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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Current infrastructure and systems to enforce and monitor the connected and intelligent mobility

Youssef Chehab

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences

SUPERVISOR :
Prof. dr. ir. Ansar-Ul-Haque YASAR

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Autonomous & Connected Vehicles in European Urban Mixed Traffic: Infrastructure and Systems for Connected and Intelligent Mobility

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Preface

The future of autonomous driving is one of the megatrends disrupting not only the automotive industry but the transportation sector in general. There has been a lot of optimism based on industry participants and media predicting a widespread adoption. However, after the hype cycle has now peaked, the challenges that need to be overcome before autonomous vehicles can be rollout have become clearer. Urban mobility is currently going through a radical transformation, and I am proud to be part of it with my contribution to the autonomous and connected vehicle research field. Working for IHS Markit, a leading provider of automotive data and insights has allowed me to combine my learnings from the Master of Transportation Science Degree with my day-to-day job. This provided me with a unique opportunity to work closely with industry-leading experts and access relevant resources for my master thesis. I am thankful for the support received from my colleagues and Uhasselt supervisors during the last 12 months.

Summary

Germany will be the first country to introduce autonomous vehicles from research onto public roads. Germany's digital test beds in the public road environment are essential to the Federal Government's research and innovation funding. Germany has the ambition to establish itself as a pioneer and international catalyst for automated and connected driving.

City stakeholders, the education sector, and the industry have formed various partnerships to test infrastructure technologies and related systems in dedicated environments in real-life. 12 out of 26 test fields are located in urban city environments, representing different density levels. However, recent testing in Germany as part of the 144 test-field projects has shown the current limits of automated driving. It became apparent that some road sections, i.e., intersections, cannot be equipped with cameras and radar systems in the future. Today, various systems are still under development and need further extensive testing.

The automotive camera sensor is a critical component of the autonomous driving sensor suite, along with ultrasonic, radar, and lidar sensors. Advancements in automotive imaging technology will be playing a critical role in the development of fully autonomous driving technologies. Automated driving systems will continue to use an ever-increasing number of sensors to enable vehicles to handle all the aspects of driving functions under all environmental conditions. Nevertheless, functional safety and cybersecurity issues pose a significant risk to automotive camera sensors. Next-generation camera sensors and image recognition processors need to support a high level of functional safety (ASIL B and above) and resilience toward cyberattacks.

Advanced driving assistant systems (ADAS) primarily focus on collision avoidance technologies and are set to feature in all new vehicles based on a phased approach. These safety measures are mandated by the European Union and enforced through General Safety and Pedestrian Safety Regulations Committee. With the increasing complexity on all levels, the European regulators must establish a comprehensive assessment of safety and maturity of the automated vehicles before they are placed on the EU market. They will need to cover testing procedures, cybersecurity requirements, data recording rules, and monitoring of safety performance and incident reporting requirements by manufacturers of automated vehicles (L3-L5).

Before safe and reliable operations of autonomous vehicles can be achieved in urban environments, significant technological challenges need to be resolved, which include:

Development and implementation of a suite of sensors and related sensor fusion software that helps detect, recognize and track the motions of all objectives in the surrounding area.

Reliable prediction of future motions of all moving objectives surrounding the vehicle environment to enable the L2-L3 or fully AVs to take pro-active actions.

Driver assistance systems bring more road safety but are also subject to wear and tear. A recent TÜV and British Research Laboratory study indicated a substantial risk of Sensor malfunction due to wear and tear. As more vehicles are equipped with safety features, it becomes increasingly important to establish a regular testing procedure.

The Lack of development and implementation of efficient software verification and validation (V&V) procedures for ADS software dedicated to safety needs to be addressed as a priority. Currently, available software V&V is unsuitable due to its high cost and labor intensity.

Alongside the European Transport Safety Council (ETSC) recently urgently calling for a full investigation of crashes, within the EU, most authorities do not routinely access in-vehicle data when investigating collisions due to the technical complexity and legal barriers. For traffic law enforcement and post-incident investigation work with L2-L3 vehicles in Germany, access to the in-car data would benefit the relevant authorities.

Vehicle technology is rapidly evolving, but the required urban infrastructure and systems for autonomous and connected cars are lagging. Rolling out 5G wireless technology requires extensive investment in infrastructure to cater to the sheer volume of data.

As it is likely that ADS deployment will still take a significant time to be implemented in an urban environment, it will provide stakeholders and policymakers sufficient time to develop necessary processes and plans to steer the deployment process.

Connectivity will likely be implemented well before automated driving systems feature in the dense urban city environment. With more connectivity finding itself in urban environments, city officials and regulators will adapt current law enforcement methods to cater to L2-L3 and fully autonomous vehicles. As it stands, there is currently no concept being tested in Germany. Additionally, there is an issue with data protection in Germany that might pose further challenges.

In the presence of the emerging technology of automated and connected vehicles, it is predicted that the future traffic system would be consist of both self-driving autonomous vehicles (AVs) and human-driven conventional vehicles. Several models have been studied; however, further research is required to understand better which model works best for the various traffic scenarios in congested urban environments. It is also impossible to test for all potential scenarios.

Lastly, recent surveys around public perception and acceptance of automated driving (ADS) systems indicated that there is still a lack of awareness and trust in automated systems. In order to earn and retain public trust, it is vital to continue to educate the public about the risks linked with ADS usage, based on an actual assessment carried out by professional and impartial organizations.

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Introduction

The automation of road traffic is one of the most significant changes in everyday life associated with digital transformation. It basically promises accident-free traffic, optimized traffic flows, and individualized mobility offers. It is expected that highly and fully automated and autonomous cars will enjoy a market share of around 20 percent by 2035 (IHS Markit, 2022).

In the car, automation has kept up with the increasing distribution and diversification of driver assistance systems for some time: the combination of lane departure warning system and automatic distance control today it is already possible to take the hands off the steering wheel for a few seconds when driving on the motorway or on country roads. Parallel to this, local public transport piloted driverless shuttle buses, which have a variety of flexible Enable mobility services, e.g., convenient last mile connections in residential areas or affordable ridesharing offers for the accessibility of city centers from the surrounding area. Several trails are experimenting with delivery robots that enable highly optimized and reliable delivery of goods in the city and could also be used at night.

From a technical point of view, road traffic automation is a paradigm shift. Until now, it was the task of motorists, cyclists, and pedestrians to pay attention to traffic rules, the anticipation of what is happening on the road, and mutual responsibility for accidents. In the case of automated driving, on the other hand, it is up to the electronic control systems in the vehicle and not down to drivers to make the right decisions. This can ideally rule out human error but inevitably comes up against potential performance limitations of the sensors, algorithms, and actuators. In the city, this is especially relevant because the traffic situations there are complex and automated vehicles would have to look "around the corner" to fully understand what is happening. Therefore, road traffic automation, especially in the city, relies heavily on information from communication with other vehicles, from sensors and cameras in the infrastructure, which is ultimately coupled with artificial intelligence. Automated driving is, above all, a systemic innovation in which vehicles, infrastructure, and people must work together seamlessly. Communicating data with high bandwidth and low delay is one of the essential requirements that can only be achieved with state-of-the-art networking and embedding in the cloud can succeed. It is then critical to involve and educate citizens concerned about their safety and the reliability of the system functions. Adjustments to the legal framework are also necessary to develop sustainable business and operator models and create new digital infrastructures.

Nevertheless, before fully automated or even self-driving vehicles are part of everyday life, there are still considerable (technical) hurdles to be overcome. In addition to new sensors for recording complex environments and robust algorithms and architectures for vehicle control, dynamic geo-maps, for example, have to be developed that enable automated vehicles to work together without accidents. At the same time, the methods for interacting with vehicle occupants and other road users must improve, and the communication systems used permanently against misuse and cyberattacks from the outside are secured.

Reliable and safe autonomous driving technology and applications are the significant aspects driving the connected car market and the general acceptance of autonomous vehicles. The availability of advanced radar, camera, and lidar sensor technologies monitoring the car's surrounding environment support safe vehicle reaction. Advanced driving assistant systems (ADAS) primarily focus on collision avoidance technologies (for example, lane departure warning and blind-spot applications), driver aids, driver alertness, and adaptive cruise control, which are increasingly becoming standard.

The development dynamics in the field of automated, autonomous, and networked driving are permanently high. In order to be able to leverage the potential of these technologies and allow society to participate in them, further measures need to be taken to implement corresponding systems in regular operation. Progress of autonomous driving in an urban environment will not be solely dependent on technological advances. A crucial key to automated and connected driving should instead be citizens' acceptance and the successful networking of the various social, economic and political actors.

This thesis aims to understand better what infrastructure and systems are required to support the safe and reliable deployment of autonomous and connected vehicles (L2-L3) in urban environments. Since the autonomous vehicle market is rapidly evolving, the legal framework plays an essential role in this industry's latest innovative developments and market changes.

This thesis is organized in the following way: chapter 1 starts with a literature review on the regulatory framework, focusing on Europe and Germany. The current and future vehicle automation technologies are presented in chapter 2. Chapter 3 reviews the current infrastructure and systems that are in place today. It also discusses the challenges needed to be overcome and critical enablers for reliable and safe deployment in the urban environment. It continues with a view on current and future traffic management and law enforcement methods. Chapter 4 deals with Automated Driving System (ADS) and Advanced Driving Assistant System (ADAS) benefits and risks. Public perception is addressed in Chapter 5. Finally, the thesis concludes with a discussion on future work needed.

Regulatory framework

This chapter discussed the current regulatory framework and related standards for automated vehicle technology in Europe and internationally. Due to variations and complexity in local law implementation, this thesis focuses on Germany. Establishing regulations and standards are essential priorities in order for automated driving technologies to advance further.

European Union

General Safety and Pedestrian Safety Regulations (GSR) must report to the European Parliament and the Council on progress on safety technology. This includes the monitoring and assessment of new advanced safety features and their feasibility and cost-effectiveness for possible inclusion in the regulations on general vehicle safety. This relates to protecting pedestrians and other vulnerable road users (VRUs)well.

The United Nations Economic Commission for Europe (UNECE) World Forum for Harmonization of Vehicle Regulations (WP.29) revised the vehicle GSR and adopted new type-approval requirements in November 2019). The regulation defines safety technologies and design features that must be standard in the European Union's new passenger cars and other road vehicles. The GSR must integrate certain ADAS functions as per the implementation schedule. In its plan to bring down road deaths to almost zero by 2050, the European Union has stated that vehicle technology will play a critical role in achieving its goal. The binding introduction date for the first functions is July 7, 2022, for new vehicle types and July 7, 2024, for new vehicles. The following table highlights all the camera-based ADAS features mandated by the new GSR rule and deployment dates.

The GSR rules are required to be implemented in a phased approach. Further safety features are regularly studied and reviewed by General Safety and Pedestrian Safety Regulations Committee and implemented accordingly.

Feature	New type approvals	New vehicle sales
All vehicles (Class M1 N1)	Required as of 6/7 July of following years:	
AEB Vehicle	2022	2024
AEB Pedestrian and AEB Cyclist	2024	2026
Reversing Detection	2022	2024
Emergency Lane Keeping Assist	2022	2024
Intelligent Speed Assistance	2022	2024
Driver drowsiness and attention warning	2022	2024
If automated: Driver availability monitoring system	2022	2024

Table 1: Mandatory ADAS deployment dates for European Union

Euro NCAP

Euro NCAP provides information on the safety of new vehicles. Euro NCAP stands for European New Car Assessment Program and more security. Euro NCAP has designed a 5-star rating scheme to offer all car buyers - a basis for comparing vehicle safety when choosing a vehicle.

The safety assessment is carried out through a series of vehicle tests developed by Euro NCAP and carried out accordingly. These tests simulate the most common accident scenarios from practice in a simplified way, which can lead to injury or death to vehicle occupants or other road users.

Although such safety ratings can never fully reflect the complexity of the real world, vehicle improvements and new safety technologies in recent years prove that European consumers and society at large have tangible benefits from higher safety standards.

Since 2014, Euro NCAP has required vehicles to be equipped with Assisted Emergency Braking (AEB) for a 5-star safety rating. It further modified this rule in 2016 to include AEB with pedestrian detection, and with the new protocols due to be rolled out in 2022, it is expected that AEB with cyclist detection will also be included for a 5-star safety rating. However, due to the COVID-19 pandemic, the European Automobile Manufacturers Association (ACEA) has requested the Secretary-General of Euro NCAP for a two-year delay in introducing the 2022 protocols.

Since 2018, Euro NCAP has also been encouraging the deployment of intelligent speed assist, lane departure warning, and lane-keep assist systems by rewarding extra points in the overall safety ratings of the vehicles. This has encouraged OEMs to offer vehicles equipped with Lane departure assistant (LDW/LKA), intelligent speed assists, and Blindspot detection (BSD) features either as standard or optional equipment in their passenger vehicles. Most of these features require a camera sensor, but a single camera sensor is capable of supporting multiple applications (Euroncap SAS Protocols, Jan. 2018)

International testing bodies

The Insurance Industry of Highway Safety (IIHS) is an insurance industry body in the United States that releases safety ratings and crash statistics through the Highway Loss Data Institute (HLDI). IIHS tests passive and active safety features of vehicles sold in the US. In passive safety, IIHS assesses the vehicle's front and side collision performance, as well as roof strength, whiplash protection, child restraint system ease of use, and headlamp performance. In terms of active safety, the evaluation is based on the efficacy of technologies that can prevent or decrease the severity of a crash. Since 2013, the IIHS has put active safety to the test through its front collision prevention rating program, which evaluates forward collision warning (FCW) and autonomous emergency braking (AEB).

The advent of new automotive assistance technologies has prompted safety agencies such as Euro NCAP to revise their assessment criteria of vehicles to include the latest highly automated active assistance systems offered in the market. Similar to Euro NCAP'sNCAP's Assisted Driving tests and the IIHS assessment of Partial Automation, other safety agencies such as China-NCAP, US NCAP by NHTSA, Japan-NCAP, and perhaps eventually Global NCAP are anticipated to incorporate new tests into their assessment criteria in the near future.

OEMs often label active assistance technologies with their own branded terminology that creates confusion among consumers but may also mislead users or create safety risks through misunderstanding or inconsistent functionality. Standardizing an industry-wide series of generic ADAS terms would eliminate the confusion around ADAS terminologies (IHS Markit, 2022).

Similarly, automated driving systems pose a risk of a potential safety issue when the systems are not safeguarded with appropriate monitoring and fail-safe measures. IIHS has recently revised the Assisted Emergency Braking (AEB) crash test speed to higher levels to be more relevant at speed levels where crashes occur more. Additionally, it will implement the Driver Monitoring Solutions (DMS) rating criteria in its vehicle assessments later this year. All these revisions in the assessment criteria on time could make roads safer for everyone.

Current status and development in international and European legislation

Since the autonomous vehicle market is evolving, the legal framework needs to be designed to sustain the latest innovative developments and market changes in this industry. It is essential to draft the legal framework that allows autonomous vehicles (AVs) to operate on public roads with openness, technology-friendliness, and flexibility.

For conventional vehicles, the type-approval procedure is well-established because traditional vehicle systems and supply processes have been less complex to handle. This is one of the main reasons there has been less focus on specific legal issues. With the increasing complexity on all levels, European regulators must establish a comprehensive assessment of the safety and maturity of fully automated vehicles before they are placed on the EU market. They will need to cover testing procedures, cybersecurity requirements, data recording rules, and monitoring of safety performance and incident reporting requirements by manufacturers of fully driverless vehicles.

International and European bodies and national governments are currently working toward developing the legal framework for road traffic and the operation of AVs on public roads.

One of the challenges is identifying the roles those different entities might play in the development of AVs, especially regarding the role and definition of traditional vehicle manufacturers. The eligibility to apply for the type approval and further issues that may be considered for AVs and ADS (e.g., retrofitting) may make adapting to current and future developments more challenging. In recent years more and more traditional technology or software companies are trying to move into the automotive market with their vehicles, creating further pressures on the traditional Automotive OEMs.

International level

The Geneva Convention on Road Traffic in 1949 and the succeeding Vienna Convention on Road Traffic in 1968 both defined the international legal road traffic framework.

Even though the Vienna Convention has been open to automated driving technology in recent years, it still presents a few challenges for deploying autonomous vehicles on public roads. One of them is the presence of a human driver who can take over control.

The UNECE's Global Forum for Road Traffic Safety ("WP.1"") developed a recent amendment to the Vienna Convention, which is due to enter into force in 2022. This amendment will form the framework for the responsible use of automated driving systems (ADS).

A new Article 34bis provides that the driver requirement "is deemed to be satisfied" while the vehicle is using an ADS, which complies with (i) domestic technical regulations and any applicable international legal instrument concerning wheeled vehicles, equipment, and parts that can be fitted and/or be used on wheeled vehicles, and (ii) domestic legislation on an operation which means that the article is applicable only in local, regional level. This amendment aimed to keep the legal setting as open as possible; however subject to domestic implementation (Patrick Ayad, Susanne Schuster, and Katharina Göpferich, 2021). It must be said that the amendment does not stipulate any requirements as to who should be eligible to bring vehicles equipped with an ADS on public roads

Regulation (EU) 2018/858

Regulation (EU) 2018/8585, which came into force on September 1, 2020, and is applicable in all EU Member States, stipulates harmonized rules for the approval and market surveillance of motor vehicles and their trailers, as well as systems, components and separate technical units intended for such vehicles (EU-Lex,2020).

Within the type-approval regime, the "manufacturer" is generally responsible for demonstrating compliance with requirements toward technical services and authorities to obtain approval from a Member State authority to be allowed to sell the vehicle and let that vehicle be operated on public roads. Regulation (EU) 2018/858 is open to different manufacturers, arrangements between manufacturers, and future developments (Official Journal of the European Union, 2018).

Draft EU ADS Regulation

The EU Commission is currently working on the implementation of the Regulation by laying down rules for the application of Regulation (EU) 2019/21446 ("EU General Safety Regulation" or "GSR"") as regards uniform procedures and technical specifications for the type-approval of motor vehicles concerning their ADS ("Draft EU ADS Regulation," EU Commission, 2022). The first version of the Draft EU ADS Regulation was provided on March 16, 20217, by the EU Commission's Directorate-General for Internal Market, Industry, Entrepreneurship & SMEs ("DG GROW"") to the EU Working Group on Motor Vehicles ("MVWG"") and its subgroup on automated/connected vehicles.

On September 22, 2021, the second version of the Draft EU ADS Regulation 8 was published. The draft addresses several positive developments that can be summarized as follows:

● Newly added reference in Regulation (EU) 2018/858 addressing the broad manufacturer's definition. The first version of the Draft EU ADS Regulation did not contain a definition for the term "manufacturer" and further used this term next to "vehicle manufacturer." Clarification has been provided on the term "manufacturer" under the Draft EU ADS Regulation is to be understood in accordance with the definition in Art. 3 (40) Regulation 2018/858. This enables any entity suitable and willing to prove responsibility and expertise toward the authorities to submit an ADS for type-approval. This paves the way for a flexible framework.

● Requirement of a driver or the requirement for transition demands to be given to the driver (not necessary according to ISO/SAE Levels 4 and 5) have been removed.

● Multi-stage type-approval procedure in accordance with Regulation (EU) 2018/858 has been incorporated. This enables retrofitting scenarios, i.e., installation of an ADS into base vehicles (conventional), which have been already type approved by another (vehicle) manufacturer.

Standards

Automated vehicle technology poses a significant challenge to legal and standardization bodies. Since this is a new, rapidly emerging domain, multiple standards exist. Whereby regulations and standards seem to have different objectives, they often interconnect and, in particular cases, act as a policy instrument to address safety and environmental aspects. Standards usually complement regulations to set the specific requirements for a product that it has to meet to be approved for market introduction. Therefore, standards play an essential role in developing new technologies and markets.

ISO 26262, ISO/PAS 24148 (SOTIF), and UL 4600 are the three primary standards related to autonomous driving. There is still substantial work to be done to determine more precisely how to define safety in autonomous vehicles, much less how to implement and evaluate safety.

Germany's local laws and regulations

Germany has passed a new law on autonomous driving, which entered into force on July 28, 2021, and amended the German Road Traffic Act (Straßenverkehrsgesetz – "SVG").

In Germany, it was previously only allowed regular operation by a driver up to ISO/SAE Level 3. The new law that came into force no longer requires a driver and intends to allow "autonomous driving functions" up to ISO/SAE Level 4 to be used in regular operation in defined functional areas.

Germany is looking to play a leading role in the autonomous and connected vehicle industry with the Federal Government, therefore, investing heavily (1 billion Euro between 2021 bis 2025, BMVI 2019).

In order to make the best use of the potential of autonomous driving and connected vehicles, the Federal Government focuses on advancing research and development to make future mobility safer, environmentally friendlier, and user-centric.

The Federal Ministry for Digital and Transport (BMVI) has been working on further improving the framework conditions, starting with the Act on Automated Driving (which entered into force on June 21, 2017). Since July 2021, the new legal framework for automated driving came into force so that autonomous vehicles (level 4) are permitted to operate in areas in public road traffic – nationwide.

The Federal Ministry for Digital and Transport plans to evaluate the law's effects at the end of 2023 by looking at progressions in the autonomous driving field and data protection regulations. Germany introduced the autonomous driving law (Act July 21) as an interim solution until harmonized international regulations.

Therefore, Germany will be the first country to bring autonomous vehicles from research onto the public roads.

The new legal framework focuses on flexibility. This means that the use of various deployment scenarios under the operation of the driverless autonomous vehicles is permitted to operate and only limited by the geographical scope. The requirement where the driver is needed constantly to intervene, and individual approvals have been removed and are therefore redundant.

Autonomous driving scenarios include the transportation of people and/or goods in the first and last mile, shuttle traffic, people movers, HUB traffic, and demand-oriented offers in off-peak times. Dual mode vehicles used for automated valet parking are example use cases.

Vehicle automation technologies:

Since launching in 2014, SAE (Society of Automotive Engineering) J3016 is commonly referenced as the "SAE Levels of Driving Automation" and has been the most-cited source for driving automation in the industry SAE's six levels of driving automation (SAE J3016) define the SAE Levels from Level 0 "no automation" to Level 5 "full driving automation" with regards to motor vehicles and their operation on roads (SAE, 2022).

Vehicle automation technologies can be classified into various levels (Level 0-6). Furthermore, multiple alternative definitions of the levels of National Highway Traffic Safety Administration (NHTSA), SAE, and Verband Deutscher Automobile (VDA) exist that define the degree of automation of a system (Gasser et al., 2012). The jump between the SAE categories of Level 2 to Level 3 is a significant step change, demanding the advancement of the technology from a driver support feature to an automated driving feature. Level 2 + was introduced to link the gap between Level 2 and 3 and shifts liability from the driver to the system. The Level 2+ automated vehicle technology supporting functionalities such as hands-off motorway driving is an intermediate level between Level 2 and Level 3 autonomy. This does not fall under either SAE J3016 or previous National Highway Traffic Safety Administration (NHTSA) definitions. Level 2+ automated vehicle technology allows hands-free driving under certain road conditions, such as on motorways or urban expressways with a clear physical barrier between the opposite lanes. However, the driver still has the responsibility for monitoring the driving environment and intervening if the system seems to malfunction. While the Level 2+ technology is comparable to Level 3 autonomy considering capability, it does not assign the liability from the driver to the system, like in the case of Level 3 autonomy.

In current projects in Germany, however, it has repeatedly turned out that the currently used definitions of the Level 0 to 5 are often not a perfect fit. For example, a vehicle in a limited area with the appropriate sensors, already on SAE Level 5 operates but not outside of this area.

A more precise definition would be desirable here to better describe the actual capabilities of autonomously driving vehicles (Buchholz, 2018). Furthermore, the levels at Bundesanstalt für Straßenwesen (BASt), VDA and SAE are defined and described differently as per table below (Figure 2).

Level	BASt	VDA	SAE
0	Driver only	Driver only	No Automation
1	Assisted	Assisted	Driver Assistance
2	Partially automated	Partially automated	Partial Driving Automation
3	Highly automated	Highly automated	Conditional Driving Automation
4	Full automated	Full automated	High Driving Automation
5		Driverless	Full Driving Automation

Table 2: Autonomy level definition comparison

Current sensor technologies in the market

ADAS and Active safety continue to grow, driven mainly by changing consumer preferences towards a more comfortable and safer driving experience changing consumer preferences towards a more convenient and safer driving experience, and regulation. Safety assessment bodies such as Europe NCAP, along with the other regional NCAPs, are putting more emphasis on installing active safety technologies for all the passenger vehicle segments. For achieving the desired level of safety offered by assisted and automated driving vehicles, OEMs and automotive suppliers are putting together a suite of sensing, perception, and computing resources for creating a 360° safety cocoon around the vehicle. Today, automotive camera sensors form the backbone of vision-based perception in ADAS and automated driving systems. With the proliferation of ADAS applications and growing technological advancements, high-quality image sensors are being placed in and around the vehicle.

Automotive camera sensors usually have to exceed the visual ability of the human eye to achieve the desired safety level. Advancement in semiconductor technology has resulted in significant improvements in image sensing and processing capabilities that have broadened the scope of ADAS functions. This chapter provides an overview of typical sensor technologies, including camera, radar, ultrasonic, and lidar. Furthermore, key benefits and challenges associated with each sensor type are discussed.

Automotive camera sensors

ADAS and automated driving functions require a vision system that can handle imaging, high-speed communications, and downstream image processing functions. Automotive vision systems supported by image recognition technology can effectively augment the driver's vision and highlight potential safety issues before they arise, followed by a corrective action either by the driver or the driver assistance system.

Camera sensors for automotive sensing

The below table highlights the key benefits and challenges associated with the sensor type:

Sensing technologies comparison		
Sensors	**Benefits**	**Challenges**
Camera	• Reads signs and sees color • Provides classification and interpretation • Is cost effective • Provides depth perception (3D cameras)	• Delivers poor performance in inclement weather and dark environments • Performance depends on ambient light • Performance affected by sun glare
Radar	• Measures velocity and distance • Works well in harsh environments and low-light conditions • Is cost effective	• Lower resolution and accuracy • Cannot read signs or differentiate color • Lower object recognition and classification
Lidar	• Provides mapping in 3D • Works well in low-light conditions • Features high resolution and accuracy • Offers real-time velocity with FMCW technology	• Is expensive • Inefficient in bad weather • Has potential for eye safety issues
Ultrasonic	• Detects distance and motion • Is cost effective	• Lower resolution • Lower range

Note: FMCW=frequency-modulated continuous wave
Source: IHS Markit

Table 3: Sensing technologies comparison, (IHS Markit, 2021)

Camera sensors are well suited for vision-based detection of objects such as other vehicles, pedestrians, cyclists, traffic signals, and road signs. Camera sensors are the only sensing technology to perform color perception and read traffic and road signs. Vision technology has significantly matured over the years and is also quite affordable. Additionally, camera modules are highly compact and can be easily integrated into the vehicle's body. Advanced image processing techniques and camera sensors provide highly reliable object detection and classification (IHS Markit, ADAS Report 2021).

However, camera sensors have their own limitations: they work poorly under low-lighting conditions and adverse weather conditions such as rain, fog, snow, and muddy driving conditions. Combining other sensing technologies such as radar and lidar can compensate for these performance limitations.

The following section highlights some of the most common camera technology trends adopted by automotive stakeholders to achieve a higher degree of perception and sensing in ADAS and automated driving systems.

Camera technology trends					
Technology trends	**Camera-radar integration**	**Camera-lidar integration**	**3D imaging**	**Camera SoCs**	**Smart camera**
Companies	• InnoSenT • Silicon Radar • Jabil Optics • AVL • John Deere	• Kyocera • Stradavision • Ushr, Inc. • AEye	• Infineon Technologies • Texas Instruments • Melexis • Panasonic Corporation	• Mobileye • Ambarella • OmniVision Technologies • Renesas Electronics	• Sony • Bosch

Source: IHS Markit © 2021 IHS Markit

Table 4: Camera technology trends, (IHS Markit, 2021).

Sensor fusion

Sensor fusion or data fusion is the technique used to unite multiple different data streams to improve the system's overall perception and sensing capability, achieving a better result than each technique individually. Each of the automotive sensing technologies, radar, camera, ultrasonic, and lidar sensors, has its limitations. Therefore, each of these sensors must be combined with other complementary sensing technologies to reduce perception uncertainties, increase accuracy, and improve redundancy and fault tolerance.

Sensor fusion can be done at different levels of complexity and with different types of sensor data. It can take place at the edge level. In other words, it can be done within the sensor itself as in the case of a distributed architecture or can be done centrally where all data processing and fusion take place at the central ECU, known as "centralized architecture." In edge-level sensor fusion, a high level of data processing and fusion occurs locally in the sensor module, and meta-data is transferred to the central ECU. This requires smart sensors with integrated processing capability. Different suppliers and automotive OEMs opt for different sensor fusion architectures as per the requirement. The two most common examples of sensor fusion in automated vehicles are camera-radar integration and camera-lidar integration. Automotive suppliers have developed image recognition platforms with dedicated sensor fusion architecture and with multilayer sensor fusion algorithms to improve perception capabilities (IHS Markit, 2021).

Camera radar integration

Camera image sensors provide a low accuracy (or show a low performance) in dense fog, rain, sun glare, and low light conditions. In contrast, radar lacks the high resolution of camera sensors. Therefore, radar and camera sensor integration are especially useful for front sensing applications for Assisted Emergency braking (AEB), Assisted cruises control (ACC), Lane Keeping Assisted (LKA), and automated driving applications.

ADAS usually takes 0.5 seconds to engage the autonomous braking system when a pedestrian is detected, compared with 1.6 seconds taken by a human driver (Ucińska, Monika and Pełka, Małgorzata, 2021). However, even with the presence of AEB, a vehicle traveling at 50 kmph will travel an additional seven meters before coming to a complete stop.

In collaboration with several commercial partners, Fraunhofer Institute is developing an integrated radar camera module. The core of this integrated camera radar module is its integrated signal-processing capacity. All the signal processing takes place directly within the module; the system selectively filters data from the radar and camera sensor. No relevant information is filtered out, and sensor fusion is applied to combine the data from both radar and camera; neural networks then evaluate the data to determine the real-world traffic implications. The module then directly sends the reaction instruction to the vehicle, saving crucial time. This new sensor integration approach should have a reaction time of fewer than 10 milliseconds, making it 50 times faster than the current detection systems and 160 times faster than an average human driver (IHS Markit, 2021).

Camera lidar integration

Camera and lidar sensor integration or fusion of 3D lidar sensor data with 2D data of image sensors enables automated vehicles to locate objects and determine their distance and size using classification, and text and color perception, along with image recognition. Development is ongoing with fusing lidar and camera sensor data in real time for a high level of perception and sensing.

Increasing implementation of Deep Neural Networks and machine learning techniques

Automated driving systems will be unusable if they are unable to make sense of the data captured by their sensor suite. Therefore, recognition and real-time condition monitoring play a role as critical as the sensing and detection functions. Advancements in AI and machine-learning technologies have achieved astounding results in object detection and classification using camera image sensors. Further implementation using Deep Neural Networks (DNN) and convolution neural network (CNN) techniques have resulted in even higher perception and classification accuracy for automated driving systems.

Automotive vision systems running DNN and CNN algorithms can precisely detect and classify vehicles (cars, buses, trucks, and two-wheelers), traffic signs, road markings, pedestrians, cyclists, and other vulnerable road users. AI-based interior monitoring systems can also read the facial expressions of drivers and passengers. However, the effectiveness of DNNs is highly dependent on the training data sets used by the developer. Automotive OEMs, suppliers, mobility service providers, and autonomous vehicle companies are increasingly implementing AI and ML-based vision systems within their automated driving systems (IHS Markit, 2021).

Future sensor technologies & Vehicle to Everything communication

Next-generation automotive vision systems require new silicon architecture for supporting Deep Neural Network and machine learning.

Automated driving systems are supported by multiple sensing technologies, with each one complimenting the other for effective and reliable perception. The number of these sensors, especially camera and radar sensors, is continuously increasing as OEMs and automated driving companies move towards higher levels of automation. Semi-automated vehicles are already being rolled out with 8–10 camera sensors along with multiple radars and ultrasonic sensors, and in some cases, even lidar sensors. For example, a Tesla Model S has nine camera sensors located in and around the vehicle body.

Automotive vision systems with intelligent visual processing capabilities based on AI and machine-learning techniques are highly compute-intensive applications. An ADAS vision system has to handle high-resolution imaging, high-speed serial communications, downstream processing, and recognition functions for effectively understanding the vehicle's environment. The image resolution must be high enough that the recognition processors can precisely decipher road signs and differentiate between objects and surroundings. All these functions require computational performance, which is not possible using the traditional semiconductor architecture. High-performance multi-core silicon architecture with capabilities for running DNN and CNN algorithms is required. The architecture should be scalable to serve multiple levels of autonomy (IHS Markit, 2021).

3D imaging

3D imaging technology is increasingly being used in automotive applications as it provides accurate depth-sensing capabilities using low-cost CMOS image sensors. 3D imaging is being used in a wide range of automotive use cases within and around the vehicle. As cars evolve to support a higher degree of automated driving capabilities, the requirement for accurate and robust 3D sensing technologies is gaining traction.

3D image processing can be achieved through stereovision techniques, time-of-flight (ToF) cameras, and a structured light approach. Compact construction, low cost, ease-of-use, fast response time, and high accuracy and frame rate make stereovision and ToF cameras attractive solutions for automotive applications.

Automotive use cases of 3D imaging include:

- Forward-facing detection for AEB, ACC, and Forward Collision Warning (FCW) applications
- Curb detection for park assist applications
- Occupant detection and classification
- Child presence detection
- Rear-facing baby seat
- Leftover object detection
- Fastened seat belt detection
- Driver monitoring with eye-closure detection, head pose, sitting posture, and drowsiness detection
- Driver's hand position detection for ascertaining hands-off driving

Stereovision technique

The Stereovision technique is commonly used for depth sensing in the case of exterior ADAS applications. Stereo cameras offer precise depth-sensing across wide distance ranges in operating conditions such as illumination variances and weather and environmental effects.

Stereo camera

A stereo camera has two or more lenses with separate image sensors for each lens. A stereo camera can simulate the binocular vision of the human eye and thereby creates stereoscopic images. This enables it to capture 3D images with the capability of depth perception, at least when considering relatively short distances that typically vary based on the distance between the two image sensors.

Stereo videos/images captured by these cameras contain more information per frame/image as compared with the image captured by mono cameras. A stereo camera utilizing two camera sensors can, therefore, more accurately detect objects and determine their size and distance at a relatively close range. However, triangulation suffers at medium and long distances.

The challenges associated with stereo cameras include their higher pricing as compared with mono cameras and a higher computational requirement for extracting information from the captured images. Furthermore, the camera module size is typically larger, which makes the stereo camera more difficult to integrate within the vehicle's body. That is why they are mostly deployed behind the windshield of the vehicle (Gehrig, Stefan & Franke, Uwe 2016).

Smart camera or intelligent camera

Camera modules with increasing intelligence are one of the emerging trends in the automotive camera ecosystem. Camera suppliers are integrating more edge-computing capabilities into their camera modules, enabling them to detect and make sense of the environment. An intelligent camera is a standalone vision system; apart from capturing images, it can also extract application-specific information from them. Intelligence is added at the sensory node by fusing multiple sensory data streams such as RGB camera + NIR, RGB camera + shortwave infrared (SWIR), RGB camera + lidar, and RGB camera + radar. Advancements in semiconductor technologies, such as multicore processing chips in compact packaging, development of image accelerators, and ISP-integrated camera sensors, are powering the increasing intelligence of camera modules.

The Driver Monitoring System (DMS) is increasingly being deployed within vehicles owing to Euro NCAP 2020 mandates, making it a primary safety feature required for a 5-star rating. OEMs offering up to Level 2 automated vehicles or developing up to Level 2.5/Level 3 automated vehicles are also relying on driver monitoring systems for detecting instances of hands-off driving. Smart camera modules will play a critical role in deploying such systems. Integrated image processing and AI capabilities within the camera module are used for driver distraction detection, where the on-board algorithms can precisely read facial expressions, head movement, and eyelid movements to determine the distraction level (IHS Markit, 2021)

Vehicle to everything communication (V2X)

When autonomous vehicles are produced in larger volumes, they are expected to have two embedded connections. One for the electronics systems and one for the passengers' content usage. This will give autonomous vehicles two embedded wireless connections. One intended for the autonomous vehicle's electronics and one dedicated for passenger infotainment, including a smartphone-to-infotainment connection.

The emergence of V2X communication

Vehicle to Everything (V2X) is an umbrella term that describes the communication between the vehicle and its environment. This can entail other road users such as cars, cyclists, or pedestrians, the traffic infrastructure such as traffic lights, but also other networks such as the smart home. Since V2X technology globally is permitted to operate in the 5.9-GHz frequency band, it has been harmonized in a technology-neutral manner for safety-related ITS applications. The 5.9 GHz band continues to remain the preferred spectrum for V2X communications technology globally, except for Japan.

On-board sensors such as radar, infrared night vision, lidar, and ultrasonic cameras are limited to line-of-sight communication and struggle to operate by conditions such as fog, snow, and heavy rain. However, a Wi-Fi-based V2X communication system can communicate around curves, over hill crests, and through other non-line-of-sight barriers to notify vehicles of unseen hazards.

V2X is an umbrella term that encompasses V2V, V2I, V2P, and V2N communications. Every V2X-enabled vehicle acts as a node capable of broadcasting its data omnidirectionally and simultaneously receiving data from the nearby nodes. The sharing data, such as their position and speed, with surrounding vehicles and infrastructure, V2X systems are able to improve driver awareness of upcoming potential dangers and dramatically improve collision avoidance, resulting in reduced fatalities and injury severity (Sewalkar, P., & Seitz, J. 2019).

Additionally, the technology is supposed to enhance traffic efficiency by providing warnings for upcoming traffic congestions, proposing alternative routes, and ensuring eco-friendly driving, thereby reducing emissions and enabling smarter transportation management.

Some of the potential V2X use cases include a variety of application that goes beyond collision avoidance. The below figure illustrates some examples of use in both urban city and sub-urban environments (rural roads and motorways).

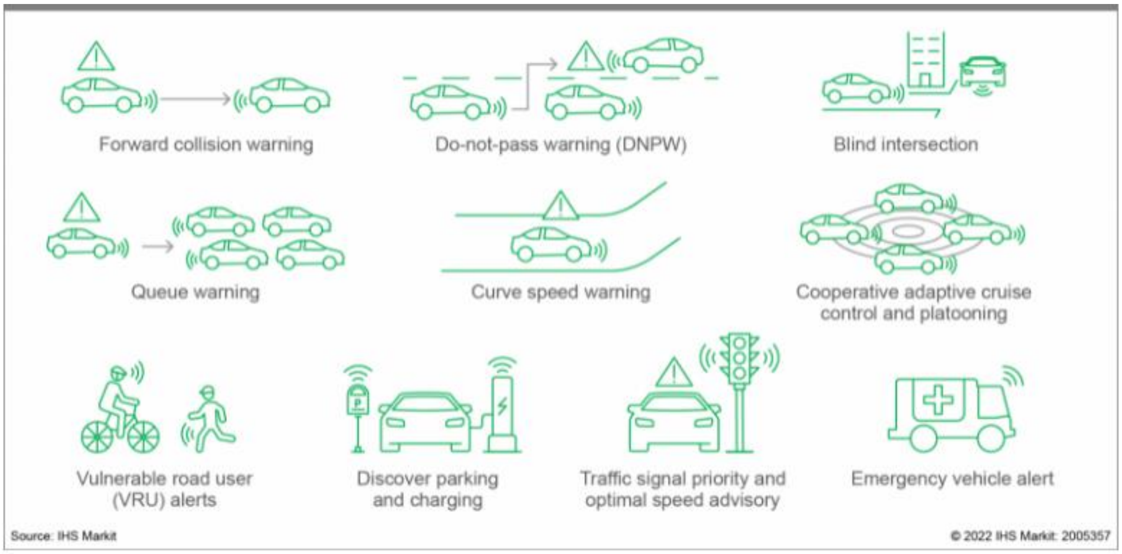

Figure 1: Potential V2X use cases, (IHS Markit, 2021).

V2X solutions by connectivity type

The way that V2X technology works is that it uses a wireless signal to communicate with compatible systems, thus enabling vehicles to improve their situational awareness of objects and events in their environment. Currently, two key sets of standards for V2X communication exist, known as DSRC and C-V2X.

The first specification for C-V2X, called Release 14, was completed in late 2017 to be used with 4G LTE networks. The subsequent version of C-V2X is called Release 15, which introduced 5G New Radio (5G NR) capabilities as a follow-on next-generation to 4G LTE with regards to network communication at the Uu interface (LTE uplink and downlink). 5G NR in Release 15 provides a higher data rate and lower latency for V2N communications, and it was completed in June 2019.

Figure 5 below illustrates the difference between the two communication modes Uu-based LTE V2X (left) and PC5-based LTE-V2X (right

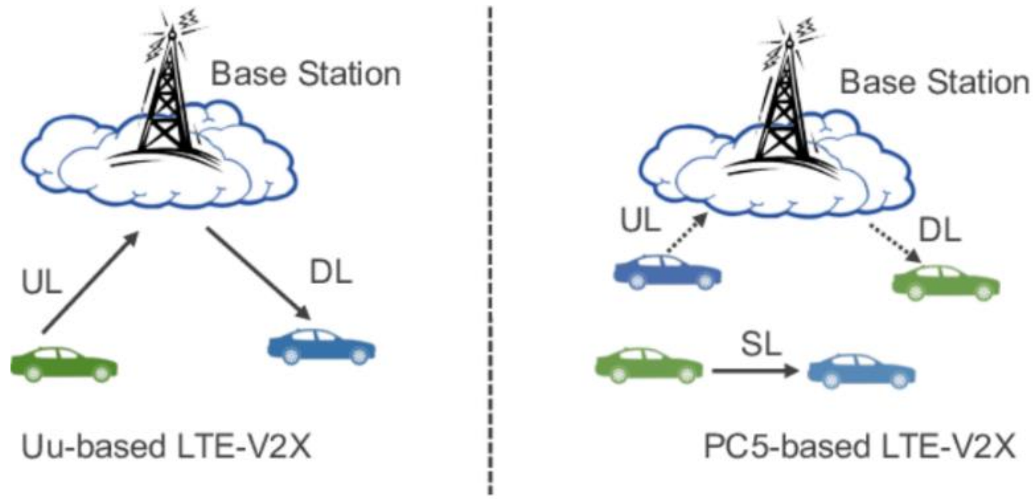

Figure 2: LTE-V2X communication modes: Uu-based LTE-V2X vs PC5-based LTE-V2X

Uu-based LTE-V2X (left): vehicles are communicating with traditional uplink (UL) and downlink (DL) channels using base station; PC5-based LTE-V2X (right): vehicles use sidelinks (SL) to communicate with each other with or without assistance from base stations using UL and DL for scheduling sidelink resources (Hasan, Monowar & Mohan, Sibin & Shimizu, Takayuki & Lu, Hongsheng).

The third version is called Release 16. This version is a major release for the mass deployment of C-V2X as it introduced the additional capability to 5G NR, specifically in terms of short-range direct communication, an increasing bandwidth, and reducing latency further and is sometimes referred to as ultra-reliable low latency communications (URLLC). The 3GPP, after delaying Release 16 by three months until June 2020 due to the COVID-19 pandemic, finalized it on 3 July 2020. The new Release 16 set of specifications includes a new NR-based C-V2X for applications like coordinated driving and sensor sharing.

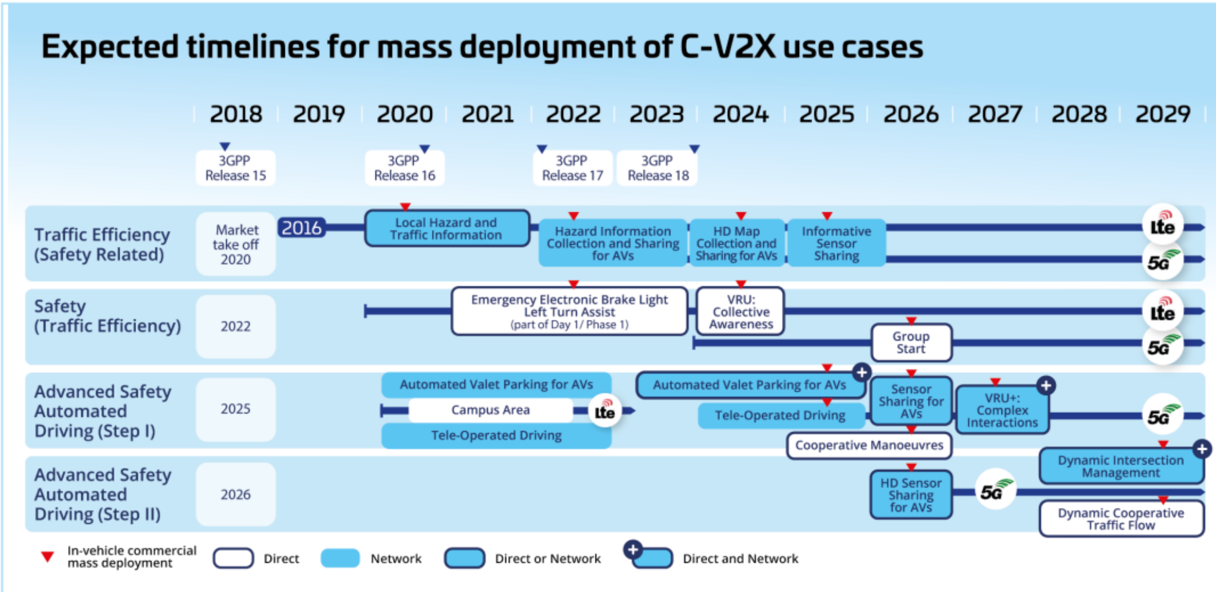

Figure 3: Roadmap for mass deployment, (5GAA, 2020).

Due to be published in the first quarter of 2022, Release 17 introduces support for new use cases, including public safety, non-terrestrial networks, and nonpublic networks. The primary aim of Release 17 is to improve 5G System (5GS) performance and provide ubiquitous connectivity in different deployment conditions and scenarios.

3GPP Release 18 represents a major evolution of the 5GS and is therefore being touted by the 3GPP as the first release of 5G Advanced. Early planning of Release 18 indicates it will significantly evolve 5G in the areas of artificial intelligence and extended reality (5GAA, 2020).

According to the 5GAA members, Europe, China and US are representing today the largest automotive markets and generate significant momentum around connected vehicles and advanced driving.

As illustrated in figure 5, the use case timelines can be divided into four phases. Each phase reflects increasing complexity level and technical requirements.

From 2022 onwards, advanced use cases such as the sharing of Hazard Information or HD maps for Automated Vehicles (AVs) will increasingly contribute to the building blocks required for automated driving.

V2N use cases, such as remote-controlled driving and automated valet parking, are already available today by several OEMs with LTE-V2X network-based communications and on-board sensors in controlled environments. By 2025/26, 5GAA expects that these use cases will more commonly operate in more complex environments and scenarios. They will make their way into public roads and in parking garages, leveraging 5G-V2X connectivity.

As per 5GAA timeline, all new AD vehicles are predicted to be equipped with 5G-V2X from 2026, in line with their mass production and to enter the market. By 2027, complex interaction between vehicles and vulnerable road users (VRUs) via mobile phones (PC5 and Uu- V2X communication modes).

It is very clear that in the future, we will have a combination of connected and automated vehicles co-existing with vehicles that do not feature automated driving functions. Connectivity will not only support automation levels but also bring benefits to mixed traffic situations. HD Sensor sharing, based on 5G, will help the development of further automation with respect to the driving levels in the future. The first pilots are expected to be on the road after 2026. Enhanced urban and highway pilots will be introduced from 2029 in dedicated areas, allowing Dynamic Cooperative Traffic Flow and Dynamic Intersection Management.

V2X and 5G

It is almost certain that LTE-V2X will transition to 5G under the more generic umbrella of C-V2X. This statement is based on the fact that most new vehicles are expected to feature embedded cellular connectivity in 2022, with some automakers set to enable virtually all their vehicles with cellular modems in the near future (IHS Markit, V2X Report 2021).

5G is expected to play an increasingly large part in trials, and testing as operators and others investigate its potential for low-latency C-V2X. The deployment of commercial 5G networks from 2021 onward based on the 3GPP standards has enhanced C-V2X in several different ways. Since C-V2X technology is designed to be fully compatible with 5G, investments in infrastructure and modules will not need upgrades for a long time to come. Infrastructure and mobile network operators recognize comparable synergy, as the infrastructure ecosystem features high-density 5G network deployment. Operators can integrate the functionality required for V2I applications with 5G infrastructure. Alternatively, RSUs deployed to improve road safety can include the necessary functionality to support 5G network infrastructure build-out and thus yield win-win opportunities for public-private partnerships.

In the 5G NR era, C-V2X will be able to support:

- Very precise positioning and ranging to support cooperative and automated driving
- High throughput and low-latency connectivity to enable the exchange of raw or processed data obtained through local sensors or live video images
- High throughput to build local, dynamic maps based on camera and sensor data, which can then be distributed at street intersections. For example, C-

V2X could be used to provide a driver or an on-board computer with a bird's eye view of an intersection or see-through capability when driving behind a truck.

- Very low latency and high reliability to support high-density platooning
- 5G NR will also be able to support a high number of simultaneous connections in a small geographic area, allowing each vehicle to gather more information about its immediate surroundings and, thus, increase situational awareness for safer driving.

Vehicle to infrastructure communication (V2I) development in Germany

Vehicle-to-Infrastructure (V2I) communication is a wireless exchange of data between road vehicles and road infrastructure. A system of hardware, software, and firmware enables typically wireless and bi-directional V2I communication. Traffic lights, lane markings, and road signs can wirelessly feed information to the vehicle and vice versa. Large volume of data being captured and shared in this process can provide timely information that can be used for a wide range of mobility, safety, and environmental benefits.

Mobile Edge Computing Based Object Detection for Automated Driving (MEC)

The MEC-View project was introduced with the objective of automated driving in complex urban traffic scenarios. This project aims to achieve safer and more efficient automated driving in urban traffic. The project received funding from the Federal Ministry of Economic Affairs and Energy (BMWi) on behalf of the German Parliament.

The MEC-View system is designed to focus on the evaluation of a secondary roadside sensor setup. Due to the fact that automated vehicles could miss relevant objects in complex urban traffic when relying solely on the on-board surround sensors (Camera, Radar, Lidar), the roadside sensors help to expand the direct field of view of the onboard sensors. The MEC View System architecture consists of high-performance mobile network (5G), high-precision digital map (HD), and mobile edge Computing (MEC) server to enable reliable data fusion from both roadside and onboard sensor objects in the environment.

On Motorways, automated driving has been successfully tested and validated over the past few years. However, deploying automated driving in a complex urban environment, with traffic scenarios, different road users (pedestrians, cyclists, buses, etc.), and a variety of situations (crosswalks, oncoming traffic, and heavy traffic). Since onboard sensors cannot detect all of the road users nor driving areas in typical urban situations due to blockings by obstructions or barriers like parking cars, for this reason, the automated vehicles need further information about the environment from other sources than their on-board surround sensor systems. Figure 4 illustrates the automated vehicle interaction (data exchange) with the roadside sensors (bi-directional) through 5G network and the MEC-server.

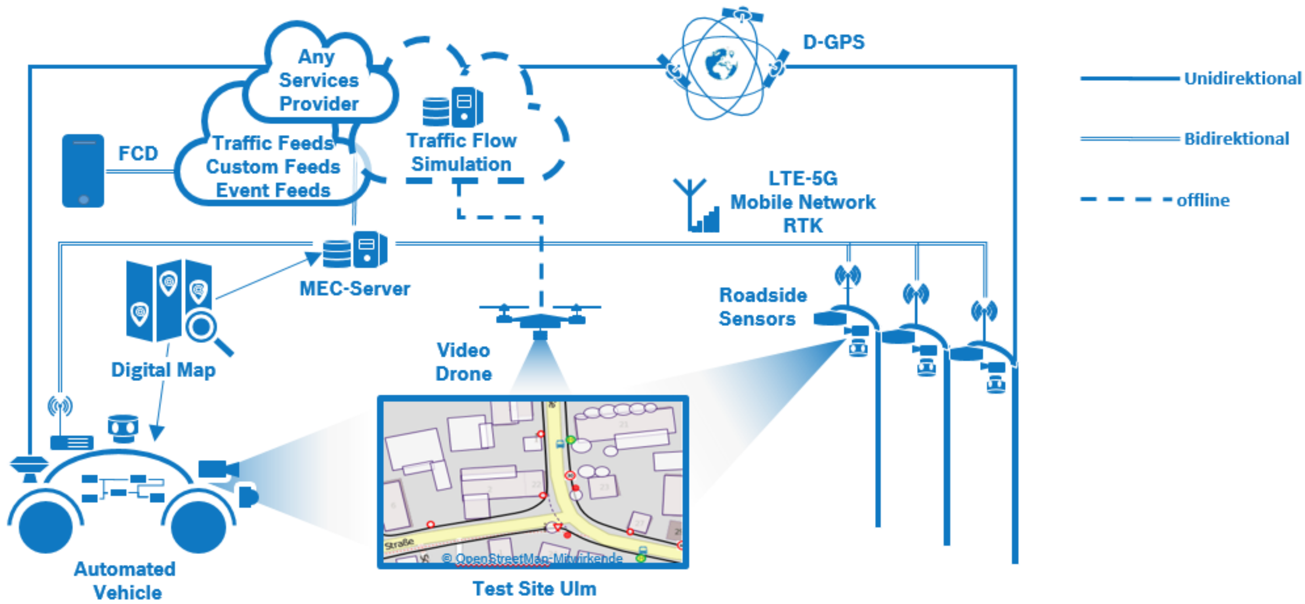

Figure 4: MEC-View project, (Uni Darmstadt/MEC, 2021)

In order to meet the positioning requirements of the road users in a local environment model, the sensor data is required to be transferred in real-time operation. The MEC-View project utilizes a low-latency prototype LTE/5G mobile radio network and a mobile edge computing (MEC)-server to meet the timing requirements. The MEC-server hosts an algorithm designed for the data fusion and tracking of the roadside sensor data and links these data on a precise digital map.

In the near future, traffic control and information systems of urban city administrations could make use of MEC-servers to provide this local environment model information. The precondition for efficient deployment would be area-wide coverage of the LTE/5G mobile radio network. The German telecom regulator, Bundesnetzagentur (BNetzA), says that 53% of the country is now covered by 5G services. Eighty cities in Germany have 5G coverage, with the aim to achieve country-wide coverage by 2025 (BNetzA).

Current infrastructure and systems for L2-L3 vehicle deployment

The previous chapter discussed the regulatory framework required for the safe deployment of autonomous and connected vehicles in an urban city environment. While the regulatory framework certainly is a prerequisite for accepting autonomous driving within society, this chapter reviews the current and future infrastructure and systems required to enable the safe deployment of L2-L3 vehicles. It discusses the critical enablers for self-driving autonomous vehicles (AVs) and human-driven conventional vehicles (HVs) to safely deploy into urban cities. This chapter covers some of the main challenges that need to be resolved before automation can be deployed in widespread use. How law enforcement and monitoring for L2-L3 vehicles can be implemented to effectively work in this mixed traffic environment (AVs and HVs) and adhere to local data protection laws at the same time still need to be further researched. Since the implementation of particular laws and regulations differs from country to country, the scope of this literature review is limited to Germany.

In the presence of the emerging technology of automated and connected vehicles, it is predicted that the future traffic system would be consist of both self-driving autonomous vehicles (AVs) and human-driven conventional vehicles. Therefore, it is crucial to develop new traffic management measures that help manage the future traffic system complexity.

A study of a mixed traffic system based on the cellular automation model (Bokui Chen, Duo Sun, Jun Zhou, Wengfai Wong, Zhongjun Ding, 2020 investigated the use of sensor technology with mutual information exchange, where each AV will have a 'foresight' and will be able to obtain specific metrics (i.e., speeds, position, etc.) of vehicles in front of it. It investigated how the traffic capacity is predisposed by the degree of foresight in a road scenario. Analyzing the ratio of HVs to AVs, the probability of random deceleration of HVs, and vehicle density. There are multiple studies (Al-Turki, Mohammed; Ratrout, Nedal T; Rahman, Syed Masiur; Imran Reza, 2021) and (Jian Wang, Srinivas Peeta, Xiaozheng He, 2019) that discuss various models for AVs and HVs co-existence in urban traffic.

In general, it is claimed that AVs have great potential to improve traffic capacity, efficiency, and safety of existing mobility systems (Q Lu, 2020). The existing scientific literature has already studied the potential impacts of AVs use on the transportation system, discussing AVs positive impact on highway capacity, especially with high penetration levels. Few studies (e.g., Lu, Q.; Tettamanti, T.; Hörcher, D.; Varga, I 2020) have investigated the impacts on urban transportation with various AVs adoption levels. Most of the research primarily focuses on improving highway capacity.

Another study (Smirnov N, Liu Y, Valid A, Morales-Alvarez W, Olaverri-Monreal C) investigated a game theory-based approach for modeling AV behavior in congested urban lane-changing scenarios. In this scenario, the AVs were required to determine the level of cooperation with other vehicles in the adjacent lane, so they could proceed with the lane change. This study showed a prediction accuracy of 100% in all cases in which the participants allowed the lane change. In 83.3% of the other cases, false predictions cooccurred because of delays in continuing driving after the traffic light showed green.

It can be said that further research needs to be conducted to better understand which model works best for the various traffic scenarios in a congested urban environment. It is also impossible to test for all potential scenarios.

Figure 5: German urban test-fields (BMVI, 2022)

There are currently 26 test fields in Germany with specific infrastructure for automated and connected driving. Over 140 projects are being carried out on these test fields or in real traffic. The individual projects have different focal points and are in different phases. 12 out of 26 test fields are located in urban city environments, representing different density levels. City stakeholders, the education sector, and the industry have formed various partnerships to test infrastructure technologies and related systems in dedicated environments in real-life. Several projects are generally focused on testing: In-Vehicle Signage (IVS), Hazardous Location Notification (HLN), Road Works Warning (RWW), Signalized Intersections (SI), Probe Vehicle Data (PVD), Automated Vehicle Guidance (AVG), Digital HD traffic control system, predictive perception (BMVI Test fields, 2022). It seems connectivity is likely to be implemented well before automated driving systems feature in the dense urban city environment. With more connectivity finding itself in urban environments, city officials and regulators will adapt current law enforcement methods to cater to L2-L3 and fully autonomous vehicles. As it stands, there is no concept being tested right now in Germany.

Additionally, there is an issue with data protection in Germany. A recent example is the lawsuit against Tesla for the filming functionality in their cars without obtaining specific consent from the person being filmed. The use of cameras or CCTV for monitoring and law enforcement has proven effective in other countries (UK, US, etc.); however, data protection laws prohibit the use in Germany.

Infrastructure and system requirements to support L2-L3 vehicles deployment and enablement for traffic law enforcement and monitoring

The interaction with the outside world and rapid data evaluation is crucial for the sensor systems discussed in the previous chapter. This cannot be done in the vehicles alone, as there is limited computing power within the car itself. Edge computing, 5G, and V2X radio connections (Vehicle-to-X) play an essential role here. The support of vehicle sensors by additional sensors on the road is also an essential building block for self-driving cars. It could look like this: Cameras, LiDAR scanners (Light Detection and Ranging), and radar monitor danger spots such as intersections or certain road sections on elevated positions such as a street lamp. The system collects the incoming data and sends it via 5G to a nearby edge cloud system, which evaluates the data with AI support. This creates a picture of all road users with their respective speeds and distances from one another. The system utilizes deep learning to analyze the traffic situation, communicates this back to the vehicles via 5G, and recognizes dangerous situations. For example, the edge cloud system recognizes the dangerous situation if a non-autonomous car is on a collision course with an autonomous vehicle. Now it sends a warning via 5G to the self-driving car, which then autonomously corrects the course or performs an emergency stop. Currently, this project is in the testing phase involving Easyride and Tempus in Munich and is supported by the Bavarian State Ministry of Economic Affairs, Regional Development, and Energy.

Recent testing in the city of Düsseldorf, Germany, has shown the current limits of automated driving. It became apparent that not every intersection can be equipped with cameras and radar systems in the future. Another part within Düsseldorf city showed that automated driving through communication with the traffic lights is possible where there are no complicated points. This means no oncoming traffic when turning left on this circuit. Today, various systems are still under development and need extensive testing.

Significant technological challenges need to be resolved before safe and reliable operations can be achieved in urban environments:

- Development and implementation of a suite of sensors and related sensor fusion software that helps detect, recognize and track the motions of all objectives in the surrounding area. This should also include any objects that could cause damage to the vehicle in the event of a crash. Sensors must be robust about adverse environmental conditions and potential cyberattacks (Petit, J.; Shladover, 2015). Damaged road surfaces (i.e., potholes) or flooded areas present significant challenges for all current perception systems.
- Reliable prediction of future motions of all moving objectives surrounding the vehicle environment to enable the L2-L3 or fully AVs to take pro-active

actions. This will help reduce false-positive and false-negative automated driving system (ADS) responses to a minimum (Steven E. Shladover,2022).

- Lack of development and implementation of efficient software verification and validation (V&V) procedures for ADS software dedicated to safety. Currently, available software V&V is unsuitable due to its high cost and high labor intense (Steven E. Shladover,2022).

As it is likely that ADS deployment will still take a significant time to be implemented in an urban environment, it will provide stakeholders and policymakers sufficient time to develop necessary processes and plans to steer the deployment process Development of comprehensive safety case to provide adequate evidence that ADS will be safe to be deployed in public (Steven E. Shladover, 2022). This can form the basis of a safety case framework; however, it will require extensive collaboration involving expertise and resources internationally.

The framework will need to cover thorough documentation of the engineering process used to detect and mitigate hazards during the ADS development process. Determining the right mix between the methods used to measure the safety-relevant performance of ADS, similar to what is currently implemented in the German test fields (closed-track, public-road, and simulations). Documentation of results for predefine KPI (Key performance indicators) and engineering processes, which can be read and interpreted by all stakeholders (government safety regulator, industry risk manager, public) and media (Steven E. Shladover, 2022).

Supporting Physical and Digital Infrastructure

In the early stages of ADS development for private vehicles, the focus was primarily set on technology that can work independently from any particular supporting infrastructure. Nowadays, the focus has shifted to location-specific implementation to help exchange data both ways and make the systems more reliable. The supporting infrastructure can be physical or digital, or both.

Physical supporting infrastructure may include:

- High-contrast pavement markings;

- Road signs recognized by computer vision systems (static and variable messages);

- Adequate illumination to improve visibility in challenging locations;

- Dedicated lanes for exclusive use by ADS vehicles;

- Roadside sensors and communication devices to transmit information to the vehicles

Examples of the digital supporting infrastructure include:

• Digital maps of variable degrees of detail;

• Real-time traffic signal phase from the local traffic signal controller;

• Location-specific traffic control information (such as variable speed limits, prohibited parking zones/hours);

• Alerts out location and status of events, i.e., work zones, crashes.

• Traffic condition information from traffic management centers.

Traffic center

It is suggested to set up a "traffic center" that would oversee the inner-city area. All traffic and environmental data come together in the central traffic center. In a traffic jam, vehicles can be diverted directly before they enter the city area.

In the future, administrative staff will be able to access and evaluate the data for enforcement purposes, and other stakeholders who, for example, develop a new mobility app or optimize delivery routes. Traffic monitoring systems can record traffic flow in different lanes and directions. All data would flow together in a traffic center, which controls all traffic throughout the city.

Data requirements and data center

Data is the prerequisite for Artificial Intelligence (AI)

However, a prerequisite for any AI system based on neural networks is data, a lot of data. The mobility providers Waymo and Uber seem far ahead in the industry. However, clearly structured US cities are not so easily comparable to small German towns.

The federal autobahn A9 in Bavaria, one of the most frequented autobahns throughout Germany, the Digital Motorway Test Field (DTA) has been set up. After completion in 2021, it has more than 280 kilometers on the autobahn, country road, and city range. Especially in cooperation projects, individual participants are pretty willing to share the data they have obtained with other companies. However, due to data protection is not an easy task because the state data protection officers are responsible. So it happens that, e.g., for Volkswagen in Wolfsburg in Lower Saxony, other rules apply than for Continental in Frankfurt/Main, i.e., Hessen, or Daimler in Stuttgart, Baden-Württemberg.

Fortunately, "real" data, i.e., data from real sensors (cameras, radar, LIDAR, etc.) on real cars from authentic trips. The majority comes from the computer. Such simulated data are either real rides modified (a ride in sunshine becomes one in cloudy, rainy, snowy, or foggy conditions) or simulate the real environment. Such simulated rides have the benefit that too critical situations, such as those in which a child is running into the street - can be trained by the neural networks.

A neat equipped data center can simulate neural networks with approx. Six hundred fifty thousand in one day feed kilometers driven: a value, in reality, would probably never be attainable. Therefore, puts the lead of the Americans into perspective for their competitor.

The development of extensive, flexible, autonomous driving systems is already far advanced in the laboratory. Very important, especially for them, Homologation (the "type approval") is the question of security.

Uniform procedures are, therefore, a prerequisite to secure such systems, i.e., methods and tests that ensure that the systems work perfectly. Since there is a sheer infinite number of situations out there in which an autonomous vehicle can come enough, it does not matter, with the Homologation only one to take the final test. Already the development must be subject to appropriate quality criteria. This is the case; for example, when selecting the training data of a neural network, caution is advised so that the network does not unintentionally learn incorrect connections.

Also, this topic has the German automotive industry accepted early on. With the project "PEGASUS – project for the establishment of generally accepted quality criteria, tools and methods as well as scenarios and situations for enabling highly automated driving functions" (Duration 01/2016-06/2019) was able to do the basics which are now included in international standardization, also thanks to close cooperation with Japan flow in. Two follow-up projects also started to continue the work: "VVMethods - Verification and Validation Methods automated vehicles level 4 and 5" and "SET Level 4to5 – Simulation-Based Development and testing of Level 4 and 5 systems". All three projects were supported by the BMWi together and funded by around 60 million euros.

Urban mobility concept

Figure 6 illustrates a traffic monitoring system developed by Vitronic. This solution is designed for the urban city environment and is intended to help with the following use cases: Measure excessive speeds, record red light violations, toll check, passage, and section control. In general, the collected traffic data can also be used for traffic control. Existing infrastructure elements can be expanded for this purpose. An additional benefit of the Vitronic system is the ability to record environmental data. This includes the measurement of nitrogen dioxide, nitrogen monoxide, carbon monoxide, etc. As European cities increasingly seek to reduce pollution from inner cities, the collected environmental data can help implement restrictions for specific vehicle types.

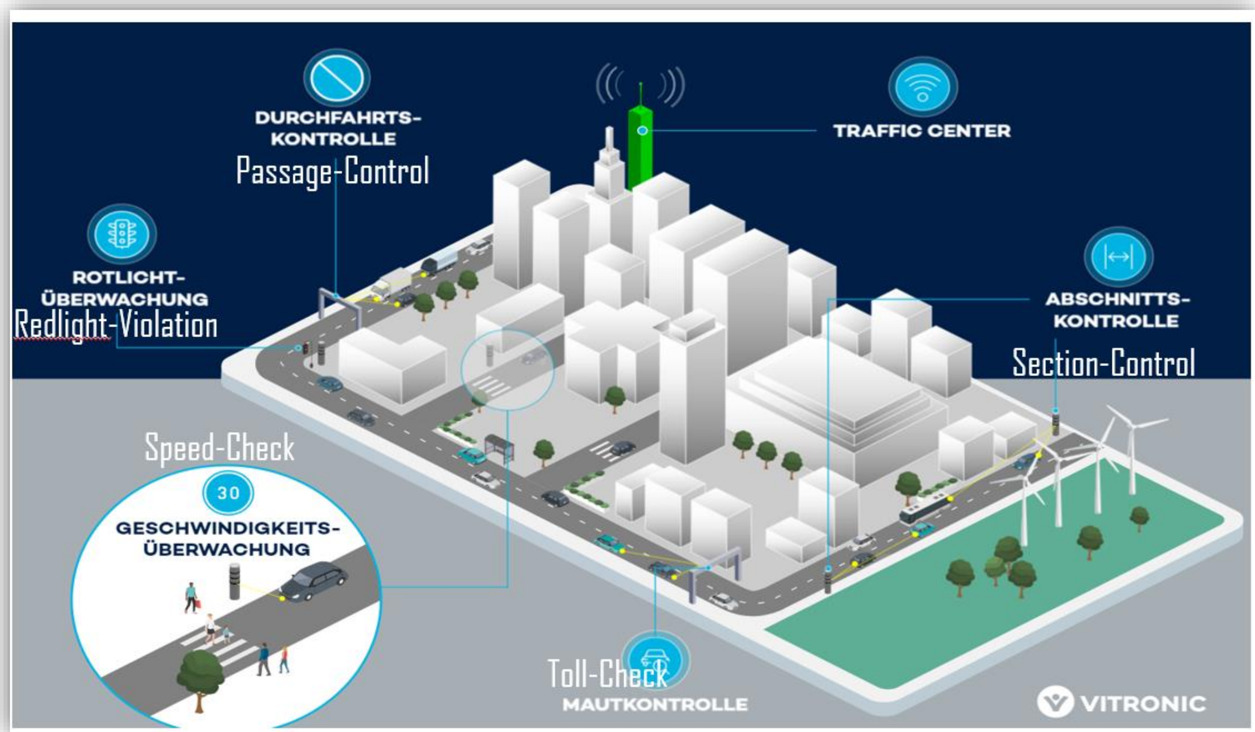

Figure 6: Urban traffic monitoring and enforcement solution (Vitronic,2022)

The examples given for future infrastructure and system deployment is based on the largest traffic enforcement provider Vitronic in Germany. Further solutions exist on the market for V2V and V2I technology (Yanex, Siemens etc.) including the use of drones. Further research needs to be carried out to gain a better understanding about all the types of systems and infrastructure solutions.

Traffic law enforcement and monitoring

The examples given for future infrastructure and system deployment are based on the most prominent traffic enforcement provider Vitronic in Germany. Other solutions exist on the market for V2V and V2I technology (Yanex, Siemens, etc.), including the use of drones. Further research needs to be carried out to better understand all types of systems and infrastructure solutions.

Traffic surveillance is an essential part of the work of the police and public order office (Ordnungsamt). Countless road users are on German roads every day. In order to reduce accidents, everyone involved must comply with the rules. Traffic monitoring is essential to ensure that traffic flows smoothly and that the risk of accidents is kept as minimal as possible, while drivers can be informed of possible misconduct.

There are also regulations for stationary traffic, such as stopping and parking. The future implication of traffic monitoring due to the appearance of connected and autonomous vehicles on the road will be discussed in this chapter. How traffic monitoring must be adapted to cater to mixed traffic environments (fully autonomous & regular vehicles) is a crucial question that needs to be addressed.

Traffic monitoring

As already mentioned, there is a very high volume of traffic throughout Germany every day. This affects private individuals who use the vehicle to get from A to B and commercial trips with trucks.

There are binding rules to which all road users must adhere to ensure that interaction on the road can run smoothly. These are set out in the Road Traffic Act (StVO), which represents the traffic regulations set by the Federal Transport Ministry (BMVI) in Germany.

Traffic surveillance is intended to check compliance with these rules of conduct and punish violations of the rules accordingly. But there are other goals that police traffic surveillance should fulfill:

- Reduce traffic accidents
- reducing the consequences of accidents
- Increasing safety for particularly vulnerable road users (e.g., children and senior citizens) and
- Creation of cooperative and considerate behavior of road users towards each other

Monitoring of stationary traffic: municipal traffic monitoring and surveillance (KVÜ)

While the police mainly control moving traffic, stationary traffic is usually the individual municipalities' responsibility. When traffic is stationary, the control is mainly carried out by employees of the public order office (Ordnungsamt).

Their tasks in traffic monitoring in the municipal area include, for example:

- Monitoring compliance with the provisions of the Road Traffic Code for stationary traffic
- Moving vehicles in the event of disabilities (especially in front of fire brigade access roads, etc.)
- Penalties for cyclists on sidewalks and in pedestrian zones
- Monitoring compliance with the time limits on the short-term parking lot

Stationary, i.e., fixed speed cameras, are used throughout Germany for traffic surveillance. They can detect speeding, red-light violations, and also a short distance.

The speed traps can be used in urban areas or on the freeway. There are different models of speed measurement. A relatively new method of traffic surveillance is the so-called section control.

The time a vehicle must pass is determined within a previously defined measuring range. From this, the average speed can then be determined in the next step.

However, laser measurement ("Lidar") is much more widespread in stationary traffic monitoring in Germany. It works as follows: Column-shaped measuring systems emit electromagnetic signals that are reflected as soon as they hit a vehicle. The reflection can determine the distance between the vehicle and the measuring device. The driven speed can be determined by how quickly this decreases or increases. If this is above the speed limit, an integrated traffic surveillance camera is triggered and takes the well-known "speed camera photo".

Mobile Traffic Monitoring

In addition to stationary speed cameras, which most road users who drive regularly have long been familiar with, there is also mobile speed measurement. This can certainly create a surprise effect, as the control points are usually not known in advance.

Mobile speed cameras can work differently; a blanket statement about their functions cannot be made. Like stationary speed measuring devices, some work with light barriers.

Other models work through so-called descendants. Disguised officers drive behind a speed offender and measure his speed. The speed camera photo does not serve as evidence, but rather a video is made.

Telematic data for traffic law enforcement

Germany is among the first European countries to introduce telematics services; BMW introduced telematics in the country in 2000. The majority of light vehicles currently produced in Europe now offer some type of factory-installed telematics systems. The eCall mandate, which came into force in April 2018, requires an embedded connection in vehicles for automatic crash notification and SOS calls, which essentially obligates all OEMs to offer either embedded or hybrid telematics in Europe.

Many insurance providers are already using telematics to offer clients who opt-in lower car insurance premiums. As the market share of vehicles with telematics-equipped cars continues to rise, traffic law enforcement authorities will also have the opportunity to use in-car data. Before this can occur, the traffic law regulation (STVO) must be amended. Specific data protection laws also need to be met.

Requirement for access to crash recording data

Since the market for vehicles equipped with Level 3 systems will significantly grow over the following years, the European Transport Safety Council (ETSC) urgently calls for a full investigation of crashes with vehicles featuring an autopilot system. The results are disclosed to the public.

ETSC believes that it is negligent for the EU and its member states to allow the permitted operating speed for L3 systems without a system of vigorous oversight and investigation process when the incident happens. Currently, no data is available on the number of crashes that occurred while the vehicle had assisted driving system (ADS) active.

For this reason, ETCS is calling for:

- An EU agency to supervise or conduct investigations into crashes with automated systems and carry out the publication of all findings in order to help prevent future collisions;
- Mandatory reporting to the EU agency by manufacturers of all collisions where active automated systems on public roads are involved in the EU as well as collisions involving existing Level 2 assisted driving systems;
- Direct access to in-car data for relevant authorities to enable in-depth, independent, forensic crash investigations.

In the United States, the National Transport Safety Board (NTSB) has investigated several collisions involving Level 2 assisted driving systems and provide valuable recommendations to manufacturers.

The UK is consulting on setting up a road crash investigation authority.

Significant injuries or fatalities were allegedly reported in 11 of the 98 recorded collisions involving vehicles equipped with SAE Level 2 ADAS.

In June 2021, the National Highway Traffic Safety Administration (NHTSA) issued a Standing and General Order to report vehicle crashes related to vehicles involved with advanced driver assistance systems (ADAS). The data provides the NHTSA with timely information regarding crashes involving vehicles with various degrees of automated systems deployed at least 30 seconds before the event. The crash could include a vulnerable road user or result in a fatality, a vehicle tow-away, an airbag deployment, or anyone being transferred to a hospital for medical treatment.

The NHTSA has released two reports—Level 2 Advanced Driver Assistance Systems (ADAS) crash report and Level 3- Level 5 crash reporting for automated driving systems (ADS) vehicles (autonomous ride-hailing cars, robotaxis, and autonomous trucks) crash report. In Level 2, when the driver assistance or automated driving system is activated, it offers steering and speed input but requires human supervision on the task of driving at all times.

Since the reporting requirements were implemented, around 130 crashes have been reported for ADS in the United States. Initial data analysis indicates that one incident involving an ADS-equipped vehicle resulted in significant injuries, and 108 crashes resulted in no injuries. Of the 130 incidents involving ADS-equipped cars, 108 included a collision with another vehicle. At the same time, 11 had a vulnerable road user involved, such as a pedestrian or bicycle (7 with cyclists, 2 with motorcycles, and 2 non-motorist). The ADS-equipped cars typically damaged their rears when there were reports of damage.

According to the NHTSA, nearly 400 crashes were reported in the United States in the last 10 months, including vehicles equipped with Level 2 advanced driver-assistance technologies. Serious injuries or a fatality happened in 11 of the 98 crashes where crash severity was reported (6 fatal and 5 serious); 22 moderate, 19 minor, and 46 crashes resulted in no injuries. At least 116 of the recorded SAE Level 2 ADAS accidents included another vehicle, and at least 4 involved a vulnerable road user (1 with a cyclist and 3 with pedestrians).

In the case of crash reporting for Level 2 ADAS crash reporting, the information from crash reports was most frequently sourced through telematics, followed by complaints and claims. Similarly, telematics, personnel field reports from reporting entities, and testing communications were the primary sources of ADS crash reports.

According to a recent statement from NHTSA, new vehicle technologies have the potential to help prevent crashes, reduce crash severity and ultimately save lives, making collecting this data an essential step in that effort. As NHTSA gathers more data, NHTSA will be in the position to better identify any potential risks or trends and try to learn more about how these technologies are performing in the real world."

Some of the limitations of the data collected by the NHTSA are worth highlighting: The data needed to contextualize event rates is limited. As a result, data on the number of reported collisions for any specific manufacturer or operator have not been normalized or amended by any measure of exposure, such as the operational driving domain. These data are not standardized by the number of cars deployed by a manufacturer or vehicle mileage driven by the cars. This information is presently retained by manufacturers and is not disclosed to the NHTSA. Therefore, these statistics cannot be used to compare different manufacturers' safety.

Some personal and associated data, as well as company-specific information, are redacted. There are fields in the Data Element Definition file that list ADAS-related data; however, few entries include relevant information. For instance, the ADAS version is one field, whereas the following field identifies it as private business information. Tesla and Ford concealed the ADAS version fields. Also, the crash data do not absolutely reflect that the assisted driving system in the vehicle was activated at the time of the accident.

The NHTSA's objective of this study was to try and understand what can be changed either with ADAS system performance or concerning driver engagement, driver monitoring, and how to engage the driver in the assisted type of a cooperative driving system. The driver must be in the loop and actively supervise these ADAS and automated driving systems such as autopilot, but the system will generally deactivate just before the crash. So, if looking at a narrow view of what the car was doing when it crashed, it was under human control, and the autopilot was not active. Car manufacturers generally feel okay with it because, in the Level 2 ADAS, the driver is supposed to monitor the environment all the time. However, this point was reportedly part of the interest in transparency for the NHTSA.

This study's fundamental argument is that car manufacturers are using ADAS to support drivers. However, suppose the system fails to avoid a crash. In that case, it is difficult to determine whether the system was functional or deactivated or the system was active before it went offline one second before the crash. As a result, it gets difficult to measure and improve the system's performance or improve the driver's engagement so that drivers pay attention and act early enough to help avoid the crash after the system failure.

In June 2022, the NHTSA announced a proposal to require vehicle manufacturer car manufacturers to obtain more crash data from event data recorders (EDRs), also known as black boxes. The safety agency has suggested that black boxes must be implemented to obtain 20 seconds of pre-crash data at a higher frequency to better understand the actions that ultimately lead to an accident. For cars with EDRs, the NHTSA currently requires five seconds of pre-crash data at a slower collection rate for vehicles.

When technology fails or cannot manage a specific circumstance, drivers may be unprepared to take over swiftly. The NHTSA has been making extensive efforts to assess the safety of advanced driving technologies as they become more widely available. According to analysis, the NHTSA's decision to publish monthly ADAS and ADS crash reports is a welcome effort to ensure safer implementation and achieve higher levels of autonomy in the US.

The ADAS data provided by the NHTSA include a lot of information, but further research and additional data around system utilization are required before any comparable conclusions can be drawn. To provide a more accurate study of the trends in Level 2 ADAS and ADS improvement, vehicle kilometers traveled are especially crucial against the number of crashes. The data that is not shared with the agency by the OEMs could include more relevant information. Also, the information about the crash report—whether the ADAS was equipped in the vehicle—is not accounted for.

Aggregate data should be public data. Similar data for individual companies would be valuable, but most vehicle OEMs would undoubtedly resist it. Such information will allow us to monitor the development of ADAS and ADS technology to determine which methods are most effective and allow the NHTSA to identify candidates for recall (or at least further evaluation) more quickly than today.

Within the EU, most authorities do not routinely access in-vehicle data when investigating collisions due to the technical complexity and legal barriers. The Netherlands has taken a leading role in investigating collisions involving automated systems and has found a method for accessing in-vehicle data without the manufacturer's involvement.

For the purpose of traffic law enforcement and post-incident investigation work with L2-L3 vehicles in Germany, access to the in-car data would be highly useful to the relevant authorities. Based on the gathered data, the infrastructure and systems can potentially be further adapted and improved to reduce incidents.

ADAS and human interaction: Benefits and risks

Advanced driver assistance systems (ADAS) are expected to enhance driving safety, comfort, and efficiency significantly. This chapter discusses the main benefits of ADS systems and their potential risks.

An Advanced Driver Assistance System (ADAS) supports the driver when driving a vehicle. Depending on the system, it can provide more comfort, more safety, or more efficient driving. Driver assistance systems are capable of taking on various driving or operating tasks right through to fully autonomous driving. Technically, an ADAS uses sensors to collect information and information technology to process it.

The impact of ADAS in traffic accidents was studied extensively e.g. (Kahane & Dang, 2009; Kuehn et al., 2009; Golias et al., 2002; Jermakian, 2011). Results showed a positive impact on forward collision warning/mitigation systems, which could prevent up to 20% of the total 5.8 million reported crashes in the US annually. It was shown that the lane departure warning system could prevent or mitigate up to 3% of all crashes, including 7,529 fatal and 37,000 injury accidents per year. Since lane departure warning systems do not usually work at low speed (inner-city) in an urban environment, the potential impact must be researched further when this system can be used at low speed.

The European New Car Assessment Programme (Euro NCAP), in collaboration with the Australasian New Car Assessment Programme (ANCAP), has also published a study on low-speed Autonomous Emergency Braking (AEB) impact on rear-end collisions (Fildes et al., 2015). The data was collected from Australia and five European countries. Results showed a 38% overall drop in rear-end crashes for vehicles fitted with low-speed AEB compared to those without. Moreover, results demonstrated no statistical difference when comparing the AEB effect between Urban (below 60km/h) and rural (above 60km/h) speed zones.

Advanced Driving Assistance Systems “Wear and Tear”

Driver assistance systems bring more road safety but require full-service life consideration. This is the current study's finding of TÜV Rheinland and the British Transport Research Laboratory (TRL). As part of the study on the performance of driver assistance systems over their entire service life, the experts addressed the issues of long-term operation and wear. For this, the experts used the example of lane departure warning systems to examine how age-related wear, damage to the system, accidents, or inadequate camera calibration when replacing windshields substantially affect the function of assistance systems. The study is based on findings from publications, the exchange with experts, and a practical part with driving tests on a test track.

According to experts from TÜV Rheinland and the British Transport Research Laboratory (TRL), there could be an average of around 790,000 risk events per year on EU roads in 2029, which are solely due to the reduced performance of lane departure warning systems. One welcomes the obligation that assistance such as lane departure warning, emergency braking functions, or reversing systems will be part of the mandatory equipment in the EU from next year.

However, not enough is known about how accidents, improper repairs, or wear and tear affect the long-term functionality of the systems and thus road safety, according to mobility expert from TÜV Rheinland. The study has provided initial insights into the circumstances under which lane departure warning systems may only function to a limited extent and how this affects safety.

Depending on the scenario, the current study showed that the estimated number of average annual risk events due to system malfunctions could even be up to 2.3 million. Risk events are errors in the system that reduce performance. According to the TÜV, a risk event can occur when an outdated lane departure warning system switches off as intended because it can no longer "see" properly in certain situations due to damage to the windshield. The automatic deactivation of the system becomes problematic if the driver is not fully concentrated at that moment. During the test drives, the experts compared how the modified car behaved in different sections of the route.

TÜV recommends regular maintenance of the ADAS. Since the average age of passenger cars registered in Germany is currently 9.8 years and is constantly increasing, further knowledge should be gained about how the reliable functioning of driver assistance systems can be ensured over their entire service life. According to Schubert, the current study has confirmed that only regular maintenance and technical checks can show how well a technical system works in the long term. Among other things, access to the system data for independent third parties such as TÜV Rheinland as part of the recurring central inspections is critical (TÜV, 202

Public Perceptions of ADS Safety and low ADAS usage rate

Studies conducted by JD Power and AAA in 2021 about the public perception of ADS safety indicated that the results vary based on location and population groups (age). Whereby age moderates the influence on ADS acceptance (Alexandrakis et al., 2020; Martins et al., 2014), further factors may influence the acceptance of ADS, i.e., choice of driver assistance systems. It can also be said that media reporting tends to polarize, which further influences the opinions of the public. Industry advocacy groups generally know the actual risks; however, transportation safety advocacy groups may lean towards overstating the risks (Steven E. Shladover,2022). In order to earn and retain public trust, it is vital to continue to educate the public about the risks linked with ADS usage, based on an actual assessment carried out by professional and impartial organizations.

A further study by Reagan et al. (2018) revealed that the driver assistance systems are switched off in 49% of the vehicles. The low utilization rate of assistance systems limits drivers' potential benefits, especially older ones (Trübswetter & Bengler, 2013). The reasons why drivers do not use driver assistance systems are complex. One of the main reasons is the lack of information and knowledge about these systems, combined with a lack of awareness about the functional limits of such systems. Due to limitations in sensor and camera technology and software (artificial intelligence in the interaction of the individual systems still in the development stage), driver assistance systems do not yet reliably function certain driving situations (Sullivan et al., March 2016, Larsson, 2012). For example, the adaptive cruise control system has difficulty identifying motorcycles or bicycles, which may lead to system failures and malfunctions.

Other studies in the past show a tendency to evaluate safety-related systems differently from systems that serve comfort (Davidse, 2006). It would be helpful to extend the research to investigate different assistance systems.

Consumer Survey

S&P Global Mobility conducted a consumer survey with nearly 8000 participants worldwide regarding advanced driver-assistance system (ADAS) features and automated/autonomous driving technology to understand consumer sentiment toward feature desirability, willingness to pay, and general interest in the respective technologies. Results showed that respondents find Level 2 and Level 2+ automated features currently on the market most desirable but are most willing to pay extra for the highest level of self-driving functionality. Consumers indicated a greater openness to conditional autonomy with efficiency and safety as critical reasons since the last iteration of the survey in 2021.

The survey was conducted earlier this year among a sample of nearly 8,000 adult respondents aged 18 and older with access to the internet. The sample was split across eight countries (UK, US, Germany, Switzerland, Japan, Brazil, China, and Thailand) to represent established and emerging markets and serve as reasonable proxies for other markets in that region. All respondents were asked to complete an online survey in their local language with specific questions indicating region-specific details, such as brands, pricing, and some technology standards. A quota system was used to gather samples for this survey to develop a representative sample of the region being studied. Quotas varied by country based on local demographics, with gender, age, household income, and region splits applied where necessary. In addition to essential demographic quotas, survey respondents were screened and filtered based on the following criteria:

- The respondent's household already owns a vehicle.
- The respondent has purchased or leased a new vehicle in the last year or plans to buy a vehicle within the next three years and for personal use only.
- The respondent must be involved in the next vehicle purchase decision.
- The respondent does not work for an automotive manufacturer.

These criteria were essential to distinguish within the sample to target potential end users of vehicle technology with control over the purchasing decision.

Demographics

Number of vehicles in household: All respondents owned at least one vehicle in the household as part of the survey qualifiers, with more than 34% owning more than one. For example, in Germany, around 68% own one vehicle, 32% possess two vehicles, 8% have three, and 2% with more than three cars. The US and UK have a very similar distribution. Further data is required to make the additional comparison within Europe.

Most respondents (59%) live in an urban area, with around one-third just outside the city "suburban" (Figure 7).

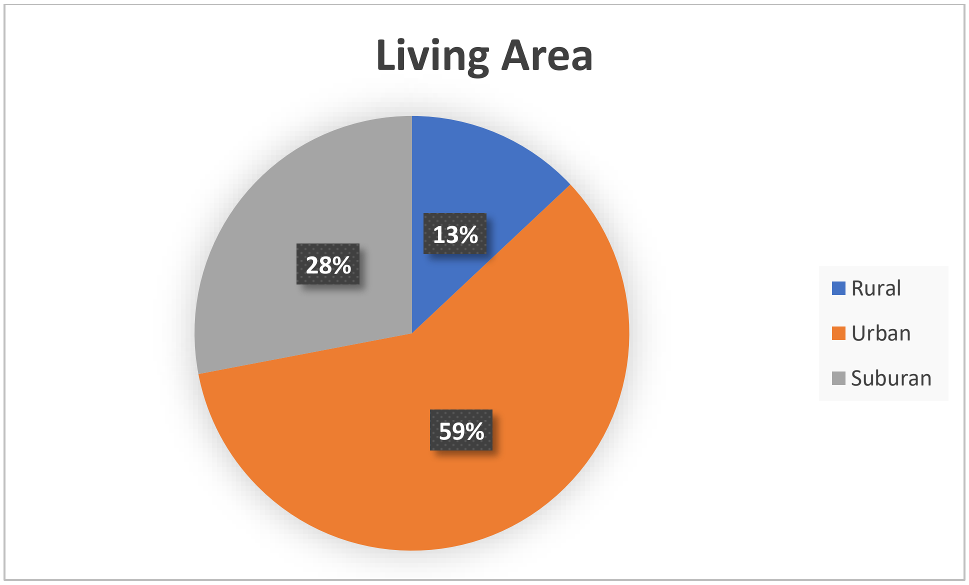

Figure 7: Living Area (S&P Mobility, 2022)

The previous survey conducted in 2020 found cautious but optimistic desirability toward future technologies related to automated and autonomous vehicles. However, compared with ADAS features, the least desired features were typically those linked to the highest levels of automation. This aligns with increased automated driving feature availability from major OEMs across global markets, familiarizing consumers with the technology and functionality.

This decision between Level 3 automation and Level 2/Level 2+ systems often create heated debates in the industry. A fundamental assumption of Level 3 systems is that the car manufacturer assumes liability for its safe operation in "autonomous mode", and this has led car manufacturers to focus on expanding functionality within Level 2+ systems while placing any potential Level 3 upgrades further out on their roadmap. In the chart below, Level 2 variants can be mapped to the motorway and city Automated Driving features; Level 3 variants add conditional automation. Level 2 versions score higher on feature desirability than Level 3. However, the desirability scores decrease directly in relation to the autonomy level. Consumers may be perceiving these step changes in functionality. (S&P Global Mobility, 2022)

A self-driving car, categorized in the Level 4 and 5 space, was found to be the least desirable, similar to the 2020 survey. Many consumers do not have enough or even any exposure to these higher levels of automation. They likely remain skeptical of the technology or its impact on their driving experiences. So it may be expected that the less the consumer is in charge of the driving experience or control of the vehicle via the feature or application, the less they are interested in wanting it. European respondents in the United Kingdom and Germany and respondents from the US appeared to be the most skeptical of these features compared with other surveyed markets. Interestingly, Thai respondents were the keenest on nearly every feature, except for the self-driving car. Interestingly, Chinese respondents claimed the highest desirability score of nearly 80% for self-driving.

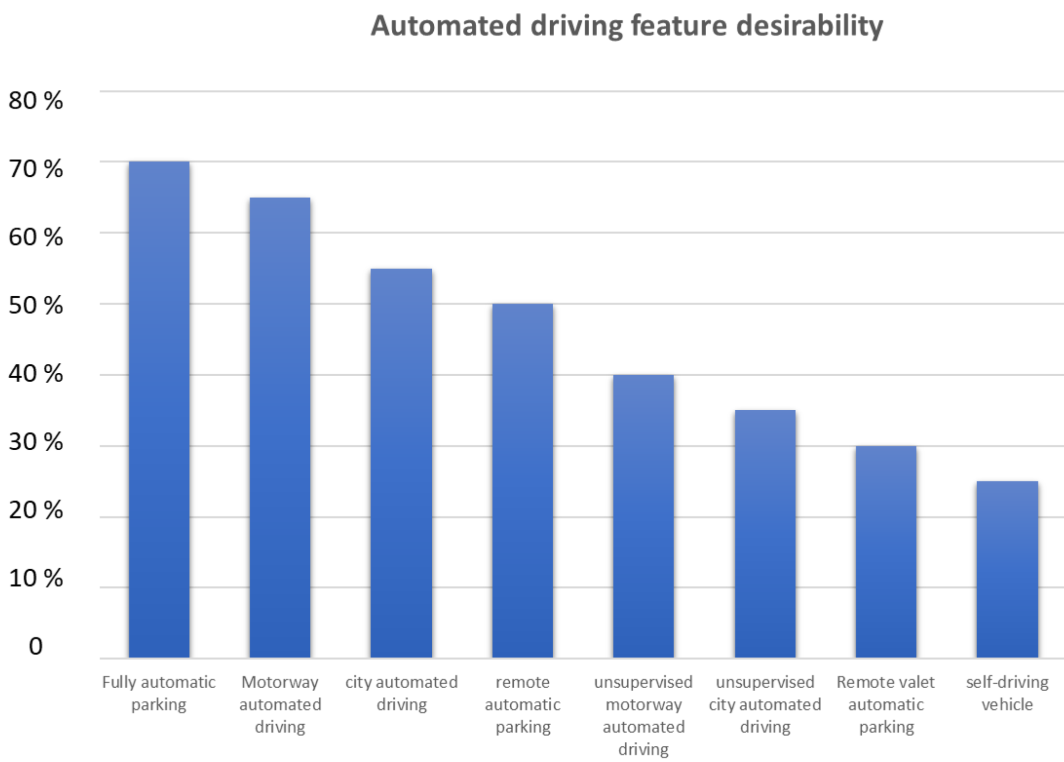

Figure 8: Automated driving feature desirability scores, (S&P Mobility, 2022)

Despite being the least desired autonomous driving features, respondents were most willing to pay extra for the self-driving car. While caution and skepticism exist for this feature when referring to desirability, respondents likely also recognize not just the increased cost that may be associated but also the value proposition in making driving not only a safer experience but one where attention on the road is not required and other activities are available to passengers.

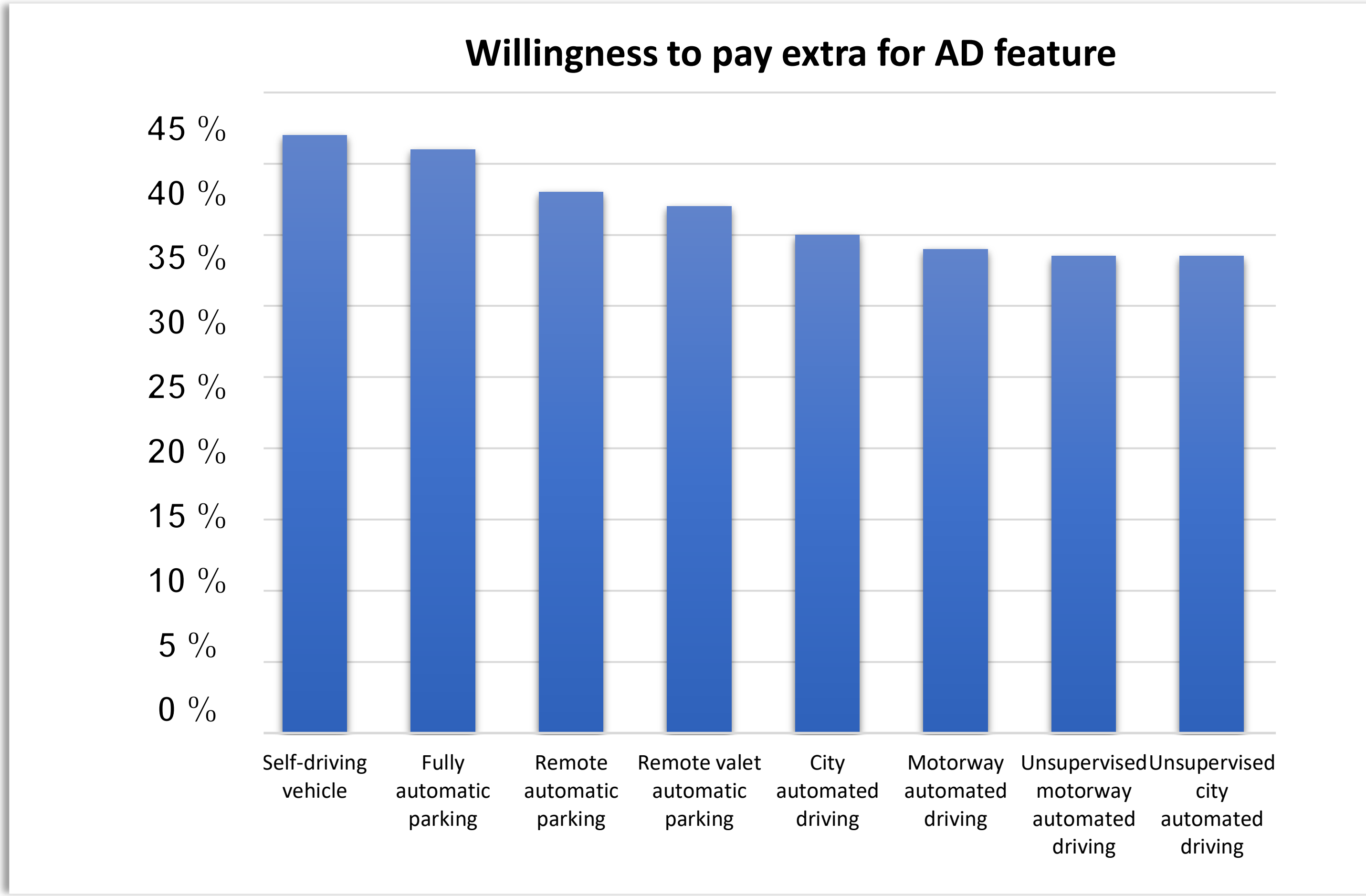

Figure 9: Willingness to pay extra for Advanced Driving (AD) feature (S&P Mobility, 2022)

Camera-based driver monitoring systems are essential in automated driving, especially as automated driving systems advance beyond Level 2+ automation (generally described as eyes-on/hands-off driving). In this setting, the vehicle performs steering, acceleration, and braking independently but with constant supervision from the driver and availability to take over with no advance alert.

So, respondents were asked if they would be willing to purchase an automated driving system (Figure 9) if it included a driver monitoring camera that observes your face. 71% of the respondents indicated that they would agree. This suggests that consumers are interested and want an automated driving system for the convenience that it brings to their time in the vehicle and that they either accept the camera as a necessary safeguard for reliable use of the automated driving system, or they are at least not put off by this feature.

Overall, this positive convenience value is not outweighed by the potential privacy concerns. Perhaps consumers are satisfied with existing data and privacy protections and how they are implemented in these driver monitoring systems today. The study does not reveal how the respondent answered on country-level, which limits the ability to interpret the data further.

Self-driving and trust

The success of autonomous driving depends not only on the effectiveness and reliability of the technology that enables it but also on the trust and positive consumer perception. Trust in the technology will take time as it continues to evolve and improve. However, car manufacturers and suppliers have strategically positioned themselves to introduce partial or conditional autonomy via automated driving systems. In the long term, however, many car manufacturers and technology and mobility companies are working toward new mobility services leveraging fully autonomous vehicles. For both automated and autonomous driving systems, the area of operation is deliberate and inherently related to the hardware and software fit to the vehicle (S&P Global Mobility 2022). Highway driving is most common, with more urban scenarios planned in future launches. Rural driving is less common overall, but many respondents would value the use of automation in all three scenarios at somewhat similar levels.

The reasons for wanting to use automated driving systems are as important as where they may be used. More than half of global respondents believed the automated car would drive more efficiently, and 46% believed it would be safer. Safety is often touted as the primary driver, but there is an opportunity to emphasize efficiency in operation as well. This may capture even more consumer interest overall. Both of these use cases or reasons for automated driving have grown since the last survey, and the increased openness to conditional autonomy should be a good sign for the growing trust in this technology. Greater trust in this technology to the level of fully autonomous driving will undoubtedly take more time, but these are signs they are moving forward. Respondents are still wary of greater levels of autonomy, with just under half felt comfortable riding in an automated car (which steers, accelerates, and brakes on its own) in all driving conditions, with removable controls (foldaway steering wheel, retractable pedals) and adjustable seating, but that still represents an increase from 2020 survey.

Understandably, respondents were far more comfortable in a driving scenario where their hands and eyes were on the road while the vehicle steered, accelerated, and braked. This system is available across different car manufacturers and represents a hands-on Level 2 system. Newer systems then relieve the hands-on requirement as these systems provide Level 2+ functionality with constant driver supervision.

Overall, however, respondents became less comfortable as the level of driver interaction went down. Interestingly, respondents in the UK, Germany, and Japan were far less comfortable compared to other countries with higher levels of automation. Interestingly, these markets have longer histories of personal car ownership and tremendous enthusiasm for the act of driving, which they may be more reluctant to leave behind. In contrast, in markets where car ownership is lower, and transportation is more of a normality, the scores for comfort are generally higher across the spectrum of automation.

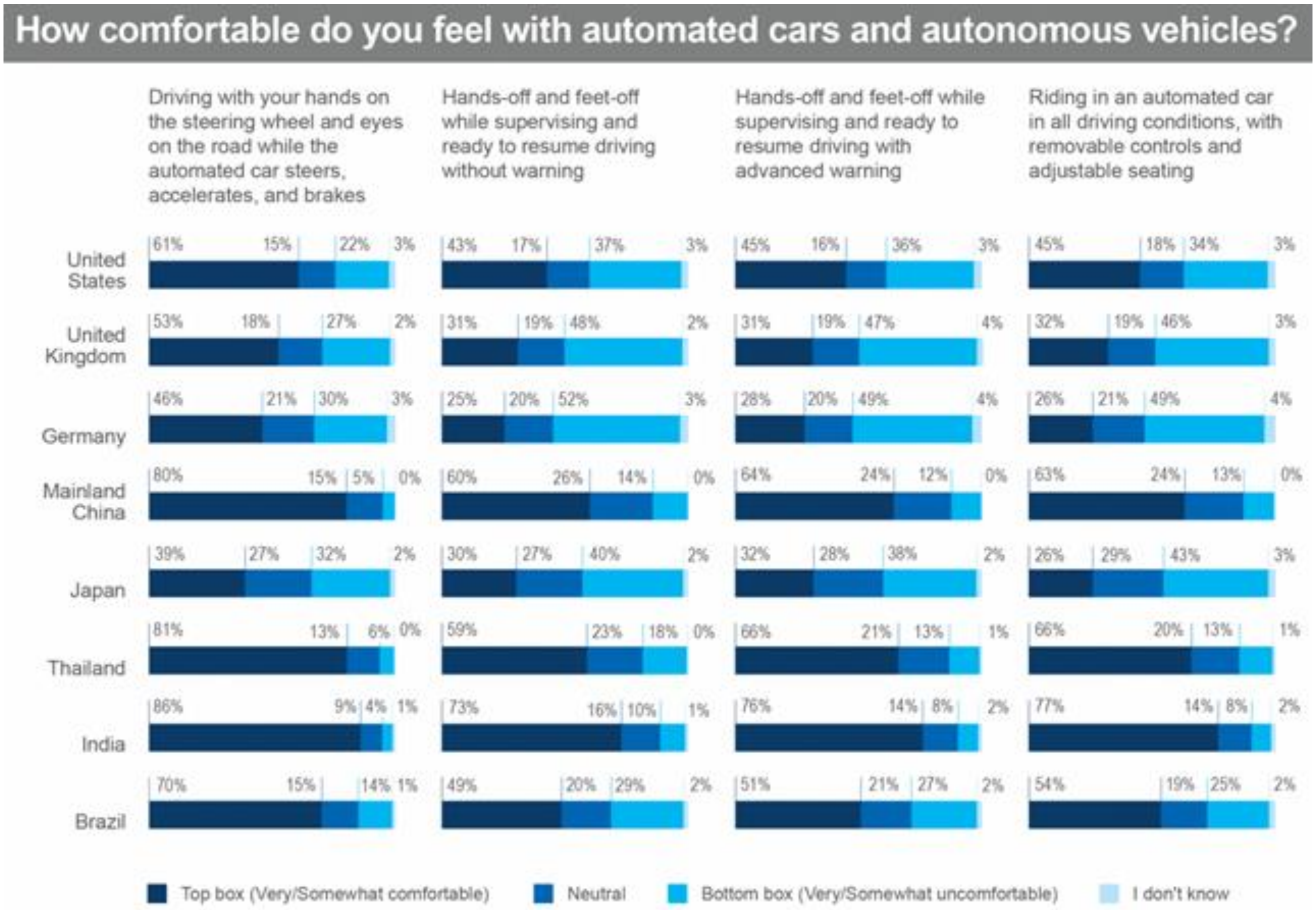

Figure 10: Survey results by country (S&P Mobility, 2022)

Despite some of the technical and regulatory hurdles causing delays in deployment plans, car manufacturers and mobility providers continue developing what many views as the long-term future for the automotive industry. However, cautious optimism remains from the consumer perspective. General thoughts toward self-driving vehicles appear more positively than in the previous consumer survey. However, general consumer awareness remains very low compared with every other form of technology in the survey.

As car manufacturers develop systems to enable an autonomous future, consumer perception of the technology becomes increasingly more critical. Beyond this, consumer perception of the car manufacturer and technology companies behind these systems is just as important.

In summary, while two years may not be enough to see significant changes in consumer views, the 2022 Autonomous Driving/ADAS survey has revealed increased interest in automated driving technology. This matches the increased feature availability in major automotive brands across several markets, with the first Level 3 vehicle entering sales in 2022. With the industry divided between Level 3 automation and Level 2/Level 2+ systems, consumers have almost naturally assumed Level 3 features and variants as those with greater autonomy. Features such as self-driving cars, categorized as Level 4 and Level 5, were found to be the least desirable. This is neither surprising nor unexpected as many consumers likely have not had the experience and are therefore more skeptical of the technology and how it relates to their driving experiences. Overall, respondents have indicated more openness to conditional autonomy since the last survey, with a more significant opportunity to emphasize efficiency in operation as a critical use case. That said, skepticism and a certain level of discomfort remain as the level of driver interaction decreases. Consumer perception and trust in the technology will likely take more time to grow, but this trust also seems to remain with established brands associated with quality and reliability (S&P Global Mobility, 2022).

Conclusion

Vehicle technology is rapidly evolving, but the required urban infrastructure and systems for autonomous and connected cars are lagging. The legal framework needs to be designed to sustain the latest innovative developments and market changes in this industry. It is essential to draft the legal framework that allows autonomous vehicles (AVs) to operate on public roads with openness, technology-friendliness, and flexibility. It is recommended to address the following as a matter of urgency:

• Functional safety: For autonomous systems to be widespread in the future, functional safety must be guaranteed. In addition to corresponding certifications that certify the functional safety of such systems, users must be informed about the functionality and the limits of autonomous systems in order to be able to intervene in case of doubt.

• Data protection: Due to the intensive networking, the constant and precise localization, and the comprehensive evaluation of environmental information, autonomous vehicles and systems generate databases from which personal data can be easily extracted. For a social acceptance of such systems, transparency about the collected data must be guaranteed, allowing users to decide for themselves whether and how the systems are set. Existing data protection guidelines must be observed or adapted for use in public spaces.

• Security certifications and test environment: Certification tools are, e.g., Driving simulators used to test sensor systems in autonomous vehicles . They serve to ensure a defined system behavior. Certification will have to be very different in all application areas since the individual requirements differ significantly depending on the application and the operating environment. The certification also includes operational standards, IT security, and data protection; ethical considerations and regulations are incorporated.

Legal regulation: Very similar to the technical standards that exist in the current areas of application of autonomous systems are comprehensive laws and regulations, such as road traffic regulations and regulations of commercial professional associations, which must also be applied to autonomous systems. Because Autonomous systems are moving from less automated at a few key points, systems differ, and adjustments are necessary. This applies to both technical standards as well as regulations. These processes have only just begun and are far from complete.

The mobility sector is facing significant challenges, on the one hand, due to the increasing need for mobility of people and goods worldwide, on the other hand, due to the requirement for mobility to make the future more efficient, safer, resourcefriendly, and climate-friendly. At the same time, it applies the demands of an aging society on individual mobility and thus achieves social participation.

The increasing networking and automation of vehicles and infrastructure can contribute to addressing these challenges. The future mobility system will consist of a mix of different forms of mobility in which (partly) autonomous vehicles are located. Systems exchange object statuses, route data, and environmental influences in real-time and thus enable intelligent and efficient control of traffic flows and data-based mobility services. At the same time, increasing automation can help make the mobility system safer. Technologies in the vehicle sector, such as lane departure warning, emergency braking, and parking assistants are already being used in various ways in the form of driver assistance systems.

In the long term, however, the development is aimed at driverless driving, in which the vehicles in unstructured environments, such as road traffic, all decisions and perform tasks without human intervention.

Formal differentiation criteria have been defined for the different levels of automation up to the autonomous system, as described in this thesis. However, the transitions between the individual levels remain fluid and can vary and differentiate according to application area or usage scenario. For example, Autonomous driving in Germany is divided into five levels of automation. In the USA, four levels of automation are defined by the road traffic authority NHTSA. Levels one to three correspond to the German system, while level four combines fully automated and autonomous driving.

Recommendation for action: The interaction of systems with different levels of automation and intelligence must be designed so that incorrect decisions, the risk of accidents, and inefficiencies are avoided as far as possible. This requires targeted research that uses pilot projects to identify the application-specific potential for conflict and danger systematically examined and the users with the introduction of such a parallel operation supports. Pilot projects in which (partly) autonomous systems are introduced into existing infrastructures and necessary measures for creating a functioning mixed operation are pointed out; appropriate guidelines should be developed with scientific support. Research into virtual simulation methods that can simulate longer-term system behavior in mixed operations and different situations is fundamental.

In addition to technical solutions, appropriate standards, certifications, and to develop legal regulations. This applies not only to the application area of autonomous driving but to all areas in which systems of the most varied levels of intelligence or automation levels must interact in a sensible, safe, and efficient manner. Consistent behavior and corresponding user interfaces are often more important than the latest functionality.

Research on the interaction of different autonomous systems with each other and with strengthening the infrastructure

Autonomous systems enable entirely new application scenarios that connect previously largely separate areas. This results in extensive contact points with various autonomous systems and the surrounding infrastructure. It will therefore

Methods and technical rules are required to ensure a meaningful, safe, and efficient interaction to fulfill the intended tasks in the best possible way. It applies the broader interoperability challenges arising from this interplay to address. However, questions about the implementation of the respective autonomous behavior, whether this is, for example, "more aggressive" or "more defensive," must be clarified. Hierarchies are conceivable for transmitting "instructions" to subordinate systems, such as an autonomous traffic control system to an autonomous vehicle and a smart city.

Furthermore, creating a suitable infrastructure and systems that react resiliently to failures, hacker attacks, or the non-availability of the surrounding infrastructure requires further efforts. Research and development work is required to examine which functions and information from a surrounding infrastructure are necessary or valuable for the functioning of an autonomous system. Also, Failure and security strategies are necessary that substitute missing information or otherwise trigger dedicated emergency programs to hand over control to humans or to transfer systems to a safe state or safe behavior.

A suitable legal framework can be created by supplementing existing road traffic regulations. Due to this legal framework, autonomous motor vehicles can be operated in public transport, provided that the responsible authorities have approved these vehicles and their respective operating areas for the respective vehicles. So far, there is no adequate legal framework for motor vehicles at the European level with autonomous driving. On the other hand, autonomous driving functions stand out because they do not provide for a person driving the vehicle. In order to take into account the innovative drive of the technology of autonomous driving, for the meantime until the harmonization of Union law by the national legal framework, suitable conditions for introducing regular operations are created. The law amending the Road Traffic Act and the Compulsory Insurance Act on Autonomous Driving of July 12, 2021 (Federal Law Gazette Part I, p. 3108). on July 27, 2021), the basic requirements have been created to allow driving on public roads in Germany. In addition to the technical requirements, procedural regulations on the granting of operating licenses for motor vehicles with autonomous driving functions, on the approval of defined operating areas, and road traffic are also to be based on this ordinance be issued by regulation as well as requirements and due diligence regulations for the am Persons involved in the operation of motor vehicles with autonomous driving functions.

Traffic law enforcement needs to be adapted based on the progress in deploying the required infrastructure and systems. The in-car telematics feature can already be utilized for crash investigation and traffic law enforcement. However, issues with data protection law in Germany need to be resolved.

Appendix

Overview of regulations and laws in Germany (IHS Markit, 2022)

Table 1 - Regulations and laws

Region	Country	Subject	Code	Regulatory body/issuing authority	Type of act	Status	Regulatory mechanism	Applicability	Technology Application	Impacted system/application/feature	Autonomy Level	Operational domain	Effective date
Europe	Germany	EU GSR - Intelligent speed assistance systems	EU Regulation 2021/1958	European Union	Regulation	Published	Mandatory	New type approval	ADAS	Intelligent speed assistance systems (ISA)	L0	All	Jul-22
Europe	Germany	EU GSR - Intelligent speed assistance systems	EU Regulation 2021/1958	European Union	Regulation	Published	Mandatory	All vehicles	ADAS	Intelligent speed assistance systems (ISA)	L0	All	Jul-24
Europe	Germany	EU GSR - Intelligent speed assistance systems	EU Regulation 2021/1958	European Union	Regulation	Published	Mandatory	New type approval	ADAS	Traffic Sign Recognition (TSR)	L0	All	Jul-22
Europe	Germany	EU GSR - Intelligent speed assistance systems	EU Regulation 2021/1958	European Union	Regulation	Published	Mandatory	All vehicles	ADAS	Traffic Sign Recognition (TSR)	L0	All	Jul-24
Europe	Germany	EU GSR - Driver drowsiness and attention warning systems	EU Regulation 2021/1341	European Union	Regulation	Published	Mandatory	New type approval	ADAS	Driver drowsiness and attention warning systems (DDAW)	L0	All	Jul-22
Europe	Germany	EU GSR - Emergency lane-keeping systems	EU Regulation 2021/646	European Union	Regulation	Published	Mandatory	New type approval	ADAS	Emergency lane-keeping systems (ELKS)	L0	Highway	Jul-22
Europe	Germany	EU GSR - Alcohol interlock system	EU Regulation 2021/1243	European Union	Regulation	Published	Mandatory	New type approval	ADAS	Alcohol interlock system	L0	Urban	Jul-22
Europe	Germany	EU GSR - Alcohol interlock system	EU Regulation 2021/1243	European Union	Regulation	Published	Mandatory	All vehicles	ADAS	Alcohol interlock system	L0	Urban	Jul-24
Europe	Germany	EU GSR - Event data recorder	EU Regulation 2019/2144	European Union	Regulation	Draft phase	Mandatory	New type approval	ADAS	Event data recorder	L4	All	Jul-22

Europe	Germany	Uniform provisions concerning the approval of motor vehicles with regard to the Advanced Emergency Braking System (AEBS) for M1 and N1 vehicles [2020/1597]	UN R152	UNECE	Regulation	Published	Mandatory	New type approval	ADAS	Advanced Emergency Braking System (AEBS)	L0	Urban	Sep-20
Europe	Germany	Cyber Security and Cyber Security Management	UN R155	UNECE	Regulation	Published	Mandatory	New type approval	Cybersecurity	NA	All	All	Jan-21
Europe	Germany	Software Update Processes and Management Systems	UN R156	UNECE	Regulation	Published	Mandatory	New type approval	Software	Software	All	All	Jan-21
Europe	Germany	Event Data Recorder (EDR)	UNR 160	UNECE	Regulation	Published	Mandatory	New type approval	ADAS	Event data recorder	L2+	All	Jan-21
Europe	Germany	UN Regulation on Automated Lane Keeping Systems	UNR 157	UNECE	Regulation	Published	Mandatory	New type approval	Automated driving	Automated Lane Keeping Systems (ALKS)	L3	Highway/Motorway	Jan-21
Europe	Germany	UN Regulation on Automated Lane Keeping Systems	UNR 157	UNECE	Regulation	Published	Mandatory	New type approval	Automated driving	Driver monitoring system	L3	Highway/Motorway	Jan-21
Europe	Germany	German Road Traffic Act. -Road Traffic Act Amendment (Strassenverkehrsgesetz, “StVG”)	Federal Law Gazette 2021 Part I No. 48,	German Federal Motor Transport Authority (KBA)	Federal law	Published	Mandatory	All vehicles	Automated driving	NA	L3 -L4	All	Jul-21
Europe	Germany	Ordinance to supplement German Road Traffic Act	Unknown	German Federal Motor Transport Authority (KBA)	Ordinance	Published	Mandatory	Test vehicles	Autonomous driving	EDR	L4	All	Jun-22
Europe	Germany	Compulsory Insurance Act (Autonomous Driving Act-1)	Amended by Article 2 of the law of July 12, 2021	German Federal Motor Transport	Federal law	Published	Mandatory	All vehicles	Automated driving	NA	L3	All	Jul-21

			(BGBl. I p. 3091)	Authority (KBA)									
Europe	Germany	The approval of prototypes for testing on public roads	Sections 19 ff. of the German Road Traffic Act. StVZO.	German Federal Motor Transport Authority (KBA)	Federal law	Published	Mandatory	Test vehicles	Automated driving	NA	L3-L5	All	Unknown

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