15.1 Introduction

15.1.1 Motivation for Automated Driving

The increase of comfort, safety and efficiency is the motivation for introducing Highly Automated Driving from the point of view of BMW. Highly Automated Driving [1] allows the driver to withdraw from the driving task to a certain degree, depending on the required takeover time needed by the driver [2].

Comfort

Maximum comfort is achieved when the driver can exploit his or her optimal performance in any driving situation. The performance is strongly dependent upon the situation and can be divided into three states: under-demanded, balanced and over-demanded. The transition between these states is smooth and variable, dependent on the current state of the driver. The relationship between the driver’s workload and its performance is derived from the Yerkes–Dodson curve [3] and visualised from the point of view of the driver assistance in Fig. 15.1.

There is no need for automated driving functions when the driver is in the optimum range (competence). The driver can take advantage of his full capability and perceives driving as pleasant. But, the need for and the opportunity to assist the
driver with HAD (Highly Automated Driving) functions and Active Safety Systems\(^1\) exist when the driver is over- or under-demanded. Driving in a traffic jam or a monotonous traffic on the motorway can result in under-demand. In these situations, the driver does not use his potential performance. In this case, potential exists for Highly Automated Driving, if the driver delegates the driving task to the vehicle and uses his additional available mental capacity for other tasks.

**Safety**
A goal of HAD functions is to increase traffic safety. For this reason, a vehicle for Highly Automated Driving must be at least as safe as current traffic is; there must be no worsening in the traffic safety compared to today’s global safety level. To fulfil this requirement and to bring HAD functions on the road, new and advanced technologies are necessary (for further details, see Sect. 15.2). These technologies can be used to improve Active Safety Systems for non-Highly Automated Driving and thus address the “protection” workload (over-demanded) of the Yerkes–Dodson curve (see Fig. 15.1).

**Efficiency**
A further motivation for Highly Automated Driving is to increase the efficiency by reducing the energy consumption. Automated driving functions, for example, can regulate more accurately in regard to upcoming speed limits or vehicles in front. Route planning can be improved by vehicle connectivity; information provided about the traffic flow of road sections collected by other vehicles can be considered

\(^1\)Active Safety Systems in this chapter are systems which provide information to the driver or intervene in the vehicle control.
to calculate an optimal route. Thus, a microscopic efficiency enhancement can be achieved in the short term. In the long term, optimized route planning with traffic flow management is feasible, where vehicles receive a proposed route from a global instance to achieve an optimal total traffic volume. Thus, efficiency enhancements are also possible on a macroscopic level.

15.1.2 Development of Automated Driving Functions

The first steps have already been taken to bring Highly Automated Driving to the road. In 2013, the partially automated driving function, traffic jam assistant [4], was introduced by BMW. More automated driving functions will follow in the next few years to finally achieve—step by step—the preliminary goal: Highly Automated Driving.

The expectations regarding the timeline should not be too high. It must not be forgotten, with each increase in the degree of automation, the complexity of the overall system increases considerably [5] and legal issues are still not solved.

15.1.3 Introduction of Highly Automated Driving: Motorway

As the first use case for Highly Automated Driving, BMW sees HAD functions exclusively on the motorway (Fig. 15.2). This is explained by the following two reasons:

1. Motorways are in many cases monotonous and do not make high demands of the driver. In such situations on the motorway, where the driving task is not enjoyable, the driver can be assisted by HAD functions. The driver dedicates his mental capacity for other tasks.

**FUNCTION OVERVIEW**

- Remains in the lane.
- Overtakes.
- Cooperative characteristics on entrances to the motorway.
- Observes all traffic rules.
- Speed 0 – 130 km/h.
- In appropriate situations the driver can delegate the entire driving task to the vehicle.
- Highly automated changes between motorways.

Fig. 15.2 Function overview—Highly Automated Driving on the motorway
Function Overview

- Remains in the lane
- Overtakes
- Cooperative characteristics on entrances to the motorway
- Observes all traffic rules
- Speed 0–130 km/h
- In appropriate situations, the driver can delegate the entire driving task to the vehicle
- Highly automated changes between motorways

2. The “low” complexity of the use case on the motorway is likely to be manageable in the near future. Demonstrations with prototypes of different vehicle manufacturers [6–8] and suppliers have already shown on public roads. The number of possible driving manoeuvres and interactions with other road users is limited, compared with manoeuvres on urban and rural roads. Complex crossing manoeuvres or situations with pedestrians/cyclists can be excluded as far as possible. In addition, motorways have less complex road geometries and also a more stationary environment with no permanent changes. Thus, a highly accurate localisation of landmarks (e.g. guardrails, bridge piles, lane markings, etc.) is easier to implement. Despite of the relatively simple use case on the motorway, the vehicle validation is much more complex in comparison to today’s available driver assistance systems. The average driver drives safely on the motorway; a fatal traffic accident occurs statistically approximately every 12 million km on German motorways [9]. These circumstances make it very difficult to validate the safety of HAD functions with traditional methods. Multitudes of test kilometres on motorway would have to be covered to obtain a statistically validated statement of evidence of safety [9].

15.1.4 Direct Safety Benefit

HAD functions must not have negative effect on the traffic; there must be no worsening in the traffic safety, compared to today’s global safety level. As a result, a direct increase in safety on the motorway is expected, but this will not lead to a large reduction of traffic accidents and fatalities. The following three points explain why HAD will not lead to a considerable reduction in road fatalities on the motorway:

1. The motorway is not an accident black spot

   Accident and traffic statistics from Germany show that 11% of traffic fatalities are caused by accidents on the motorway [10], although 30% of all journeys are covered on motorways [9]. This shows clearly that on motorways, fewer accidents occur per kilometre as on urban or rural roads (Fig. 15.3).

2. Accidents addressed with ADAS on market on motorway

   In the beginning, no great benefit is to be expected for road safety by means of Highly Automated Driving. Relevant accidents can be already avoided
or mitigated on motorway by ADAS offered today [11]. The distribution of accidents on the motorway shows that 60% of the accidents happen between vehicles moving along in carriageway and 27% of accidents are caused by driving accidents, in which no other road user contributed to the cause of the accident [12]. Most of the accidents on motorways are already addressable by current ADAS, as they are available in the current BMW 7 series [13]:

- Adaptive cruise control with emergency brake
- Lane keeping assistant with active side collision protection
- Steering and lane control assistant
- Driver drowsiness detection
- Traffic jam assistant
- Advanced eCall
- Active protection

3. **Low market penetration**

In the beginning, the market penetration of Highly Automated Driving functions will be limited to high-priced fully equipped vehicles. The market for this class of vehicle is small and, therefore, a low market penetration of HAD functions is initially expected in the entire vehicle fleet.

**15.1.5 Indirect Safety Benefit**

In addition to a direct increase in safety, there will be an indirect increase in safety with the usage of technology from Highly Automated Driving. From the beginning, HAD technology can be used for improving Active Safety Systems while the vehicle is not in Highly Automated Driving mode. In the long term, a cost-down effect will additionally result in a greater market penetration of HAD technology and derived Active Safety Systems.
1. Highly Automated Driving Technologies for non-Automated Driving

The first use case for Highly Automated Driving on the motorway does not address the majority of accidents, because most traffic accidents occur in situations on urban and rural roads. Precisely, in these situations there is the possibility to assist the driver by means of lower levels of automation (see Fig. 15.4). Vehicles with HAD functions will be equipped with extensive technology for environment recognition and automated vehicle control. These technologies can be used to improve Active Safety Systems. A more accurate detection of the environment around the vehicle and a more detailed interpretation of the traffic situation are possible, which can be used for the design of advanced functions (e.g. higher speed range, stronger deceleration) and for new Active Safety Systems (e.g. evasion assistant). The potential of optimisation of Active Safety Systems is discussed in Sect. 15.2.

2. “Democratisation” of HAD Technology

In the long term, a higher market penetration of Highly Automated Driving functions can be expected in all vehicle classes. The past has shown how new safety systems were introduced in upper class vehicles first, then were successively optionally available in all models and finally became part of the standard equipment for all passenger vehicles. Examples with a high impact on vehicle safety are the airbag, ABS, DSC (ESP) and, most recently, the Autonomous Emergency Braking (AEB) Systems.

The comfort function Adaptive Cruise Control (ACC) was available for the first time in the BMW 7 Series in 2000. Meanwhile, ACC is available in each vehicle class offered by BMW in different variants. These variants, depending on the vehicle class, use different sensor layouts from a mono camera to a fusion system with stereo camera and radar for object detection. The safety function
Forward Collision Warning (FCW) including Autonomous Emergency Braking assistant (AEB) has been derived from the comfort function ACC. In case of a potential rear-end collision, the system detects the critical situation, warns the driver and initiates autonomous braking. This safety function has high demands on the overall system: it must be reliable; the strength of deceleration can vary depending on the identification and validation of the object in question up to full deceleration levels and must be controllable for the rear traffic at any time. Despite these high safety requirements, this function has become part of the basic equipment (e.g. in the BMW 2 Active Tourer) and will have an even higher market penetration in future.

Different scalable variants of comfort and safety systems can be offered across all vehicle classes; the variants differ in the offered speed range and the maximum possible deceleration of the emergency brake assistant. Figure 15.5 shows exemplary differences between the basic variant in the 2 Series Active Tourer and the high-end variant in the X5.

### 15.2 Future Development of Active Safety Systems

#### 15.2.1 Required Technologies: Highly Automated Driving

In order to offer HAD functions, it is not sufficient to combine existing driver assistance systems. Necessary requirements pertaining to environment recognition, trajectory planning and vehicle management cannot sufficiently be fulfilled by available driver assistance systems today. Existing systems must be improved and new technologies need to be integrated into the vehicle. If these premises are fulfilled, HAD functions can bring safety on the road. Figure 15.6 shows the necessary captured environmental parameters and the required simplified technologies.
15.2.2 Difference Between Highly Automated Driving and Assisted Driving

From a vehicle’s safety point of view, the main difference between Highly Automated Driving and assisted driving is that the driver must not monitor the system all the time in every driving situation. As a result, critical situations must be solved by the system and not by the driver. To meet this requirement, all variables which are necessary to describe the traffic situation adequately within the limits of the system must be determined and interpreted correctly.

During manual driving, a critical situation arises by means of a chain of interacting parameters, which are ignored or not recognised by the driver. Driving too fast for a specific situation creates a risk, but does not necessarily lead to an accident. The accident happens only if additional critical parameters occur, such as, e.g. an obstacle after a blind curve. This chain leads to an accident, which is generally due, in approximately 90% of cases, to misbehaviour of the driver [12]. However, it must be noted that the driver solves a critical situation with the right response in most of the cases.

Even in Highly Automated Driving mode, it is not possible to drive entirely risk free because road transport is per se risky, since unexpected hazards cannot be excluded. Therefore, an action is already initiated when a defined risk level exceeds a limit, in order to reach a safe state, for example, speed reduction or to abort a lane change manoeuvre.
Perhaps, Active Safety can or must learn from the described strategy in the above paragraph, because a critical situation cannot be addressed by automated intervention in the vehicle dynamics at any time. In an early stage, intervention in the vehicle dynamics cannot be undertaken due to the uncertainties in the interpretation of the traffic situation. The uncertainties would result in a too high false positive rate. An excessive frequency of false reactions would lead to reduced acceptance and would cause a negative impact on road safety [15]. Therefore, early intervention can only occur if the critical situation is unavoidable and the driver has not addressed the danger as such.

### 15.2.3 Benefits for Active Safety Systems

Detailed recognition and correct interpretation of the environment are essential for Highly Automated Driving functions to perform a safe trajectory planning and to respond to oncoming threats [16]. To fulfil these requirements, a 360° environment recognition is needed, which provides much more details of the traffic situation than systems available today are able to provide. Sub-areas are covered by different sensors (such as camera, radar, laser scanner); this leads to intended overlapping areas in the sensor view (redundancy). Thus, a plausibility check of the provided data is possible and an advanced function design can be implemented, such as a higher deceleration or to initiate steering torque to evade an obstacle.

HAD vehicles will be connected with a backend. Necessary information is exchanged in both directions via data connection to safely perform HAD functions. The backend is a server infrastructure and provides data such as updated map data, hazard points or track clearance for HAD functions. As an extended sensor, the backend can indicate threats which are not collectable from the vehicle or are out of the detection range of the onboard sensors. The backend collects data from different sources and evaluates and processes this data to provide useful information for other vehicles. A typical application could be the recognition and warning of a traffic jam. The backend analyses the traffic jam from real time data and forwards this information to relevant vehicles. If this information is available, a safe and efficient speed reduction can be realised, as shown in [17]. Another way to provide useful data is by learning from fleet data. From recorded vehicle data, driver assistance-related parameters are learned by the backend, such as speed limits, cornering speeds or hold lines at intersections. These useful parameters can be used for a better assessment of the traffic situation [17]. This requires strict compliance to the legal framework for data protection.

Highly accurate digital maps contain information such as, e.g. lane-accurate track models, traffic signs, lane markings and landmarks. This information offers the opportunity to gain a better understanding of the traffic situation. Other road users can be associated on the road with the help of the environment recognition and the highly accurate digital map [16]. Available spaces for movement and possible points of conflict can be determined. The map is continually updated by the backend.
By use of highly accurate positioning [18] and highly available actuators, automated vehicle control at the physical limits [19] can be used to showcase Active Safety Systems and were in fact already demonstrated by BMW [20]. Emergency braking, evasion, automated lateral and longitudinal vehicle control at higher speeds and a safe hold on the roadside in case of an emergency [21] are possible.

Driver monitoring can be used for an advanced function of Active Safety Systems. By analysing gaze behaviour, it is possible to determine whether a critical traffic situation was theoretically recognised or not by the driver. In case of an existing information deficit, the driver can be specifically warned without increasing unjustified warnings. As a result, greater effectiveness at an acceptable false positive rate can be achieved [22]. Upcoming manoeuvres can be recognised with the help of a driver’s gaze behaviour. The possible movement of the vehicle can be restricted; with this information, a better interpretation of the traffic situation can be realised [23].

15.2.4 Development Process for Active Safety

Available Active Safety Systems already address a high proportion of the most common accidents. However, not all accidents can be addressed with the current system design, because today a complete interpretation of the traffic situation is not possible. This limitation is based on a too large variation in traffic situations and too many parameters (road topology, road users, driver condition, etc.) which define a traffic situation. Therefore, the system design of Active Safety Systems is focused on common types of accidents (e.g. rear-end collisions) with few possible causes of accidents (e.g. insufficient stopping distance). This approach works very well and a high coverage in the field is reached, e.g. for rear-end collisions, as described in [11].

A detailed analysis of accident data has shown [24] that there are 5313 meaningful combinations of types and causes of accidents, which covers all possible road accidents. Interestingly, 50% of all accidents are covered by the 26 most common combinations of types and causes of accidents (see Fig. 15.7).

An additional linear increase of the coverage of types of accidents and causes of accidents leads to an exponential increase in the effort that is necessary for developing Active Safety Systems. To gain a greater coverage of accidents, this approach is no longer practicable. Too great effort in the development of individual Active Safety Systems is required to cover only a small number of accidents. The number of different system designs of Active Safety Systems would lead to a no longer manageable complexity of the overall system. For a manageable system, new approaches are needed, which are able to address a larger variation of critical situations.
15.2.5 Future Requirements and Perspectives

For a greater coverage of critical situations, the variation of potential traffic situations is too great and can only be solved if all relevant properties are included in the calculation of the criticality of the traffic situation. New approaches are required for the functional development of Active Safety Systems, especially when more and more properties of the traffic situations under consideration are recognised, due to the increasing degree of automation. Particularly in the interpretation and evaluation of traffic situations, Rodemerk et al. [25] and Wachenfeld and Winner [26] demand a more generic approach. Future approaches should not be restricted to a few types of accident with a limited variation. They should interpret the traffic situation as a whole.

To address more accidents, an earlier resolution of the cause of the accident is needed and not only a reaction at the latest possible time, when a collision is unavoidable. To achieve this, it is necessary to interpret the traffic situation correctly and to derive the potential cause of accident. In the first step, all relevant properties of the traffic situation must be determined and assessed; see Fig. 15.8. The first challenge is to determine which properties are relevant (such as road topology) and how these properties can be determined (e.g. with highly accurate digital maps). Only if all relevant properties are captured, the cause of the critical situation can be identified and addressed in the next step.

Not all properties can be captured without additional new technologies. A pedestrian who is hit by a vehicle, accident black spots on a road section or the road conditions are not fully identifiable with currently available systems in the vehicle.

In the next step, the captured properties of the traffic situation need to be evaluated so that the critical variables of this situation can be derived. An example
would be: pedestrian is partially hit, crossing trajectory, wet road, driver distracted, school on the left side, 07:09, etc.

After identifying the critical variables, an assessment of risk is performed in the next step. The risk assessment must not only cover selected types of accidents but must be carried out using a generic approach. As a result, factors such as the type of threat, criticality, probability of occurrence and time until threat are provided by the risk assessment.

In the final step, the vehicle reacts on the basis of the risk assessment. Depending on the escalation level, the reaction can range from warning information to an automated driving manoeuvre. The challenge here is not to disturb or to overstrain the driver with too much information. To solve this problem, only dedicated information can be distributed to the driver when there is an information deficit.

New technologies from Highly Automated Driving move the function development of Active Safety Systems in three directions:

1. An improvement of current Active Safety Systems (e.g. evasion assistant [27]), with an interpretation of more properties of the traffic situation and an advanced actuation strategy.
2. New Active Safety Systems (e.g. emergency stop assistant), which resolve critical situations when the driver is no longer able to control the driving task.
3. The development of a continuous risk assessment of the entire traffic situation to enable an earlier resolution of a critical situation by means of a better interpretation of the traffic situation. Thus, the driver can mitigate the critical situation by himself with information provided specifically for this purpose, if an information deficit exists [23].
15.3 Prospective Evaluation of the Effectiveness of Active Safety Systems and HAD Systems

15.3.1 Challenges

Highly Automated Driving functions and Active Safety Systems are safety relevant; Daimler [28] also discussed the challenges and the safety-relevant validation associated with HAD functions. It is clear that the development and the usage of Active Safety Systems require prospective and quantitative statements regarding the impact of Active Safety Systems on traffic safety, requested in [15]. For homologation of HAD functions, it has to be proven that there is no negative effect on traffic safety. Available driver assistance systems must provide evidence that the driving functions are safe and manageable. This validation of available driver assistance systems is still manageable; the traffic situations in which the systems operate are complex, but the systems evaluate and operate the driving function only based on a limited number of properties of the traffic situation.

It is not feasible to perform the validation of the safety aspects of Highly Automated Driving functions on the road: according to Winner [9], HAD functions for the highway would have to cover around 100 million km road tests to generate a statistically valid statement that the system can be classified as safe. Any changes to the system require a renewed assessment. Both technically and economically, it is not possible to provide the necessary evidence using road tests alone.

Another problem is the almost infinite number of possible traffic situations. This necessitates a validation of perception and cognitive capability of the system. With currently available methods, the validation of Highly Automated Driving functions or complex Active Safety Systems is not possible.

15.3.2 Variability at the Model Design

HAD functions and Active Safety Systems are designed to perform automated vehicle guidance and to avoid and minimise the consequences of critical situations. To achieve this, all relevant parameters pertaining to the driver, the traffic situation and the system itself need to be captured and necessary reactions need to be performed. This leads to a widespread of possible variations, shown in Fig. 15.9. Each variation can entail thereby in principle positive or negative effects on traffic safety and must, therefore, be considered. For example, a stochastic modelling is recommended to cover the variation of the relevant influencing factors [15].
15.3.3 Evaluation of the Effectiveness

An objective metric, as required by Kompass et al. [15, 29], is necessary to determine a quantifiable prognosis regarding traffic safety benefits. Different interests of vehicle manufacturers, suppliers, official decision makers, insurance companies and consumer protection organisations need to be considered. This requires a careful definition of a metric, which must deal with all necessary interests of stakeholders as stated above to achieve the necessary acceptance.

In addition to the safety benefit of new driving functions, also possible risks need to be considered to enable an assessment of traffic safety. Helmer shows in [30] a way to perform an assessment of safety benefits and negative effects with the help of an objective metric. By use of this, a driving function can be assessed in terms of traffic safety and optimised in the development process.

The overall consideration of a system must take into account the varying boundary conditions of the situations contemplated. A complete assessment of HAD functions and future safety functions can only be achieved with the help of virtual testing and validation, where realistic traffic scenarios must be taken into account. A possible process for effectiveness assessment of HAD functions and Active Safety Systems is described in detail in Chap. 20.

To come closer to a harmonised methodology, the “Harmonisation Group” was founded with representatives from different domains in 2012 [31]. A pilot usage of the methodology for the effectiveness analysis is applied in the project AdaptIVe [32] to analyse the iterative process in the development and validation phase of HAD functions.
15.4 Conclusion

Highly Automated Driving will increase comfort and safety on the roads. In the first HAD use case on motorways, the number of traffic accidents will not decrease enormously, because of the low number of accidents on the motorway compared to urban or rural roads, the addressing of today’s available Active Safety Systems and the low market penetration of Highly Automated Driving functions.

Highly Automated Driving can be the enabler for safety functions, which could additionally increase the safety in the field of assisted driving in any traffic situation. Current Active Safety Systems can be improved and new Active Safety Systems can be implemented, which are able to address a large number of different accidents.

The effectiveness analysis of Active Safety Systems and the validation of HAD functions require new and until now unresolved challenges. Currently available methods do not sufficiently demonstrate evidence of the safety benefits. Prospective effectiveness analyses are needed to solve this problem so that HAD function and improved Active Safety Systems can be brought on the road.

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