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Report on Scientific Publication

SCOUT

Berlin, 23rd July 2017

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Date: 23.07.2018

Document change record

Version	Date	Status	Author	Description
0.1	17/07/2018	Draft	Jörg Dubbert (VDI/VDE-IT)	Creation of document
1.0	23/07/2018	Final	Jörg Dubbert (VDI/VDE-IT)	Add content

Consortium

No	Participant organisation name	Short Name	Country
1	VDI/VDE Innovation + Technik GmbH	VDI/VDE-IT	DE
2	Renault SAS	RENAULT	FR
3	Centro Ricerche Fiat ScpA	CRF	IT
4	BMW Group	BMW	DE
5	Robert Bosch GmbH	BOSCH	DE
6	NXP Semiconductors Netherlands BV	NXP	NL
7	Telecom Italia S.p.A.	TIM	IT
8	NEC Laboratories GmbH.	NEC	DE
9	Rheinisch-Westfälische Technische Hochschule Aachen, Institute for Automotive Engineering	RWTH	DE
10	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Institute for Structural Durability and System Reliability FHG	FHG	DE
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12	Asociación Española de Fabricantes de Equipos y Componentes para Automoción SERNAUTO	SERNAUTO	ES

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1 Summary of Scientific Publications in SCOUT

This deliverable presents the scientific publications which were produced by the SCOUT project partners in the framework of SCOUT. This made sure that the SCOUT findings are presented to wider scientific audience. The ITS World Congress 2017 in Montreal and the AMAA 2018 Conference in Berlin were efficient publication platforms. Furthermore, the Springer publication series “Road Automation” is a prestigious forum for the presentation of scientific papers. SCOUT published a paper here in the fifth issue which appeared in 2018. Last but not least, the SCOUT results were presented on a Poster at the Automated Vehicle Symposium 2018 in San Francisco (USA), which is enclosed here at the end of this document.

In the Annex hereafter the following publications can be found:

- Devid Will, Lutz Eckstein, Steven van Bargen et al., State of the art analysis for Connected and Automated Driving within the SCOUT project, Scientific Paper, ITS World Congress Montreal, 2017.

- Gereon Meyer, European Roadmaps, Programs, and Projects for Innovation in Connected and Automated Road Transport, Road Automation 5, Springer International Publishing Switzerland, 2018.

- Jörg Dubbert, Benjamin Wilsch, Carolin Zachäus, Gereon Meyer , Roadmap for Accelerated Innovation in Level 4/5 Connected and Automated Driving, AMAA 2018 Conference Book, Springer International Publishing Switzerland, 2018

- Benjamin Wilsch, Hala Elrofai, Edgar Krune, Challenges and Opportunities of Artificial Intelligence for Automated Driving, AMAA 2018 Conference Book, Springer International Publishing Switzerland, 2018

- Carolin Zachäus, Jörg Dubbert, Benjamin Wilsch, and Gereon Meyer , Poster: “A COMPREHENSIVE ROADMAP FOR LEVEL 4/5, CONNECTED AND AUTOMATED DRIVING IN EUROPE”, Presented at the Automated Vehicle Symposium 2018 in San Francisco

2 Annex – Publications

In this Annex the publications are attached to this document in the following order:

1. Devid Will, Lutz Eckstein, Steven van Bargen et al., State of the art analysis for Connected and Automated Driving within the SCOUT project, Scientific Paper, ITS World Congress Montreal, 2017.

2. Gereon Meyer, European Roadmaps, Programs, and Projects for Innovation in Connected and Automated Road Transport, Road Automation 5, Springer International Publishing Switzerland, 2018.

3. Benjamin Wilsch, Hala Elrofai, Edgar Krune, Challenges and Opportunities of Artificial Intelligence for Automated Driving, AMAA 2018 Conference Book, Springer International Publishing Switzerland, 2018

4. Jörg Dubbert, Benjamin Wilsch, Carolin Zachäus, Gereon Meyer , Roadmap for Accelerated Innovation in Level 4/5 Connected and Automated Driving, AMAA 2018 Conference Book, Springer International Publishing Switzerland, 2018

5. Carolin Zachäus, Jörg Dubbert, Benjamin Wilsch, and Gereon Meyer , Poster: “A COMPREHENSIVE ROADMAP FOR LEVEL 4/5, CONNECTED AND AUTOMATED DRIVING IN EUROPE”, Automated Vehicle Symposium, San Francisco 2018

ITS World Congress 2017 Montreal, October 29 – November 2

Paper ID EU-TP1129

State of the art analysis for Connected and Automated Driving within the SCOUT project

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Abstract
This publication gives a short introduction and overview of the European project SCOUT and introduces a methodology for a holistic approach to record the state of the art in technical (vehicle and connectivity, human factors regarding physiologic and ergonomic level) and non-technical enablers (societal, economic, legal, regulatory and policy level) of connected and automated driving in Europe. The paper addresses beside the technical topics of environmental perception, E/E architecture, actuators and security, the state of the art of the legal framework in the context of connected and automated driving.

KEYWORDS:
Connected and Automated driving, State of the art analysis, Connectivity, Security, Legal

1. Introduction: Overview of the SCOUT project
Connected and Automated Driving (C&AD) is expected to significantly alter our mobility. Amongst the high expectations, there are societal benefits such as an increased traffic safety and reduced emissions at single vehicle level; on the individual level enhanced driver's comfort; and on the economic level new business models that are arising in various industry segments. In this highly dynamic and complex environment, the project SCOUT (Safe and Connected Automation in Road Transport) aims to develop viable pathways for the large-scale rollout of high-degree automated driving in Europe.

The project brings together the automotive, telecom and ICT industries in order to conceive use cases and business models that will best leverage the investments into technology development and infrastructure deployment. User needs and expectations as well as technical and non-technical gaps will be analyzed and the results will be condensed into a cross-sectorial roadmap. Figure 1 shows the overall structure of the project.

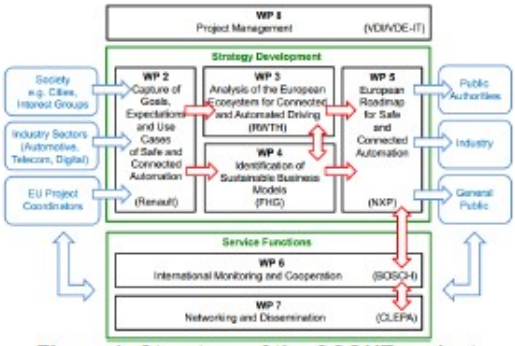


Figure 1: Structure of the SCOUT project

Work package 2 researches the essential expectations, ideas and goals, but also reservations of potential individual users and other relevant stakeholders towards automated driving. Based on this, ideas for solutions are collected in an open innovation process thereby identifying the potential use cases for automated passenger and goods transport. The overall goal of WP2 is to frame a comprehensive vision for connected and automated driving in Europe. WP3 evaluates the European ecosystem for C&AD by performing a state the art analysis (the focus of the paper) and then executing a gap analysis in comparison to the vision created in WP2. The goal of WP3 is to identify current and future gaps and challenges from technical, societal, economic, policy, legal and regulatory perspectives, in order to anticipate future development paths of the European ecosystem for C&AD. This supports the work on business models in WP4 and builds a thorough basis for defining a European roadmap for C&AD and deriving recommendations in WP5.

2. Methodology: State of the Art Analysis for Connected and Automated Driving

The field of C&AD impacts not only technology developments, but also various other domains, as reflected the 5-layer-model of Eckstein [1] on automated driving (Figure 2).

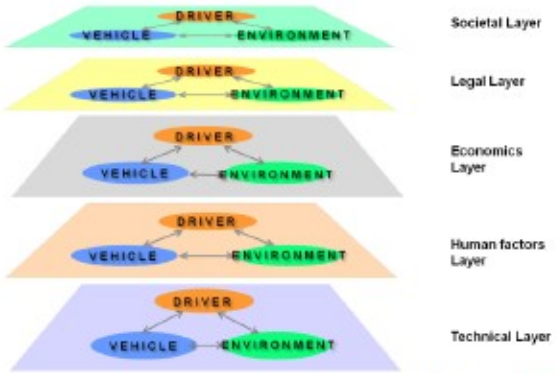


Figure 2: 5-layer model on Automated Driving [1]

The model contains the technical layer as a basis for C&AD functions. Four further layers enhance the model with mostly non-technical topics: a human factors layer; an economics layer; a legal layer; and a societal layer. In this publication, we focus the technical layer as an enabler for automated driving, as well as the legal layer. The technical layer is, as all others, subdivided into three main topics: the driver, the vehicle and the environment. These are the elements which interact all the time during driving (at least as long as the driver is in the vehicle) and the interaction needs special consideration during the development of automated driving functions. The data has been collected in desk-studies and workshops with stakeholders from the automotive supply chain in the first half year of 2017.

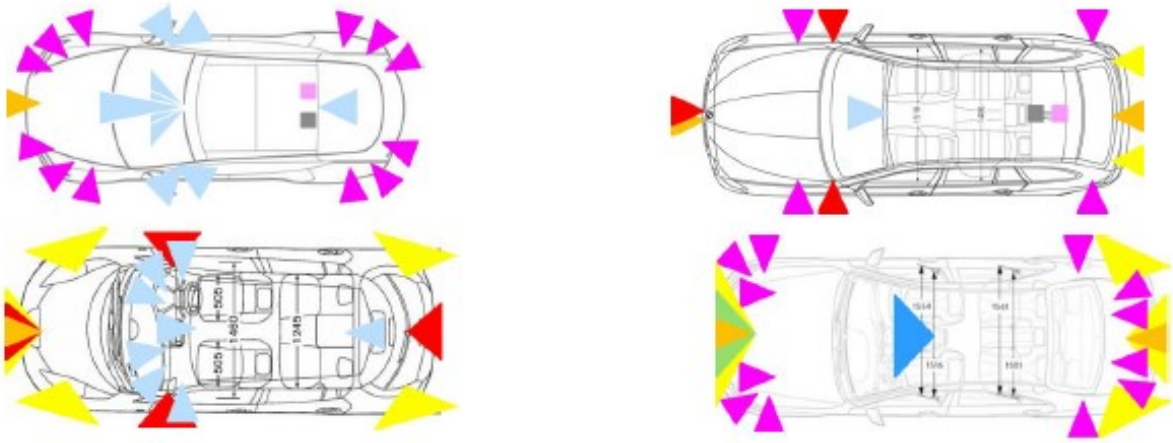
3. Results: Analysis of the state of the art enablers for connected and automated driving

The technical enablers are clustered into and discussed in the subsections perception; cognition and decision; actuation; and security. Additionally, the legal layer is discussed.

3.1 Perception

One main topic of research is the perception and understanding of the environment. Beside the choice of the sensor suite, the algorithms behind play an important role to achieve a sufficient safety level of environmental perception and prediction. The fully electric car manufacturer Tesla provides a new sensor suite in all new models consisting of eight surround cameras, twelve ultrasonic sensors and a forward facing radar processed on a new onboard computer by means of a neural net [2]. A different approach can be seen during Daimler's autonomous journey on the historical Bertha Benz Memorial Route, the S-Class S 500 Intelligent Drive was equipped additionally to the series sensor set with four short range radar sensors, two long range radars to the side, a wide-angle camera for traffic light recognition and one wide-angle camera to the rear for localization [3]. It is obvious that Daimler concentrates not only on vision sensors, but also uses long range and short range radar sensors also to achieve redundancy. Both companies are

not using laser scanners although they are extensively used in research vehicles and several start-ups are focusing on bringing them into the market. A very famous fleet of such research vehicles equipped with laser scanners was Google's autonomous driving fleet with several Lexus vehicles with a Velodyne HDL-64E on the roof of each vehicle. After Google stopped their self-driving car project, Google founded the company Waymo who still uses laser scanners for perception. The German OEM Audi announced that laser scanners are definitely needed for automated driving and they want to bring them into series production soon [4].
It is still under investigation which sensor suite is the best one for SAE level 3-5 functions. An additional difficulty is the unclear situation from the legal perspective. As long as the requirements (e.g. redundancy) are not finally defined, the final sensor suite might change over time. Figure 3 shows four examples of sensor suites which are used in production vehicles and concept vehicles (Tesla Model S (production), BMW 536i (concept) in the upper row, Nissan Leaf Pro-Pilot (concept), Mercedes S class (production) in the lower row).



Sensor Setup Examples			
Radar - Short Range	Radar - Long Range	GPS	Lidar / Laser
Camera - Mono	Camera – Stereo	V2X – Sensor	
Ultrasonic	Infrared	Maps	

Figure 3: Example of Sensor Setups

3.2 Cognition and decision making

The diversity of sensors around the vehicles presented in chapter 3.1, delivers various kind of information, but instead of single sensor sources it is essential to create a common, in the best case 360°-, representation of the environment to enable automated driving. This scene understanding (cognition) is the basis for the subsequent functional modules, namely behavior generation or decision making and trajectory planning. The whole central computing platform with its software modules which is necessary to realize this, can be understood as the brain of the self-driving car.

Since each single sensor source has its advantages and disadvantages, none of these sources can create a full understanding of the environment which leads to the necessity of a module which combines the single sources for automated driving. Therefore, the technique of sensor fusion is a well-established process to cancel out the weak points of several sensors by combining their information to gain a more robust detection with all necessary information.

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Especially the fusion of cameras with distance measurement focused sensors like radar or LIDAR have a long history. This is done to not only detect obstacles and other road participants, but to also classify them beyond the capabilities of a single sensor. To do so, a fusion of the sensor sources is necessary. In general, this process takes the information gathered by two sources and a detection selection method (for example based on the similarity of reported object positions) and then uses the individual information to enhance the overall quality of the positioning. Also, information only available from one sensor can be added to the fused object by using a specific combination method. Additionally, some approaches use a prediction of past detections to obtain an additional source and means for tracking objects. Two mostly used systems for this in the context of Connected and Automated Driving are Kalman-Filtering and Occupancy Grid Fusion.

For the creation of an environment model, the access to all sensors and in the best case the sensor information with the highest information depth available without filtering or deriving objects based on raw data.

The state-of-the-art with regard to E/E architecture and the communication between ECUs is mostly realized by a distributed approach. Each sensor has a dedicated ECU attached to it which is responsible for the signal processing of the sensor and creates higher level information for the actuators. An example would be an ACC system which is based on a radar sensor with a dedicated ECU which generates longitudinal commands (e.g. acceleration/deceleration) for the engine control unit based on the detection of the radar sensor. The raw information of this radar sensor is nowhere else available except the dedicated radar ECU.
Since for the development of a 360°-environment perception all sensors must be available at one place, the introduction of a central ECU seems to be indispensable. Figure 4 shows the shift from a distributed architecture to a centralized approach.

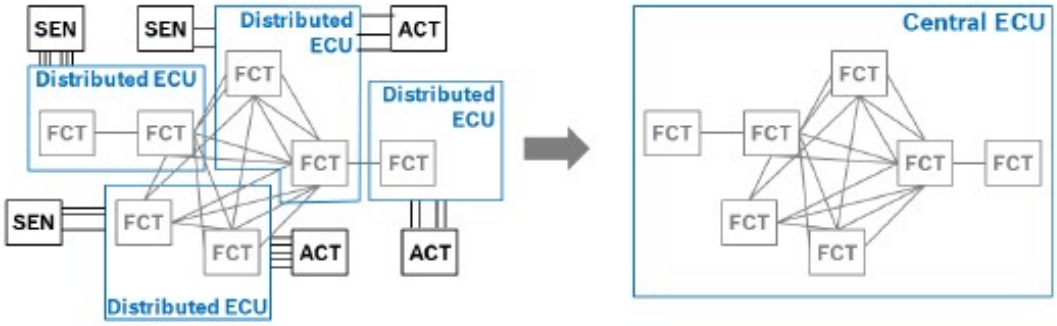

Figure 4: Distributed ECUs vs. Central ECU

Recently Audi introduced a central ECU following this motivation in the new Audi A8 called Audi zFAS. A centralized ECU with heterogenous hardware adapted to each processing task. All environment sensors (radar sensors, front camera, ultrasonic sensors) are directly connected to the zFAS and the environment representation is calculated here.[5] These central computing platforms have to deal with a massive and still increasing amount of data and therewith the need of increasing processing power is still there.

As soon as the environment is well-known and understood, the central vehicle brain of the automated vehicle is capable of making a decision based on this, i.e. choosing the next maneuver and planning a valid trajectory which is forwarded to the vehicle's actuators.

3.3 Actuation

Currently all scenarios for possible failures caused by the vehicle are using the driver as an observer and physical backup (Level 0-2 functions according to SAE levels). In case the driver does not conduct the driving task this assumption is not valid anymore. Depending on the level of automation the driver cannot take over the physical driving task fast enough or not at all.

- For common – not highly automated systems - the driver can take over the driving task. In this case the safety analysis typically could qualify the vehicle or a subsystem as "fail safe". This is possible because in case of a malfunction of the vehicle the driver has the task to bring the vehicle into a minimum risk state. Example: In case of a malfunction of the brake booster, the driver has to enforce the missing braking power and bring the vehicle to a minimum risk state as fast as possible.
- For future - highly automated systems – the driver cannot be considered as mechanical backup. In this case the safety analysis requests the system to be "fail operational". Thus - in case of a possible malfunction of the vehicle - the vehicle has to bring itself into a minimum risk state. Consequence out of this "fail operational" requirement: For certain possible malfunctions, e.g. a single point failure of a system, the vehicle has to cover a remaining driving task to ensure a minimum risk scenario.

The state of the art requirement for actuation systems is "fail safe" which leads to a "serial" dependency of actuation systems (braking and steering) and their supporting systems as power-net and data-processing-net.

Thus the state of the art of brake- and steering systems

- do not require functional redundancy in terms of using the ESP system to cover up the steering system within given constraints,
- do not have strong interdependencies concerning redundancy as e.g. multiple power net plugs for steering systems.

For future - highly automated systems all solutions applying redundancy to the systems and subsystems highly belong on the level of automation. All solutions will be carefully selected between concepts for functional redundancy and internal redundancy. The redundancy-distribution of the power-net and the data-system strongly depends on the concepts for braking and steering systems.
The given interference leads to a considerable complexity – especially because every kind of redundancy or even only changes cause additional costs.

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3.4 Security

85% of vehicles are expected to be connected to the internet by 2020 with more than 50 vulnerable points opening the door for cybercrime [6]. Prominent examples are the "Jeep-Hack" and the "Tesla-Hack" [7], where researchers took over the remote control of a Tesla Model S to interfere with the brakes. These incidents show that functional safety needs to be supported by functional security in a connected vehicle. A multi-layer security model should be considered on all layers of the vehicle's architecture in the design process ("Security-by-Design"). The layers are the Interfaces, Gateway, Network and Processing. Adding Car Access as classical part of security, this model results in a 4+1 Layer Model (Figure 5). We briefly describe the available security solutions already in the market, or soon to be implemented for each layer.

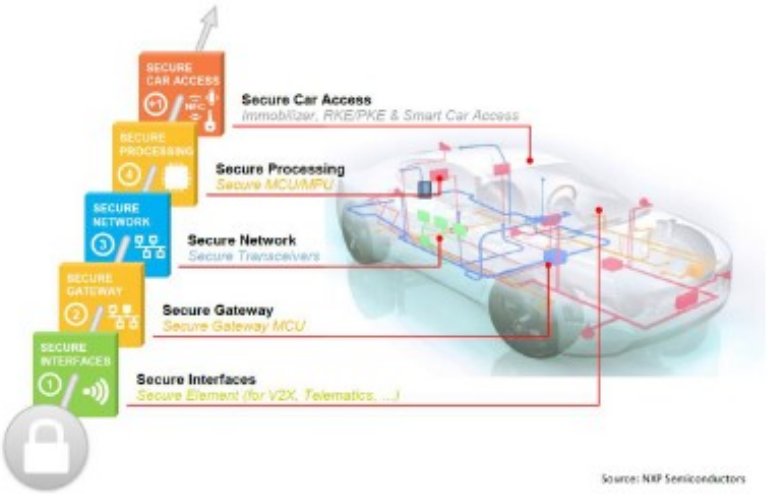

Figure 5: The 4+1 Layer Model for a Secure Connected Vehicle

Secure Interface: the external interfaces of the In-Vehicle-network (IVN), such as the Telematics Control Unit (TCU) or the On-Board Diagnostics port need to prevent unauthorized access. A strong M2M authentication can be implemented by attaching a Secure Element. These are dedicated security microcontrollers with advanced cryptographic accelerators and proven advanced physical and electrical attack resistance that can be used to establish an end-to-end secure channel to the external world. They also act as an ultra-secure vault for keys and certificates. To prove the level of security it is necessary to have 3rd party assessment and certification in the future, like e.g. Common Criteria EAL6+ or EMVCo.

Secure Gateway: A central gateway is needed to prevent attackers from getting access to the IVN once they hacked the interface (as in the "Jeep-Hack"). The gateway's firewall separates the interfaces from the safety-critical IVN. The gateway includes accelerated crypto capability (HSM/SHE), bus monitoring, public key cryptography and a security software library for message authentication. The adoption rate of a central gateway in vehicles is around 20% today, with an expected increase to 50% by 2020.

Secure Network: One way to secure current CAN-based IVNs is to use secure transceivers. These secure transceivers can help containing spoofing attacks by monitoring and filtering messages based on their CAN ID. They can also help preventing denial-of-service attacks by applying rate limitation. A network-centric approach would be the economical upgrade path. By implementing such security features at the network level, inside the transceiver, security can be retrofit to existing networks with existing ECUs, while significantly reducing the amount of ECU software re-development.

Secure Processing means to ensure that the software running on the processor is genuine and trusted and has not been manipulated. Modern microcontrollers feature a secure boot and run-time integrity checking schemes using SHE and/or HSM. In addition, mechanisms for controlled lock-down of the MCU and ECU through manufacturing are employed to lock out debug and serial download features, which would be

invaluable to hackers. Further, a secure upgrade mechanism such as over the air updates are already state of the art in some OEM's. The security standard for OTA updates must be high, as an altered firmware could cause serious damage to a high number of vehicles at once.

Secure car access is the traditional part of security in a car. Traditional car keys and immobilizers helped preventing intruders from getting physical access to the car (esp. to prevent theft). Today, car keys feature Passive Keyless Entry (PKE), a feature that ensures that the car is locked and secured as soon as the driver exits and leaves the surrounding of the car. Soon, they will be equipped with even more additional features, for example to enable remote vehicle monitoring, or to enable car access via NFC or BLE with a mobile device like a smartphone or wearable.

3.5 Legal

European legislation on traffic in general is subject of the Vienna Convention (VC). It is the main legal basis for regulation in the EU and thus necessary to look at, regarding potential roadblocks for connected and automated driving (CAD) in Europe and what has already been done to enable it. Furthermore, national regulations regarding CAD and (cross-border) testing possibilities must also be considered to round off the picture. Besides the regulation for road traffic, other legal questions like e.g. liability, privacy, security or type approval must be solved.

A recent amendment of the VC enables a system taking control of the driver's task, e.g. automated steering up to 10 km/h for parking scenarios. It was incorporated in the Articles 8, 13 and 39 and was a first step to enable CAD to a certain extent. It states that the driver must have the possibility to override or switch the system off and the system that takes over driving duties has to fulfill certain technical requirements. Fully autonomous driving without a driver is not possible with this amendment.

The nearly 50 years old VC has several more roadblocks for CAD which are in particular:

- The definition of the driver (extension to include technical systems necessary) (Art. 1 v)
- The need of a driver to maintain permanent control of the vehicle (Article 8)
- Keeping a certain distance between two vehicles while driving (Article 13)
- The technical requirements of vehicles (Article 39)
- Regulation regarding the steering system (UN-R 79)

Especially the UN-R 79 needs an amendment, as it regulates the technical requirements for steering functions and prohibits most use cases of CAD including some ADAS functions. Amendments are already issued by several signatories (incl. the EU), but are not in effect yet. To cover all needed changes and guarantee a holistic approach that enables all facets of CAD, an amendment should be issued by the EU on behalf of all member states.

Considering the slow process to align regulations with the technical development of CAD, member states reacted by allowing Field Operational Tests (FOT) and amended their national legislations accordingly. Extensive FOT in Europe are e.g. the "European Truck Platooning Challenge" [8] or "Drive Me" [9] in Sweden. Some member states like e.g. Germany [10] also prepared their law for future possible changes by allowing higher levels of CAD if the VC allows it as well and open the door for special approval under Art 20 of Directive 2007/46/EC.

Besides road regulation some other topics need attention too. Foremost, it's the question of liability and consequently insurance systems. With driving tasks being transferred from the driver to the system (in different shaping over the development-cycle) the question who should be liable in case of an accident is arising. The question is a hot topic, discussed by policy makers, academia and other stakeholders. This question has the potential to become a major barrier for CAD until it is solved. Other topics are privacy and data protection, with forecasts assuming a production of up to 25GB of mostly private data per car per hour. Furthermore, functional security will be needed to ensure functional safety for CAD. With lives at risk, security must have a high standard like safety already has with ISO 26262. EU-Directive 2007/46/EC which regulates the type approval of cars will very likely also need a revision to adapt to the technical development of CAD. Other (national) regulations to be assessed do concern e.g. driving licenses or maintenance.

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4. Conclusion

During the state of the art analysis in the field of connected and automated driving within the context of the project SCOUT, it became obvious that there are still great research needs in each module of connected and automated driving and also pending decisions of the legislation. Today there is no approval plan available which deals as a guide for market introduction of connected and automated vehicles higher than SAE level 2. But also for the technical side, there needs to be funded research and development to solve the various problems and answer all open questions. As one example, the transition from "fail-safe" components and architectures to "fail-operational" vehicles, is a huge step, which needs to be solved before connected and automated driving in higher automation levels (> SAE level 2) is possible.

Overall it can be stated that with vehicles transforming into automated and connected vehicles, a new era in terms of complexity and connectivity is dawning. These vehicles are even more vulnerable to new kind of (cyber-)threats from the outside, which already exists today, as shown by several hacks in the near past. These hacks indicate that security is often still an afterthought – something that must change, especially in the light of the wireless connectivity that opens new entries for hackers into the vehicle networks. There won't be functional safety without functional (cyber-)security for the connected car. The increasingly complex software to secure a car needs a matching hardware as a trust anchor. Therefore, the car of the future needs security-by-design – next to the existing safety-by-design. With some technologies being already available and state of the art, the complete design of vehicle security still needs to be implemented.

The idea of connected and automated driving is triggered since some years, but there is still a lot of time and research needed to introduce the technology in mass market products.

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European Roadmaps, Programs, and Projects for Innovation in Connected and Automated Road Transport

Gereon Meyer

Abstract This chapter is summarizing the current initiatives in support of connected and automated driving taken by public authorities, academia and industrial stakeholders in Europe. It is covering the actions by the European Commission, such as the GEAR 2030 strategy, the C-ITS platform, the cooperation of automotive and telecom industries for connectivity, and the strategic transport research and innovation agenda (STRIA). At the same time, the roadmaps of European technology platforms and public private partnerships such as EPoSS, ERTRAC, ECSEL and EATA are explained. Also, an analysis of funding calls and projects for the Automated Road Transport (ART) topic of Horizon 2020 is given, and additional programs such as ICT, ECSEL, PENTA, and the Urban Innovative Actions are introduced. The results of a worldwide benchmark study are reported as well. Finally, the two Coordination and Support Actions forming the connectedautomateddriving.eu initiative, SCOUT and CARTRE are presented and their efforts to establish a comprehensive roadmap to accelerate innovation of connected and automated driving in Europe are summarized.

Keywords Europe · Connected and automated driving · Horizon 2020 GEAR-2013 · C-ITS · STRIA · 5G · EPoSS · ERTRAC · EATA SCOUT · CARTRE

1 Introduction

In the 1990s, European vehicle manufacturers and automotive suppliers were among the pioneers to introduce advanced driver assistance systems like e.g. electronic stability control (ESC) after essential technologies had been developed within research and development programmes such as PROMETHEUS, heavily

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G. Meyer and S. Beiker (eds.), *Road Vehicle Automation 5*, Lecture Notes in Mobility, https://doi.org/10.1007/978-3-319-94896-6_3

funded by European member states. Hence, ambitions are high to remain in the lead when it comes to the development, piloting and early deployment of connected and automated driving of SAE levels 3–5, despite many European countries are bound to the Vienna Convention. Thus, in the Amsterdam Declaration of 14 April 2016, European state leaders called for a shared strategy on automated and connected vehicles, and in a Letter of Intent signed by high level government representatives on 23 March 2017 in Rome, member states committed to jointly carry out testing and large-scale demonstrations of connected and automated driving. In parallel, the European Commission has launched a multitude of strategic initiatives and established research and innovation funding programs, acknowledging the roadmaps and recommendations by European Technology Platforms. The joint European strategy was discussed at the first European Conference on Connected and Automated Driving organized by the European Commission on 3–4 April 2017 in Brussels, and future research needs and roadmaps were compiled at an Interactive Symposium on Research and Innovation for Connected and Automated Driving in Europe, held on 19–20 April 2018 in Vienna.

2 European Union Policy Initiatives

The European Commission has established a number of policy initiatives to support an accelerated deployment of cooperative, connected and automated driving, recently.

2.1 Gear 2030

In view of the game-changing trends and challenges the automotive industry is facing, the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROWTH) of the European Commission in October 2015 established a High Level Group on Automotive Industry (GEAR 2030). The group, which involved representatives of European Member States, industrial and societal stakeholders, made recommendations to reinforce the competitiveness of the European automotive value chain. Its members jointly edited roadmaps that set objectives, specify milestones and define the responsibilities. Discussing the impacts of the introduction of autonomous vehicles in their final report, [1] they note that EU governance would be needed to take the full benefit of large scale testing and research and financing programs both at the EU and at Member State level, and they are pointing to the need for data handling rule, coherent traffic and vehicle rules, and new approaches for vehicle type approval. According to GEAR 2030, the required connectivity needed to be provided in the vehicle and the infrastructure, and the socio-economic impacts had to be assessed.

2.2 C-ITS Deployment Platform

The interaction between road vehicles and infrastructure is the subject of Cooperative Intelligent Transport Systems (C-ITS). Such systems provide road users and traffic managers with the opportunity to exchange data and to apply those data for traffic flow coordination. Communication between vehicles, infrastructures and road users is particularly essential to ensure the safety of automated vehicles and their integration in the transport system. Cooperation, connectivity, and automation thus are technologies that work together in a synergetic way. In 2014, the Directorate-General Mobility and Transport (DG MOVE) of the European Commission launched a C-ITS Deployment Platform that includes national authorities, C-ITS stakeholders and the European Commission for a dialogue on the path towards interoperable deployment of C-ITS. Based on the work of the platform, the European Commission adopted a European Strategy on Cooperative Intelligent Transport Systems (C-ITS) [2]. The objective of that strategy is the EU-wide coordination of investments and regulatory frameworks to prepare for the availability of C-ITS services in 2019 and beyond. The C-ITS platform is strongly liked to the C-Roads platform which is gathering real-life deployment experiences from various sites in the European Member States [3]. Currently, the C-ITS platform is working on draft security and certificate policies for C-ITS to enable connected and automated driving.

2.3 Connectivity for Automated Driving

Safety concerns would limit the feasibility of higher level automated driving, particularly at SAE levels 3–5, to very few use cases of reduced complexity, if the environment perception of cars were based on in-vehicle sensors only. Vehicle-to-vehicle data communication, and even more, connectivity with sensor systems in the infrastructure and links to dynamic maps, artificial intelligence and big data analytics in the backend, could increase the capabilities of automated vehicles to understand complex traffic situation. They may even become a requirement for allowing the operation of self-driving cars e.g. in urban environments. This requires data links providing high bandwidths and low latencies, as they are offered by either (long range) 5G mobile communication or (short range) wireless internet. EU-Commissioner Guenter Oettinger (then in charge of the Digital Agenda) in 2015 launched a round table to bring together the automotive and telecom sectors for a closer cooperation and development of a roadmap on connected and automated driving [4]. As a result, the European Automotive Telecom Alliance (EATA) was formed.

2.4 Strategic Transport Research and Innovation

The research and innovation needs in connected and automated driving are covered in the roadmap "Connected and Automated Transport" of the Strategic Transport Research and Innovation Agenda (STRIA) that the Directorate-General Research and Innovation (DG RESEARCH) of the European Commission compiled in 2017 [5]. Like the other six STRIA reports, it was published as part of the European Commissions communication package "Europe on the Move" [6]. According to this roadmap, short-term research needs are seen in: Large-scale cross border demonstration, human factors, testing and validation procedures and in the assessment of socio-economic and environmental impacts of connected and automated driving. On the longer term, perception systems and artificial intelligence ensuring road safety, and infrastructures supporting the integration of connected and automated vehicles into the wider transport system will require additional research. Currently, the European Commission is setting up a governance structure for the implementation of the STRIA roadmaps. It involves EU institutions, Member States, local administrations and other relevant stakeholders. Since 2016, research and innovation projects have been funded in the framework of the Automated Road Transport (ART) section of the Transport Work Program.

3 European Stakeholder Positions and Roadmaps

European stakeholders from industry, academia and civil society are contributing significantly to the strategic discussions on research, innovation and deployment of connected and automated driving through a multitude of platforms. With the support by their members and an in close cooperation with associations such as European Council for Automotive Research (EUCAR), European Association of Automotive Suppliers (CLEPA), European Automotive Research Partners Association (EARPA), ERTICO—ITS Europe, and the Cities and Regions for Transport Innovation (POLIS), the European Technology Platforms ERTRAC and EPoSS, the Joint Undertaking ECSEL and the European Automotive-Telecom Alliance (EATA) recently have released roadmaps and strategic positions.

3.1 ERTRAC

The European Road Transport Research Advisory Council (ERTRAC) just recently published a new edition of its Automated Driving Roadmap that had originally been released in 2015 [7]. It summarizes the challenges of connected and automated driving in three categories: vehicles, systems and services, and society. For vehicles, in—vehicle technology enablers, as well as production and industrialization

are listed as fields requiring further research. For systems and services, human factors, connectivity, digital and physical infrastructure, big data and artificial intelligence, new mobility services, shared economy, and business models are mentioned. For society, user awareness and societal acceptance and ethics, needs for policies, regulation and European harmonization, socio-economic assessment and sustainability, as well as safety validation and roadworthiness testing are considered. Recommendations are derived for the 2018–2020 calls for proposals of the Horizon 2020 work programs.

3.2 EPoSS

In its "European Roadmap Smart Systems for Automated Driving" the association of the European Technology Platform on Smart Systems Integration (EPoSS e.V.) is describing the goals and challenges as well as the state of the art of automated driving [8]. A particular focus is put on the enabling role of smart electronic systems and architectures. These include navigation systems for localisation and positioning, sensing and perception systems, sensor networks and fusion, vision systems for guidance and control as well as self-learning algorithms. The sensor suite of a highly automated vehicle comprises several smart systems such as high-end laser scanners creating a 3D surface map of the environment, as well as camera and radar sensors that complement each other by lateral and spatial resolution. The roadmap covers evolutionary and revolutionary development paths and related milestones. Action fields have been classified in the following categories: Technology inside car, infrastructure, big data, system integration and validation, system design, standardization, legal framework and awareness measures. For each of the action fields, the content and the timescale of actions in R&D, demonstration and industrialisation is indicated. Currently, this roadmap is being complemented by an EPoSS position paper that emphasizes the user centric perspective, a vision for connected and automated driving 2030, the links to robotics, safety and security issues of automated driving, and synergies between automation, electrification and shared mobility.

3.3 ECSEL

The Joint Undertaking Electronic Components and Systems for European Leadership (ECSEL) is a public-private partnership of the European Union, Member States and three associations, EPoSS e.V., AENEAS and ARTEMIS-IA, representing the actors from smart integrated systems, micro- and nano-electronics, and embedded or cyber-physical systems domain. In its recently published Joint Strategic Research Agenda, "Transport & Smart Mobility" is considered an important application field, and "Ensuring secure, connected, cooperative and

automated mobility and transportation" is seen as a major challenge [9]. According to the roadmap a number of issues require further research, development and innovation, in particular environment recognition, localization, maps and positioning, control strategies, hardware and software platforms for control units for automated mobility and transportation (including also support for artificial intelligence), communication inside and outside the vehicle, testing and dependability, swarm data collection and continuous updating, predictive health monitoring for connected and automated mobility, functional safety and fail-operational architecture and functions (sensors, electronics, embedded software and system integration), as well as management of mixed automated and manual traffic. To enable the related functionalities, electronic components and systems (ECS) are considered to be key, e.g. interacting information systems for safe and secure connection between vehicles and between vehicles and infrastructure, intelligent on-board traffic management and navigation systems, energy harvesting sensor and actuator systems, multi-core/many-core-based architecture, AI-based systems, safe fallback vehicle sensing and actuation systems as well as methods and tools to virtually validate and approve connected, cooperative, automated vehicles. ECSEL recently launched the Lighthouse Initiative Mobility.E that shall increase the impact of research and innovation projects promoting collaboration and fostering a continuous dialogue with the ECS community and between the ECS community and technology users, decision-making bodies and society. It is supported by a Lighthouse Initiative Advisory Service" (LIASE) that shall develop, maintain and implement a dedicated Lighthouse Initiative Roadmap.

3.4 EATA

The European Automotive Telecom Alliance (EATA), an umbrella organization of companies and associations, recently presented a roadmap for the deployment of connected and automated driving functionalities [10]. According to that roadmap, the deployment shall happen in three steps. At first, highway chauffeur and high-density truck platooning shall be supported by the pre-deployment of hybrid communications, network slicing, and LTE broadcasting in five EU countries. Thereafter, also valet parking shall be added and cross border functionality be available on motorways, then building also on 5G radio and evaluation relative localization, and finally, automated driving shall be deployed and commercialized on authorized highways. Part of the planned activities are co-funded by the European Commission and some partners of EATA in the project "Connected Corridor for Driving Automation" (CONCORDA).

4 Programs and Projects

The European Union has funded research and innovation in the domain of automated driving for more than a decade. The EUREKA project "PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety" (PROMETHEUS) which took place between 1987 and 1995 and received 749 million euros in funding from the EUREKA member states, already covered many of the issues of automated driving that sometimes are still of concern today [11]. Automated driving also was the subject of funding in the European Commission's sixth and seventh research framework programs. In the current Horizon 2020 program, specific call sections of the transport work programs have been dedicated to "Automated Road Transport" (ART, for 2015/16) [12] and "Digitising and Transforming European Industry and Services: Automated Road Transport" (DT-ART, for 2018–20) [13] with an allocated funding budget of more than 200 million euros. A summary of call topics and budgets is shown in Table 1.

Additional European funding opportunities for the topic of connected and automated driving have been provided by the ECSEL Joint Undertaking and the EUREKA cluster PENTA on micro and nano electronics [14]. Recently, the Directorate-General Communications Networks, Content and Technology (DG CONNECT) of the European Commission also launched a call for proposals on the topic "ICT-18-2018: 5G for cooperative, connected and automated mobility" providing a total of 50 million euros for Innovation Actions [15].

All current and previously funded EU-funded research and innovation projects on connected and automated driving are summarized in Fig. 1, distinguishing four research fields: Networking and Challenges, Connectivity and Communication, Driver Assistance Systems and Highly Automated Urban Transport Systems.

Automated road transport is covered by the "Urban Mobility" theme of the Urban Innovative Actions that provide funding from the European Regional Development Fund (ERDF) for highly innovative technology deployment projects to municipalities in Europe. Shared automated vehicles were among the most prominent solutions presented by the 86 applications submitted to the second call for proposal [16]. Two of the selected projects will receive funding for such solutions, namely "Transforming Urban Planning Providing Autonomous Collective mobility" (TUPPAC) by the City of Albertslund in Denmark, and "Collaborative Mobility Management for Urban Trafic and Emissions reduction" (COMMUTE) by Toulouse Metropole [17].

Table 1 Automated road transport calls in the EU Horizon 2020 program

Call ID	Topic	Type[a]	Budget (million euros)
ART-02-2016	Automation pilots for passenger cars	IA	48
ART-04-2016	Safety and end-user acceptance aspects of road automation in the transition period	RIA	13
ART-05-2016	Road infrastructure to support the transition to automation and the coexistence of conventional and automated vehicles on the same network	RIA	
ART-06-2016	Coordination of activities in support of road automation	CSA	3
ART-01-2017	ICT infrastructure to enable the transition towards road transport automation	IA	50
ART-03-2017	Multi-Brand platooning in real traffic conditions	IA	
ART-07-2017	Full-scale demonstration of urban road transport automation	IA	
DT-ART-01-2018	Testing, validation and certification procedures for highly automated driving functions under various traffic scenarios based on pilot test data	RIA	6
DT-ART-02-2018	Support for networking activities and impact assessment for road automation	RIA/ CSA	6/3
DT-ART-03-2019	Human centred design for the new driver role in highly automated vehicles	RIA	8
DT-ART-04-2019	Developing and testing shared, connected and cooperative automated vehicle fleets in urban areas for the mobility of all	IA	30
DT-ART-05-2020	Efficient and safe connected and automated heavy-duty vehicles in real logistics operations	tba	50
DT-ART-06-2020	Large-scale, cross-border demonstration of highly automated driving functions for passenger cars	tba	

[a]*CSA* coordination and support action, *IA* innovation action, *RIA* research and innovation action

5 International Benchmark

In a recent study on behalf of the European Commission, the maturity of the transportation systems was assessed in six different countries—Brazil, China, India, Japan, South Korea, USA—in comparison to the EU. The study covered all transportation modes and had five focus areas including automation and connectivity. It also provided actions plans on how to overcome existing European barriers towards a single and innovative European Transport System based on best practices and lessons learned in the countries under study. In addition to the actions plans, the recommendations for international collaboration were made [18].

According to the results of the study, the degree of maturity automated and connected transport is about alike ("good") in Europe, the U.S. and Japan, whereas

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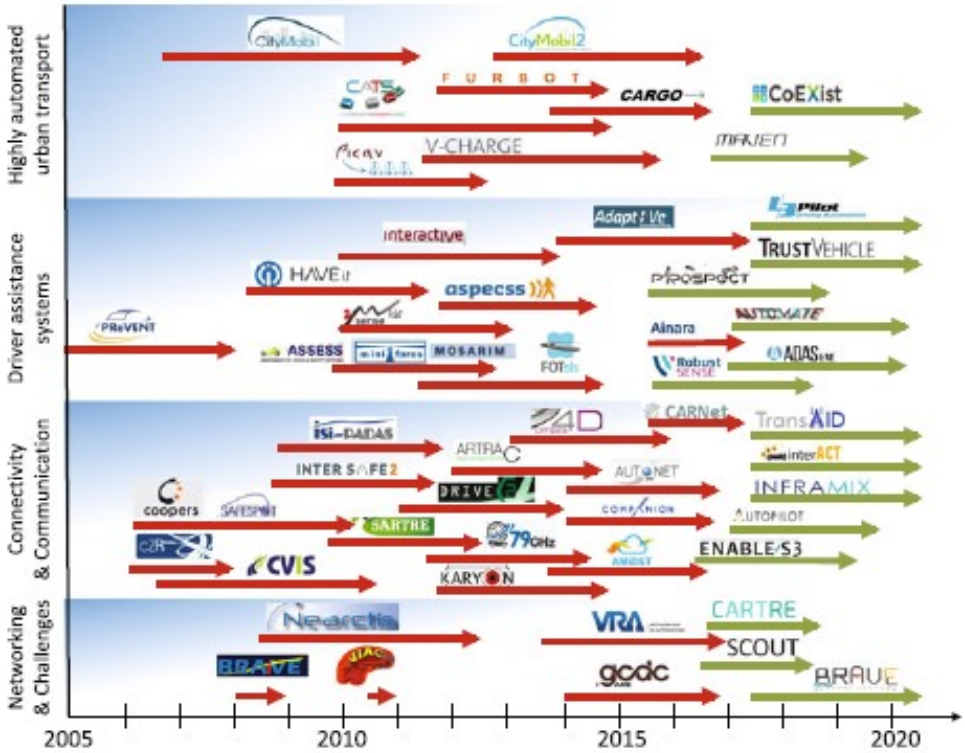

Fig. 1 EU-funded research and innovation projects in connected and automated driving

South Korea and China are just slightly lagging behind ("fair"). In terms of best practices, in particular the advanced regulatory framework for automated and self-driving cars in California and the comprehensive strategic initiative, SIP-ADUS, in Japan are highlighted. Moreover, the pilots of automated, electrified and shared vehicles in Singapore are considered to be trend-setting. Consequently, the study recommends for Europe (a) to establish the necessary regulations for testing and usage of automated driving in early anticipation of and parallel to the innovation process, (b) to integrate the three revolutions automation, electrification and mobility-as-a-service under one funding scheme, and (c) to combine research, piloting and deployment of connected and automated cars in one strategic program.

6 Comprehensive Roadmaps

The European Commission in 2016 launched two Coordination and Support Actions to assist the strategy development processes and the network building in the field of connected and automated driving: CARTRE, funded by DG RESEARCH, and SCOUT, funded by DG CONNECT. Both initiatives appear under one common umbrella and coordinate their work in terms of content development and dissemination, e.g. jointly supporting the European Commission in the preparation

of the first European Conference on Connected and Automated Driving in 2017 and the Interactive Symposium on Research and Innovation for Connected and Automated Driving in Europe in 2018 [19]. In particular, both the CARTRE and SCOUT projects in close cooperation with ERTARC and EPoSS are working on strategic recommendations and comprehensive roadmaps for research and innovation in connected and automated driving in a mutually complementing way.

6.1 CARTRE

CARTRE focuses on identifying detailed research needs in a multitude of relevant technical and non-technical domains, including in-vehicle technology enablers, physical and digital infrastructure, connectivity, shared an automated mobility services, human factors, user acceptance and societal awareness, as well as socio-economic assessment. CARTRE therefore has established a wide network of working groups involving a multitude of relevant stakeholders.

6.2 SCOUT

SCOUT aims to establish a comprehensive and structured roadmap for connected and automated driving that reveals the interdependencies of technical and non-technical issues and identifies opportunities for accelerating the innovation process. The project therefore assesses use cases as well as societal goals and challenges, and formulates a vision for connected and automated driving. It also analyses the state of play in technologies and business models and identifies gaps and risks for the development and deployment of connected and automated driving.

The vision for connected and automated driving developed within the SCOUT project is putting the user into the center and tries to describe a desirable 2030 future scenario from his or her perspective. This has been achieved with the support of various stakeholders from e.g. city governments, vehicle manufacturers and telecommunication experts. The vision combines a number of solutions for connected and automated driving spanning a geographical sphere starting from cities over suburban, rural and interurban environments towards international areas. The suggested solutions such as robot taxi, universally designed vehicles and services, logistic hubs as well as connected traffic systems have been categorized into four areas of interest, namely mobility as a service, passenger transport, goods delivery and infrastructure. It turns out, that the essence of that vision consists in level 4 and 5 automated driving in different use cases. The technical challenges are very similar, though, and may be solved by smart systems that combine sensing with connectivity and intelligent decision-making. However, as such most advanced automated or self-driving functionalities have not yet reached full maturity, depend on a complex interplay of technical and non-technical issues, and are not

yet allowed in most places, the process of roadmap development is particularly challenging.

The SCOUT consortium decided to apply the five-layers model that already was found to be appropriate for a description of the state of the art [20] to also grasp the complexity of the action plan to be established. According to that model, besides the technical layer as a basis for connected and automated driving functions, further layers describe the relevant non-technical issues, i.e. human factors, economics, legal, and societal aspects. The layers are strongly interlinked and they each are covering three interrelated topics, the driver (or passenger), the vehicle and the environment.

At two public workshop with the involvement of dedicated experts for all the five layers, actions were identified for each layer, linked to actions in other layers, and aligned on the time scale. It turns out that technical and non-technical challenges are highly related to each other with one action requiring the outcome of another one before it can start. The many inter-dependencies are creating a kind of Gordian knot indicating that the development and deployment of level 4 and 5 connected and automated driving may be heavily delayed if it is not comprehensively coordinated—a typical feature of complex innovation processes that touch a multitude of technical and nontechnical dimensions.

However, as can be seen from the simplified structure of the 5-layer roadmap of connected and automated driving (Fig. 2), solutions are possible and the innovation process is accelerated if roadblocks are anticipated and agile shortcuts are taken.

7 Conclusions and Outlook

In view of the legacy of innovation in technologies for connected and automated driving in Europe, and acknowledging the arising global competition in this domain, public authorities, academia and private stakeholders have launched a number of strategic initiatives: The European Technology Platforms ERTRAC and EPoSS have compiled research needs, the European Commission has allocated substantial budgets, and networks like the CARTRE and SCOUT project created added benefits by analyzing programs, bundling projects and giving advise for future directions. The various actions are still quite diverse and at risk to loose momentum if not comprehensively coordinated mutually and with the actions by European member states. One issue is the complexity of the paradigm shift connected and automated driving is representing due to the strong interplay of technical and non-technical factors. As shown in this paper, a more agile innovation process may be a way out. If well coordinated with all stakeholders, critical mass could be generated, and the multitude of diverse competencies available in Europe could be leveraged. In the near future, there will be a number of opportunities for this, ranging from the implementation process of the STRIA roadmap on connected and automated driving with the involvement of Member States, via potential new public-private partnerships under the upcoming Horizon Europe framework

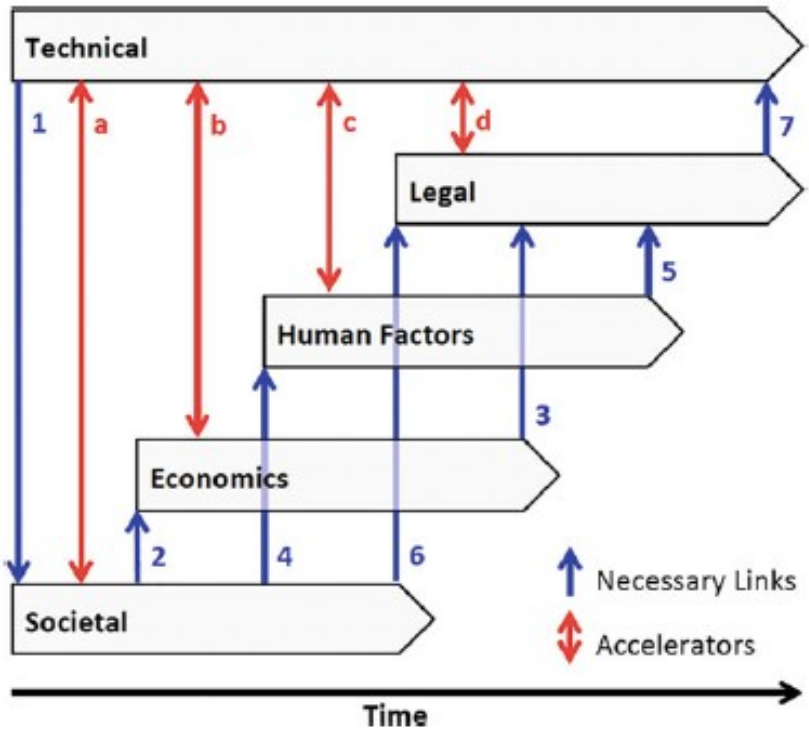

Fig. 2 Simplified structure of 5-layer roadmap for the highly interlinked innovation process in connected and automated driving. Delays are caused by sequences of actions on different layers that are determined by necessary links: (1) invention—e.g. a new robotic driving feature, (2) customer demand—e.g. readiness to pay more for the feature, (3) business model—e.g. sharing concept to operate the car and generate revenues, (4) user needs—e.g. requirements by other road users, (5) product design—e.g. new functionalities for communication with pedestrian, (6) norm—e.g. expected safety level of automated road transport, (7) regulation—e.g. approval for operation of new vehicle. The process may be accelerated by creating agile short cuts: (a) demonstration—e.g. automated driving pilots allowing the public to experience the pros and cons, (b) sandboxes—e.g. hackathons to develop new digital financing schemes, (c) co-creation, e.g. sessions applying universal design rules, and (d) living labs e.g. experimental legislation and standardization

program of the European Commission, to the game-changing "missions" the European Union intents to promote. Hence, there is a unique chance that Europe will drive forward disruptive innovation in connected and automated road transport as one of the main levers of the imminent transformation of mobility towards higher integration across the modes, better sustainability and greater societal benefit. This is well in line with the ambitions objectives expressed in a recent communication of the European commission [21].

Acknowledgements The author is indebted to all stakeholders of the European connected and automated driving community, particularly to the European Technology Platforms EPoSS and ERTRAC, to the JU ECSEL and the SCOUT and CARTRE projects. Financial support by the European Commission's DGs CONNECT and RESEARCH is kindly acknowledged.

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Challenges and opportunities of artificial intelligence for automated driving

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Abstract

The advancement of automated driving (AD) depends on a multitude of influencing factors, however, achieving higher levels of automation fundamentally hinges on the capabilities of Artificial Intelligence (AI) to perform driving tasks. Improvements in AI hardware and the availability of large amounts of data (Big Data) have fueled the rapid increase in AD-related research and development activities over the past decade and are thus also the key indicators for future development. The shift from humans to AI in vehicle control unlocks many of the well-established potentials of AD, but is also the root for many non-technical issues that affect its introduction. Starting from the state of the art of AI for AD this chapter discusses key challenges and opportunities that mark the development path.

1 State of the Art

Although the possibility of using computers to control cars was already proposed in the late 1960's [1] and a suitable software algorithm for lane recognition based on Artificial Neural Networks (ANNs) was developed as early as 1989 [2], research and development for automated vehicles (AVs) did not become a prime and widespread interest until the late 2000s. This was principally due to the fact that the use of ANNs for image/object recognition (via classification or prediction) requires both sufficiently efficient hardware for the parallelized execution of matrix multiplications and adequate amounts of data for training ANNs. In the course of two decades the former restrictions were gradually alleviated. The CPU performance initially increased in line with Moore's Law, but, more importantly, it was possible to fundamentally boost the performance of relevant algorithms with the switch to GPUs in 2009 [3]. The functional and widespread application of ANNs in Machine Learning (ML) was further enabled by the availability of large amounts of training data (Big Data), which has increased in an unprecedented manner with the introduction of digital and mobile devices as well as corresponding storage and communication technologies. The subsequent success of ML in several fields, e.g. speech recognition, image analysis and machine language translation have made this subdomain of AI methods the dominant solution for practical applications.

For the analysis of the role of AI for AD it proves meaningful to take a step back and analyze the landscape of current research and development efforts in the field.

While Advanced Driver-Assistance Systems (ADAS) support human drivers in certain driving tasks, e.g. by maintaining a specified velocity or keeping the vehicle in lane, increasing automation with the successive transfer of driving responsibilities to AI requires a complete set of capabilities spanning environment recognition as well as motion planning and control. The methods and hardware that can be employed to meet these requirements are detailed in the following sections.

1.1 AI methods for automated driving

The concept of Artificial Intelligence (AI) originates from the development of artificially intelligent robots in the first half of the 20th century. In 1950 the logical framework of AI was formulated [4]. The academic research field of AI was founded in 1956 at the Dartmouth Summer Research Project on AI. It was anticipated by scientists, mathematicians, and philosophers that AI would make a machine as intelligent as a human.

ML was the root of the successful development of AI-based applications over the past decade, but it is important to note that it only represents one subcategory of AI that emerged three years after AI became a recognized academic research topic. At the time, ML was pursued in parallel to a knowledge-based approach and built on the theory of neural networks developed in the 1940s as well as statistical reasoning to allow decision-making based on probabilistic models rather than relying on explicit programming.

In ML, a knowledge representation is deduced from a given training data set that describes an application lacking an analytical model. The computer system thus gains experience which can subsequently be applied to previously unseen data to make predictions, recommendations or decisions [5]. The insufficient efficiency of neural networks led to a decades-long standstill in the field of ML, which was only overcome in the 1980s with the development of backpropagation as a method to optimize the weights in an ANN. Backpropagation is a method used primarily in reinforcement learning, in which the computer system is presented with inputs and outputs and the model is adapted to reproduce the desired behaviour. More specifically, input values are processed in multiple intermediate and hidden layers (forming a Deep Neural Network [DNN]) to produce the output values, with the underlying principle inspired by the current understanding of the human brain. Weights are then assigned to the individual nodes of the layers and, in backpropagation, the gradient of the error in the output (the loss function) is used to adjust the weights of the nodes. As a result, ANNs can be employed to approximate complex non-linear functions and successively improve performance on new data.

ML also encompasses supervised and unsupervised learning methods, which can be used to identify patterns in labelled and unlabelled data respectively. Reinforcement learning is closely related to supervised learning but may rely solely on the attribution of a reward in response to an output rather than requiring labelled data. The three ML methods can be applied for classification, regression and clustering tasks based on large data sets and the specific algorithms include linear and logistic regression, decision trees (e.g. iterative dichotomiser 3 or random forests), support vector machines and Bayesian models. Amongst the ML methods and algorithms DNNs have been the focus of ML-related research efforts over the past decade, yielding variations adapted to specific learning tasks and algorithms, including feedforward networks, convolutional neural networks, recurrent networks, generative adversarial networks (GANs) and long short-term memory (LSTM) [5].

For AD, deep learning methods using ANNs are of fundamental importance for environment recognition (object detection based on image classification) which provides the basis for motion planning and control. As discussed above, the application of these methods was enabled by ignificant advances in computer hardware, which will be detailed in the following section.

1.2 AI hardware

Training an ANN requires High-Performance Computing (HPC) to process the big data. Therefore, compute-intensive technology became essential for the progress in AI making companies with the corresponding know-how and infrastructure the drivers of the AI technology. Moreover, inference requires high computing power and is thus not easily performed on edge devices with restrictions on the energy supply. Additionally, some applications require real-time capabilities. Fortunately, strong hardware improvement is possible by means of optimization of the chip architecture to the arithmetic operations of the ANNs which correspond mainly to matrix multiplications. The basic optimization strategy is based on parallelization thanks to the so-called “embarrassingly parallel workload”. A straightforward solution was to perform general-purpose computation on GPU to accelerate the training significantly. GPUs enable much higher data throughput compared to CPUs and reduce the

power consumption at the same time. Another hardware solution is based on Field-Programmable Gate Arrays (FPGAs) which enable designers to reprogram the underlying hardware architecture to support the parallel computing operations. Application-Specific Integrated Circuits (ASICs) outperform FPGAs since they are specifically designed and optimized for a certain task. Such multi-processor System-on-Chips (SoCs) incorporate GPUs, CPUs as well as accelerator cores optimized for certain operations like image processing. Their big disadvantages are their inflexibility and the high development costs. Today, off-the-shelf hardware is not optimized for ML. Therefore, there is a high demand for hardware innovations. Fortunately, there are several approaches to increase the computing power and to minimize the power consumption [6].

The enormous potential impact on all industry segments led to a race for more efficient chips between IC vendors, tech giants, IP vendors and various start-ups. It is remarkable that various start-ups try to compete with the big IC giants in such a cost-intensive industry branch. Designing an ASIC can cost up to hundreds of millions of dollars requiring a large team of experienced engineers. The long design process (typically 2-3 years) necessitates a large number of chip sales and regular improvement is necessary to adapt to fast changing software development. Especially the early state of the AI technology can lead to significant changes in the hardware development in the upcoming years. Only the enthusiastic conviction that the new chips tailored for AI applications can strongly outperform state-of-the-art hardware can justify such investments and the confidence to compete with heavily experienced IC giants.

In the automotive sector and for CAD developments in particular, there is a high demand for better hardware and various innovations are expected in the near future. As an indication, several trends and developments are provided in the following:

- MobilEye introduced its fifth generation SoC “EyeQ5” for fully autonomous driving at the CES 2018 which will be in series production by 2020. The performance target is to achieve 24 trillion operations per second (TOPS) under a power consumption of 10 W. The most advanced TSMC 7 nm-FinFET process is considered for production to address the performance targets. Intel plans to combine the EyeQ5 with its “Intel Atom” processor and to develop an AI computing platform for autonomous driving. Intel and MobilEye claim that two EyeQ5 SoCs and an Intel Atom processor will be sufficient to enable fully autonomous driving.
- The automotive supplier ZF built the “ZF ProAI” supercomputing self-driving system which is based on the “Nvidia DRIVE PX 2 AI” computing platform. ZF claims to follow a modular and scalable system architecture that can be applied to any vehicle and tailored according to the application, the available hardware and the desired automation level. Audi is using this self-driving system in the worldwide first level 3 vehicle where self-driving capabilities are achieved in jam traffic on an autobahn up to a speed limit of 60 km/h. Baidu cooperates with ZF and announced to use the “ZF ProAI” for automated parking.
- Nvidia introduced its new SoC “Xavier” at the CES 2018 which will offer up to 30TOPS under a power consumption of 30W. The chip will be fabricated by the TSMC 12nm-FinFET process and the series production starts in 2019. True level 5 autonomous vehicles will need at least two of such chips to provide sufficient computing power. Therefore, Nvidia’s new “DRIVE Pegasus AI” computing platform will incorporate two “Xavier” SoCs and two discrete GPUs. It will enable 320 TOPS and consume up to 500 W. According to Nvidia the computing power should be sufficient for fully autonomous driving.
- NXP developed its “BlueBox” autonomous driving platform. It incorporates an automotive vision and sensor fusion processor capable of processing AI applications. The performance is stated as 90,000 Dhrystone million instructions per second (DMIPS) under a power consumption of 40 W.
- Renesas has a similar automotive computing platform with its “R-Car” SoCs which achieve 40,000 DMIPS.

More general hardware solutions are necessary due to the demand for higher computing power, lower power consumption and cost reduction. More sensors will be attached to the car in the future. Under the frame of the ImageNet contest the performance of object detection was increased by means of higher model complexity in the last years. This tendency implies higher amount of parameters of the ANNs. Safety is a crucial issue for the breakthrough of self-driving cars. Therefore, more complex

models will be presented to increase the robustness of object detection and inference. This corresponds directly to more complex AI algorithms and a growing demand for computing power and higher energy efficiency. In automotive the new SoCs tailored for machine learning tend to be more complex since high data throughput is necessary and moving data between different chips deteriorates the performance. Moore's law still assures continuous increase of the number of integrated transistors on chip. Therefore, the size of future optimized SoCs should scale up. For example, Nvidia's new "Xavier" SoC is one of the most complex systems to date with more than 9 billion transistors. Both market leaders MobilEye/Intel and Nvidia plan the first series production of their new SoCs and already mentioned the development of next SoC generations (Nvidia's "Orin", MobilEye's "EyeQ6"). It is important to note that Nvidia's Xavier SoC architecture was recently certified with the highest safety rating ASIL-D of the automotive industry's standard for functional safety ISO-26262 by TÜV SÜD. This is an important step since autonomous driving requires maximum safety.
Standardization of an open automotive AI platform can increase competition between IC manufacturers and make OEMs and Tier1s more independent from IC giants. Another possibility are close cooperation between IC manufacturers, OEMs and Tier1s leading to distinct solutions for automotive AI computing platforms. In such a scenario e.g. an "Intel Inside" label could be a unique selling point if the performance differs significantly between IC manufacturers. One argument for distinct solutions could be a higher efficiency thanks to a hardware-software co-design process.
Today, Nvidia and Intel/MobilEye offer hardware as well as software solutions. But both market leaders offer separate solutions as well. It enables modular hardware integration in open platforms such as "Apollo" from Baidu. Both approaches can be successful. At this point it is not obvious which approach will ultimately find widespread application.
On the basis of the current state of AI hardware and methodology for AD, which was established above, it is now possible to examine the opportunities and challenges intertwined with their application in the following section.

2 Opportunities

Besides its decisive role in enabling automated driving, AI in the form of ML also provides the key capabilities for the interaction between the driver, who will successively transition into a user of autonomous services, and the vehicle. In this field of human-computer interaction, applications can draw directly from the success of ML in the field of natural language processing and facial recognition. Such functionality can be employed initially to enhance safety as driver assistance systems in low-level automation, e.g. by detecting driver fatigue and alerting the driver, may then be employed for gesture recognition to enhance driver comfort in higher level automation, before eventually enabling the provision of new services to users of autonomous vehicles. For example, a face scan could be used to access a vehicle and the integration of digital assistants in vehicles paves the way for various new service offers for drivers/users increasingly freed from driving obligations.
The use of brain-machine interfaces further unlocks potentials in vehicle operating by providing alternatives to mechanical controls such as gas pedals or steering wheels and thus providing access to humans not capable of operating the established control system [7]. Such applications present prime examples for the potential of AI to reproduce and eventually surpass human capabilities in a given task. In autonomous vehicles, the effect of the AI-enabled augmented social inclusion in mobility will be complete, since all humans will have access to mobility services, independent of physical and mental capabilities or age. If the current progress can be sustained, then AI driving systems will ultimately not only succeed in emulating human capabilities but will achieve superhuman driving capabilities, thereby eliminating human error as the dominant cause of road accidents.
AI can further shape the future of mobility by enabling improved traffic flow and vehicle usage, a field that is ideally suitable for the application of ML and which thus naturally hinges on the availability of large data sets on vehicles distribution and movement. An optimized management of both individual vehicles and fleets can further be achieved by employing predictive maintenance to increase the vehicle service time.

The potentials of AD discussed above, which are unlocked by the use of AI methods, present the central motivation for pursuing its development. In many cases, precautions must be taken to ensure that the objectives are achieved and not negated, e.g. if achieved levels of social inclusion in terms of physical capabilities are thwarted by limiting access to mobility services based on price and thus income. While such circumstances are marked by a strong uncertainty and are thus difficult to foresee, the development of AD based on AI faces some key technical and non-technical challenges that must be resolved before high-level automation can be achieved. These are examined in the following section.

3 Challenges

Utilizing AI to achieve vehicle automation presents a fundamental shift in mobility, which cannot be adequately addressed by focusing solely on the technical development. The EU Coordination and Support Actions (CSAs) CARTRE and SCOUT, which started in 2016 and will end in 2018, attempted to tackle the complexity of Connected and Automated Driving (CAD) development by establishing a category framework to guide discussions.

In SCOUT, hurdles and accelerators along CAD roadmap paths were analyzed using a five-layer model differentiating between technical, legal, human, economic and societal factors. The majority of the non-technical aspects that may hinder CAD deployment can be traced back to the transfer of driving responsibility from humans to AI. Questions pertaining to e.g. ethics or liability essentially concern the appropriate and regulated application of AI. User acceptance further critically hinges on the societal understanding and expectations of AI. It is thus important to remember that CAD is one of the various applications of AI, which has the potential to disrupt mobility as it is known today and which must be approached with great caution given its critical role in the safety of all road users. For certain issues of CAD development, user acceptance, it will thus be possible to learn valuable lessons from other AI applications and, inversely, successful and widespread implementation of AI-controlled vehicles can pave the way and serve as a model for other AI applications, e.g. in health, where ethics and user acceptance are equally critical aspects. It is clear that humans are prone to be far more forgiving with respect to the humanly more easily comprehensible errors of drivers that cause accidents than with computer errors. This skewed perception is further amplified by the disparity in media attention attributed to rare but entirely new and unusual accidents caused by computer error in comparison to common human errors. In consequence, research indicates that AI-controlled cars would need to outperform humans by one to three orders of magnitude to ensure user acceptance [8].

The CARTRE project tackled the complexity of CAD using eleven topical categories, one of which was dedicated to “Big Data, AI and their application” and thus reflecting the central importance of each of these two fields for the successful application of the other. During the course of the project, links to other topics were established and again showed clearly that even if CAD cannot be equated with AI, many of the issues that must be resolved for its implementation are direct consequences of the use of computer intelligence. The input for the EU research agenda that was presented in the respective CARTRE position papers[1] for Big Data and AI covers legal (regulation and insurance) and ethical aspects as well as requirements for data availability and testing and validation methods. Although the development of new AI-based CAD functionalities will always have to occur within the ethical and legal framework, it is the questions concerning data availability, AI training and validation and the traceability of AI-based decision-making that are at the root of the discussion of ethical and legal aspects and will further be decisive for future improvement of vehicle intelligence and CAD implementation. These issues will thus be examined in more detail below.

[1] available online at www.connectedautomateddriving.eu

3.1 Data availability

AI performance relies strongly on the available training data. This data has to cover all traffic scenes under different weather situations in an adequate amount to assure appropriate action of the AI driven vehicle in every situation. The lead in the development of AD is often measured by the accumulated data although synthetic data gained more and more importance in recent years. It should be noted that both traffic and driver behaviour differ strongly between countries. Therefore, car manufacturers and suppliers are running their own vehicle fleets collecting data in different countries which correspond to important markets. One of the highest amounts of data was collected by Waymo and currently amounts to 11.3 million driven km.
There are also open data sets such as Kitti or CityScapes but they are very limited and cannot compete with the data collected by the companies. Recently, ApolloScape was released as the largest open data set under frame of Baidu's AD platform Apollo. The volume is 10 times higher than any other open data set. Moreover, open data sets created in a virtual environment such as Synthia are also available. But these are also orders of magnitude smaller than the 8 billion km simulated by Waymo.
In general, it is questionable what amount of data is necessary to ensure that autonomous vehicles cause fewer accidents than humans. Statistical estimations suggest that data from up to hundreds of billions of driven kilometres have to be collected to provide an actual advantage of AD over human capabilities. For example, according to a Rand Corporation report [16] 100 vehicles have to drive non-stop for 500 years to achieve 20 percent safer driving capabilities than humans.

3.2 Training and validation

If AI is to replace humans in driving, it must be able to accurately and reliably detect the location and environment of the vehicle and then make the correct decision for action based on this information. As discussed, in ML the correct interpretation of visual or radar images is achieved by training the AI system on large amounts of data so that it can subsequently also correctly categorize previously unseen images. The collection of relevant data can be achieved by driving a car equipped with the typical sensors around and the total distance travelled in such test drives can serve as a first quantitative indicator of R&D activity in the field. The test drive distance does, however, not allow conclusions about the quality and completeness of the training data, i.e. on the one hand a test drive could take place on private grounds with no or limited traffic or in dense urban traffic, and on the other hand, critical situations are, by design, extremely rare. Even extensive test drives will thus not provide sufficient data on edge cases to ensure that these can be handled by AI. Critical situations, i.e. those that are dangerous for vehicle passengers or other road users, can, furthermore, not be recreated for test drives. It is thus necessary to supplement real-world test drives with AI training on synthetic data generated from simulations of real-world scenarios. For example, Waymo has produced training data from over eleven million kilometers of real-world testing and combined this with over three billion virtual kilometers, while e.g. Nvidia has provided a simulation environment (AutoSIM) to developers. Synthetic data also offers the advantage that it is, by nature, already labeled, while labeling is an additional step that must, at least to a given extent, be performed manually for data acquired by imaging sensors.
Even after combining real-world and virtual training data, the question remains, whether this allows AI to react appropriately in rare but critical situations. This is the central prerequisite for the validation of AI-based driving functions. An answer is proposed by the GENESIS project [9] of the German Research Center for Artificial Intelligence (DFKI) and the German certification body TÜV Süd and relies on the assertion that it will be possible to define the comprehensive scope of driving scenarios, to translate this into constraints for the virtual training scenarios and to then run a large number of simulations with incremental variations until the testing regime may be considered complete. Such a procedure could allow for a benchmarking of the development process using reproducible and standardized test scenarios, scalable and fast simulations and, ideally, open architectures for the

integration of different models and simulations. The ultimate objective would be to establish a virtual homologation agency for AI driving functions.

3.3 Traceability of AI-based decision-making

Due to the lack of analytical model to link the inputs and outputs of ANNs used in deep learning methods, a decision-making process relying on their application is intrinsically not traceable and thus raises fundamental questions concerning the use of AI for AD. Since the given inputs and monitored outputs of an ANN are linked via a complex deep layer structure in which the weights between nodes have been adjusted in an extensive training process until the desired behavior is obtained, it is eventually impossible to deduce how a specific decision was made. ANNs thus essentially present a black box for which only the inputs and outputs are known, while the process by which outputs are produced can only be defined in terms of linkage weights. For AD, a system with this lack of traceability poses problems concerning the liability in case of accidents and also presents questions relating to the ethicality of entrusting ML-based AI with potentially life-threatening tasks. Moreover, if an autonomous vehicle is trained as an end-to-end system, the inability to model the decision-making process results in a lack of modularity, since individual components of the AD system cannot be replaced without necessitating a renewal of the entire training process to once again translate given inputs into desired outputs (decisions) [9]. While the limited traceability of ML-based decision-making is not an unsurmountable hurdle for the introduction of AI, it does require the development of specific solutions, e.g. module-specific training algorithms, and is also an intrinsic characteristic of ML, which has led researchers to pursue alternative AI methods (see section 5.1).

The previous sections have highlighted the central challenges faced by ML-based AI applications for AD, which can present significant roadblocks on the way to its deployment. The question of how these problems can be resolved is, however, usually accompanied by the question of where AD will be introduced first. Influencing factors that may affect this race for AD and which ultimately revert to questions about AI capabilities are thus discussed below.

4 International competitiveness

Since extensive competences in AI are essential to achieve high-level automated driving, they can also be used to assess which country or region provides the best breeding ground and is thus likely to be the frontrunner in AD introduction. From a historical viewpoint, the U.S. has long been a lone leader in the field, but past years have seen the emergence of China as a serious competitor, driven not least by substantial government support and funding. In 2017 the Chinese government presented its plan to become the world's primary AI innovation center in both research and applications by 2030, which it backed, e.g., with a 1.8 billion Euro investment in an AI technology park in Beijing. By that time, Chinese researchers and developers had already succeeded in closing the gap on the U.S., ranking second in patents filed on AI-related topics and first in the number of research papers on deep learning (since 2014) [10]. While the U.S. also presented a strategic plan on AI in 2016, the EU is yet to present a strategy[2] that assures its competitiveness in the field and thus currently relies primarily on national strategies, as have been introduced recently in France or Finland. The need for imminent action has, however, been identified and several initiatives were launched in the first half of 2018, primarily: the signing of a Declaration of cooperation on AI by 27 EU member states and Norway (as of May 2018) followed by a call for private and public investments in AI amounting to at least 20 billion

[2] A coordinated plan has been announced for the end of 2018.

Euro by the end of 2020[3]. The latter cannot match the venture capital provided to companies in China, where around 425 billion Euro of funds were expected to be raised via Government Guidance Funds in 2016 with another 250 billion Euro coming from private funds [11], and in the U.S.
In the outline for a European approach, the European Commission (EC) also acknowledged the need to modernize education and training systems to establish a talent pool that can advance AI technologies. Currently, the availability of ML experts cannot match the demand, resulting in a significant surge in salaries and strong international competition over available talent (including a significant brain drain from China to the U.S.). The U.S. clearly leads the world in terms of the size and average experience of the workforce [12], a field where China is also trying to catch up, after the first undergraduate course in AI was established as recently as 2004. The advantage held today by the U.S. is in large a result of substantial investments in STEM education in the 1960s, which should thus also be a priority of governments today. As an example, the German Federal Association for AI has included a call for data science education starting in third grade as part of its 9-step plan to advance AI in Germany [13], an initiative that has already been implemented by the Chinese Ministry of Education with both a plan for increased education in coding starting in primary schools and an "AI Innovation Action Plan for Colleges and Universities". To respond to the expected spike in demand of AI talent, the EC planned to invest 2.3 billion Euro specifically in digital skills between 2014-2020.
The non-technical implications of AI and the way in which these are approached and handled will also have significant effect on international competitiveness. Specifically, regulations concerning data protection and privacy, which impedes the access to data as the fuel of ML, and the comprehensive discussion of ethical issues can have a restrictive effect on the speed of innovation in AI. With the introduction of the General Data Protection Regulation (GDPR) and the planned presentation of ethical guidelines for AI development by the EC by the end of 2018, researchers in the EU certainly face the strongest constraints. It must, however, be noted that given the fundamental societal transformation that a widespread application of AI technologies could trigger as well as the potential threats of AI, a cautious and balanced approach is justified.

5 Outlook

AD can unquestionably only be achieved by developing AI that is capable of reliable and safe vehicle control, therein matching, if not exceeding, human capabilities. The explanation of the role, opportunities and challenges of AI for AD above has, however, also underlined that, although major advances have been achieved over the past decade, comprehensive development efforts will also be required over the next one and that substantial non-technical issues must also be resolved in the process. Some potentials that either serve to accelerate development or provide alternatives if, e.g., legal or ethical problems prove to be substantial roadblocks, are presented as an outlook in the following two sections.

5.1 Alternative methods

As explained above, the current success of AI in various applications and particularly in the field of AD rests entirely on ML. Other AI methods should, however, not be disregarded, especially if they provide the opportunity to circumvent the non-technical issues. Some research efforts are thus directed towards the development of "explainable AI" methods that provide full traceability and an in-depth understanding of the decision-making process. For example, so called "grey-box solutions" are intended to integrate physical models in existing algorithms, in order to increase the control over the intermediate steps of decision-forming.

[3] 1.5 billion as part of the Horizon 2020 programme, 2.5 billion from public-private partnerships and over 0.5 billion via the European Fund for Strategic Investment.

An interpretable, mathematical model for safety assurance is proposed by MobilEye where rule-based driving results from analytical description of the driving state. As long as the vehicle fulfills certain conditions it should not be able to cause an accident [8]. This could result in a fully retraceable white box solution and enable validation and certification of self-driving capabilities. In this case planning will be explainable while sensing the environment will still rely on classification by AI. But the sensor redundancy (camera, lidar, radar) should assure reliability. A key argument to follow this path is that safe and reliable AD cannot be assured just by collecting training data. According to statistical estimations the necessary amount of collected data is too high [14] as well as the necessary energy to process this data. The sensitive public reactions to accidents of self-driving cars demand explanations for the cause and it is highly unlikely that the users would accept a black box explanation.
Other approaches include solutions inspired by cognitive science, which intend to imitate the way in which humans understand and learn models of the physical world and which may include methods such as detecting intentions of road users from facial expressions. For example, the MIT spin-off iSee aims to mimic human common sense, thereby reducing the dependency on large amounts of data and enabling traceable decision-making that is easier to validate. Perceptive Automata unites neuroscientists and computer scientists to develop autonomous vehicle software with an intuitive understanding of driving scenarios. If successful, such AI methods could significantly boost the system's ability to cope with unfamiliar situations.

5.2 New hardware development

The aforementioned chip designs correspond to a software implementation of ANNs and its execution on conventional von Neumann chip architectures. Here, a major factor contributing to the power consumption and the training or inference duration is the data transfer between the memory and the processing units. The complexity of more powerful ANNs increases and so does the amount of weights representing the synapses. These have to be transferred between memory and the processing units while processed data input propagates through the ANN. The latencies and bandwidth limitation associated with the data transfer is called the "von Neumann bottleneck" and restrict the data throughput. Moreover, the data amount of the weights can be too large to be stored on a local on-chip memory.
An alternative way is to implement ANNs directly in hardware by means of neuromorphic chips. Here, the memory and the processors are not separated. Every artificial neuron represents a processing unit and has its own memory so that the computing is performed at the data location by means of the neuron connections. Furthermore, the neuron communication is not controlled by a central clock. The communication is only initiated if the corresponding neurons are stimulated. This is a much better imitation of biological neural networks. The lack of data transfer between memory and the processing units and the asynchronous communication concept raises the potential to reduce the power consumption significantly. A vast variety of implementation concepts can be found in the literature [15]. So far, this approach is mainly investigated by academia and is widely ignored by the industry. IBM was the first company investigating neuromorphic computing and presented its "TrueNorth" chip in 2011 before the actual breakthrough of deep learning and the resurgence of convolutional neural networks (CNNs) in 2012. In 2016 it was shown that a trained ANN can be mapped to such a neuromorphic chip and approach state-of-the-art classification accuracy [16]. The huge advantage was the very low power consumption of only 275 mW while processing 2600 frames/s. Currently, Intel is working on its own neuromorphic chip "Loihi". Here, the signal processing is based on asynchronous spiking similar to biological neurons. According to Intel this chip combines training and inference, supports different ANN topologies including recurrent neural networks (RNN), can be used for supervised as well as for reinforcement learning and is continuously learning. Intel calls it a test chip and is going to share it with universities and research institutions. Samsung announced collaboration with leading Korean universities to develop a neuromorphic chip. In Europe, neuromorphic computing

is investigated under the frame of the Human Brain Project since 2013. The Belgian research institute Imec introduced its own neuromorphic chip in 2017.
This technology is very young and a lot of research has to be done to explore its full potential and to verify its capabilities. The claims about the potential performance are orders of magnitude of higher power efficiency and orders of magnitude of faster learning capabilities. If these promises are only half true, neuromorphic computing should attract high interest of the industry in the future. Neuromorphic chips are ideal for classification tasks but not for precise calculations like conventional processors. Therefore, these have to be embedded in conventional hardware which deals with rule-based navigation in traffic. Furthermore, new software has to be designed to integrate such chips in conventional hardware systems.

6 Conclusion

Based on the experience from work in the European projects SCOUT and CARTRE the objective of this chapter was to highlight the role of AI for the development of AD. Beside an overview of current AI hardware and ML-focused methodology, key opportunities and challenges for the application of AI have been discussed and may, in the case of non-technical issues, also serve as examples for the application of AI in other fields. Future development paths and alternative methods that may help to resolve specific non-technical issues have also been explored. Due to the central importance of AI for AD, future development and international competitiveness in particular will be closely related to AI-specific capabilities.

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Acknowledgements

The authors are grateful for fruitful cooperation with the contractual partners of the Coordination and Support Actions "Safe and Connected Automation of Road Transport" (SCOUT) and "Coordination of Automated Road Transport Deployment for Europe" (CARTRE). The SCOUT and CARTRE projects have received funding from the EU's Horizon 2020 programme under grant agreements No. 713843 and 724086, respectively. The section on AI hardware further draws from investigations carried out as part of the SCORE project, which has also received funding under the EU's Horizon 2020 programme.

Keywords

Artificial Intelligence, Machine Learning, Training, Validation, Hardware, Big Data, Vehicle Automation, Autonomous Driving, SCOUT, CARTRE, European Commission.

Roadmap for Accelerated Innovation in Level 4/5 Connected and Automated Driving

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Abstract

This chapter is summarizing the findings of the EU-funded Coordination and Support Action "Safe and Connected Automation in Road Transport" (SCOUT) that has established a comprehensive and structured roadmap to describe innovation paths towards an accelerated development and deployment of high degree automated driving, i.e. particularly SAE levels 4 and 5. With the involvement of a multitude of experts, the project assessed a number of use cases and development trends, identified societal goals and challenges, and formulated a future vision for connected and automated driving (CAD). It also analysed the state of play in technologies and business models and identified gaps and risks. Hurdles for achieving the vision have been recognized, actions to overcome those hurdles have been found at technical, societal, economical, human factors and legal layers, and interlinks between those actions have been described. Finally, opportunities to leapfrog hurdles for innovation in level 4/5 automated driving by a coordinated interplay of actions have been described for five specific use cases: automated on-demand shuttle, truck platooning, valet parking, delivery robot, and traffic-jam chauffeur.

1 Introduction

Field operational tests and pilot projects with vehicles capable of fully automated driving or self-driving functionalities have started in cities and regions all around Europe and the world. In particular, autonomous on-demand shuttles and robot taxis are popular among policy makers and city planners, both in the U.S. [1] and in Europe [2]. The reasons are manifold: Such vehicles may provide a cost-efficient opportunity to fulfill obligations in public transport, particularly for the last mile, they use road space more efficiently, and thus reduce the number of cars on the road. Furthermore, they show the way towards a IT-enabled future of shared transportation of people, goods, and probably equipment and services. Therefore, it can be expected that such vehicles will have a high disruptive innovation potential in mobility. [3]

Equipped with advanced systems for environment perception and decision making, automated vehicles conventionally follow a reactive bottom-up safety paradigm. Like humans, such systems may fail. There are opportunities for making an automated car close to 100% safe by a more proactive, communication based approach [4]: One could equip the infrastructure with sensors that "look around the corner" and tell the car what they see, and one could further advance the artificial intelligence of the control system to better understand particular traffic scenes, e.g. whether a pedestrian standing at the curb will cross a road or not. One could also aim for a top-down safety concept, limit the use of

automated vehicles to fenced lanes, or apply control from a central traffic manager. Whether and when what solution will be feasible depends merely on money and law than on technical concept.

The purpose of this chapter is to report on the findings on the interplay of technical and non-technical factors of innovation in level 4/5 automated driving made by the Coordination and Support Action entitled “Safe and connected automation in Road Transport” (SCOUT) that the European Commission funded between July 2016 and June 2018. [5] The project’s objectives comprised:

- To identify pathways for an accelerated proliferation of safe and connected high-degree automated driving (SAE 3-5)
- To take into account user needs and expectations, technical and non-technical gaps and risks, viable business models as well as international cooperation and competition.
- To help the automotive, the telecommunication and digital sectors need to join forces and agree on a common roadmap

The consortium, which was coordinated by VDI/VDE-IT, included Renault, FCA, BMW, Bosch, NXP, Telecom Italia, NEC, RWTH, Fraunhofer, CLEPA, and Sernauto. A number of public expert workshops with external stakeholders representing supply and demand side of technology development, and particularly individual user groups were organized, and steps towards a comprehensive roadmap were taken. For the creation of the roadmap, a story mapping process was applied, that started from analyzing the innovation context, then defined a future vision, analyzed the state of the art, and finally recognized opportunities and hurdles as well as ways to close the “gap” between state of the art and vision with concrete actions. It can be expected that the SCOUT project by its structured and comprehensive approach will add cohesion and insight to the diverse landscape of for building a common European Strategy on CAD. [6]

2 Future Vision on CAD

User-centric approaches have proven to be particularly effective for developing vision and roadmaps on the future of transportation, recently. [7] Implications of CAD are specific for each use case and business model, and for all partners in the value creation process. In the discussions with societal stakeholders representing different user perspectives, the SCOUT project found a number of high, but common expectations, though: zero fatalities, no traffic jams, productive travel time, social inclusion, reduced operation costs, and vanishing borders between the transport modes. Consequently, when asked about their future vision on CAD, users sketched an ambitious picture. From their point of view, the basic idea of CAD is strongly connected with the concept of seamless mobility of people and goods on demand. Ideally, the implementation of such concept needed to ensure that no compromises are made on safety, solutions are effective and affordable, and save or free time for the user. Asked about specific solutions that would embody the key elements of the vision users referred to a great number of advanced ideas, ranging from robot taxi, universally designed vehicles and services, logistic hubs as well as connected traffic systems and more. Putting those potential solutions on a simplified map of geographical spheres, starting from urban via suburban, rural and interurban environments towards the international area, the great diversity of use cases becomes evident. Actually, there are four areas of particular interest, namely mobility as a service, passenger transport, goods delivery and infrastructure. It turns out, that the essence of the common future vision consists in level 4 and 5 automated driving in the different use cases. The technical challenges are very similar, though, and may be solved by smart systems that combine sensing with connectivity and intelligent decision-making. [8] However, due to a complex interplay of technical and non-technical issues, advanced automated or self-driving cars have not yet reached full maturity, oftentimes miss a viable business case and are not yet allowed on public roads. Hence, the process of roadmap development could be expected to be particularly troublesome.

3 State of the Art

The analysis of the state of the art for high level connected and automated driving carried out by the SCOUT project was structured with reference to the five layers model: Besides the technical layer as a basis for connected and automated driving functions, further layers describe the relevant non-technical issues, i.e. human factors, economics, legal, and societal aspects. The layers are strongly interlinked and they each are covering three interrelated topics, the driver (or passenger), the vehicle and the environment.

The in depth analysis was primarily focussed on the technical, the legal and the economic layer, as reported elsewhere [9], though, all layers were covered by the project's activities. Regarding the state of the art of CAD on the technical layer, the SCOUT project distinguished three major functional domains, environment perception ("sense"), decision making ("think"), and control ("act"). It was concluded that technical solutions have been found for most issues already, even though some significant challenges remain, e.g. sensing under adverse weather and lighting conditions, decision making fully acknowledging intentions of people on the road, and control with fail operational capabilities. Moreover, the availability digital infrastructure for connectivity and communication turned out to be understood as critical for making CAD a safe product, even though discussion whether it would rather be a necessary than just a sufficient condition, particularly in complex urban environment, are on-going. It was also concluded that awareness of cyber security issues of CAD exists, as for level 4/5 all control functions are safety critical; concepts for a long-term protection are missing, though.

For the state of the art of CAD in the legal layer, it was concluded that the Vienna Convention, which most European Countries have ratified and turned into national law, due to an amendment that entered into force in early 2016 [10], now is covering level 3 automation, but not yet levels 4 and 5. National regulations may grant exceptions, however, e.g. for testing.

On the state of the art of CAD at the economic layer, a number of use case of CAD were analysed regarding value proposition, value creation partners, and monetization potential, e.g. valet parking, truck platooning and automated on-demand shuttles.

4 Comprehensive Roadmap Approach

Aiming to map out the paths towards the users' ambitious future vision on CAD while acknowledging the state of the art, the SCOUT project took a structured and comprehensive story mapping approach of roadmap development: The five-layers model that already was found to be appropriate for a description of the state of the art, was applied to build an action plan on level 4/5 automated driving. At two public workshops with the involvement of dedicated experts for fields of all the five layers (technical, social, economic, human factors, legal), gaps between state of the art and vision were recognized and actions were identified for each layer, linked to actions in other layers, and aligned on the time scale. While the outcome was a close-to-complete list of research, innovation and framework needs that complemented one another, it lacked coherence completely. In contrary, the links that the experts indicated in between the actions, revealed that technical and non-technical he challenges are highly related to each other with many actions requiring the outcome of others before they can start. The many inter-lead to locked-in situations, creating a kind of Gordian knot. This indicates that the development and deployment of level 4/5 CAD be heavily delayed if it is not comprehensively coordinated. This is a typical feature of complex innovation processes that comprise a number of technical and nontechnical dimensions. The SCOUT project consortium therefore concluded that for delivering useful indications, the roadmap approach needed to be distinct not just for the five layers but for specific use cases, and focused on well-defined milestones on the way towards the vision.

Supposedly, such use case specific and targeted roadmaps could help to anticipate roadblocks and highlight agile shortcuts, enabling an accelerated innovation process.

5 Use Case Specific Roadmaps

In order to properly address the complexity of the comprehensive innovation planning process for level 4/5 connected and automated, the SCOUT project thus developed a simplified and use case specific roadmap template covering (a) a story map with hurdles and opportunities on the way from state of the art to future vision, (b) goals in terms of milestones on the timeline towards the vision, and (c) a plan of timely sequenced actions in the five layers back-casted from one of the milestones. It is assumed that the actions in the roadmap trigger each other, e.g. by an invention, customer demand, business model, user needs, product design, norm or regulation. As this helps to anticipate time sinks and risks for delays in the innovation process, opportunities for taking agile shortcuts between the layers should be incorporated into the design of the action, e.g. demonstrations, sandboxes approaches, co-creation session, and living labs. [6]

Taking into consideration the expert inputs on gaps and necessary actions gathered at the public project workshops the template has been used to establish roadmaps for five different use cases and specific milestones of level 4/5 CAD, namely:

- Automated on-demand shuttle (fig. 1)
- Truck Platooning (fig. 2)
- Automated valet parking (fig. 3)
- Delivery robot (fig. 4)
- Traffic jam chauffeur (fig. 5)

These roadmaps have been validated at an additional workshop with experts for all five layers, and were presented at the Automated Vehicles Symposium 2018 in San Francisco, CA (USA). [11]

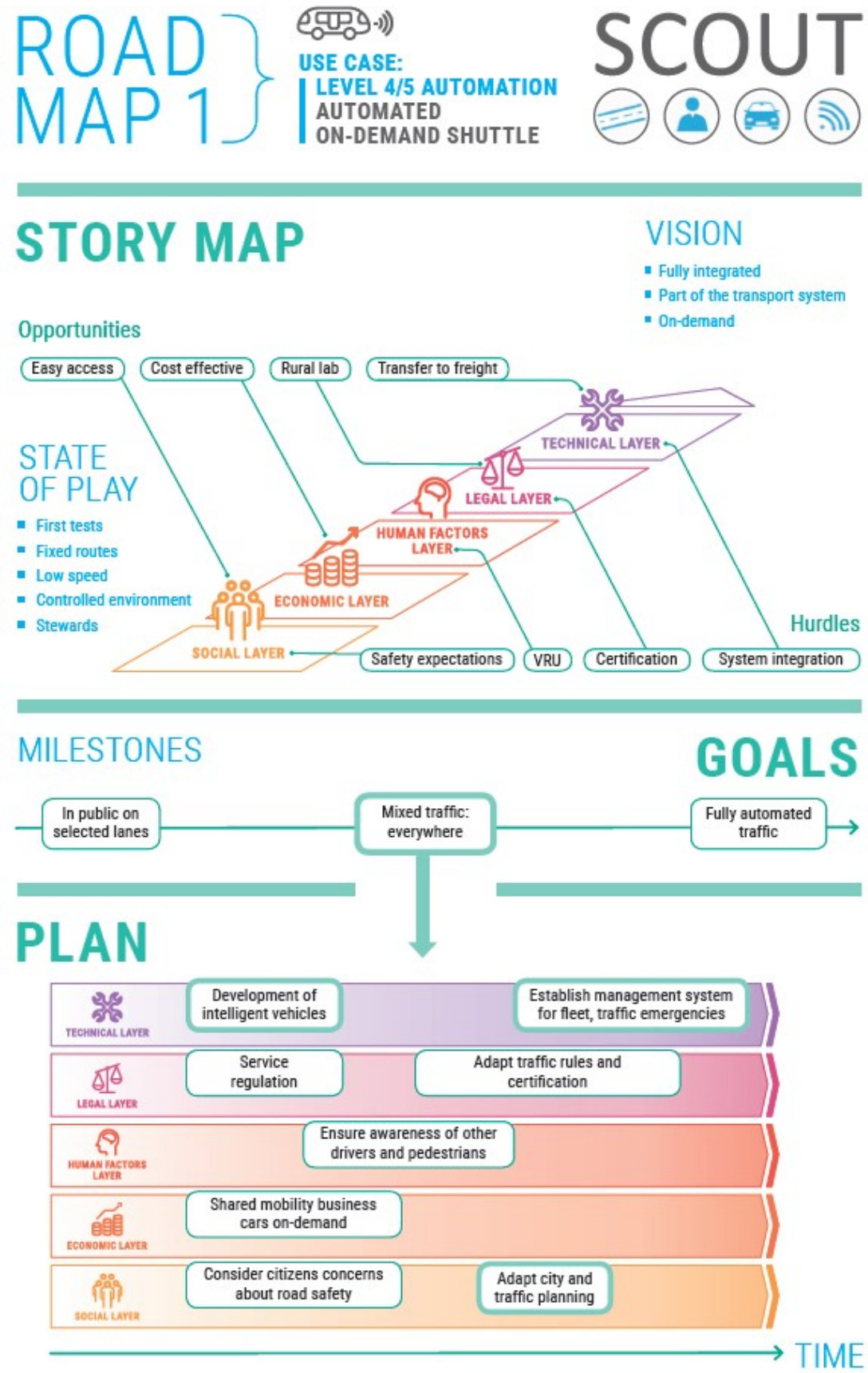

Figure 1: Roadmap for the automated on-demand shuttles use case.

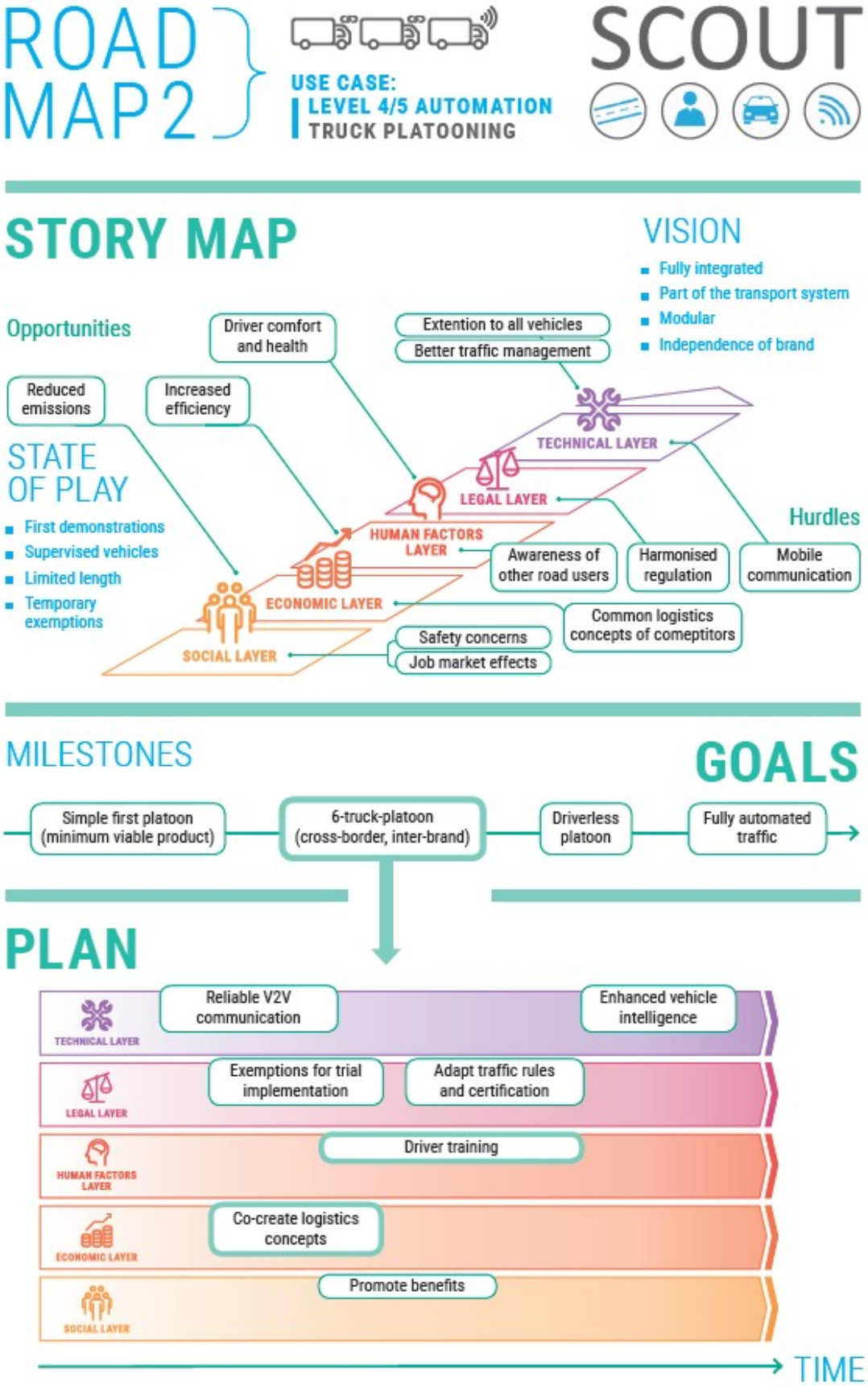

Figure 2: Roadmap for the truck platooning use case.

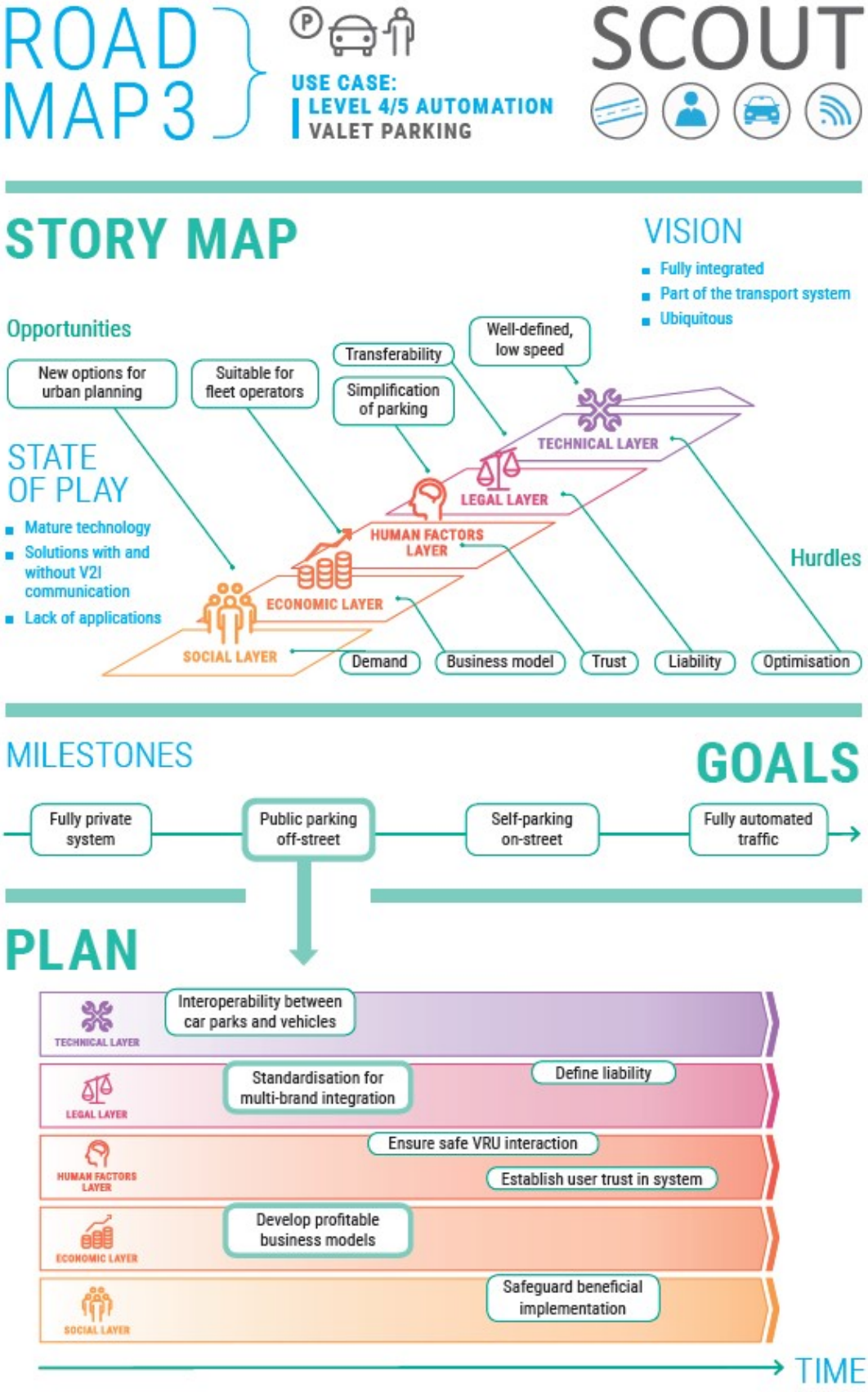

Figure 3: Roadmap for the (automated) valet parking use case.

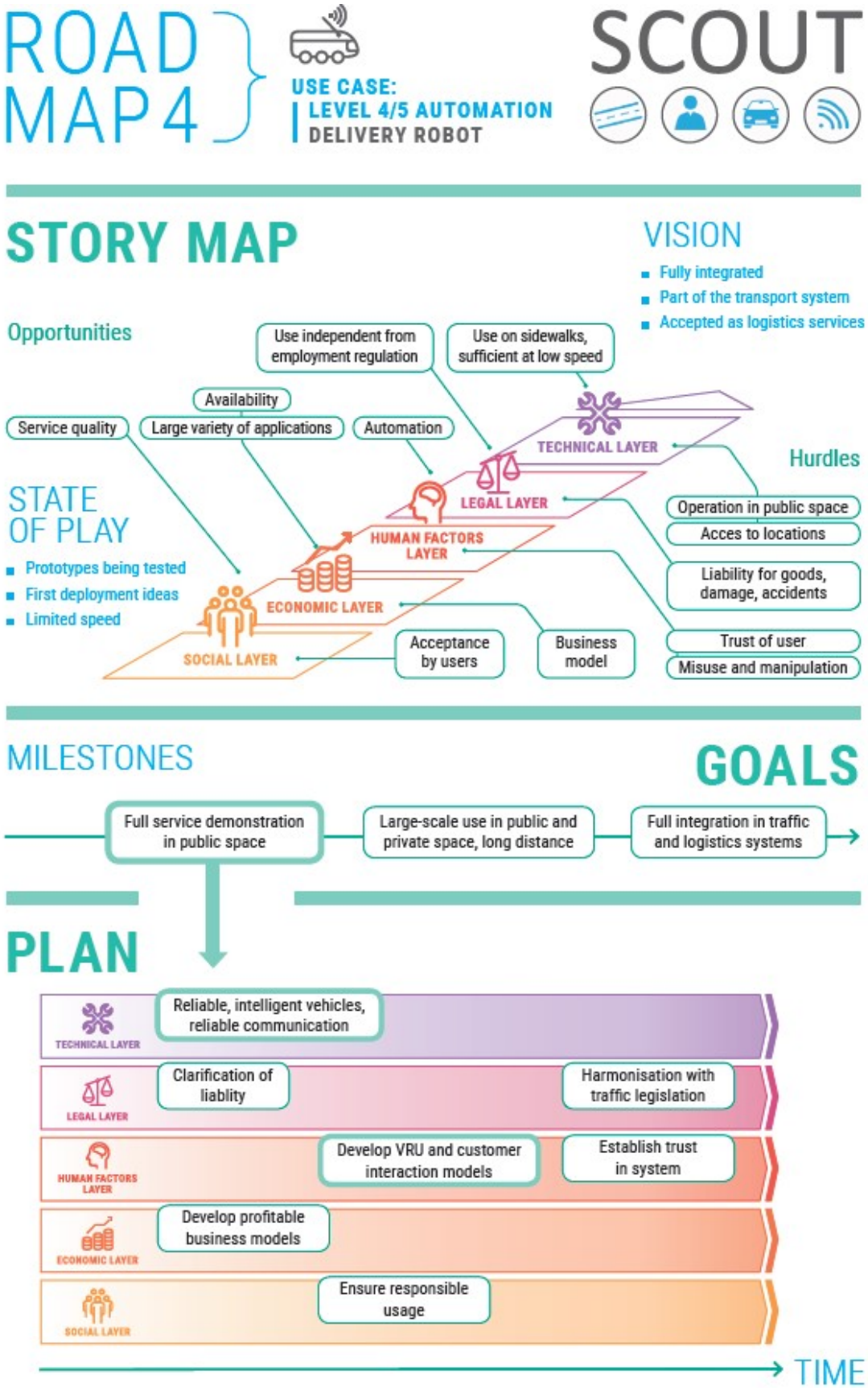

Figure 4: Roadmap for the delivery robot use case.

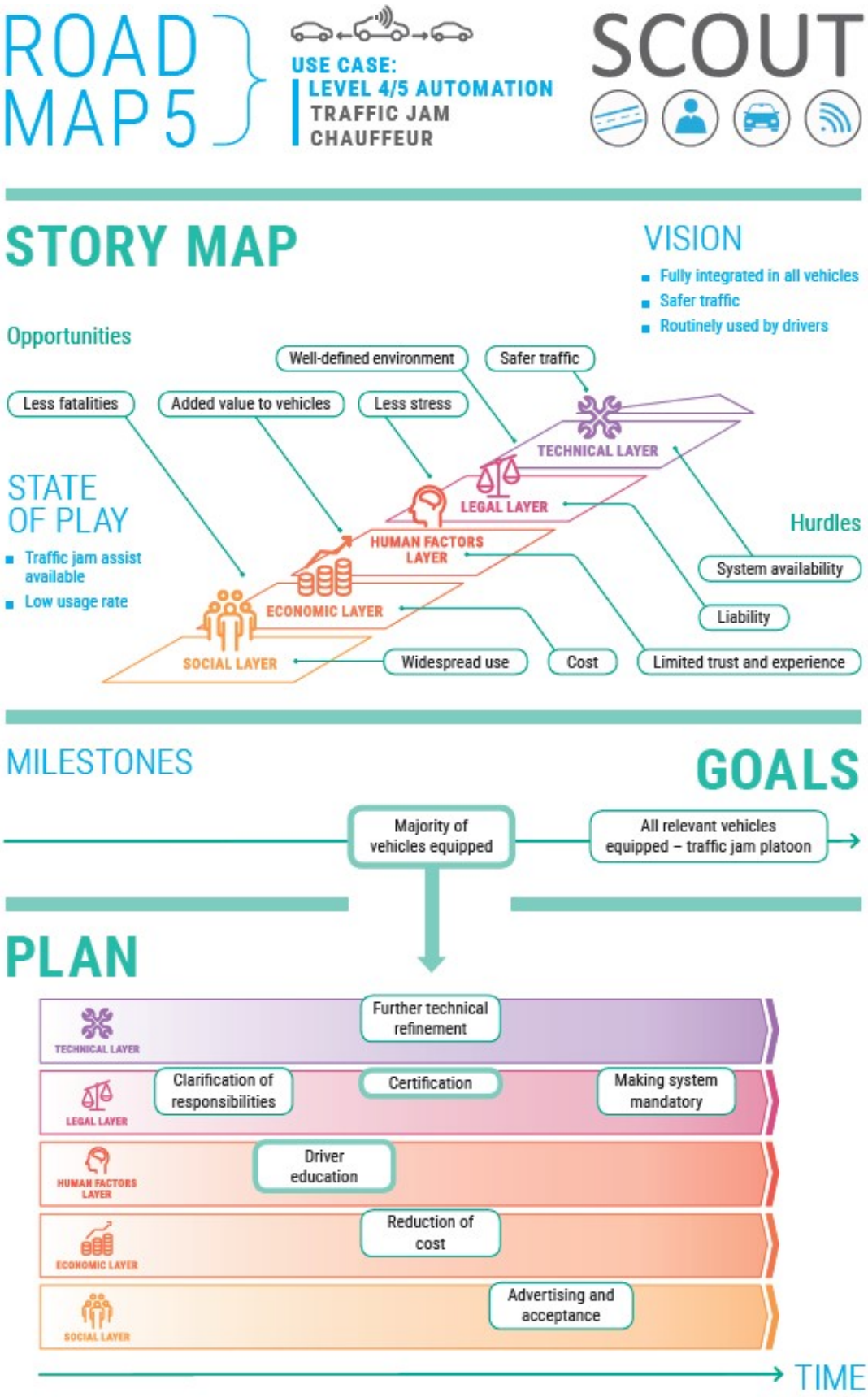

Figure 5: Roadmap for the traffic jam chauffeur use case.

6 Conclusions and Outlook

The SCOUT project succeeded to solve the Gordian knot of locked-in interdependencies between required actions that occurred when it was tried to describe the innovation path towards level 4/5 connected and automated driving in terms of a comprehensive roadmap covering technical, social, economic, human factors and legal aspects. For this, a clear distinction of use cases and a focus on milestones were key. The roadmaps on automated on-demand shuttles, truck platooning, delivery robots, valet parking, and traffic jam chauffeur resulting from the SCOUT project are highly relevant in view of the European Commission's ambition to become a world leader in connected and automated driving as stated in a strategy communication that was launched with the 3rd mobility package, recently. [12] According to that strategy, e.g. low-speed self-driving urban shuttles and delivery vehicles may be available on European streets from 2020 on, though further development of those technologies will take yet another decade. Even though the SCOUT roadmap is not able to be more specific on the actual time line, it points out the necessary actions on the five layers of the plan, and highlights opportunities for accelerated innovation. Thereby, it will be an important input to current process of building an implementation plan of the Strategic Transport Research and Innovation Agenda (STRIA) on Connected and Automated Driving that the European Commission has launched. The methodology and the results of the project may by applied to related topics in the near future, e.g. on assessing the potential synergies of electrification and automation at technology and application levels, and on describing the options of technology transfer from the 2-dimensional road transport domain to the 3-dimensional world of taxi and delivery drones.

Acknowledgements

The authors are grateful for fruitful cooperation with the contractual partners of the Coordination and Support Action "Safe and Connected Automation of Road Transport" (SCOUT), i.e. Luisa Andreone and Leandro D'Orazio (CRF), Franz Geyer (BMW), Yves Page (Renault), Roland Galbas and Andi Winterboer (Bosch), Steven von Bargen (NXP), Giovanna Larini (TIM), Roberto Baldessari and Francesco Alesiani (NEC Europe), Devid Will and Adrian Zlocki (RWTH), Heiko Hahnenwald and Thilo Bein (Fraunhofer LBF) and Beatrice Tomassini and Alessandro Coda (CLEPA). Important inputs were provided by Jochen Langheim, Benjamin von Bodungen, Wolfgang Gruel, Suzanne Hoadley, Stella Nikolaou, Natasha Merat, Alizee Stappers, Klemen Kozelj, Wolfgang Schulz as well as member of the CARTRE project and EPoSS and ERTRAC. Roadmap designs were created by Juliane Lenz from Berlin. The SCOUT project has received funding from the EU's Horizon 2020 programme under grant agreement No 713843.

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Keywords

Connected Car, Vehicle Automation, Autonomous Driving, Roadmap, Level 4/5 Automation, Automated Shuttle, Truck Platooning, Automated Valet Parking, Traffic Jam Chauffeur, SCOUT, CARTRE, EPoSS, ERTRAC, European Commission

A COMPREHENSIVE ROADMAP FOR LEVEL 4/5 CONNECTED AND AUTOMATED DRIVING IN EUROPE

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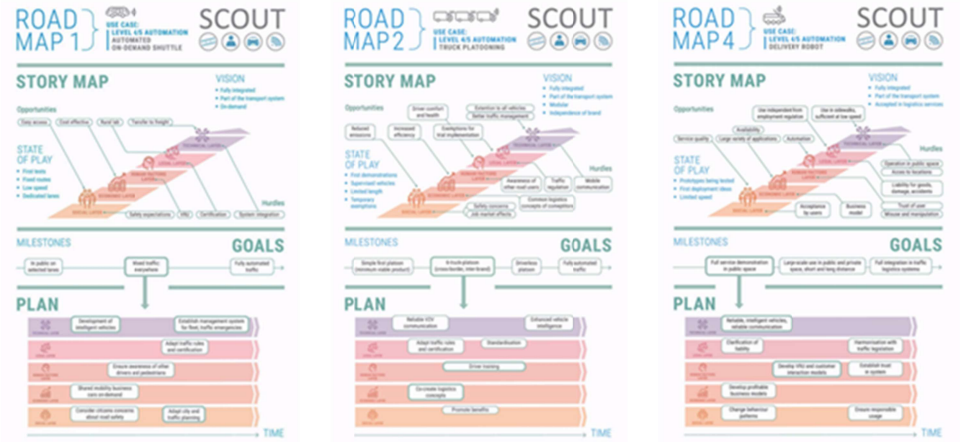
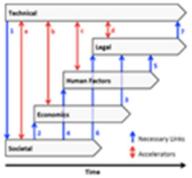
ABSTRACT

The EU-funded Coordination and Support Action *Safe and Connected Automation in Road Transport* (SCOUT) has established a comprehensive and structured roadmap for accelerated innovation in high degree automated driving, i.e. SAE levels 4 and 5. Based on stakeholder consultations, the state of the art was determined, and a future vision for connected and automated driving was formulated for a number of use cases. To close the gap between state of the art and vision, action plans were developed, and opportunities to leapfrog hurdles were highlighted.

ROADMAPS



APPROACH



- Story map showing gaps between SoA and vision
- Gaps in technical, social, economic, human factors, and legal aspects covered by action plan
- Links between actions highlighted, and actions aligned on the time scale
- Problem: Outcomes lacking coherence and interlinks creating a "Gordian knot"
- Solution: Roadmaps need to be distinct for use cases, and focused on goals and milestones
- Impact: Innovation can be accelerated by agile shortcuts anticipating hurdles and roadblocks

PROJECT

Coordination and Support Action
"Safe and Connected Automation in Road Transport" (SCOUT)

SCOUT

Partners: VDI/VDE-IT, Renault, FCA, BMW, Bosch, NXP, Telecom Italia, NEC, RWTH, Fraunhofer, CLEPA, Sernauto

Duration: July 2016 – June 2018

Funding Agency: European Commission, DG CNECT
Grant No. 713843

PUBLICATIONS

D. Will, L. Eckstein, S. von Bargen, T. Taefi, R. Galbas, State of the Art Analysis for Connected and Automated Driving within the SCOUT project. ITS World Congress 2017.

G. Meyer, European Roadmaps, Programs, and Projects for Innovation in Connected and Automated Road Transport. In: Road Vehicle Automation 5, ed. by G. Meyer / S. Beiker, Springer 2018.

J. Dubbert, B. Wilsch, G. Meyer, Roadmap for Accelerated Innovation in Level 4/5 Connected and Automated Driving. In: Advanced Microsystems for Automotive Applications, ed. by J. Dubbert, B. Müller, G. Meyer, Springer 2018.

SCOUT