment (position, coordinates of the road, traffic conditions, etc.) the current condition of the driver can be determined on the basis of a success-evaluated on-line action analysis using classification concepts [8]. Basic idea of the determination of the current condition/capability of the driver is the success-evaluated analysis of the behaviour of maintaining distance to objects, paring attention to road signs, the adherence to the course and detectable physiological parameters of humans, etc. It is suggested to make an on-line determination of a driver's condition c_D by sensor fusion according to the structure in Figure 4, which is then compared with a specific driver condition using classification concepts.

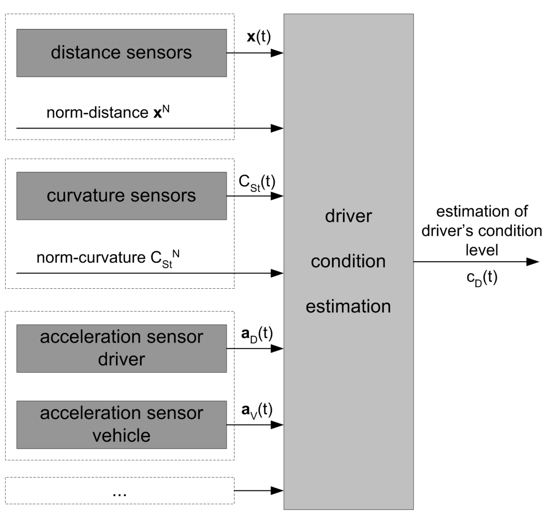

Fig. 4. Structure for on-line determination of driver competence.

The novel concept addresses the expected standard equipments of vehicles in the coming years. This concerns the distance regulation to ahead-driving, behind-driving and to the vehicles on the other lanes. One of the unresolved tasks is the maintenance of safety distances between road users [9]. The autonomous drives accomplished by the used test vehicles BMW 730 and MB 609D showed that the test vehicles could keep their safety distances from other vehicles. However, the majority of the other road users would not keep their safety distances. This behaviour generally led to the extreme dynamic reactions of the automatic control loops of the test vehicles and to the reduction of their driving speed. Hence it follows from the observations that the standard distances x^N for e.g. the situations: follow-up drivers, approaching, track switching, in-shearing and out-shearing should be determined driver-specifically. If the actual recorded distances x deviate significantly in the mentioned situation classes over a certain period from the standard distances, a change of the driver competence or an emergency situation should be assumed. Of course the evaluation of the difference in distances alone is not sufficient for the determination of the degree of competence. Therefore, in the first phase of the investigations, the curvature determined from maps C_{St}^N is compared with the curvature taken by the vehicle due to steering C_{St}. For the determination of the actual followed curvature, position data can also be included. This evaluation is likewise supplied to the system for the determination of the degree of competence of the driver. At present, the three-dimensional acceleration vectors of the driver $a_D(t)$ and of the vehicle $a_V(t)$ are taken as the third inputs. It is assumed that by fatigue or other conditions of reduced driving fitness of the operator, the relation of the values of the acceleration vectors from driver and vehicle changes significantly. Investigations in connection with the condition estimation of pilots make the basis of this strategy [10]. The use of the change of orientation of the driver for the determination of the current competence is preferred in this concept to the observation of the eye movements or the recording of other medical parameters due to cost and acceptance reasons.

The structure for the determination of the current driver competence, represented in Figure 4 will be supplemented in the context of further investigations by the inclusion of simple measurable variables. As a result of this step, an estimation of the current driver condition can be expressed in the form:

$$
\begin{aligned}
c_D(t) \quad = \quad & f(||\boldsymbol{x}(t) - \boldsymbol{x}^N(t)||, \\
& ||C_{St}(t) - C_{St}^N(t)||, ||\boldsymbol{a}_D(t) - \boldsymbol{a}_V(t)||)
\end{aligned} \tag{5}
$$

B. Competence assignment

The next task in the multi-level global structure as illustrated in Figure 3 is to design an adapter for the competence assignment between driver and vehicle. The goal is to give recommendations for safe driving though short or long term limitations do exist and under the current driver assistance systems, the vehicle provides. So the main tasks of the overall system are:

1) Estimation of the current parameters $g_{j,i}(t)$ and $\tau_{j,i}(t)$ of the driver and his capability or condition regarding

the driving task respectively.

2) Establishment, whether the overall system driver- vehicle possesses the capability for the requirements.
3) If the total capabilty or fitness of the driver and vehicle is no longer sufficient, delimitations must be realized (travel time, speed, etc.).

In this manner competence assignment to the driver may mean warnings and/or the recommendation of limitations in regard of travel time or speed, whereas competence assignment to the vehicle may involve the execution of autonomous securing measures. The structure to determine the competence to assign to driver and vehicle is shown in Figure 5.

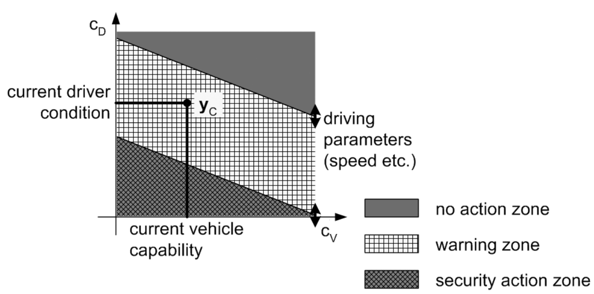

Fig. 5. Determining competence assignment to driver and vehicle.

Regarding Figure 5, on basis of the current driver fitness c_D and the vehicle capabilities including assistance systems c_V, the competence adapter (CAP) checks if the overall system is in safe state or if warnings / security measures are neccessary to secure safe travel of the driver. Therefore corresponding zones are defined as functions of the environment vector q_E^{CAP}. The CAP's decision is then based on c_D, c_V and the current driving parameters like speed or total travel time. These driving parameters are also variables in the sense of competence assignment to driver and vehicle in case the system driver - vehicle is not in normal state at current time. The system illustrated in Figure 2 will be extended for competence assignment based on the actual conditions and capabilities of the driver and vehicle. Therefore, the schema illustrated in Figure 6 results.

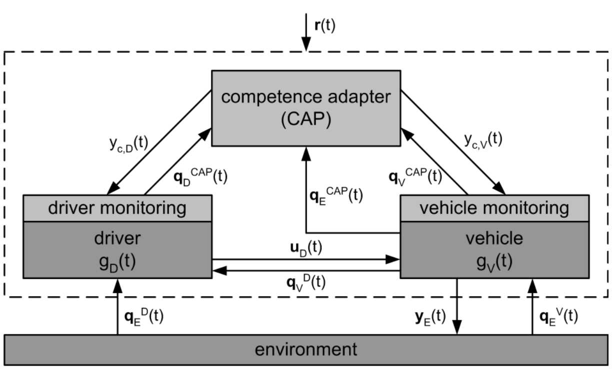

Fig. 6. Extended structure from Figure 2 including the driver-vehicle competence adapter.

If it is assumed that the vehicle fully maintains its competence in the levels, mission, manoeuvre and autopilot, the novel module for condition determination and competence assignment have the following tasks, depending on the result of evaluation according to figure 5:

- Warning the driver on abnormal behaviour (distances, steering angle,) using optical, acoustical, haptic actuators.
- Initiation of autonomous security measures in regard of driver and vehicle, if there is no reaction of the driver in his standard reaction time. The vehicle is surely stopped and emergency call sent to traffic services, police and paramedical services.
- If the vehicle loses its essential capability properties, the driver should initiate the necessary measures independently.

If both subsystems simultaneously fail, an emergency system situated in the vehicle should automatically at least inform the paramedics with the position information.

V. SIMULATION

To demonstrate the aspect of varying driver delay time in relation to driving behavior, several simulation runs were conducted. In the simulation used for this work appropriate models for the driver and the vehicle were created within the MATLAB Simulink environment. Concerning the vehicle, the longitudinal and the lateral dynamics were modeled separately according to the well-known single-track model [17][18]. The lateral submodel calculates the Yaw and attitude angle speed of the vehicle. With this the resulting speed vector of the vehicle is obtained. In result the lateral part may be considered as a velocity dependent second order transfer function. The longitudinal dynamics and the conversion of the steering angle to the actual wheel angle are modeled using first order transfer functions. The driver functions are divided as mentioned earlier into the layers autopilot, maneuver and mission. While the mission layer and part of the maneuver are not considered here, the parts beneath are modeled in appropriate ways. For the autopilot layer a simple nonlinear tracking controller was designed, whose task is to keep the vehicle on the course. For the maneuver layer a state machine is used, which simulates the drivers awareness over time.

VI. RESULTS

As mentioned earlier the driver's fitness is intended to be monitored using diverse sensory signals. This method is preferred against the pure measurements of the movement of driver's body or eyes only. It is assumed that the driving style is a parameter which is able to be used for the estimation of his state in terms of awareness or distraction respectively. As a first step in investigating the presented approach, a specific scenario was selected to show the effect of different driver delay times τ on the driving commands directed to the vehicle. In this scenario the driver's task is to drive on a straight road with an obstacle to be circumscribed. Three drivers differencing in their total delay time are investigated.

Driver 1 is assumed as an average reacting driver, while drivers 2 and 3 have greater reacting times supposing some form of distraction. Table I compromises the data used for simulation. Driving speed is $v_0 = 16.6 m/s$.

	τ_{ij} [s]	δ_{ij} [m]
Driver 2	τ_{12}=1.5	δ_{12}=25
Driver 3	τ_{13}=2.1	δ_{13}=35

TABLE I

SIMULATION PARAMETERS

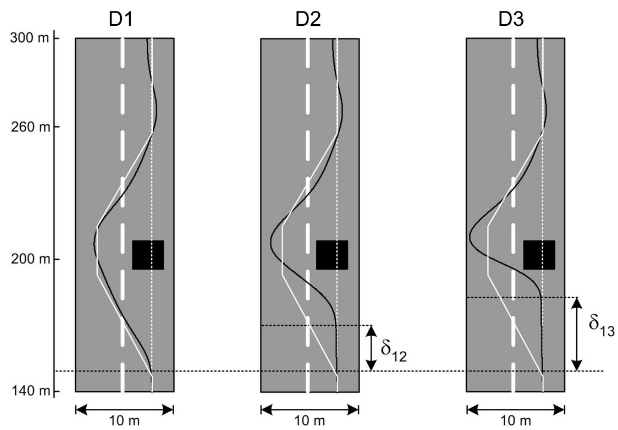

Fig. 7. Tracks driven by Driver 1 (D1), Driver 2 (D2) and Driver 3 (D3) (from left to right). Shown is the desired course (bright) and the actual course driven (dark) for each driver.

The Figure 7 shows the different courses taken by the different drivers (D1, D2 and D3) in regard to their different total reaction times. As also seen from the Figure these tracks do differ increasingly from the desired course with increasing reaction times. In addition the steering maneuvers executed by the drivers tends to be more hardy in relation to the reaction time. Therefore, it can be projected, that the driver's behavior and it's derivations may be used as objective variables in conjunction with other measurement data to estimate the driver's condition. This result builds the basis for further work of the authors to determine driver's condition and to assign competence in relation to the vehicle's state to both, the driver and vehicle.

VII. CONCLUSION

In this article the determination and assignment of competence between driver and vehicle were introduced. This concerns i.e. a growing part of the population, the people in the late phase of life, who undergo some individual changes that occur with increasing age. Basis of the suggested strategy is the determination of the competence of driver and vehicle. Thus it is possible to make the current competence assignment decision condition- or capability-based. The task of the competence adapter presented in this work is to identify the driver and vehicle condition and then allocate competence appropriately. If a durable and/or brief competence loss of the driver cannot be balanced by the vehicle, a mission cannot be realized. Therefore, a separate emergency system should stop the vehicle in a controlled manner. Despite the proposed models for driver and assistance systems are quite simple, they can be used as starting point for further research and present a possibility to gain insight into the thematic and for achieving the goals discussed here in the mid-term. It is clear for the authors, that these suggestions will not be legally realizable fully in the near future. The necessary autonomous inference in steering, acceleration and braking have been hindering further developments since years now. Though this situation, the development is going further and the first aspect of the driver condition adaptive assistance system, which integrates warnings and recommendations to the driver is under development.

VIII. ACKNOWLEDGMENTS

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