Chapter 1
Introduction to Automated Driving

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1.1 Introduction

Innovation and action plans of public authorities (see, e.g., www.gov.uk) around the world aim to clear the way for a stepwise introduction of automated vehicles. The plans comprise a number of aspects like standardization, testing, safety, or in-vehicle technology. It is expected that automated driving will [1].

• Improve safety by reducing human driving errors
• Significantly contribute to the optimization of traffic flow
• Help to reduce fuel consumption and CO₂ emissions
• Enhance the mobility of elderly people and unconfident drivers

Several forecasts predict a limited availability of automated driving functions in 2020 (partial and conditional automation) and a wide availability by 2040 including high and full automation [2–4]; see Sect. 1.2 Today’s advanced driver assistance systems (ADAS) like Automatic Cruise Control (ACC), Lane Departure Warning (LDW), or Pedestrian Detection (PD) will form the backbone of tomorrow’s mobility. Vehicles will communicate with each other and with infrastructure [5]. Vehicle-to-Vehicle (V2V) communication allows vehicles to exchange relevant information like local traffic data (e.g., nearby accidents) and about their driving intention. Vehicle-to-Infrastructure (V2I) communication will be used to optimize the road network usage and thereby helps to reduce environmental pollution. The
role allocation between human drivers and automated driving systems in this scenario is specified by the six levels of driving automation (see www.sae.org).

This chapter is organized as follows: Sect. 1.2 briefly introduces the different levels of automation as defined by SAE J3016 [6]. The three layers specifying the key technologies of automated vehicles are outlined in Sect. 1.3. Section 1.4 summarizes the research challenges, which have to be mastered in order to enable automated driving; Sect. 1.5 concludes the chapter and gives an overview of the topics covered by the book.

### 1.2 Levels of Automation

Figure 1.1 briefly summarizes the levels of automation according to the definitions of SAE J3016 [6]. They span from *no automation* to *full automation*. The table gives a narrative definition of the respective levels as well as responsibilities (steering, monitoring, fallback scenario) and specifies minimum requirements. The term “system” in this context refers to the respective driver assistance or automated driving system. It should be noted that warning and momentary intervention systems are excluded as they have no impact on the driver’s role in performing the driving task. Furthermore, the table shows the correspondence between the levels of the German Federal Highway Research Institute (BASt) and those of the US National Highway Traffic Safety Administration (NHTSA) in its “Preliminary Statement of Policy Concerning Automated Vehicles” in 2013.

Between levels 2 (“Partial Automation”) and 3 (“Conditional Automation”) is a key distinction as in the latter case the system performs the entire dynamic driving task (execution of steering, acceleration, deceleration, and monitoring of environment).

![Fig. 1.1 Summary of levels of driving automation for on-road vehicles [6]](image)
Table 1.1 Current and future systems/functions for vehicle automation [1–4, 7]

| Level of automation | Current and future vehicle automation systems and functions                          | Market introduction |
|---------------------|------------------------------------------------------------------------------------|---------------------|
| 0                   | Lane change assist (LCA)                                                          | Available           |
| 0                   | Lane departure warning (LDW)                                                       | Available           |
| 0                   | Front collision warning (FCW)                                                     | Available           |
| 0                   | Park distance control (PDC)                                                        | Available           |
| 1                   | Adaptive cruise control (ACC)                                                     | Available           |
| 1                   | Park assist (PA)                                                                   | 2016                |
| 1                   | Lane keeping assist (LKA)                                                          | Available           |
| 2                   | Park assistance                                                                    | Available           |
| 2                   | Traffic jam assist                                                                | 2016                |
| 3                   | Traffic jam chauffeur                                                              | 2017                |
| 3                   | Motorway chauffeur (MWC)                                                          | 2019                |
| 4                   | Highway pilot                                                                     | 2020+               |
| 4                   | Piloted parking                                                                    | 2020+               |
| 5                   | Robot taxi (fully automated private vehicle)                                       | 2030+               |

In contrast to level 4 ("High Automation"), the driver is expected to be ready for taking over control (within a predefined time period) at all times in level 3.

Table 1.1 gives a brief overview of already introduced driver assistance systems (for both passenger and commercial vehicles) and of systems which are on the way to enter the market. For an in-depth discussion and analysis of the different driver assistance systems and automated driving functions listed below, the following supplementary readings are recommended: [8–12].

1.2.1 Scenarios and Impact of Automation Levels 2–5

According to [7]

Level 2: Partial Automation

- Improved driving comfort (driver is actively engaged)
- Increased safety is expected
- Increase in energy efficiency and traffic throughput (if cooperative)
- Scenario: highways with limited access, traffic jam assistant

Level 3: Conditional Automation

- Improved comfort and convenience
- Impact on safety strongly depends on ability to retake control in emergency conditions
- Increase in energy efficiency and traffic throughput (if cooperative)
- Scenario: traffic jam chauffeur, highway chauffeur
Level 4: High Automation

- Drastically improved driving comfort
- Increased safety improvement due to automatic transition to minimal risk conditions
- Further increase in energy efficiency and traffic throughput due to close-coupled platooning (cooperative)
- Scenario: trucks on dedicated truck lanes, automated valet parking, highway pilot

Level 5: Full Automation

- Ultimate comfort and convenience
- Efficiency gains in energy and road network usage
- Scenario: electronic chauffeur service, driverless urban goods pickup, and delivery service

1.3 Building Blocks for Automated Driving: Key Technologies

The building blocks for automated driving are shown in Fig. 1.2. They constitute three layers covering vehicle control (layer 1), sensing (layer 2), and processing and decision-making (layer 3).

Vehicles capable of (highly) automated driving are controlled agents integrating environment perception and modeling, localization and map generation, path planning, and decision-making; see Fig. 1.3.

The block “Environment Perception and Modeling” provides a real-time model of the surrounding environment. The required data is collected from the environment

![Fig. 1.2 Building blocks for automated driving](image-url)
sensors like cameras, radar, lidar, or ultrasonic sensors. From the gained data original data features are extracted such as lane edges, lane markings, traffic signs, and vehicle types (passenger, commercial…). Semantic objects are recognized using classifiers, and scenarios, driving context, and vehicle positions can be computed.

The blocks “Localization and Map Building” symbolize the vehicle’s ability to generate a global map via combination of local maps, global information, and data from environment models. In the context of automated driving, the term “Localization” refers to the estimation of road geometries or of the vehicle position with respect to roads in known or unknown maps.

The block “Path Planning and Decision-Making” guarantees that the vehicle is operated in accordance with the requirements to be met such as safety and legal aspects. The purpose of the three blocks making up “Path Planning and Decision-Making” is to find an optimal (in the sense of safety, speed, distance, energy saving) path in the road space from an initial position to the desired destination while avoiding collisions. Figure 1.4 illustrates the principal structure of these three blocks. It includes a strategic component (global path planning, e.g., navigation), a tactical component (e.g., lane selection), and a reactive component (local path planning, e.g., obstacle avoidance). Decision-making consists of behavioral reasoning and
adaptive mission planning by incorporating new observations and by generating and implementing new rules.

Finally, vehicle automation requires lateral and longitudinal control of motion with respect to the desired objectives and constraints. This task is reflected by the block labeled “Vehicle Motion Control” in Fig. 1.3.

Putting it all together, the overall vehicle architecture to enable automated driving which includes additional control blocks, new sensors, and advanced human–machine interaction (HMI) can be envisioned as shown in Fig. 1.5. The blue boxes indicate new and emerging technology bricks—compared to conventional driving—but also those fields of action where advances are strongly required and expected.

### 1.4 Enabling Automated Driving: The Research Challenges

Over the last two decades, automated driving has been a challenging research topic. However, despite tremendous improvements in sensor technology, pattern recognition techniques, robust signal processing, control system design, computational power (multi-core and many-core technology), communication bandwidth (Ethernet . . .), V2X, and other system technology areas, market introduction of a fully automated vehicle that is capable of unsupervised driving in an unstructured environment still remains a long-term goal. Even for structured environments,
Fig. 1.6 Overview of the maturity of different automated driving functions according to the SAE levels [17]. Currently, SAE level 2 functions are still limited [The current UN Regulation No. 79 (Steering equipment) allows only corrective steering (lateral assistance) above 10 km/h. Due to that, steering capabilities of today’s level 2 functions is still limited]

Further research is needed to exploit the full potential of road transport automation. In order to be accepted by drivers and other stakeholders, automated vehicles must be reliable and significantly safer than today’s driving baseline. A couple of roadmaps for automated road transport has been released by different stakeholders over the last 2 years giving a comprehensive view on the proposed way forward [2–4, 14–16].

As the technology for automated driving becomes more and more advanced, the research focus is shifting towards the emerging issues for their implementation. It is common sense from the industrial point of view that automated driving will be introduced following a stepwise approach. Figure 1.6 illustrates that the maturity of automated driving functions at low speeds in a structured environment is already quite high while high speed maneuvers in an unstructured and complex environment—ultimately fully automated driving—is still facing many technological (and legal) challenges.

Figure 1.7 classifies the automated driving roadmap in midterm (3–6 years) and long-term (7–12 years and beyond) challenges in alignment with the SAE automation levels. The typical approach to enter the market consists of three steps: technological research (long-term relevant), followed by piloting, field operational tests, and large-scale demonstrators (midterm scenarios) and completed by industrialization (market introduction). It is worth mentioning that commercial vehicles follow different roadmaps since other use cases have priority (e.g., platooning).

In the following, we give an overview of fields of action that have to be addressed in order to succeed in terms of technology readiness and public acceptance:

1Without raising a claim of completeness.
1.4.1 Demonstrating Safety, Reliability, and Robustness

Automated vehicles by nature rely on sensing, planning, reasoning, and acting (or re-acting). A suite of vehicle sensors based on different sensing modalities (radar, lidar, camera, ultrasonic, GPS...) along with external sources (V2X) and detailed digital maps gather raw data of the vehicle environment, driving situation, and ambient conditions. Sophisticated algorithms interpret the data, process it, and convert it to commands for the actuators (steering, braking). Within this complex chain of sensing–processing–controlling–actuating, several types of failures can occur and have to be avoided:

- Sensors fail to recognize and respond to a hazard (false negative), e.g., the vehicle should brake but it does not (in terms of an emergency braking system).
- Sensors detect and respond to a nonexistent event (false positive), e.g., the vehicle brakes without any reason.
- System performance is degraded due to inoperable sensors or the vehicle is completely inoperable.

Consequently, there is a strong need for an independent and reproducible validation of automated vehicles. Without a traceable demonstration of the maturity (technological readiness), reliability, and safety, the societal acceptance will lack. Reliable and safe enough means rare enough, i.e., the failure probability rate should be less than $10^{-n}$/h. If somehow an adequate sample size $n$ can be argued—which is currently not the case—then appropriate safety and reliability can be demonstrated by driving (testing) in the order of $10^n$ h. For $n > 5$, this becomes effectively infeasible since effort and related costs increase tremendously.
As a result and based on current fail-safe and fault-tolerant architectures, automated driving needs further explorations in order to ensure a safe and fail-operational driving (concept of redundancy). For that, we need to:

- Evaluate failure modes and their impact.
- Investigate the enhanced capabilities that can self-detect, self-adapt, self-learn, and predict failures/situations in an evolving traffic scenario.
- Explore what additional requirements might be needed for fail-operational driving in terms of software, hardware, V2X communication, advanced HMI . . .
- Determine required safety levels (update the ISO26262 regarding fail-operational systems).
- Develop methodologies for testing to demonstrate safety and reliability (mixed traffic should have midterm priority). Recent publications pointed out that approximately 100 million road driving kilometers are required to prove that automated vehicles are as safe as manually driven ones [18].
- Provide standardized and certified test procedures and test environments for fail-operational vehicles for any ambient condition (traffic and weather).

Furthermore, automated driving has to be considered a self-learning and adapting system based on field operational tests in order to enhance the number of relevant scenarios and to dynamically extend the list of requirements. This feedback loop of real world data will support agile development and agile validation of automated driving functions and increases safety and reliability. A set of basic scenarios and related parameters for each level of automation should be defined in accordance with certification bodies across countries.

### 1.4.2 Demonstrating Security and Privacy

Consumers expect privacy and security in their cars. Consequently, the collection, processing, and linking of data have to be in accordance to the laws of privacy. At present, a lot of personalized data is already collected via navigation systems, smartphones, or during vehicle maintenance. Automated vehicles are capable of recording and providing large amounts of data that might assist crash investigations and accident reconstructions. Such data is of high relevance for improving active safety systems and system reliability but also for resolving liability issues. Existing accident data bases such as the GIDAS project (German in-depth accident study) should be updated continuously and extended by automated driving information (SAE level classification of involved vehicles, driver/automated mode . . .).

Furthermore, cyber security (vulnerability to hacking) has to be considered in order to avoid that the vehicle or driver lose control due to hacking attacks. Car manufacturers and their suppliers are in agreement that V2I and V2V communication, i.e., communication protocols, have to be developed with security embedded along the entire development phase (typical automotive v-cycle). Recent investigations show that nearly all modern vehicles have some sort of wireless connection that
could potentially be used by hackers to remotely access their critical systems [19]. In addition to security weaknesses, many car companies are collecting detailed location data from their cars and often use unsecure transmission paths.

### 1.4.3 Dependable Power Computing

In order to fully deploy the opportunities of next generation ADAS technology, greater on-board computing power based on multi-core and many-core technology is strongly required. Approximately, 1 GB of data will need to be processed each second in the real-time operating system of the vehicle. This cognitive data will need to be analyzed and mined fast enough that decisions can be made and vehicle actions can be performed. The vehicle has to react to changes in the environment, i.e., adapt itself to evolving scenarios, in less than a second based on a range of variables such as vehicle speed, road, and weather conditions. Furthermore, the vehicle will need to account for unpredictable behavior of vulnerable road users and other cars while in the city and to gauge the flow of traffic, e.g., to merge onto a motorway. The current automotive software architecture (AUTOSAR) for electronic control units which has primarily been developed for vehicle control functions is facing its limits when it comes to real-time cognitive data processing. The AUTOSAR development cooperation is well aware of that and has already taken action. The AUTOSAR Adaptive Platform (configurable and adaptive runtime environment layer) is currently under development, mainly driven by BMW, Daimler, Renault, Continental, and Bosch and will be available on midterm scale. Edge computing (networked and distributed computing) will also play an important role in the future. Nevertheless, there is also a strong need for hardware standardization (“plug and play”) and service-oriented architectures.

### 1.4.4 Human Factor (SAE Level 3/4)

It is still an open question how much time is needed for the driver to reengage. Currently, the range of 5–10 s is considered depending on the vehicle speed. As a major requirement, taking back control must happen safely and seamlessly with minimal risk for vehicle occupants and road users. Research has also to be undertaken for the vehicle–driver interface and related communication methods in order to ensure a safe transition between automated and non-automated mode. This includes overriding strategies, i.e., the driver can always override the automated driving mode and regain control. Driver awareness also plays an important role since an increased driver distraction and loss of skills due to reduced driver tasks and experience is expected. Consequently, driver training in particular for SAE level 3 and 4 vehicles will have to be deliberated. In this context, the development of human
factor software tools for testing and evaluating driver and vehicle performance for different SAE levels will be essential.

1.4.5 Environment Modeling and Perception

Perceiving the vehicle environment in real-time and in a very accurate and reliable manner as well as adapting to evolving scenarios is seen as one of the key enablers for automated driving. Along with an increased robustness of sensors, several research fields can be identified including

- Reliable image processing and decision-making (object recognition, tracking, classification, interpretation)
- Accurate road representation and positioning (strongly relying on high resolution digital maps)
- Advanced sensor fusion technologies
- Common and standardized architectures
- Quality assessment including functional safety of both (embedded) software and hardware
- Plausibility checking, monitoring, onboard diagnosis, and sensor failure detection

Furthermore, a couple of research questions has to be answered rather quickly since the vehicle intelligence (in particular traceable decision-making required for SAE levels 3–5) heavily depends on environment modeling and virtualization:

- Capturing of artifacts of the vehicle environment (traffic situation) and required confidence level
- Prediction of the situation (traffic) evolvement
- Integrity of such models
- Dealing with uncertain information

1.4.6 Vehicle Control and Actuation

Vehicle automation directly relates to fail-operational control and actuation (redundancy in hardware and software). Recent advances in in-vehicle computation enable to run more sophisticated, model-based, and robust control algorithms in real-time and onboard. The core of an automated vehicle is its intelligence (path planning, path tracking, prediction, reasoning, decision-making, and control) embedded in a flexible and re-configurable architecture. Although control theory and algorithms are well developed, advances are still needed. These include:

- Controllability of the execution of planned maneuvers at any time and always maintaining fail-operational behavior of the vehicle
• Integration and management of uncertainties (e.g., map-based uncertainties)
• Dealing with sensor insufficiency and related misinterpretations (sensor false positive)
• Dealing with sparse data in case of unreliable sensor data
• Dealing with big data in real-time
• Cooperative control and planning (interaction with other road users)
• Interaction with digital infrastructure
• Driver–vehicle interaction

1.4.7 Digital Infrastructure

Currently, almost all car manufacturers worldwide have released research prototypes at different SAE levels. Even though it is well understood and agreed that the embedding in a digital infrastructure is inevitable (V2X and X2V communication), a common development roadmap is still not existing. Vehicle research and infrastructure research follow parallel paths; however, joining forces will also drive innovations forward. From the infrastructure point of view, several topics have to be addressed [16):

• Traffic management in particular within urban environments (informative vs. influencing systems).
• Digital infrastructure (e.g., 50 Mbit/s by 2018 in Germany, nationwide)
• Data backbone, cloud data, and cloud computing (fog computing, i.e., several clouds with handover depending on driving route)
• Standards for intelligent roads
• Interaction of vehicles and their infrastructure
  – Open-source data cloud for geographic and mobility data, digital radio board (Germany: DAB+ to retrieve detailed and locally precise data in real-time)
  – Swarm intelligence
  – High-precision digital maps (from the infrastructure point of view)
  – Intelligent communication to traffic lights, traffic signs, signaling
• Standardization of IT security
• Privacy (collection, processing, linking of data) according to data privacy laws
• Legal constraints (international and national frameworks, approval of vehicles, technical maintenance and monitoring, driver training)

All of the above-mentioned fields of activity require further investigations to exploit the potential and benefits in order to ensure a safe, reliable, acceptable, and understandable (to the driver and other stakeholders), and secure behavior of the automated vehicle embedded in its intelligent environment at all times. Along with the technological advances, progress legislation, liability, and insurance are obligatory and urgently needed (for details see, e.g., [8, 20–22]).
1.5 Conclusion

This introductory chapter gives a brief overview of the current state-of-the-art of automated driving according to the SAE J3016 levels of automation and based on different recently published roadmaps. We also discuss and list relevant midterm and long-term development steps and innovation fields as well as related research challenges to be faced in order to foster societal acceptance of automated road transport. The following and carefully selected articles of this book will give an in-depth analysis of the currently most relevant technological topics from the perspective of the industry but also from renowned research institutions. The different chapters cover recent advances in environment sensing, sensor fusion, perception, decision-making, and predictive control methods for path planning and tracking. Furthermore, the increasing importance of in-vehicle architectures and embedded power computing is addressed. A major part of the book is dedicated to the demonstration and assessment of reliability and functional safety of automated vehicles along with security requirements. A sampling of ongoing collaborative European research projects and European initiatives finally reflects the strong European movement to automated driving.

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