

COMPREHENSIVE DEFINITIONS FOR AUTOMATED DRIVING AND ADAS

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ABSTRACT

The levels of continuous vehicle automation have become common knowledge. They facilitate overall understanding of the issue. Yet, continuous vehicle automation described therein does not cover “automated driving” as a whole: Functions intervening temporarily in accident-prone situations can obviously not be classified by means of continuous levels.

Continuous automation describes the shift in workload from purely human driven vehicles to full automation. Duties of the driver are assigned to the machine as automation levels rise. Emergency braking, e.g., is obviously discontinuous and intensive automation. It cannot be classified under this regime. The resulting absence of visibility of these important functions cannot satisfy – especially in the light of effect they take on traffic safety.

Therefore, in order to reach a full picture of vehicle automation, a comprehensive approach is proposed that can map out different characteristics as “Principle of Operation” at top level. On this basis informing and warning functions as well as functions intervening only temporarily in near-accident situations can be described.

To reach a complete picture, levels for the discontinuous, temporarily intervening functions are proposed – meant to be the counterpart of the continuous levels already in place. This results in a detailed and independent classification for accident-prone situations. This finally provides for the visibility these important functions deserve.

INTRODUCTION

Systematic structure is a prerequisite for the understanding of vehicle automation. Abstraction and overview is the basis for guidance in this field. This allows unambiguous communication. The understanding of vehicle automation so far is very much limited to the continuous principle of operation. This paper broadens the view to Advanced Driver Assistance Systems (ADAS) and vehicle automation and resolves ambiguities.

The levels of continuous vehicle automation have originally been established by the BASt Project Group on the “Legal Consequences of an increase in vehicle automation” [1]. This was the basis for SAE-International Standard J3016 [2]. On continuous

vehicle automation these terms are the only internationally established reference so far.

Nevertheless, the levels of vehicle automation according to BASt or SAE are not satisfactory in respect of classification for well-established functions on the market today. These are e.g. “Autonomous Emergency Braking”, “Frontal Collision Warning”, “Lane Departure Warning”, or the merely corrective variant of “Lane Keeping”. These functions cannot be assigned to the terms of the continuous principle of operation described by SAE. The same is true for “Emergency Assist” functions that intervene in case of pathologically induced paralysis or temporary incapacitation and have the objective of returning the vehicle to a comparatively risk-minimal-condition (“risk-minimal” here is a term applied as a relative concept only – compared with the uncontrolled). In

the past it has been attempted to categorize all of these functions according to the levels of continuous vehicle automation (usually as a Level 1). This is inconsistent against the background of these functions being discontinuous in nature. This has therefore been considered a separate “Principle of Operation”.

Innovative approach now is to rank the continuous principle of operation (as defined by BAST/SAE) as one principle among several. This fundamental understanding of “principles of operation” needs to be established as a superordinate concept in order to come to a full picture. It finally allows defining vehicle automation comprehensively. This is outlined in the following.

Additionally, to obtain a full picture, it is necessary to resolve the issue of informing and warning functions as well. Their main characteristic is a lack in direct influence on vehicle control (only informing or warning the driver – this is not to be equated with vehicle automation). This feature is considered stand-alone (and leads to the assignment of a “Principle of operation” in this respect as well).

This approach has been developed in a project funded by the German Federal Ministry of Economic Affairs and Energy (BMWi) within the German UR:BAN-Project [3]. The following content is based on the technical input by the colleagues of the sub-project “KAB” cited under [4].

CONTEXTUAL PLACEMENT ACCORDING TO THE THREE-LEVEL-HIERARCHY OF THE DRIVING TASK BY DONGES

The three-level hierarchy of the driving task by Donges [5] describes the task of driving on the layer of vehicle navigation, the layer of vehicle guidance and the layer of vehicle stabilization.

The navigation layer includes the choice of the appropriate route on basis of the existing road network and travel time as a cognitive planning process. The dynamic process of driving takes place on the layers of vehicle guidance and stabilization. Vehicle guidance thereby describes the process of control that is determined by the own movement of the vehicle as well as other vehicles as a permanent change of the respective constellation in a given scenery. For the driver this consists in estimating the appropriate command variables as are target-track and target-speed and applying them by intervening in

the open control loop in order to achieve only small deviation between command and target value. The layer of vehicle stabilization in contrast is focused on the stabilization in the closed control loop by minimizing the offset to the minimum – as accepted by the driver [5]. The layer of vehicle guidance corresponds to the rule-based behavioral level and the layer of vehicle stabilization to the skill-based behavior of the driver according to Rasmussen [6] as contextualized by Donges [5].

For the means of the following classification concept of ADAS and vehicle automation functions the layers of vehicle navigation and vehicle stabilization are left aside (and thereby all types of function taking effect at these layers). The following concept is therefore limited to ADAS and vehicle automation taking effect on the layer of vehicle guidance.

This is not to argue against the possibility to categorize functions on the layers of vehicle navigation and stabilization by means of an even further extension of the systematic approach taken here. This paper, however, concentrates on ADAS and automation-functions based on environmental perception with effect on the layer of vehicle guidance. In addition, a system like ESC only has indirect environmental perception of road-surface condition (via wheel-speed-sensors and yaw-rate).

ABSTRACTION IN FUNCTIONAL CLASSIFICATION: ‘PRINCIPLE OF OPERATION’

This paper suggests a classification scheme according to ‘Principle of operation’. This approach was first described by Gasser, Seeck, Smith [7] and incorporated into own understanding by OICA [8]. Based on the technical input of project colleagues from the German automotive industry, Gasser and Auerswald refined the existing definitions and presented first presented the structure at the final event of the UR:BAN-project [9].

Key aspect is the superordinate categorization scheme of ‘Principle of operation’ and following this the establishment of “abstract” and “concrete” hazard for further classification (cp. below). The structure has been discussed and accepted by the EuroNCAP Working Group “Information, Warning, Intervention (IWI)” and is the basis for their categorization of design-principles and requirements.

For the means of further specification, ADAS and vehicle automation are referred to only in abstract classes of “functions” relating to the respective ‘principle of operation’ at a certain level. Abstraction hinders the description of complete “systems” (as packaged by manufacturers): Systems may combine and vary the following classes of functions and might even be subject to more than one principle of operation. Yet, the great benefit lies in additional clarity that comes along with abstraction. Following figure depicts the suggested classification according to ‘principles of operation’ as conclusive classification:

Principle of Operation A: Informing and warning	Principle of Operation B: Continuously automating	Principle of Operation C: temporarily intervening in accident-prone situations
Only indirect influence on vehicle guidance via the driver. 1. Status information 2. Warning (abstract hazard) 3. Warning (concrete hazard)	Take direct influence on vehicle guidance (conscious activation by the driver – divided responsibilities in execution of the dynamic driving task). Always overrideable.	Preventive machine intervention in case of negative situation prediction. Either: I. driver as controller does not react conform to expectation or is inaccessible II. in accident-prone situations drivers/ controllers cannot handle due to performance limitations

Table 1.
Superordinate Principles of Operation

Principle of Operation A: Informing and Warning Functions

This principle covers informing and warning functions. Characteristic is the *indirect effect* since only driver action can realize an effect for vehicle guidance. It is possible to distinguish between the following types of information and warning:

- **Status information:**
This type of information communicates information relevant on the vehicle guidance layer to the driver. Examples: Traffic sign recognition (as environmental status), display of brake-system-failure (as vehicle status), drowsiness detection (as driver status).
- **Abstract Warnings:**
A warning is provided to the driver in case vehicle control does not comply with the expected for a given traffic situation. Example: Lane-departure-warning or latent time-headway warning.

- **Concrete Warnings:**
These warnings are designed to draw driver attention to an accident-prone upcoming situation. These warnings usually occur in the same situations that allow for temporary intervention according to Principle of Operation C (usually, however, designed to occur earlier than an intervention would). Examples at system-level are Forward Collision Warning or Lane-Change-Assist (in case the system can identify lane occupancy and detects probability of collision).

Principle of Operation B: Continuously automating functions

This principle of operation is characterized by the immediate control taken by continuously active automation. A function of principle of operation B will automate at least part of the task of driving. This ‘Principle of Operation’ covers SAE-Levels 1 up to 5 and is described more closely therein. Since these levels have become common knowledge, it shall be referred to SAE-Standard J3016 [2] (and the respective BAST-report [1]).

Principle of Operation C: Temporarily intervening functions in accident-prone situations

Classifying this ‘Principle of Operation’ more closely was the core objective of the definitions prepared in the framework of the UR:BAN-KAB-Project. The further differentiation allows for a better understanding and visibility of these vehicle automation functions that are highly beneficial for improvements in traffic safety.

Functions of Principle of Operation C intervene only temporarily in accident-prone situations. Vehicle control is immediately influenced within the open control loop of the vehicle guidance layer (cp. above and [5]).

According to the underlying structural approach to a comprehensive concept of definitions it is the same if the open control is controlled by a driver or an independent machine action at the time of intervention: In both cases there is an overlay in vehicle control by an independent machine action (executed by Principle of Operation C).

It is characteristic, that either in case of

- *abstract hazard:* The driver as a controller (or the machine as controller according to Mode of Operation B) does not react conform to expectation or fails to operate/ take action. The temporarily necessary

intervention takes place to keep up a steady condition of traffic as the risk-minimal-strategy. The impending risk of collision thereby remains abstract since there is no immediate collision to be expected.

- **concrete hazard:** The situation is highly accident-prone (near collision situation). Only immediate intervention can mitigate or avoid the accident. These situations are usually characterized by the fact that drivers have lost control over a situation they in fact can no longer control (due to human reaction times). In these cases immediate intervention is required.

OVERVIEW OVER STRUCTURAL CONCEPT

Principles of Operation are the superordinate structural element in the classification scheme of this paper.

For the further details – as is already the case for continuous Automation– the levels of SAE-Standard J3016 take effect. Therefore, in case of Principle of Operation B the resulting structure can be visualized as the following:

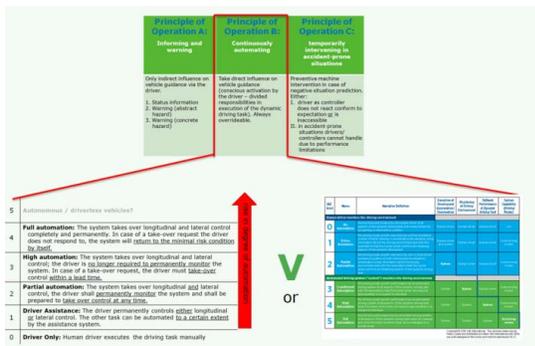


Figure 1: Principle of Operation B – detailed structural overview over continuously automating functions

Likewise it is possible to depict the overview over Principle of Operation C. The details of the levels for Principle of Operation C will be presented in greater detail in the following.

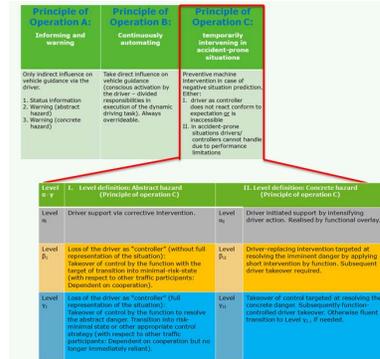


Figure 2: Principle of Operation C – detailed structural overview over temporary interventions in accident-prone situations

DETAILED STRUCTURE AND CLASSIFICATION OF PRINCIPLE OF OPERATION C

In advance to the presentation of the detailed structure of levels for Principle of Operation C the following terms shall be defined:

- Driver and machine are equally considered “controllers”. (The human driver might be substituted by a controller of Principle of Operation B).
- Principle of Operation C has a temporarily overlaying function. (Functions of Principle of Operation C can overlay the “primary controller” – subsequently this can either be the driver or again the controller of Principle of Operation B).
- Principle of Operation C is designed to be overrideable in order to enable controllability. (significant driver action can deactivate or override the functions of Principle of Operation C). Nonetheless, core-concept of Principle of Operation C is that the Driver will in general not be able to perform significant action in time/ override – since this might be a characteristic limit of the controller in an accident-prone situation.

- Further differentiation is made between abstract and concrete hazards. Depending on whether the hazard remains abstract (accident-prone) or has become concrete (near collision situation), further differentiation is made. In both cases the primary controller is no longer able to resolve the situation.

Level α, γ	I. Level definition: Abstract hazard (Principle of operation C)	Level	II. Level definition: Concrete hazard (Principle of operation C)
Level α_I	Driver support via corrective intervention.	Level α_{II}	Driver initiated support by intensifying driver action. Realised by functional overlay.
Level β_I	Loss of the driver as "controller" (without full representation of the situation); Takeover of control by the function with the target of transition into minimal-risk-state (with respect to other traffic participants; Dependent on cooperation).	Level β_{II}	Driver-replacing intervention targeted at resolving the imminent danger by applying short intervention by function. Subsequent driver takeover required.
Level γ_I	Loss of the driver as "controller" (full representation of the situation); Takeover of control by the function to resolve the abstract danger. Transition into risk-minimal state or other appropriate control strategy (with respect to other traffic participants; Dependent on cooperation but no longer immediately reliant).	Level γ_{II}	Takeover of control targeted at resolving the concrete danger. Subsequently function-controlled driver takeover. Otherwise fluent transition to Level γ_I , if needed.

Table 2: Levels for Principle of Operation C

Exemplary mapping of functions to the levels of Principle of Operation C in case of concrete hazard (II):

The concrete hazard is characterized by collisions immediately impending. Here the roman number "II" represents the abstract hazard as an index indicating the type of hazard depicted in the right column of Table 2.

Level α_{II}

In case of *Level α_{II}* the collision is immediately impending. At this level the driver action is intensified. This level is already available in case of e.g. Emergency braking that applies the necessary pressure to the system only after the *driver initiates* the braking. The same can be designed in case of evasive steering assist that intensifies the driver steering action by means of overlay.

Level β_{II}

In case of *Level β_{II}* the collision is immediately impending. The intervention by the *function replaces an intervention* by the driver in order to resolve or mitigate the primary hazard. After temporary interaction driver-takeover is immediately required. Examples are Autonomous Emergency Braking (AEB) or – possibly to come – autonomous evasive steering.

Level γ_{II}

In case of *Level γ_{II}* the collision is immediately impending. The intervention here not only replaces an intervention by the driver but *takes over complete*

control to resolve the concrete hazard. The takeover by the driver is also controlled by the machine. In case the driver takeover remains absent, a fluent transition to Level β_I or Level γ_I takes place.

Exemplary mapping of functions to the levels of Principle of Operation C in case of abstract hazard (I):

Abstract hazards are defined by the fact that the driver/ primary controller does not perform according to expectation or remains unattainable. Here the roman number "I" indicates the type of hazard as an index at the respective level. This type of hazard is depicted in the left column of Table 2.

Level α_I

In case of *Level α_I* the hazard remains abstract. The controller is supported via a *corrective, temporary intervention*. An example can be corrective steering assist that intervenes only in case the vehicle is leaving the lane. Another example might be an Intelligent Speed Adaptation that reduces the speed to the permitted maximum in case of speeding.

Level β_I

In cases of *Level β_I* the hazard remains abstract. The controller fails to take action. This level is characterized by automated control without full overview over the respective traffic situation and therefore dependent on the cooperation of other road users. An example can be an emergency assist function that performs limited longitudinal and lateral control with the aim of reaching the risk-minimal situation at short term.

Level γ_I

In cases of *Level γ_I* the hazard remains abstract. Again, the controller fails to take action and the function here provides full takeover of control in order to reach a satisfactory minimal risk condition or continues vehicle control for as long as is necessary to do so. The control at this level only differs in terms of objective from continuous automation at Levels 4 or 5 (which is here the minimum-risk-state as well as positive knowledge of driver inavailability).

CONCLUSIONS

This paper broadens the understanding of ADAS and vehicle automation beyond the levels of continuous automation defined so far by SAE-Standard J3016. The structural concept is therefore comprehensive and covers all ADAS and any kind of vehicle automation taking effect at the layer of vehicle

guidance. This is achieved by introduction of the superordinate concept of 'Principle of Operation'.

Furthermore a concept of detailed levels for Principle of Operation C is suggested that can accompany the levels of continuous automation (Principle of Operation B) as a counterpart in order to offer structure for these highly safety-relevant functions of Principle of Operation C.

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