

## **DEVELOPMENT of REQUIREMENTS for AUTOMATICALLY COMMANDED STEERING FUNCTIONS**

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## **ABSTRACT**

Except for corrective steering functions automatic steering is up to now only allowed at speeds up to 10 km/h according to UN Regulation No. 79. Progress in automotive engineering with regard to driver assistance systems and automation of driving tasks is that far that it would be technically feasible to realise automatically commanded steering functions also at higher vehicle speeds. Besides improvements in terms of comfort these automated systems are expected to contribute to road traffic safety as well. However, this safety potential will only be exhausted if automated steering systems are properly designed. Especially possible new risks due to automated steering have to be addressed and reduced to a minimum. For these reasons work is currently ongoing on UNECE level with the aim to amend the regulation dealing with provisions concerning the approval of steering equipment. It is the aim to revise requirements for automatically commanded steering functions (ACSF) so that they can be approved also for higher speeds if certain performance requirements are fulfilled. The paper at hand describes the derivation of reasonable system specifications from an analysis of relevant driving situations with an automated steering system. Needs are explained with regard to covering normal driving, sudden unexpected critical events, transition to manual driving, driver availability and manoeuvres to reach a state of minimal risk. These issues form the basis for the development of test procedures for automated steering to be implemented in international regulations. This holds for system functionalities like automatic lane keeping or automatic lane change as well as for addressing transition situations in which the system has to hand over steering to the driver or addressing emergency situations in which the system has to react instead of the driver.

## **STARTING POSITION**

### **REQUIREMENTS FOR TYPE APPROVAL OF MOTOR VEHICLES**

In order to ensure a certain level of traffic safety by means of vehicle safety, motor vehicle design is restricted by technical requirements. However, it is no longer up to individual countries to set the minimum requirements for vehicle technology. The approval of vehicle types is rather harmonized internationally. On the level of the European Union, EU directives and regulations have been proposed by the European Commission in Brussels that set the legal rules for approval. For other countries and regions as well as the EU, the United Nations Regulations (UN-R), created by the United Nations Economic Commission for Europe (UNECE) serve as basis for type approval. E.g. UN Regulations are referenced in Annexes IV and XI of the EU type approval directive and come into play as EU-vehicle type approval requirements as far as referenced. In the EU additionally a link to UN Global Technical Regulations (GTR) is in place. These regulations are being developed at the international level by the "World Forum for Harmonization of Vehicle Regulations" (WP.29) also at UNECE based in Geneva. Thus for a significant part of the world-wide vehicle market internationally harmonised requirements in terms of UN Regulations are applied.

The UN Regulations (formally known as UNECE regulations) consist of a set of internationally harmonized and uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or used on wheeled vehicles. Conditions for reciprocal recognition of approvals granted on the basis of these descriptions are also contained. Complying with the UN requirements contributes to a higher product safety and a minimization of product liability risks. The UN Regulations are the basis for the approval of motor vehicles and parts as well as equipment. The contracting parties of the UNECE group guarantee each other mutual recognition of the approvals. Overall, there are presently 138 UN Regulations. They each include their own scope in respect to different vehicles, equipment and vehicle parts or separate systems and their technical aspects. Furthermore they depict specific and detailed technical requirements.

### **TECHNICAL REQUIREMENTS OF THE RELEVANCE FOR THE APPROVAL OF AUTOMATED DRIVING FUNCTIONS**

Driver assistance systems that are able to automate longitudinal and lateral control of a vehicle and thus support the driver in performing his driving task have already been on the market since several years now. Especially ACC (Adaptive Cruise Control) and LKAS (Lane Keeping Assist Systems) can serve as examples for longitudinal and lateral control respectively. If the degree of automation rises more and more parts of the driving task are taken from the driver and are carried out by the vehicle or a vehicle system itself. An essential barrier for the development and introduction of automated lateral control may be existing requirements for the approval of motor vehicles.

While considering the automation of driving tasks together with the respective technical requirements it is obvious to start with regulations concerning braking (UN-R 13) and steering (UN-R 79). In addition automated driving can affect UN-R 48 which deals with the fitment of lighting and light signalling devices. When the needs of a revision of the regulations are discussed first hurdles in present regulations have to be determined which prohibit automated driving functions. These barriers would have to be removed to make automated systems approvable. Doing this would not be enough because this would not imply that a set of minimum requirements is put on automated systems to ensure road safety. The main task therefore is to elaborate and establish such performance requirements so that an approval is only granted if this minimum of technical specifications is fulfilled.

### **REQUIREMENTS FOR AUTOMATICALLY COMMANDED STEERING**

#### **STATUS QUO OF THE REGULATION ON STEERING SYSTEMS**

An outstanding role in the course of revising the technical regulations for motor vehicles in order to enable automated driving as mentioned in chapter 1 has UN Regulation No. 79 [1].

UN-R 79 "Uniform provisions concerning the approval of vehicles with regard to steering equipment" already knows a discrimination of steering systems into classes depending on the degree of splitting the driving task between driver and system. Even in the introduction of the regulation it is explained which kind of driver assistance is already reflected by the text of the regulation and why this was done:

*Advancing technology, coupled with the wish to improve occupant safety by elimination of the mechanical steering column, and the production advantages associated with easier transfer of the steering control between left and right hand drive vehicles, has led to a review of the traditional approach and the Regulation is now amended to take account of the new technologies. Accordingly it will now be possible to have steering systems in which there is not any positive mechanical connection between the steering control and the road wheels*

*Systems whereby the driver remains in primary control of the vehicle but may be helped by the steering system being influenced by signals initiated on-board the vehicle are defined as "Advanced Driver Assistance Steering Systems". Such Systems can incorporate an "Automatically Commanded Steering Function", for example, using passive infrastructure features to assist the driver in keeping the vehicle on an ideal path (Lane Guidance, Lane Keeping or Heading Control), to assist the driver in manoeuvring the vehicle at low speed in confined spaces or to assist the driver in coming to rest at a pre-defined point (Bus Stop Guidance). Advanced Driver Assistance Steering Systems can also incorporate a "Corrective Steering Function" that, for example, warns the driver of any deviation from the chosen lane (Lane Departure Warning), corrects the steering angle to prevent departure from the chosen lane (Lane Departure Avoidance) or corrects the steering angle of one or more wheels to improve the vehicle's dynamic behaviour or stability.*

*In the case of any Advanced Driver Assistance Steering System, the driver can, at all times, choose to override the assistance function by deliberate action, for example, to avoid an unforeseen object in the road.*

*It is anticipated that future technology will also allow steering to be influenced or controlled by sensors and signals generated either on or off-board the vehicle. This has led to several concerns regarding responsibility for the primary control of the vehicle and the absence of any internationally agreed data transmission protocols with respect to off-board or external control of steering. Therefore, the Regulation does not permit the general approval of systems that incorporate functions by which the steering can be controlled by external signals, for example, transmitted from roadside beacons or active features embedded into the road surface. Such systems, which do not require the presence of a driver, have been defined as "Autonomous Steering Systems".*

The classification of steering systems however does not mirror the well known levels of automation according to Gasser et al. [3] or SAE [4]. The definitions of UN-R 79 read:

*2.3.3. "Autonomous Steering System" means a system that incorporates a function within a complex electronic control system that causes the vehicle to follow a defined path or to alter its path in response to signals initiated and transmitted from off-board the vehicle. The driver will not necessarily be in primary control of the vehicle.*

*2.3.4. "Advanced Driver Assistance Steering System" means a system, additional to the main steering system, that provides assistance to the driver in steering the vehicle but in which the driver remains at all times in primary control of the vehicle. It comprises one or both of the following functions:*

*2.3.4.1. "Automatically commanded steering function" means the function within a complex electronic control system where actuation of the steering system can result from automatic evaluation of signals initiated on-board the vehicle, possibly in conjunction with passive infrastructure features, to generate continuous control action in order to assist the driver in following a particular path, in low speed manoeuvring or parking operations.*

*2.3.4.2. "Corrective steering function" means the discontinuous control function within a complex electronic control system whereby, for a limited duration, changes to the steering angle of one or more wheels may result from the automatic evaluation of signals initiated on-board the vehicle, in order to maintain the basic desired path of the vehicle or to influence the vehicle's dynamic behaviour.*

*Systems that do not themselves positively actuate the steering system but that, possibly in conjunction with passive infrastructure features, simply warn the driver of a deviation from the ideal path of the vehicle, or of an unseen hazard, by means of a tactile warning transmitted through the steering control, are also considered to be corrective steering.*

Besides manual steering thus there is

- the "Autonomous Steering System", which describes control of the steering system on the basis of signals and information coming from outside the vehicle,
- the "Automatically Commanded Steering Function" (ACSF), where the operation of the steering system is carried out continuously and automatically on the basis of vehicle sensors and possibly additional passive infrastructure elements in order to follow a certain path,

- the "Corrective Steering Function" (CSF), where the steering angle is discontinuously and for a short time period corrected automatically in order to follow the desired path or in order to influence driving dynamics.

"Corrective Steering" is permitted. "Autonomous Steering" is prohibited, that means it is out of the scope of UN-R 79. For "Automatically Commanded Steering Functions" the situation is less simple. These functions are only allowed in a limited speed range for steering manoeuvres up to a speed of 10 km/h:

*5.1.6.1. Whenever the Automatically Commanded Steering function becomes operational, this shall be indicated to the driver and the control action shall be automatically disabled if the vehicle speed exceeds the set limit of 10 km/h by more than 20 per cent or the signals to be evaluated are no longer being received. Any termination of control shall produce a short but distinctive driver warning by a visual signal and either an acoustic signal or by imposing a tactile warning signal on the steering control.*

#### **STEPS TAKEN TO AMEND UN-R 79**

To enable automated driving it is therefore necessary to remove the restriction for automatically commanded steering which means to delete the 10 km/h limit and replace it by new smart requirements.

Simply skipping the 10 km/h limit would allow to have a continuously automated lateral control of the vehicle so that automated steering would be approvable from a technical point of view. In addition however it is very important to consider under which conditions and with which requirements for the steering system automatically commanded steering should be permitted. Here presumably the greatest amount of work is hidden when UN-R 79 is to be revised. The pure need for revision is primarily independent of the level of automation. However the number and quality of performance requirements will of course have to differ depending on the level of automation.

To pave the way for a revision of UN-R 79 and to carry out the work, already in February of the year 2015 an "Informal Working Group" on ACSF (Automatically Commanded Steering Functions) was established under GRRF (working group on brakes and running gear of UNECE WP.29). In the following chapters some essential items being of basic importance for the work of the informal group will be presented and discussed. Even though the maturity of some proposals for changing Regulation No. 79 is already quite high care has to be taken since all proposed measures

are preliminary and might be subject to change until a new version of the regulation is endorsed. Nevertheless the findings presented here are of principal meaning and are reasonable in terms of the obligations of legislators when finding solutions to enable the approval of automated driving functions. Therefore special emphasis is laid on the logic behind the proposals for new requirements and the scientific perspective on it.

#### **BASIC ITEMS AND TASKS**

The informal working group that has been established has the accepted objective to enable automatic steering and make it approvable. The framework, scope and terms of reference of this work were given by GRRF and WP.29 [2].

There is one essential prerequisite for the development of new performance requirements for automated steering: The driver is still obliged to monitor the driving all the time. This condition follows the principle that it is not allowed for the driver to turn away from the driving tasks. Using the terminology of levels of automation according to Gasser et al. [3] which are as well mirrored by SAE J3016 [4], requirements are elaborated for level 2 systems namely partial automation. Although requirements for systems aiming at level 3 will have to be more strict than for level 2 the work of the group when finalised can serve as a sound basis for an upgrade then addressing level 3 since a lot of thoughts needed for level 3 are already reflected for level 2 systems.

Another prerequisite is that the automated steering function shall be designed such that the driver can override or switch off the system at all times.

While proposing requirements care shall be taken that automated steering shall be at least as safe as manual steering. This leads to a catalogue of needs for the demanded functionalities of the system: The system shall safely do what it is designed for (safe operation of the use case). The conditions for activation have to be defined. Precautions for functional safety and the case of a failure have to be taken; here annex 6 of UN-R 79 for complex electronic systems can serve as a basis. Provisions for periodical technical inspection have to be put as well.

Special emphasis must be laid on the design of a safe transition from automated steering back to manual steering. In addition it has to be considered how to deal with the case that the driver does not take over control of the steering even if he was intensely requested to do so.

There will have to be requirements for the arrangement of the human machine interaction

especially in terms of operation, signalling and warning. They should at least comprise:

- display of failures,
- request to the driver to steer manually in case of system boundaries (end of the use case),
- ensure mode awareness for the driver,
- detect and warn if the driver fails in surveilling the driving task so that he would not be able to follow a transition request properly.

It becomes obvious that in case of an automation of the driving task it is highly needed to take human capabilities into account because the driving task will be split between driver and vehicle. The human being has in the automated mode still the role to surveil the system permanently (if we follow the above mentioned prerequisite for the informal group or in case of a level 2 system respectively). But exactly at this point human drivers do very soon reach their limit in terms of being capable to surveil and monitor a system continuously and for longer time periods. Drivers might be unchallenged so that attentiveness and vigilance will suffer (see on this e.g. explanations from Schlag [5]). Furthermore it can absolutely be conceived that the automated driving function works that perfectly that the driver is encouraged to turn away from the driving task and starts to do something else.

All these aspects sketched above must not be neglected if provisions for automated steering are elaborated. To cope with the problems mentioned several approaches could be taken:

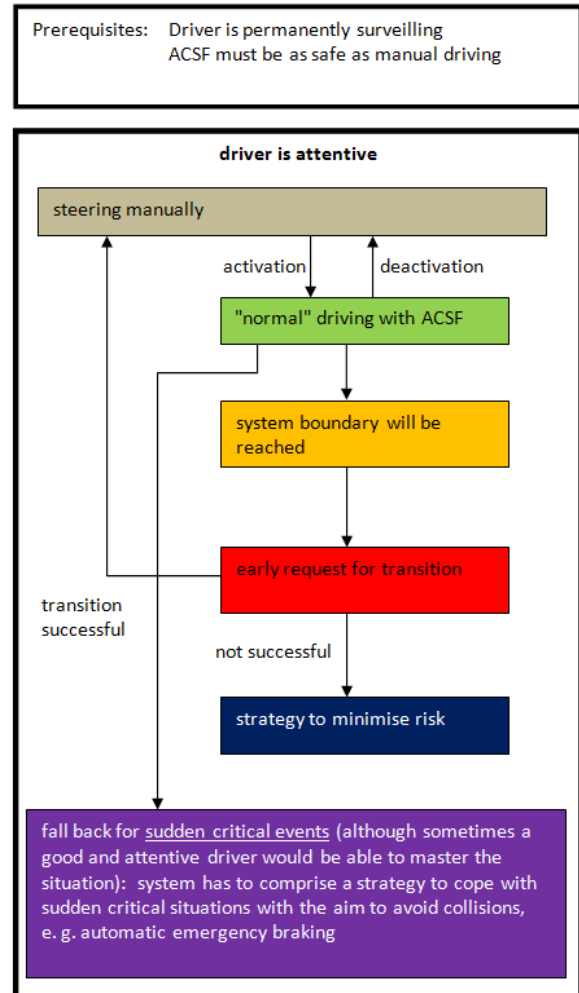
As a simple solution one could ensure that longitudinal and lateral control of a vehicle are not carried out automatically at the same time in order to force the driver to be part of performing the driving task. Automated steering would then imply that ACC (Adaptive Cruise Control) or CC (Cruise Control) or even a speed limiter cannot be activated together with the automated steering. As a result all levels of automation beginning from level 2 (partial automation) would be impossible.

Another approach would be to design the longitudinal and lateral control deliberately that poor that the driver does not dare to turn away. Here the question arises how legislation could demand a certain degree of imperfection without being accused to neglect possible safety concerns. Since both solutions mentioned above do not seem to be completely satisfying for partial automation, in the following a third approach is outlined. The basic dependencies covering this approach are as well sketched in Figures 1 and 2.

It seems to be more reasonable to care that the driver always keeps a certain level of vigilance and attention. Here a system that checks the driver

availability can be helpful by means of applying a warning or guiding the driver back to manual steering if attentiveness is imminent to decrease.

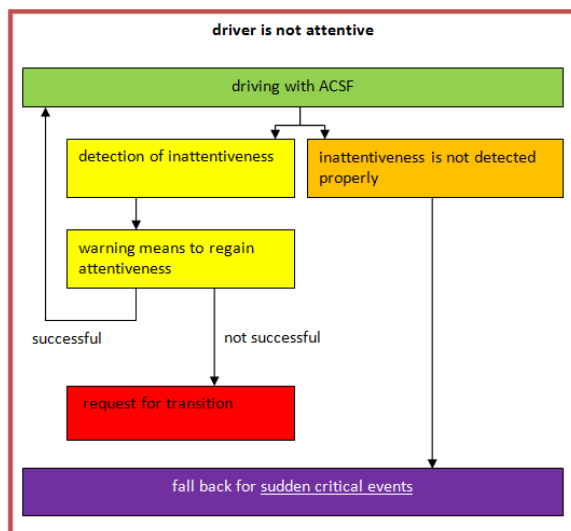
However, also a driver availability control can still fail and suppose that the driver is attentive even if he is not so that strategies have to be defined how traffic safety can be guaranteed in these situations as well. At least at this point the vehicle will have to be equipped with technology that was perhaps primarily foreseen for conditional automation (level 3).



**Figure 1. Basic sketch of dependencies to identify regulatory needs for automatically commanded steering functions, case 1: driver being attentive**

An impressive example is - as it is if the vehicle is driven manually - the danger of a sudden unexpected and critical event which might be an accident of the vehicle ahead, crossing deer or pedestrians who in an instant step on the road, narrowly cutting in vehicles or something else.

It might of course be the case that an attentive driver would master the situation even if driving was in the automated mode during the relevant situation because he reacted properly and overruled the steering by his manual input. However the assumption that this optimal behaviour would occur at every time and in every situation would be careless. It would be as well careless to hope that with a transition request the driver would be enabled to handle the situation safely since here the time for a safe transition procedure is of course too short. This leads to the conclusion that sudden unexpected events have to be handled by technical means. Up to now known and state of the art are automatic emergency braking systems (AEBS), which initiate a braking manoeuvre with the aim to avoid a collision with an obstacle or other road user.



**Figure 2. Basic sketch of dependencies to identify regulatory needs for automatically commanded steering functions, case 2: driver being inattentive**

There are already performance requirements for such systems fixed in UN-R 131 for heavy goods vehicles and buses. For passenger cars requirements would have to be defined. It can be scrutinised if UN-R 79 actually addressing the steering system is the right place to lay down such provisions. As in the case of buses and goods vehicles one could imagine a new separate regulation or discuss about integrating requirements in the existing UN-R 13 H (braking systems). In the end also an own regulation for the item "automated longitudinal and lateral control" could be an option.

It is however important to name a significant difference between automatic emergency braking systems which already exist for heavy vehicles or passenger cars and automatic emergency braking systems for automated driving. The conventional AEBS systems take into account that the driver might have in terms of driving manoeuvre another desire than full braking, e. g. steering around an obstacle. For that purpose normally the emergency braking comes only after a cascade of warnings and partial braking. Thus the driver shall be enabled to master the situation by himself without being patronised by the system. In doing so also the reaction time of the driver is considered, which leads to a reduction of the time available for full braking. In contrast, in case of an automated system with the driver being not directly involved in the driving task, time would be too short for enabling him to get situation awareness or hands on and manually solve the situation. So the system itself has to act and as an advantage the system does not have to take into account a driver wish or his reaction time but can act immediately without delay.

## CATEGORISING SYSTEMS AND FUNCTIONALITIES

Taxonomy of systems that automatically steer a vehicle can be based on different criteria. Of course all systems carry out a kind of lateral control. This control can be performed under the following conditions:

- the driver having hands on or hands off the steering control,
- lateral control within the present lane or with lane change,
- in different speed ranges,
- on different road categories,
- only for the purpose of stabilising the vehicle dynamics,
- only for the purpose to avoid a collision.

Systems for automatically commanded steering are foreseen to be subdivided into five Categories A to E.

Category A describes systems in the low speed range up to 10 km/h. This could be e.g. systems for automatic parking manoeuvres, with or without remote control. Category A and parking system will not be discussed further.

The major discrimination of the other systems is between lane keeping and lane change. Category B will describe lane keeping, category C to E will describe lane changing functions.

Lane Keeping Assist Systems (LKAS) are on the market for several years. But due to the 10 km/h

limit they could not be approved as ACSF. To overcome this barrier in the past LKAS were approved as a corrective steering function (CSF) by assuming that lane keeping is done by a series of actions correcting the trajectory of the vehicle in order to stay on a desired path. In the end this interpretation may be seen as a contradiction to the condition that CSF has to be discontinuous. Continuous lane keeping would actually have to be regarded as ACSF. Thus, in order to be able to approve present simple but indeed continuous lane keeping systems as ACSF a separate category B1 is needed together with a clarification of requirements for CSF. The latter will not be discussed here. For the approval of more advanced lane keeping systems as ACSF a category B2 is foreseen. The essential difference between B1 and B2 is the degree of driver involvement in controlling the steering. Namely to work, B1 will need a permanent driver input on the control in terms of holding the control element, i. e. hands on. B2 will describe hands off systems that are able to carry out the steering task for longer time periods without further driver input.

Also the categories for lane change can at least be divided into systems that need some driver input and other systems that do not need it. The latter just have to be monitored by the driver. The difficulty in establishing requirements for the systems demanding driver input is to define which kind of input of the driver is needed or not in order to avoid impairing traffic safety. The essential question which has not been solved yet is how far the vehicle needs to observe traffic in the adjacent lanes and approaching from behind. Again there is the dilemma that by demanding a very sophisticated system, drivers could over rely on the system and neglect their particular part during the manoeuvre; demanding less sophisticated systems the legislator could be deemed to be careless; putting less strict requirements would as well not avoid that manufacturers might bring systems on the market with improved sensing capabilities.

The category named C can cover a hands on function where the driver initiates the lane change by a deliberate action. And the driver has to care for checking the traffic environment so that the lane change can proceed safely. Additional sensing capabilities might be used to safeguard the lane change in terms of collision avoidance or blind spot monitoring. The challenge for the design of the human machine interface and the corresponding requirements is to detect and to be sure that the driver really wants to perform the lane change and to ensure that he is aware of his responsibility.

Category D instead might demand that the vehicle is equipped with sensors for recognizing the environment to the side and to the rear to be able to propose a safe lane change to the driver, which has to be confirmed by the driver so to speak as double check by both the system and the driver.

Systems of category E finally can cover the pure hands off case for lane changing as B2 does for the lane keeping. Here again the driver is just needed to surveil the system which carries out the lane change without further driver command or confirmation.

In the following sections on the one hand reasonable requirements for conventional lane keeping systems will be discussed. On the other hand sensible considerations for provisions for hands off lane keeping and lane change systems will be described. Here really new aspects of automated steering will have to be regulated, namely that the systems will work without continuous driver input. For the systems it is just presupposed that the driver monitors the system and the traffic environment and that he is at any time able to take over manual control again, especially if he is requested to do so.

#### **REQUIREMENTS FOR CONVENTIONAL LANE KEEPING SYSTEMS**

Since there are already many properly working lane keeping assist systems on the market without showing relevant shortcomings in safety the requirements for such systems might be restricted to a minimum. However some recent examples of systems are designed in a way that safety concerns have raised. For the driver it remained unclear in a lot of situations if the system has reached the boundary of its use case, i.e. remaining active although the conditions for keeping properly the lane are no longer fulfilled. This shows that the simple approach is not fully tenable.

There should be a requirement for the functionality of lane keeping so that it is checked if the system fulfils what it is designed for. The lane keeping shall be done without crossing the lane markings. Since the systems needs the driver input there has to be detection if the driver holds the steering control. Thus a warning is to be given if the system is driven hands off for a certain and short time span.

By means of this provision it is more difficult to misuse the lane keeping system in terms of turning away from the traffic scene. At the same time there is a clear borderline to systems of category B2 which work without input of the driver to the control element as long as they are active. As mentioned above every lane keeping system should

clearly inform the driver if it is no longer able to perform the lane keeping task, e. g. in case of weak markings, weather conditions or curve radius and vehicle speed.

### **REQUIREMENTS FOR LANE KEEPING AND LANE CHANGE SYSTEMS NEEDING NO CONTINUOUS DRIVER INPUT**

Every regulation for motor vehicle needs a list of definitions introducing and explaining the used terms on which requirements can then be based. So some important definitions that are essential for the system specifications are listed first. In the following sections then different kinds of reasonable requirements for the sake of road safety are explained.

#### **Definitions**

There are up to now no higher speed ACSF systems on the market due to the 10 km/h limit. One can conceive a lot of different kinds of ACSF systems having each a special use case like stop and go assist, congestion assist, highway assist, road works assist and so on. In order not to exclude a sensible application of an ACSF system the legislator should not restrict the possible use cases unnecessarily. Thus it is - except of some explicitly forbidden conditions - up to the manufacturer to define the system boundaries of his ACSF system like speed range, lateral acceleration range, possible lane width etc.. So the new concept is that the manufacturer has to specify the use case for which then the regulation sets minimum requirements. As definitions that is reflected by:

- *"Specified maximum speed  $v_{smax}$ " means the maximum speed up to which an ACSF is designed to operate under normal operating conditions.*
- *"Specified minimum speed  $v_{smin}$ "...*
- *"Specified maximum lateral acceleration  $a_{ysmax}$ "...*
- *"Normal operating conditions" mean that the ACSF system is active and does neither carry out a transition procedure nor a Minimal Risk Manoeuvre nor an Emergency Manoeuvre.*
- *"Conditions for operation" mean circumstances like traffic situation, road category, quality of lane markings, vehicle speed, curvature of the road, lighting, sensor capabilities etc. specified by the vehicle manufacturer, where the system is designed to operate.*

- *"System boundaries" mean all circumstances from which on the conditions for operation are not fulfilled anymore.*

Since parts of the driving task are carried out by the system only as long as the system is able to do this safely, handing over the steering task back to the driver is needed whenever system boundaries are reached. The need for checking if the driver is available to take over manual control is covered as well as the case that the driver fails in taking over:

- *"Transition demand" means an instruction from the ACSF that the driver has to take over control of the steering task again.*
- *"Transition procedure" means the sequence of providing a transition demand by the system, taking over steering control by the driver and deactivation of the ACSF.*
- *"Driver availability recognition system" means a function able to assess driver's availability to respond to a transition demand.*
- *"Minimal risk manoeuvre" means a procedure aimed at minimizing risks in traffic, which is automatically performed by the system, e.g. when the driver does not respond to a transition demand.*

Furthermore the definitions already mirror the need for an automatic emergency braking:

- *"Emergency Manoeuvre" is a manoeuvre performed by the system in case of a sudden unexpected event in which the vehicle is in imminent danger to collide with another object, with the purpose to avoid or mitigate a collision.*
- *"Protective deceleration" means an application of the brakes of the vehicle by the system in order to decelerate the vehicle.*

#### **System modes und activation**

For the driver it is important that he is aware which modes the system can be switched into and which is the present mode the system is in. Switching the system on changes the system mode from "off" to "standby". Also a default standby mode is thinkable. The essential change is from standby to active which has to be done by the driver deliberately. However the system shall be only able to be switched into the active mode if the conditions for a safe operation are fulfilled. That means the vehicle is in a situation within the system boundaries and all external conditions like road category, weather, properly working sensors, algorithms and actuators support the activation of the system. Deactivating the system or switching it off by the driver must be possible at any time. If a



failure occurs the system has to switch into failure mode.

### **Warnings and signalling**

It has to be displayed to the driver in which mode the system actually is (except it is in off mode). Especially the change from one mode into another has to be signalled clearly. Failures have to be indicated. Warnings have to be given if the driver is detected to be unavailable to take over manual steering control or if he has unbuckled.

Since it is the aim to absolutely avoid new risks being imposed due to the introduction of automated steering the design of the transition procedure is of highest importance. A transition demand therefore should use two warning means using different sensing channels of the driver like optic and acoustic.

### **Performing driving manoeuvres**

For the execution of driving tasks like lane keeping and lane changing there is the precondition that the manoeuvres must be clear to other road users and shall be carried out only if this is possible without impairing safety. In addition, other road users shall not be forced to undertake abrupt actions like braking or steering to avoid a critical situation. Especially safety distances to other road users have to be kept so that an operation of the brakes by the system has to be possible for an automatically commanded steering system which can be driven without continuous driver command and driver confirmation. As a consequence a kind of longitudinal control for traffic safety has to be done by the system in addition to the lateral control. When changing lanes this comprises the observation of vehicles ahead, in the adjacent lane and especially of such vehicles that approach from the back. If traffic, differential speeds, sensor shortcomings or other circumstances do not allow that the system can decide if a safe manoeuvre is possible a lane change must not be carried out. A lane change has to be signalled to other road users by the direction indicator in advance of crossing a lane marking. (for automatic activation of the direction indicator an amendment of UN-R 48 will presumably be necessary). Also cutting in after an overtaking manoeuvre must occur with the demanded safety distance and activation of the direction indicator. If it turns out during a manoeuvre that it is not possible to complete it safely, it has to be aborted in a safe manner.

Principally a system has to take into account if the vehicle is on the appropriate road category for activation and for carrying out certain manoeuvres (e. g. no oncoming traffic, constructional

separation to opposite traffic, no pedestrians or bicyclists permitted, at least two lanes for the direction of traffic). In addition the system has to consider which ambient conditions are present when deciding on the performance of certain manoeuvres or on the speed that should be selected. That means that it will be necessary for the system to reduce the maximum possible speed of the functionality whenever the weather is worse, the vision of sensors is impaired or the road does not deliver good adhesion anymore.

Altogether the requirements mentioned ensure that the system being activated regards the rules of the road code. The system shall not be active if it is not able to handle the present traffic situation correctly. Since the driver might not be good in surveilling the system or since the system might encourage the driver to rely on it too deeply a clear signal to the driver is necessary if the system boundaries are reached in any way so that then the conventional manual mode can replace the automated mode.

### **Transition**

The most important and at the same time new issue is the transition from automated to manual steering because it is characteristic for the temporary automation of a driving task. It is at the latest needed whenever system boundaries are reached. The more time is available for the transition procedure, i. e. until the driver has to carry out the driving task alone, the safer the transition should be. However due to the vast number of possible traffic situations there will of course be situations in which the time available for transition is short or even too short. Especially in case of level 2 systems where the driver is expected to be permanently attentive and ready to take over, the system will not be able from a technical point of view to cover lots of seconds of driving after having system boundaries already passed. For that purpose one could talk about a "hands on time" rather than a real transition time. Furthermore a distinction of cases has to be made:

First there may be situations for which the system knows in advance or anticipates that a transition is to occur soon. This might be the case because the system knows the route and based on the map envisages the end of a motorway or the need to exit the road or that there will be only one lane in the direction of traffic. Based on research by NTSEL (National Traffic Safety and Environment Laboratory, Japan) [6] carried out in a driving simulator an appropriate hands on time could be about four seconds so that the transition procedure has to offer the driver this amount of time before

manual driving becomes inevitable. During this time the system has to still control the steering task. As a side remark, for conditional automation with the absolute order to the driver to monitor being lacking, the requirements and parameters for the transition will surely have to be reworked.

Second there may be situations for which the system boundaries are reached suddenly, which however are not critical at all. This might be a missing lane marking a narrow curve demanding a higher lateral acceleration than foreseen for the use case or a sensor being covered by a leaf. Of course here is needed a transition request at once. The system then shall control the steering for a further few seconds, namely the hands on time mentioned above, to provide the driver with time for taking over control. This should also be feasible technically easy because at the point in time at which system boundaries are reached the system has information about the road ahead and the trajectory that was already planned. More time can be gained by moderately reducing vehicle speed in such a case.

Third there may be situations for which the system boundaries are reached suddenly and which are critical because e. g. there is the danger of a collision. This could be an obstacle on the road, a vehicle ahead braking sharply, a cutting in vehicle without safety gap, an accident ahead or a crossing big animal. Here as well a transition demand has to be given immediately. The demand however has rather the meaning of a warning that something dangerous is taking place, because in such situations the driver will very often not have the time to take over the steering and to handle the situation safely. Just the reaction time of the driver would be that long that a collision would be inevitable. It is therefore important that the system is able to act itself by initiating an emergency manoeuvre (see below) without waiting for the driver to take over control.

#### **Minimal risk manoeuvre**

Actually the following situation should not occur for partial automation, in fact that a driver does not take over control when this is needed. Nevertheless also this case should be safeguarded technically. Depending on the prevailing traffic situation there might be completely different best strategies to reach a status of less risk than before. This might be flashing the hazard lights, reducing speed, braking, stopping or even changing the lane towards the road edge. This variety nearly impedes to make a certain manoeuvre mandatory.

#### **Sudden critical situations**

In sudden critical situations in which the time for a safe transition procedure is too short because a collision is imminent and could not be anticipated before, a reasonable emergency reaction has to be carried out by the system itself. This could be emergency steering around an obstacle or emergency braking. For steering around enough space is needed beside the obstacle and traffic from behind must not be endangered so that all this has to be checked by the system. Since the conditions for a safe emergency steering manoeuvre are not always given collision avoidance by steering cannot be mandated. In contrast emergency braking is a sensible option for sudden critical situations generally. The aim must be the complete avoidance of an accident. To act this way the system has to be able to operate the brakes up to the full braking performance. Positive side effect of this capability is that sensors, algorithms and actuators are fitted to the vehicle and can be used as collision avoidance system even if ACSF is not active.

#### **Driver availability detection**

Besides checking if the driver is belted and on his seat it should be permanently observed by the system if the driver is attentive so that he can steer manually whenever this is requested. Equipment for this monitoring task is at different stages of maturity today and is partially rather on a research level than to be fitted in series production. However systems like detection of head and eye movement could be considered. Or detection of actions of the driver like operating air condition or radio could be used to detect driver availability. If such a check does not ascertain driver activity a warning has to be given to the driver and a transition could be initiated.

#### **CONCLUSIONS**

There are several issues within internationally harmonised regulations for motor vehicles that have to be dealt with to eliminate constraints and to establish reasonable requirements in order to realise automated driving functions in the near future.

The essential item that has to be overcome at first place is the permission of automatically commanded steering above 10 km/h. However, each removal of a certain barrier for automated driving functions will of course have to be accompanied by setting reasonable new technical requirements for type approval in order to ensure a desired safety level. For the case of partial

automation a set of requirements was elaborated on a scientific basis by theoretically analysing the safety relevant aspects of automated steering. It was taken into account that for automated driving functions there is obviously the need to consider human performance because the division of work between driver and vehicle carrying out the driving task is distributed differently the higher the level of automation becomes. For partial automation the role of the human being is at least to constantly monitor the system. However, drivers quickly reach their limits here: low demand may cause situations of too little workload of the driver so that attention and vigilance suffer. Furthermore, it is quite conceivable that the automated feature works so perfectly that it encourages the driver to turn away from the driving task. The result of these relationships is that requirements for automated steering already for level 2 have to cover the following major items: properly carrying out the use case in terms of driving manoeuvres without endangering any road user, safe transition procedure if system boundaries are reached, ability of the system to handle sudden critical events by automatic emergency braking, ensuring the availability of the driver and ensuring mode awareness of the driver. The findings described above are incorporated in the work of an informal working group which was established under the working group on brakes and running gear of UNECE WP.29 to prepare a revision of the UN Regulation on steering systems.

For further steps in automation (level 3 and higher) a rework of the minimum performance requirements for automated steering or automated braking functions currently being elaborated within the UNECE framework will definitely have to take place. Especially parameters of the transition procedure will have to be considered carefully again. Also issues like redundancy of sensors and actuators will play a role and have to be defined then.

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