Austrian
Research, Development & Innovation
Roadmap for
Automated Vehicles

An Initiative of ECSEL Europe, supported by bmvit, ITS Austria, ECSEL-Austria, A3PS, AustriaTech, ASFiNAG, ÖBB, FFG, Austrian industry, and Austrian research & academia

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Preface

The automotive industry faces the most significant changes in its history. Electrification and digitalization are the new challenges. The latter major trend will lead to new driver assistance systems, partially and fully automated vehicles and connected mobility systems bringing unprecedented comfort and safety to the users of vehicles. New technologies extend classical automotive engineering with new sensors, information and software technologies. The Austrian automotive supply industry represents a significant share of the Austrian gross national product. It is important to stimulate this transformation towards automated vehicles in the Austrian industry and research arena. The value of automotive parts and components exported from Austria is higher than the accumulated value of imported vehicles. The automotive sector accounts for about 14% of all researchers in the industrial sector, which is the the highest share of researchers in the Austrian industry. It is therefore important to initiate strategic support of the necessary research and development activities in order to secure Austriaôs competitiveness in this field.

The experts within the Austrian Federal Ministry for Transport, Innovation and Technology from the mobility sector and the ICT sector initiated the creation of this Austrian RDI roadmap for the development of components, parts, services, infrastructure, pilots and test areas for automated vehicles. ECSEL Austria is coordinating this activity.

The digitalization has stimulating effects for other sectors in transport industry as well. Drones will change from remotely controlled systems to partially or fully automated devices. Trains and airplanes are already in the process of conversion to more and more automated vehicles. Digitalization not only effects the vehicles themselves, but it also transforms the road infrastructure too. Intelligent vehicles take advantage of IT cloud services which get their information from sensors and communication systems along the roads.

We would like to thank all experts from the Austrian industry and academia working together in several workshops to create this ñAustrian Research, Development and Innovation Roadmap for Automated Vehiclesò to ensure the continuation of Austriaôs success in the mobility domain.

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1 Summary and Introduction

1.1 Executive Summary

The present ñAustrian RDI Roadmap for Automated Vehiclesò is a technology roadmap driven by Austrian industry with support from the Austrian research community, and reflects the view of the main Austrian players in ICT and mobility. It covers Technology Readiness Levels (TRLs) from 1-8 and a time span of about 15 years and beyond. The aim of this roadmap is not to ñre-inventò existing European and national roadmaps, but rather to align with them and to identify specific areas and focusses and related research, development and innovation (RDI) needs and topics for the Austrian automated vehicles community (see Figure 1).

The ñAustrian RDI Roadmap for Automated Vehiclesò serves several purposes:

- To give a joint view of experts and stakeholders from ICT and mobility, necessary to tackle the challenges of automated vehicles
- To prepare the ground for an Austrian contribution to establish a ĂEuropean platform for leadership in automated vehiclesñ
- To provide inputs to the future Austrian technology as well as transport policy, and particularly to future RDI funding programs
- To be a guide for small and medium-sized enterprises (SMEs), thus expanding the related Austrian eco-system
- To send a strong signal at international level of the Austrian strengths and RDI interests in the area of automated vehicles

This document is contains 5 chapters.

The first chapter provides a detailed overview of the objectives and a thorough analysis of the relation of the ñAustrian RDI Roadmap for Automated Vehiclesò to numerous other European and national roadmaps.

The second chapter focusses on the benefits and impact of automated vehicles in tackling societal needs, elaborated on the detailed goals of Austrian industry in automated vehicles, and provides an overview on the Austrian state of the art in this area, including available strengths in knowledge, areas of excellence as well as products, procedures and services.

The third chapter addresses different areas of application of automated vehicles (automotive on-road, off-road equipment, mobility infrastructure, aerospace, railways and waterways) and related challenges.

The fourth chapter, being the ñcoreò of this roadmap, identifies the main RDI task fields and topics of interest. This is complemented by timelines for the different levels of automation and the relation of the identified RDI topics and needs towards national and European funding programs.

Chapter five contains several appendices with particular focus on the procedure of how the ñAustrian RDI Roadmap for Automated Vehiclesò was developed.

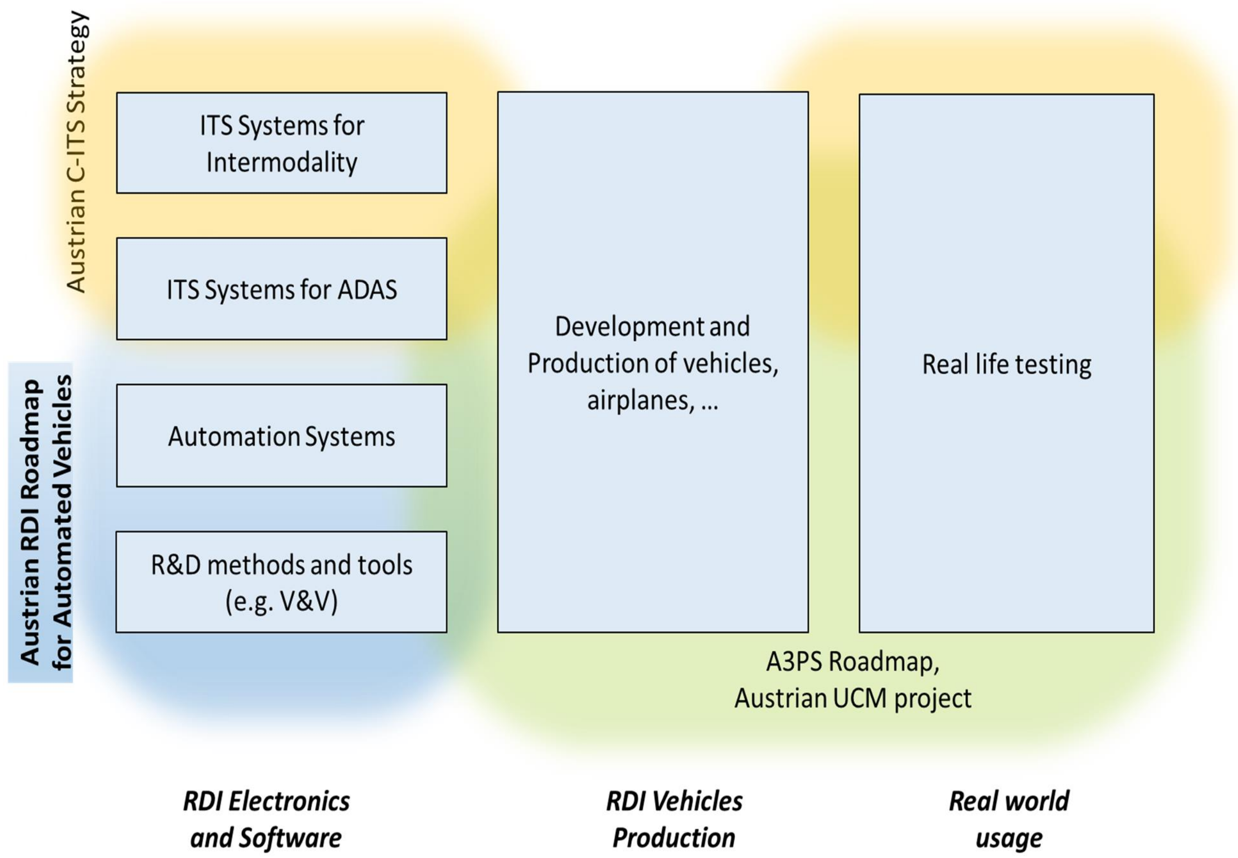

Figure 1: Positioning of the ĂAustrian RDI Roadmap for Automated Vehiclesñ with respect to other Austrian Roadmaps (see also Section 1.3 F), G), and H))

1.2 Objectives of the document

Enhanced automation of vehicles (trains, cars, trucks, ships, airplanes etc.) will be one major enabler to master the Grand Societal Challenges. In particular highly automated driving functions will increase traffic safety, reduce traffic jams, increase passenger comfort, reduce CO_2 pollution and energy consumption but also help disabled or elderly people to extend their mobility, independence and quality of living.

Automated vessel navigation systems can avoid collisions and groundings, protect the environment, reduce bunker consumption, and improve the maritime traffic flow as well as intermodal transportation. Unmanned automated vehicles can perform heavy and dangerous tasks in harsh environments, such as maintenance services on airplanes or underwater construction, or in catastrophic scenarios including mudflow, avalanches or even during nuclear incidents (e.g. Fukushima). The applications and benefits of automated cyber-physical systems are countless.

It is commonly accepted that the automated driving functionality will not come overnight to our vehicles, trucks, off-road machines, ships or airplanes. In some areas automated functions have already been in use for many years as autopilots in airplanes. In other areas only the first starts have been made to introduce automation. Concerning car traffic, ADAS systems (the driver is still fully responsible) will become more and more sophisticated up to the moment when the automated car will also be capable of taking over full responsibility from the driver (SAE level 5, see Figure 2). Estimations expect such a function to become operational in standard cars by 2030 or even later.

Summary of Levels of Driving Automation for On-Road Vehicles

This table summarizes SAE International's levels of *driving* automation for on-road vehicles. Information Report J3016 provides full definitions for these levels and for the italicized terms used therein. The levels are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. "System" refers to the driver assistance system, combination of driver assistance systems, or *automated driving system*, as appropriate.

The table also shows how SAE's levels definitively correspond to those developed by the Germany Federal Highway Research Institute (BASt) and approximately correspond to those described by the US National Highway Traffic Safety Administration (NHTSA) in its "Preliminary Statement of Policy Concerning Automated Vehicles" of May 30, 2013.

Level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**	-	

Figure 2: SAE levels of automated driving [1]

SAE defined five different levels which are commonly used to describe the degree of automation in vehicles [1] [2], see Figure 2.

Already today OEMs market vehicles with several automated driving functions of different levels. Many vehicle manufacturers promise to deliver more automated driving functionalities in the next years. An automotive expert group from the ERTRAC technology platform predicts the introduction of the next levels in automation according the roadmap depicted in Figure 3.

The importance of the new technology of automated vehicles for Europeȏs industry is clearly shown in a proposed lighthouse initiative to develop a European platform for leadership in automated vehicles. This proposal has been made by industry stakeholders in the framework of the ECSEL-JU (European Joint-Undertaking ñElectronics Components and Systems for European Leadershipò).

Lighthouse initiatives are clusters of high-impact projects that develop, test and deploy innovations in essential areas of key importance to Europe in ecosystems or along the value chain. They also involve legal, ethical and financial stakeholders creating a framework for fast market acceptance, regulation and standardization, including de facto standards when relevant. This shall unlock barriers and facilitate large scale deployment. They will require considerable efforts from the private partners and therefore deserve the support of the ECSEL JU.

Notably this will materialize in platforms for "Smart X" markets by building on and combining the strong presence of European industry, academia and research institutions in cyber-physical systems, smart systems integration and MEMS as well as low power and secure components. They shall enable closer cooperation between Europeôs key actors in innovation and regulation contributing to the overall goal of the ECSEL JU. Most important is the goal to strengthen Europe's position in key parts of future digital value chains and digital platforms.

The specific lighthouse initiative proposal on automated vehicles mentioned above emphasizes Europeôs leading position in developing highly automated vehicles such as cars, airplanes and trains. To maintain and extend this leadership, potentially enhancing it with respect to other players in this field, it is important that a solid base for the development and validation of highly automated vehicles is available for European vehicle developers and manufacturers. In this manner, European industry aims to establish worldwide standards to support its leadership in this domain.

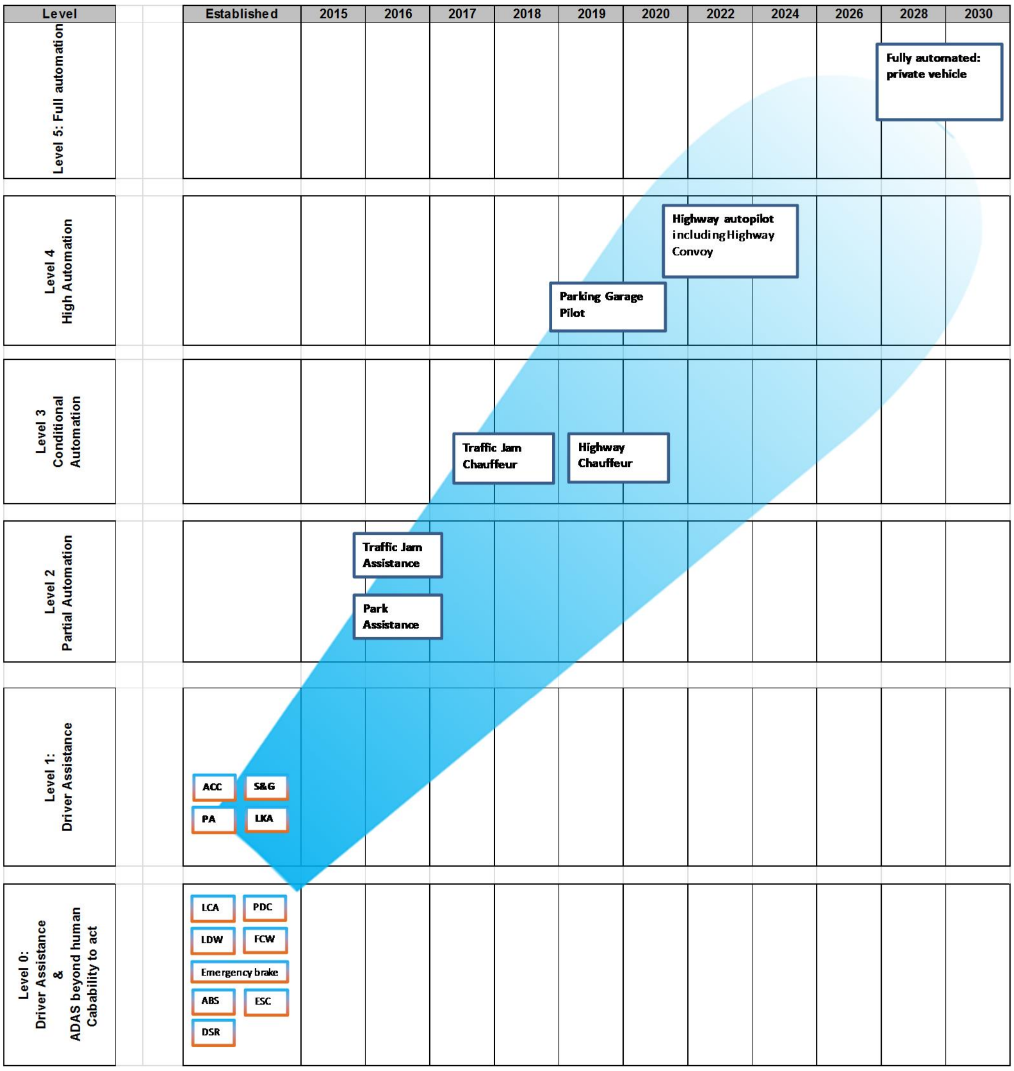

Figure 3: Deployment path for automated driving in passenger cars [1]

The Austrian Ministry for Transport, Innovation and Technology (bmvit) recognized the importance for Austrian society of the radical new technology required for ñautomated vehiclesò. In addition, these new technologies can be expected to provide substantial opportunities for the Austrian high-tech community consisting of related industry, academia and research institutions, but also for SMEs, thus expanding the related Austrian eco-system in the area of automated vehicles. Therefore bmvit has indicated its intention to support the ECSEL lighthouse initiative. In addition, this roadmap document is intended to provide substantial input to the future Austrian technology and transport policy, and in particular future national funding programs.

The topic of automated vehicles and related technologies needs the combined efforts of ICT (information and communication technologies) and mobility technologies at least. Thus, the two groups in the ministry responsible for the different technology areas jointly asked the relevant Austrian high-tech community in October 2015 to develop one research, development and innovation (RDI) roadmap for Austria, providing information on how the Austrian high-tech communityôs expertise would best support European efforts to propel the introduction of automated driving functions in next generations of vehicles.

It should on the one hand analyse where the Austrian high-tech community can contribute valuable knowledge and developments. On the other hand, Austria has proven to be most successful in specific areas in ICT, automotive, rail, maritime or aerospace domains. Therefore this ñAustrian RDI Roadmap for Automated Vehiclesò shall explore research opportunities for the Austrian high-tech community, where available knowledge and technology can support the European efforts in creating new technologies (electronic components and systems, required (embedded cyber-physical) software, tools and methods for automated vehicles and the necessary infrastructure for a successful launch in the markets for autonomous vehicles).

The following expert groups and specialists helped to create this RDI roadmap:

- ECSEL-Austria (coordinator of this document)
- A3PS
- AustriaTech
- the Austrian high-tech community consisting of related industry, academia and research institutions

This roadmap focusses on the RDI activities necessary to support the Austrian high-tech community in their efforts to strengthen market and technology leadership required to build automated vehicles. This initiative shall ensure that the Austrian economy benefits from the trend towards ñautomated vehiclesò. It will create new, secure high-tech job opportunities in Austria for the benefit of Austrian society in general. It may be stated that security aspects will also play a central role when it comes to automated vehicles in order to successfully defend against the threat of hostile intrusion and control by unauthorized individuals.

It shall be noted that this roadmap is not intended to cover efforts concerning the roll-out of the necessary infrastructure for automated driving (cars, ships, trains, airplanes) in Austria and the required investment to implement such automated traffic in Austria. It covers only the RDI efforts to develop the necessary infrastructure.

Complementary to this roadmap, A3PS analysed the necessary steps and investments to bring automated vehicles to Austrian roads. The ñAustrian Eco-Mobility Roadmap 2025^{plus}ò [3] by A3PS describes the path for the radical change for Austrian roads and cities from conventional vehicle concepts (SAE level 0) to fully automated driving vehicles (SAE level 5) in the long term. Actually, the huge effort being spent by Austrian high-tech community in participating in and leading numerous research projects, prototype and systems development will lead to an ñelectronic revolutionò with significantly reduced fatalities for vehicle occupants and other road users.

1.3 Relation to other roadmaps (whitepapers, visions and strategies)

In 2014 and 2015, numerous European and Austrian Whitepapers, Visions and Strategies (all of them being or including some sort of roadmaps), exclusively dedicated to or highly relevant to automated vehicles and/or automated driving, have been issued or prepared.

Therefore, to avoid duplication and to facilitate the optimum alignment of identified strengths and RDI requirements of the Austrian industry, the folowing documents (A-E on European level, F-H on Austrian level) have been thoroughly analyzed and taken into consideration during the creation of the present ñAustrian RDI Roadmap for Automated Vehiclesò.

A) ECSEL ï 2015 Multi Annual Strategic Research and Innovation Agenda MASRIA (2015)[1]

- Document on electronic components and systems (technologies and applications)
- Numerous areas of application / industrial domains covered
- Dedicated sub-chapter and roadmap on electronic components and systems for highly automated and autonomous transport (key application area ñSmart Mobilityò)
- Industry-driven document
- Roadmap focus (concerning automated driving): Technologies and applications / mobility services
- Roadmap timeline: 2015-2030
- TRL: Research and Innovation Actions (TRL 2-5), Innovation Actions (TRL 4-8)
- Automation: according to SAE levels [SAE J3016]
- No description of state of the art

ECSEL ï Electronic Components and Systems for European Leadership - is a partnership (joint undertaking) between the private and the public sectors for electronic components and systems in Europe. Members are i) the European Union (through the Commission); ii) Member States and Associated Countries to the Framework Programme Horizon 2020 on a voluntary basis; iii) three associations (EPoSS, AENEAS and ARTEMIS Industry Association) representing the main European actors from the areas of micro- and nanoelectronics, smart integrated systems and embedded/cyber-physical systems. These actors draws up and regularly update the Multi-Annual Strategic Research and Innovation Agenda (MASRIA).

B) EPoSS ï European Roadmap Smart Systems for Automated Driving (2015)[2]

- Dedicated document on automated driving from a smart systems integration point of view
- Emphasis on automotive applications
- Industry-driven document
- Roadmap focus: Technologies (and legal frameworks)
- Roadmap timeline: 2014-2030
- TRL: Research & Development [TRL 2-4], Demo [TRL 5-8], Production & Market [TRL 9]
- Automation: according to SAE levels [SAE J3016]
- State of the Art mainly shown by research and innovation projects funded by the EC and a brief overview on demonstrations

EPoSS - the European technology Platform on Smart Systems integration - is an industry-driven policy initiative, defining R&D and innovation needs as well as policy requirements related to smart systems integration and integrated micro- and nanosystems. It comprises major industrial companies and research organizations from more than 20 European Member States, bringing together European private and public stakeholders in the area of smart systems integration.

C) ERTRAC - Automated Driving Roadmap (2015)[3]

- Dedicated document on automated driving from a general road transport point of view
- Emphasis on automotive applications (incl. infrastructure and legal & regulatory framework)
- Document driven by all relevant stakeholders
- Roadmap focus: Technologies, applications / mobility services and regulation/standardization
- Roadmap timeline: 2014-2025
- TRL: Technological Research (TRL 2-4); Pilots and large scale demonstrators (TRL 5-7); Industrialization (TRL 8-9)
- Automation: According to SAE levels [SAE J3016]
- State of the art description on European and non-European level. Description of Austrian level is quite similar to the one given in the ñC-ITS Strategie Österreichò (see below)

ERTRAC - the European Road Transport Research Advisory Council - is a European technology platform which brings together road transport stakeholders to develop a common vision for road transport research in Europe. These stakeholders comprise automotive, energy / fuel supply, road infrastructure, ITS, public authorities (EU, national bodies, cities, regions), research, service providers, and users.

[1] http://www.smart-systems-integration.org/public/documents/publications/2015%20ECSEL%20MASRIA.pdf. Accessed February 2016.

[2] http://www.smart-systems-integration.org/public/documents/publications/EPoSS%20Roadmap_Smart%20Systems%20for%20Automated%20Driving_V2_April%202015.pdf. Accessed February 2016.

[3] http://www.ertrac.org/uploads/documentsearch/id38/ERTRAC_Automated-Driving-2015.pdf. Accessed February 2016.

D) 5G Automotive Vision (2015)[4]

- Document on connected and automated driving and new mobility services from a 5G communication point of view
- Emphasis on automotive + telecom industries (incl. business and regulatory/standardization aspects)
- Numerous connections to automated driving / vehicles incl. specific use cases on automated driving
- Industry-driven document
- Roadmap focus: mainly technologies, but also business and regulatory/standardization aspects
- Roadmap timeline: 2014-2025
- TRL: no usage of TRL (but KPIs, and - according to the C2C Communication Consortium Roadmap - 5 Phases up to accident-free driving)
- Automation: According to SAE/VDA levels [SAE J3016]
- State of the art description on limitations of existing communication technologies used in C-ITS

ERTICO ITS Europe ï the European Road Transport Telematics Implementation Coordination - is Europe's Intelligent Transportation System (ITS) organization that promotes research and defines ITS industry standards. It is a network of ITS and services stakeholders in Europe, connecting public authorities, industry players, infrastructure operators, users, national ITS associations and other organizations.

5G PPP - the 5G Infrastructure Public Private Partnership - has been initiated by the European Commission and industry manufacturers, telecommunications operators, service providers, SMEs and researchers. The 5G PPP will deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade.

E) EC ï Next Generation Computing Roadmap (2014)[5]

- General document on next generation computing (IT)
- Numerous areas of application / industrial domains covered; 7 main scenarios of the future (incl. intelligent transport)
- Dedicated section(s) on intelligent transport incl. autonomous systems and cars
- Roadmap focus: Technological challenges and milestones categorized according to complexity / costs and importance / impact
- Roadmap timeline: 2015 ï 2025/2030+ (10 to 15 years)
- TRL: no usage of TRL
- Automation: no automation levels used
- State of the art description: general world-wide assessment + SWOT analysis on European strengths, weaknesses, opportunities and threats

The European Commission (EC) Directorate General Communications Networks, Content & Technology (DG CONNECT) manages the Digital Agenda of the EU. The work of the DG focusses on ensuring that digital technologies can help deliver the growth which the EU needs. DG CONNECT provides input to the Digital Single Market Project Team, led by EC Vice President Andrus Ansip, through Commissioner Günther Oettinger.

F) AustriaTech - C-ITS Strategie Österreich (2016)

(To be published in Q1/2016.)

- Document on Cooperative ITS based on V2X (i.e. vehicle-to-vehicle and vehicle-to-infrastructure) communication
- Emphasis on automotive field incl. infrastructure
- No dedicated section on and only a few direct connections to automated vehicles / driving
- Policy-driven document
- Roadmap focus: Applications / Mobility services (demand-oriented)
- Roadmap timeline: 2016 ï 2020
- TRL: no usage of TRL
- Automation/V2X: 5 Phases up to accident-free driving according to the C2C Communication Consortium Roadmap (see also ñ5G Automotive Vision (2015)ò above)
- State of the art description on C-ITS projects and applications / mobility services on European and non-European levels. No description concerning automated vehicles / driving

AustriaTech is a private company whose mission is to maximize the societal benefits of new transport technologies. It is a 100% owned subsidiary of the Fed-

[4] https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf. Accessed February 2016.

[5] http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=6636. Accessed February 2016.

eral Ministry for Transport, Innovation and Technology (bmvit). AustriaTech assists the bmvit by pursuing a long-term strategy for developing and implementing sustainable transport solutions. Furthermore, AustriaTech is responsible for ITS planning and national implementation of the European ITS Directive.

G) A3PS ï Eco-Mobility 2025plus Technology Roadmap (2015)[6]

- Document and website on future vehicles and energy carriers
- Emphasis on automotive applications
- Dedicated section on automated driving / vehicles (advanced vehicle control systems) incl. infrastructure aspects
- Document driven by industry and research community
- Roadmap focus: Technologies incl. TRLs, type of required projects, R&D measures and targets
- Roadmap timeline: 2015 ï 2025+
- TRL: 1-9
- Automation: According to SAE levels [SAE J3016]
- No state of the art description

A3PS - the Austrian Association for Advanced Propulsion Systems ï was founded by the Austrian Federal Ministry for Transport, Innovation and Technology (bmvit) as a PPP and addresses all advanced drive train technologies contributing to the improvement of energy efficiency and reduction of emissions (for example hybrid, battery electric, fuel cell vehicles as well as advanced fuel technologies including biofuels) and supports the whole innovation cycle (research, development, deployment). A3PS members include partners from both Austrian industry and the research community.

H) Austrian Unmanned Aerial System for Civilian Missions (in progress)

This activity is currently underway in the course of the project ñAustrian UCMò, supported by bmvit and led by FH Joanneum. The goal is to establish a research agenda pertaining to unmanned aerial systems for civilian missions in Austria. This activity is driven by all relevant stakeholders from industry and research organizations. So far only a tiny share of all research activities identified can be linked to automated and autonomous aircraft and flight.

I) Other roadmaps and initiatives

Numerous other national roadmaps and initiatives bear relevance to the area of automated vehicles and have been taken into consideration when creating the present roadmap: the Smart Cities initiative of the Austrian Climate and Energy Fund[7], the Technology Roadmap for the ICT of the Future program[8], or the Roadmap on Complex Systems[9].

Furthermore, a dedicated new roadmap entitled Embedded Systems in Automated Driving, coordinated by the international SafeTRANS ("Safety in Transportation Systems") Competence Cluster[10], combining research and development expertise in the area of complex embedded systems in transportation systems, is in preparation (planned publication in 2016).Several members of the core team of the present roadmap are directly involved in contributing to the SafeTRANS roadmap.

[6] http://www.a3ps.at/site/sites/default/files/images/downloadfiles/a3ps_roadmap_eco_mobility_2025plus.pdf and www.roadmap.a3ps.at. Accessed February 2016.

[7] http://www.smartcities.at/founding/climate-funds-initiative-on-smart-cities/. Accessed February 2016.

[8] https://www.bmvit.gv.at/service/publikationen/innovation/downloads/conquering_data__in_austria.pdf. Accessed February 2016.

[9] https://www.bmvit.gv.at/service/publikationen/innovation/downloads/komplexe_ikt_loesungen.pdf. Accessed February 2016.

[10] http://www.safetrans-de.org/.

2 Towards automated vehicles in Austria

2.1 Automated Vehicles for Tackling Societal Needs

Automated vehicle technology has the potential of fundamentally changing mobility as we experience it today. Automated / autonomous vehicles (AAV) offer solutions to many of todayôs grand societal challenges. In the automotive domain many benefits are expected ranging from improved safety, congestion-free traffic and increased comfort, social inclusion, lower emissions, and better road capacity utilization due to optimal integration of private and public transport. Robots used in medical interventions will improve medical care because complex surgeries can be offered not only in specialized clinics. Unmanned autonomous vehicles (UAV) can perform heavy and dangerous tasks in harsh environments, such as maintenance services on airplanes or underwater construction. AAV applications and benefits are countless and we are only beginning to understand the new markets, business models, and products of this emerging technology.

Over the last two decades, vehicle automation has been an active research and innovation field. AAV are often discussed as a so-called ñdisruptive technologyò with the ability to transform transportation infrastructure, expand access, and provide benefits to a variety of users and customers. In this context, AAV are not only disruptive in a technical sense, but also in a social sense as we hand over part of our responsibility to the machine with all benefits and all the risks associated with automation. What AAV from different industry sectors have in common is that they use complex sensing to gain an understanding of their operational environment in order to either support humans in complex, often safety critical control tasks or even to make decisions where the human user is no longer in the loop. This poses completely new challenges for the required functionality, quality level, and reliable operation of these systems, because they have to perform their tasks without the fall back option to hand over control to the user in critical situations ï as e.g. in todayôs driver assistance systems.

Although the present roadmap technologically addresses all relevant application domains covered by Austrian industry, in the following the automotive domain is exemplarily chosen to discuss the expected societal impact.

2.1.1 Background

Public authorities around the world recently presented action and innovation plans to facilitate the development and stepwise introduction of automated vehicles. Current midterm research is targeting intelligent driver assistance functions and highly automated driving modes while long-term research is aiming at fully automated driving systems that are able to handle any possible traffic and emergency situation safely without relying on human supervision [4]. Many cars sold today are already capable of some level of automation while more advanced automated prototype vehicles are continuously tested on public roads especially in the United States, Europe, and Japan. AAV technology has arrived rapidly on the market and future deployment is expected to accelerate over the next years. As a matter of fact, most of the core technologies required for fully autonomous driving (SAE level 5) are available today.Many are mature and some are already on the way to being deployed in commercially available vehicles [5].

Automated driving is the next logical step towards future mobility that would build on maturity of demonstrated advanced environment perception systems such as radars, laser scanners, cameras, and other sensors. In that context, automated driving requires in-vehicle real-time decision making and planning capabilities as well as interaction with other vehicles, road infrastructure, and other third party services. Figure 4 illustrates the general micro architecture of an automated vehicle. During operation, automated systems typically encompass the three constantly executed tasks of sensing, planning, and (re)acting. The corresponding macro architecture features a system of in-vehicle, central and roadside systems that work in concert to provide the optimal solution for AAV on a micro and macro level.

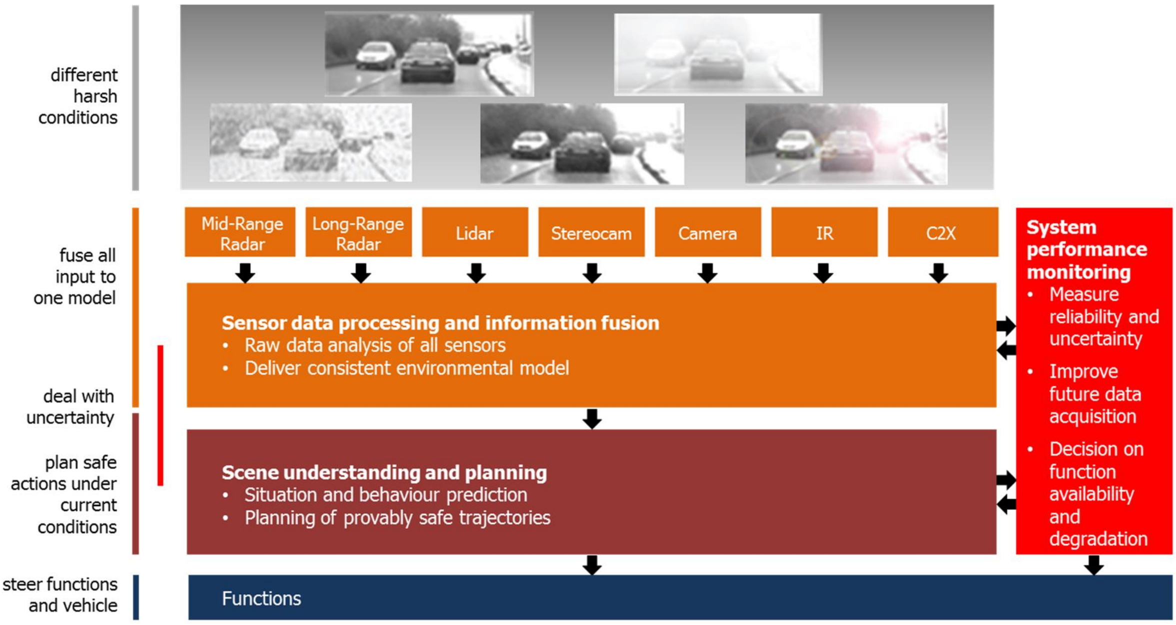

Figure 4: System architecture of an automated vehicle (Source: ECSEL Project proposal RobustSENSE)

2.1.2 Societal needs and expected impact

Automated driving is seen as one of the key technologies and major technological advancements influencing and shaping our future mobility and quality of life. Automated driving will, in the long term, contribute to the reduction of road fatalities and to social inclusion, and add value in terms of energy efficiency and the protection of the environment. Many predictions have been released over the last five years in the automotive industry stating (on average) a limited availability of (highly) automated driving functions (low speed and high speed applications) by 2020 with wide availability to the public by 2040. The main drivers for higher levels of automated driving are [1], [6]:

- Safety: Reduce accidents caused by human errors. 90 % of all accidents are caused by human errors. In 2010, the European Commission launched a new EU road safety programme which aims at halving the number of road deaths by 2020 [7].
- Efficiency: Increase transport system efficiency and reduce time in congested traffic. Fewer traffic jams and less waiting time at intersections and traffic lights are expected to improve the traffic throughput by 80 %.
- Comfort: Enable userὸs freedom for other activities when automated systems are active.
- Better public transport: AAV are ideal for delivering passengers to or from public transport systems. They can coordinate pickup and delivery with the actual timetable of the public transportation system.
- Social inclusion: Ensure mobility for all, including elderly and impaired users. The over-65-years segment is growing 50 % faster than the overall population.
- Emergency response: AAV may also perform a special role in an emergency. They might be able to switch into an emergency mode and deliver anybody to the nearest hospital at maximum speed.

Figure 5 summarizes and quantifies the top five expected societal impacts for AAV in the automotive domain.

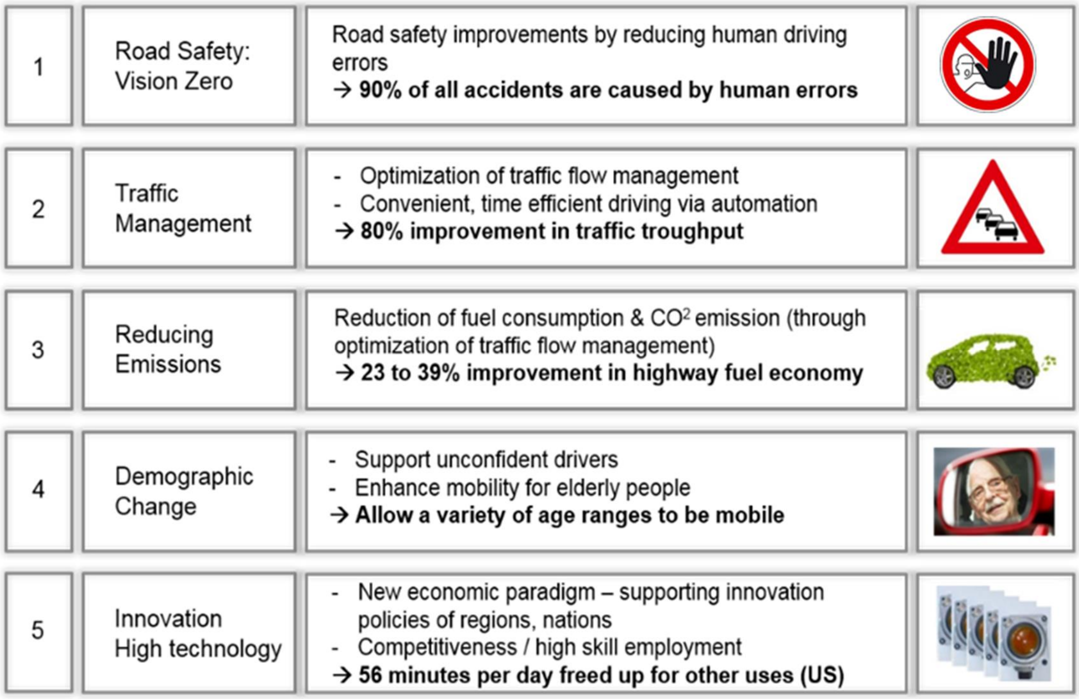

Figure 5: Expected impact of automated functions in the automotive domain

In early 2016, the Austrian government released the figures of road fatalities in 2015[11]. In total 475 persons died on Austrian roads, which is a 10% increase compared to 2014 (430 road fatalities). As a main statement, approximately 70% of all accidents are caused by driver distraction, inadequate speed, and failure to yield to traffic having the right of way. All of these issues are actually manageable by AAV, emphasizing the societal impact of such systems (Figure 6). Nevertheless it is worth mentioning that due to the missing legal framework and the technological state-of-the-art, high speed (e.g. highway pilots) and low speed functions (e.g. park assistance, traffic jam pilot) are industrial priorities. Figure 7 impressively depicts that a comparatively low number of incidents (50 fatalities) happened on highways while most deadly accidents occur on federal highways and rural roads. However, AAV for those scenarios are under development despite the lack of test methods and test infrastructures.

Concluding from the numbers, causes, and locations of road fatalities in 2015, it becomes obvious that the driver has to be unburdened. Human drivers are confronted with, and usually manage, an incredible variety of contexts (geographic areas, roadway types, traffic conditions, weather conditions, and events/incidents) for which automated vehicles have yet to be designed and demonstrated. Human factors in automation relate to understanding the interaction(s) of humans with all aspects of an automated road transport system (ART), both from within a vehicle, when taking the role of a driver/operator and also as a road user, when interacting with automated vehicles.

Knowledge and theories from social, psychological and behavioural sciences are useful to understand how humans interact with such systems. Depending on the level of autonomy (cf. SAE levels), a human driver will occasionally have to drive the car manually and simultaneously operate different autonomous functionalities (i.e. turn on and off ADAS, switch control from and to the vehicle). These interactions and handovers (both driver- and system-initiated) will have to be effective, efficient, trustworthy, safe, and easy to be learned. Apart from that it is to be expected that, with an increasing number of autonmated vehicles, de-skilling of drivers in their manual driving skills is likely to occur over time.[12]

Efforts toward full automation tend to follow one of two incremental paths. The first involves gradually improving the automated driving systems available in conventional vehicles so that human drivers can shift more of the dynamic driving task to these systems (SAE level 3 and 4). The second path involves deploying vehicles without a human driver and gradually expanding this operation to more contexts (SAE level 5, e.g. robot taxi, UAV, autonomous trains). Figure 8 illustrates midterm and long-term research and development.

[11] Austrian Ministry of the Interior (BM.I), Austrian Press Agency, January 2016.

[12] MadSAV, Maintaining Driving Skills in Semi-Autonomous Vehicles. http://www.madsav.org. Accessed 17 Feb 2016.

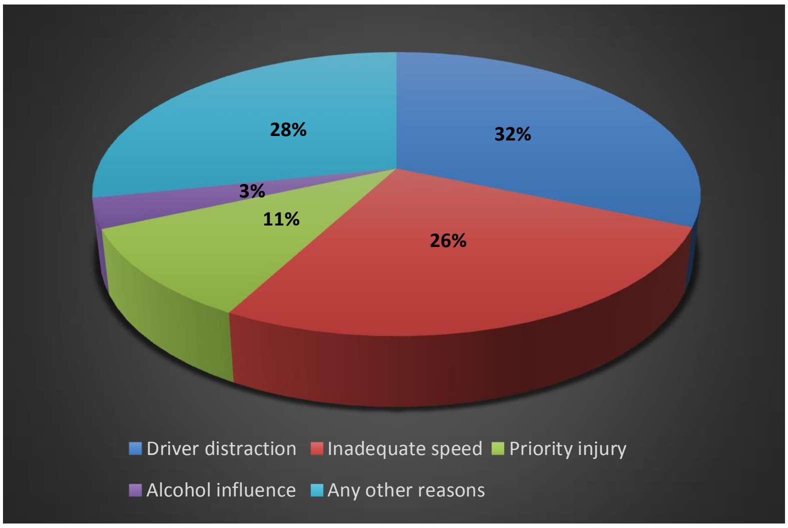

Figure 6: Road fatalities in Austria 2015

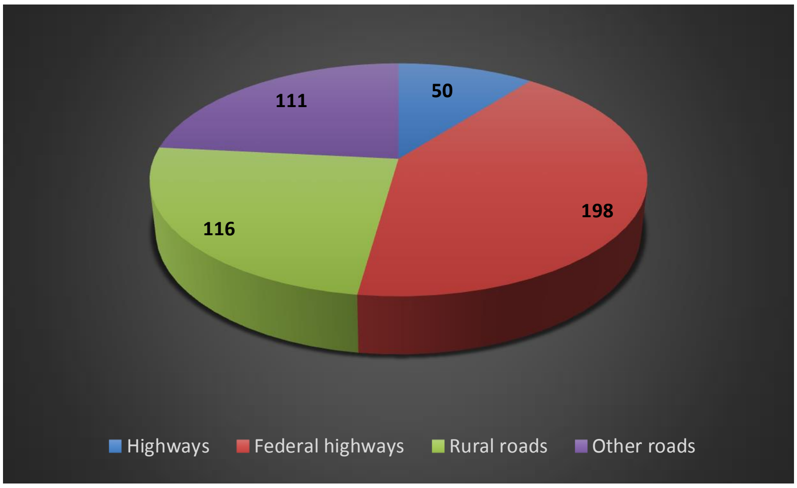

Figure 7: Accident location of road fatalities in Austria 2015

Future advances and acceptance of AAV will directly rely on safe and secure communication with other road users and the infrastructure. Examples which will directly increase end-user acceptance are

- Automated lane merging of vehicles
- Emergency stopping and warning (e.g. temporary construction areas)
- Obstacle and object avoidance
- Truck platoons with short spacing to reduce drag and save energy
- Multiple vehicle automated platoons with short separations, to increase capacity
- Speed harmonization to maximize traffic flow
- Speed reduction when approaching a queue, for safety reasons
- Shared vehicle fleet repositioning
- Driverless urban goods pickup and delivery
- User-centred design and evaluation approaches to include user requirements in the design process

In addition, safety, security and privacy have to be taken into account as societal needs expected by consumers [8]. At present, large quantities of personalized data are already collected via navigation systems, smartphones, or during vehicle maintenance. Automated vehicles are capable of recording and providing large amounts of data that might assist crash investigations and accident reconstructions. Such data is highly relevant for improving active safety systems and system reliability, but also for resolving liability issues. Furthermore, cybersecurity (vulnerability to hacking) has to be considered in order to avoid the vehicle or driver losing control due to hacking attacks.

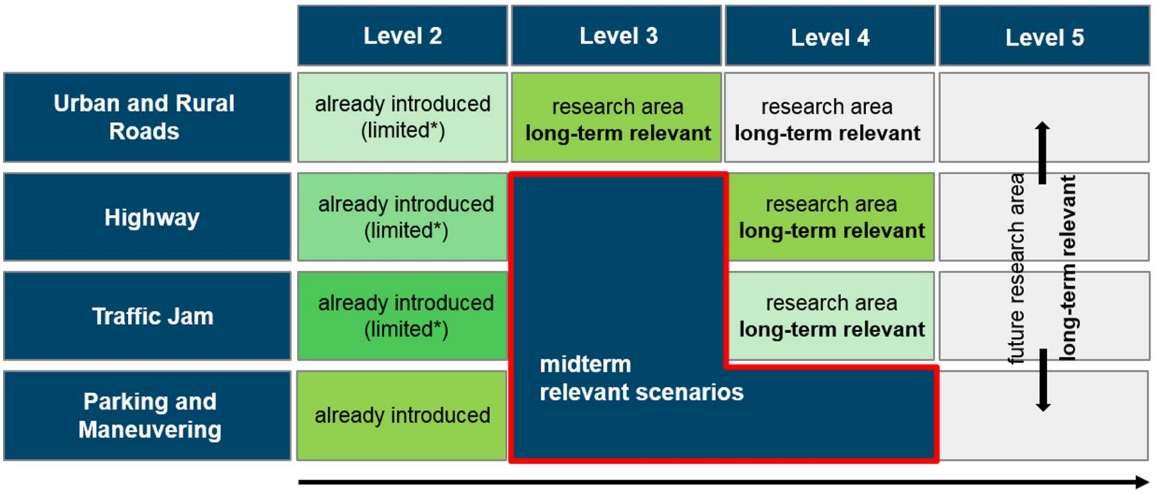

Figure 8: Relevant midterm and long-term scenarios based on [9]. Current UN R 79 allows above 10 kph only corrective steering (lateral assistance). Therefore steering capability of todayǿs Level 2 functions is still limited (*).

The global race for highly automated systems and ultimately fully autonomous systems in many domains (automotive, farming, rail, maritime, health, and aerospace) has already begun. Big competitors and global conglomerates are entering this race in all domains. Recently, the transport sector has gained special attention as new competitors from cross-cutting domains such as Google and Apple - to name just two - compete for these future markets. Impressive demonstrations have been presented by European market leaders in the automotive, farming or rail sector as well as by global competitors. Today all demonstrations have been investigated and tested under well-controlled conditions in well-defined environments. AAV will only succeed and be accepted by society if they will perform safely and securely in any situation at any time in any environment.

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2.2 Goals of Austrian industry in Automated Vehicles

The goals of the various industrial domains for different types of automated vehicles show a number of commonalities concerning the needs and are thus comparable in many aspects. However, each industrial domain has its own specific needs as well as partially specific views of the common goals. Therefore, we believe that describing both the common goals and the domain-specific goals for automotive, aerospace, off-highway and railway applications seems most appropriate.

(a) Goals Common to all Domains

For enabling full automation of vehicles, the following goals are pertinent for all industrial domains:

1) Robust environment perception and scene understanding (situation awareness). Every moving vehicle has to recognize its near environment and understand at least aspects essential for its mission. Environment, objects in it, and aspects may differ from domain to domain, but all automotive vehicles have to possess capabilities such as object detection and classification (e.g. category, obstacle) as well as understanding whether collisions or other dangerous situations (may) emerge.

2) Flexible and highly secure communication among vehicles and infrastructure. Ad-hoc broadband and individual communications between vehicles and between vehicles and infrastructure will play a crucial role in applications such as traffic optimization or ñswarm harvestingò (see 3.2). Any risk of abusing such communication for, e.g. causing misbehavior of vehicles has to be minimized.

3) Efficient means for assuring required dependability (safety, security, reliability). State-of-practice V&V methods are insufficient for highly automated vehicles, at least in an efficient way. We will need a smart combination of analysis, simulation, virtual and real testing, and formal verification, incorporating new methods, coverage measures ï and, finally, standards ï for achieving this goal.

4) Ensuring a high level of user acceptance of the applied technology among all user groups regardless of differences in e.g., gender, age, or level of education.

(b) Goals for Automotive Domain Automated Vehicles

The goals for the automotive domain foresee a seamless integration of mobility into so-called ñsmart mobility conceptsò (SMC). SMC visions predict autonomous cars that will most likely be based on e-vehicles (compare: Toyota predicts that no combustion engine driven cars will be on the market by 2050[13]) that are no longer privately owned and still satisfy ñprivate traffic needsò based on car sharing. Such vehicles will be tied into overall traffic concepts where individuals purchase the kilometer of distance to travel, regardless of which means of transportation is selected. Such a scenario might start with a car sharing vehicle taking you to the railway station and from there you use railway services and change to a plane later on. The final part of the journey may then be done by a car sharing offer again taking you from the destination airport to your final destination. All these means would be paid for as a combined single price and appropriate ñfaresò would be distributed by these ñumbrella organizationsò organizing mobility. From the automotive viewpoint, this process will result in the driverless, autonomously operated car. For this purpose the following challenges need to be tackled in advance to make an autonomous car a reality:

1) Todayôs technologies for autonomous driving have been integrated into the first impressive demonstrator prototypes (compare i.e. Audi piloted driving on the Hockenheimring). Learning from aerospace, the automotive industry is also aware that bare triple redundancy with dissimilar designs will significantly exceed reasonable price levels. Thus concepts must be identified that provide sufficient safety at an acceptable cost.

2) Centralization of ECUs in order to increase computing power using multi/many-core devices.

3) Reduction of implemented different networks in the vehicle

4) Miniaturization of ECU core electronics to reduce cost and increase computing power

5) Reduce complexity by reduction of individual ECUs and diversity of networks. Potential network to be used as a backbone as in aerospace may be automotive Ethernet

6) Increase maintainability by diagnostic routines and service request routines prior to breakdown

7) Increase reliability in order to allow vehicles to drive more kilometers (since the majority will be operated by car sharing organizations rather than private owners)

8) Pricing will be based on the number of miles used rather than a purchase price, as is the case for an owner (similar to truck concepts)

9) Provide means and platforms that allow seamless integration of applications for multi/many core device architectures. Such an approach shall also support the use of different operating systems on the same device.

10) Wireless connection (Car2Infrastructure, Car2Car é) in order to allow services and safety mechanisms beyond the individual decision level (i.e. collision avoidance in urban intersections controlled by centralized stations based on trajectory data transmitted by each vehicle and processed outside the vehicle)

11) Integrated security measures designed to avoid unauthorized intrusion into the mission computer of the vehicle.

(c) Goals for Aerospace Domain Automated Vehicles

These goals are mainly intended for the integration of UAVs and drones to be operated in the same airspace as civil and general aviation in a single European (world-wide) sky, flying free trajectories rather than on pre-defined standard routes.

1) Autonomous ATM (air traffic management) command execution: Technologies that allow UAVs and drones to fly their routes as programs via GPS waypoints but accepting and executing general ATM commands. In order to use the same infrastructure (airports, airspace etc.) as civil and general aviation, they must also be observed by air traffic control.

2) Security: Technologies that avoid unauthorized intrusion into ATM command communication requiring autonomous decisions for maneuvers in shared airspace

3) Appropriate on-board computer equipment and software implementing the technologies defined above.

(d) Goals for Off-Highway Domain Automated Vehicles

Even if such vehicles will not have to satisfy requirements in the sense of an SMC, goals will be almost identical to those defined in the automotive domain. Nevertheless, the off-highway domain will require significant enhancements and adaptations, since the infrastructure used will be significantly different. This will even have to be split w.r.t. different application areas, such as agriculture, forestry, heavy duty construction, and municipal equipment for uses including fire-fighting, garbage disposal and garbage collection, airports, harbors or industrial applications in industry 4.0 domains.

Apart from the commonalities between the automotive and the off-highway domains, different types of sensors and surveillance strategies and techniques to

[13] http://www.wsj.com/articles/toyota-maps-out-decline-of-conventionally-fueled-cars-1444824804. Accessed February 2016.

provide significant situation awareness need to be developed.

Furthermore, the off-highway domain will require fleet coordination in order to allow different vehicles to cooperate autonomously.

The different environments will potentially also require special drones to provide data for sufficient situation awareness and proper trajectory control capable of avoiding unexpected obstacles.

(e) Goals for Railway Domain Autonomous Vehicles

The goal for the railway domain is to apply up-to-date technology for improving the safety, reducing the operating cost and enhancing the user attractiveness of the rail transport system.

To reach these goals, both the vehicle itself and its surrounding ground infrastructure will have to be adapted or renewed.

The operation of automated railway vehicles should:

- limit or avoid the risks inherent to human behavior in the monitoring & controlling tasks of drivers or traffic controllers
- offer the right balance between investment in new systems and reduction of operating costs
- offer new or improved services forpassengers and freight transport

The following challenges need to be tackled in advance to make an autonomous railway vehicle a reality:

1) Developing dependable and cost effective technical solutions for new vehicles and for retrofitting existing vehicles
2) Minimizing the impact on the railway infrastructure and wayside ground systems
3) Clarifying the legal and normative frame for automated vehicle operation in a new railway category (cargo locomotive, tramwayé)
4) Generating a positive stakeholder acceptance (passengers, railway personnel, pedestrians, car driversé)

In terms of technical development for the automated railway vehicle itself, the focus will have to be placed on:

1) Selection of the right mix of sensors
2) Optimization of the sensor fusion
3) Development of secure real time video & data transmission systems
4) Development of safe, reliable, available and maintainable systems and components
5) Synergy with solutions available from other automated vehicle domains (automotive)

(f) Goals of Inland Waterway Domain

The goal for the inland waterway domain is to use up-to-date technology for improving the safety, reducing the operating cost and enhancing the user attractiveness of inland waterborne transport

To reach these goals, both the vehicle itself and its surrounding ground infrastructure will have to be adapted or renewed.

Increased assistance for nautical operation towards more automation should:

- limit or avoid the risks inherent to human behavior in the monitoring & controlling tasks of ship staff or traffic controllers
- offer the right balance between investment in new systems and reduction of operating costs
- offer new or improved services for passengers and freight transport

The following challenges need to be tackled in advance to make autonomous/assisted river ships a reality:

1) Developing dependable and cost effective technical solutions for new vessels and for retrofitting existing vessels
2) Considering the existing telematics infrastructure (RIS ï River Information Service)
3) Clarifying the legal and normative frame for automated/assisted vessels operation
4) Generating a positive stakeholder acceptance (public authority, cargo owners, passengers, ship personnel, commercial shippers and leisure boaters)

In terms of technical development for the increased assistance/automation of inland vessels, the focus should be on:

- Selection of the right mix of sensors
- Optimization of the sensor fusion
- Development of secure real time video & data transmission systems
- Development of safe, reliable, available and maintainable systems and components with attractive cost/benefit relation
- Synergy with solutions available from other automated vehicle domains (automotive)
- Integration of assistance systems into the legal framework of inland navigation

2.3 State-of-the-Art / Areas of Excellence

2.3.1 Electronics-based systems in Austria

Since one of the motivations of the current roadmap is to support ECSEL and its lighthouse initiative on automated vehicles (see e.g. Section 1.2), the Austrian electronics industry and research environment shall be loosely examined. A recent study on ñElectronics-based systems in Austria, facts and figuresò, initiated by bmvit and carried out by Joanneum Research provides comprehensive facts, figures and data for electronics-based systems (EBS) in Austria. It provides a comprehensive SWOT analysis concerning both industry and research in particular w.r.t. to other European countries, and includes recommendations for policy makers in Austria.

The main results of this study are:

- About 510,000 employees and researchers generate a turnover of close to 170 billion Euros in Austria.
- Most actors are present in global international markets and provide best in class solutions, products, and services
- EBS in Austria supports elements of various supply chains including but not exclusively: research, components, systems and related SW up to services levels and new business models.
- Industry 4.0, Internet of Things IoT, mobility, energy efficiency, connected living and health have been identified as major drivers for future growth in the EBS sector also for Austria.

2.3.2 Partner landscape

Concerning vehicles as such, Austria basically has no full vehicle manufacturers (there are exceptions to this in specific niches such as drones or powered two-wheelers) but there are numerous, world-renowned Tier1, Tier2 and specific component suppliers as well as engineering companies - mainly active in the automotive (road and off-road vehicles) and rail areas, but also in aeronautics. Therefore, either close cooperation with foreign OEMs and/or close cooperation among Austrian partners to jointly design, develop and build up platforms and demonstrators for automated vehicles is required (see Section 4.1, TF_5: Applications & Field tests).

This is substantially complemented by

- excellent industrial partners concerning road and rail technical infrastructure (incl. communication and signage)
- a broad research community, comprising both universities as well as non-university research institutions
- several road, rail as well as waterway operators such as ASFiNAG, ÖBB, Wr. Linien, viadonau
- public and semi-public authorities, institutions and associations such as AustriaTech, A3PS, ECSEL-Austria, or Austrian automotive clusters

2.3.3 State-of-the-art

All partners participating in the creation of the Austrian RDI Roadmap for Automated Vehicles were asked to provide information on the current state of the art, i.e. current level of technology/knowledge, and area(s) of excellence relevant to the roadmap, based on the following criteria:

- Current level of technology/knowledge in the area of ñAutomated Vehiclesò in the partnerôs company or research institution itself (incl. projects, patents)
- Description of the main relevant area(s) of excellence which can be used to contribute to the area of ñAutomated Vehiclesò
- Relevant products, procedures or services of the partnerôs company/company group or research institution in the area of ñAutomated Vehiclesò that are already on the market / will soon be introduced into the market

Below (Sections 2.3.3.1 to 2.3.3.3) is a summary of detailed partner inputs received.

2.3.3.1 Knowledge available

R&D projects

Austrian industrial and research partners have an excellent position in the European research landscape (ECSEL-Austria) and are leaders or participants in numerous European (ARTEMIS, ECSEL, FP7, Horizon 2020 etc.) and Austrian national RDI projects (KIRAS, ICT of the Future, Mobility of the Future) as well as non-funded projects. Topics comprise

- Automated vehicle testing
- Testing and validation of ADAS/ADF
- Radar sensor stimulation for automotive applications
- Robust sensor platforms and sensor data fusion

- Automotive electronics as well as design, verification and test of embedded systems
- V&V and safety & security co-engineering including standardization activities and certification aspects
- Development and testing of V2X communication in office and test-bed environments
- (Ultra-)Highly reliable communication
- Sensing solutions with different physical principles (audible acoustic, ultrasound, laser-optical, camera vision, radar, RFID, RF ultra-wideband time of flight measurement, inertial measurement units,...), for distance, velocity, position, and orientation estimation
- Global, local and relative inter-vehicle estimates of geometrical relationships between vehicles and their environment for subsequent path planning, obstacle avoidance, and vehicle control algorithms
- 3D vision technologies
- 3D sensing systems with 3D foveation properties endowing service robots with a higher level of motion and affordance perception and interaction capabilities
- Local position estimation for a forestry harvester in GPS-denied environments (visual odometry and inertial measurement units)
- Integration of vehicle sensors and sensor interfaces (active safety systems)
- Laser-rangefinder based driver-assist system for a tractor
- Inner-city logistics vehicle train with contactless coupling of individual powered cars (radar and ultra-sonic sensors)
- Development and integration of a collision avoidance system (CAS) in tramways
- Platform for multiple collaborating UAVs
- Analysis, design and evaluation of HMIs of automated vehicles with a focus on distraction aspects

EU funded projects (examples): COOPERS, CVIS, RobustSense, GENESYS, INDEXYS, ACROSS, POLLUX, CRYSTAL, EMC2, 3Ccar, ENABLE-S3, SafeCer, R3-COP, MBAT, ARROWHEAD

Nationally funded projects (examples): GAZELE, TASTE, HISPEED, TRUFAL, TRUCONF, SCRIPT, STEACS, COMPASS, DECS, COORDES, VECS MaDSAV, Christian Doppler Laboratory ñContextual Interfacesò

Patents

- Generating test data for vision algorithms.
- Stereo correspondence problem; visual 3D sensing and measurement; visual self-localization; visual sensor calibration
- Coordinated testing and error detection in distributed embedded microprocessor systems
- Two-dimensional antenna arrays for beamforming applications
- Dual mode radar methods and systems
- Collaborative microdrones and self-organizing intelligent networks of UAVs

Integration, V&V and Testing fields

- Concepts for functional integration of advanced driver assistance systems (ADAS) & partially-/ automated driving functions (ADF)
- Concept evaluation and virtual validation
- Testing strategies (especially for ADF)
- Functional integration demands for ADAS & ADF
- Subsystem test benches/HiL for ADAS
- Probe vehicles to gather safety critical manoeuvres, to be used in vehicle-infrastructure simulation, road safety assessment and risk analysis, in-depth accident analyses to investigate potential crash mitigation strategies for automated vehicles
- Telematics testing field for sustainable mobility with cooperative services; funded by the ñAustrian Energy and Climate Fondsò; (http://www.testfeld-telematik.at/home-en.html); the project tested how cooperative services have to be designed and employed to be able to contribute to more safety, efficiency and environmentally friendly mobility in the road network in the best possible way.
- ECO-AT (http://eco-at.info): the Austrian part of the vehicle-to-infrastructure (V2X), which extends from Rotterdam to Vienna via Frankfurt will warn drivers of appropriately equipped vehicles travelling along this route about highway construction sites. The project is designed to reduce the number of accidents and prevent traffic jams.
- Testing of automated vehicles in the DTA (Driveability Testing Alliance) - a consortium of sensor-, actor-, data-acquisition- and measurement-service providers - and by working in close relationship with leading OEMs and technical universities.
- Predefined test tracks with specific maneuver catalogues and measurement equipment
- Customer evaluation tests of collision avoidance systems (CAS) in tramways

Sensorics, Electronics and data acquisition

- Robust sensor based real-time applications
- On-line sensor data fusion, robust state estimation and fault diagnosis, as well as perception schemes and control theory
- Radar target stimulation of automotive driving scenarios; Measurement and characterization of (automotive) radar systems operating at 24 or 77 GHz. Generation and analysis of next generation automotive radar signals
- Large scale sensors - airborne LIDAR and radar systems, thermal and optical (stereo) camera systems, to small scale sensor systems used in smartphones.
- Sensor simulation and integration
- Automotive electronics as well as design, verification and test of embedded systems
- Analog and mixed-signal circuits to high-frequency and power semiconductors to embedded control solutions
- Data acquisition instrumention as central measurement and computation units to develop, test and evaluate lateral and longitudinal control systems in modern vehicles, providing various hard- and software interfaces to acquire data from virtually every sensor on the market and incorporate interfaces in actors such as driving robots

Communication, Connectivity

- Connected vehicle technology, in particular on safety and mobility related V2V and V2I communication based on 5,9GHz ITS-G5/WAVE
- Communication technologies (incl. satcom)
- 5G: high number of connections/km road (up to 30,000 and up to 200,000 connections/km2) bandwidth up to 3.75 Tb/s per km^2 with ultralow latency (1ms and below) high reliability rates of 99.999% (dependent on operation processes); applicable to all types of vehicles including airplanes (80 links per plane); IoT standardization initiative starting in 2016, which may provide similar services as in the in the 2G/3G technology
- (Ultra-)Highly reliable communication: Vehicle-to-vehicle channel measurement data and channel models, numeric link level simulation of OFDM based communication systems, frame error rate analysis of crossing scenarios, software-defined-radio prototyping of wireless transceivers
- Infrastructure for ITS (Intelligent Traffic Systems) and associated software and hardware (including roadside units) to enable vehicles to communicate with infrastructure
- Traffic control automation and cooperative, connected driving

Safety & Security

- IT security and resilient communication in various different technological environments. In-depth knowledge on the topics of (mobile) malware and malware detection, secure routing, networking in intermittent connectivity environments, also including systems security, e.g. Linux operating systems.
- Runtime verification, approximate (stochastic) verification
- Safety relevant systems for highly automated or autonomous controls, related ECUs and central vehicle computers, platforms, integration of applications on platforms, middleware and software for reliable data communication, networks & network components (switches & end systems incl. VHDL designs for miniaturized components)
- ADAS-relevant systems and highly automated controls for automotive, railway, aerospace, off highway, wind power plants etc.
- 5G: Capability to offer services for critical sectors E2E (end-to-end); security for critical infrastructure applications; protection against unauthorized access, use, disruption, modification, inspection, attack, etc.; guaranteeing a high level of security[14].
- Driver distraction research

Further knowledge available

- Expertise in real-time 3D reconstruction (mobile mapping), real-time validation of 3D mapping data
- Multicriteria (system-optimal) routing as basis for strategic traffic measures; microsimulation for multimodal traffic flows in urban, rural and highway situations; location planning for infrastructure (car parks, charging stations)

[14] next generation mobile networks ï 5G White Paper. https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf. Accessed on 28-Feb-2016.

- Autonomous navigation (used for Mars rovers)
- Neural circuits: Implementation on FPGA; Learning of behaviour; Adaptive, distributed control; Neurons + synapses
- Reconfiguration / dynamic scheduling: self-healing hardware (dynamic, reconfigurable)
- Control: robustness, adaptation, distributed control, adaptive (learning [also human models]), robust, optimal control (also distributed)
- Intelligence: machine learning
- Robust tracking and trajectory planning under the influence of erroneous measurements and environmental influence
- Design and validation of HMI systems
- User experience and user acceptance research

2.3.3.2 **Areas of excellence**

Sensors / Sensor systems

- Development of optical sensor systems (including MOEMS)
- 3D-Vision sensors, object detection, real-time 3D-environment mapping, path planning, outdoor & indoor vehicle localization
- Radar system development and interference analysis
- Microwave wave propagation analysis
- Assembly, test and measurement of radar components at wafer level up to system level
- Integrated RF-circuit design, design of passive and active RF components
- Realization of radar sensor prototypes with tailored combination of hardware and software, ranging from RF components over analog and digital baseband hardware to signal processing algorithms
- Development of magnetic sensor systems for automotive applications
- Sensor networks
- Real-time sensor data processing and sensor data fusion, state estimation and systems diagnosis and perception
- Mathematical modelling and experimental verification of sensor performance including theoretically achievable bounds

Smarts Systems / Cyberphysical Systems

- Hardware/software co-design and verification, system-on-chip design, FPGA & ASIC design, embedded systems software design, model checking & formal verification, simulation, test & diagnosis, electronic de-sign automation & tools, automotive & control networks, wireless & ad hoc networks, real-time & distributed systems
- Concept, design and prototyping of micro-mechatronic modules
- Miniaturization of sensor/package system
- 3D interconnect device prototyping
- Micro-assembly and packaging under clean-room conditions
- Mobile robotics

Communication / connectivity

- Ultra-reliable wireless vehicular communication systems, wave propagation models for non-stationary vehicular scenarios, performance test of vehicular communication systems, wave propagation measurements between multiple vehicles
- Ad-hoc networks, cooperative relaying, handling of interference in wireless networks, distributed time synchronization and consensus for wireless systems, queuing problems, multimedia communication, design of self-organizing systems and distributed decision making (teaming UAV and ground robot swarms, which may also be relevant to teaming/swarming effects or complexity handling in traffic management)
- Terrestrial and satellite based communication systems (including QV band, project Alphasat TDP5, Ka-mobile)
- Hardware and software development (protocol stack, application) for 5,9GHz DSRC in-vehicle and roadside equipment. End-to-end system development for V2X communication including central system software for co-operative traffic management applications. Standardization contribution in numerous SDOȏs for V2X (SAE, IEEE, CEN, ISO, ETSI,..)
- Integration of V2X systems into traffic management backends, provision of road operator content including comprehensive sensor data (traffic, weather, etc.), using DatexII/ETSI/ISO standards.
- Experimental assessment of even airborne signal reception (L-band and Ka-band, Aero Channel)

Simulation and Simulation Tools

- Vehicle simulation tools for ADAS/ADF development and testing
- Co-simulation platform for interconnection of simulation tools
- Multi-physical simulation
- Microsimulation of coexistence of conventional and highly automated vehicles in various scenarios (varying penetration rate of highly automated vehicles) in different vehicle maneuvers and/or use cases
- Simulation of atmospheric influences on RF sensors (radar, project Ka tropical + Alphasat propagation + Channel Forecast)

Safety & Security

- Automotive safety (functional safety) and automated driving
- Safety & security co-analysis and co-engineering: Consideration of safety & security interaction during system engineering, including safety aware cybersecurity concepts for connected ECUôs and safety & security co-analysis and co-assurance.
- IT-Security, starting at the conceptional level and going up to practical implementation and especially secure development and security testing, including designing of secure architectures and security by design. Network and signal security, e.g. GSM & LTE security, RFID, IPv6, DNS, TLS, ITS-G5 security, public key infrastructures.

Integration, Verification & Validation

- Tools for ADAS integration, V&V
- Automated system V&V (incl. objective evaluation of ADAS functionality)
- Automated system integration in light rail vehicles
- Model-based testing of behaviour (i.e. actuation & control) and non-functional properties, including robustness of visual perception against optical challenges (e.g. textures)
- Sensor integration, simulation and validation (hardware/software)
- High integration, specific and innovative sensor solutions based on novel semiconductor technologies. E.g. LIDAR technology is a key enabler for fully automated vehicles. Driver and human monitoring (presence, position, biometric, spectral) will play a key role, in order to detect how fast the switch back to a human driver is possible from the automated driving mode.
- Development of test- and validation-environments for sensors and actuators
- Living lab testing of V2X communication in real life road traffic incl. test monitoring

Measurement systems and calibration

- Modular, scalable and rugged measurement systems that are able to acquire data from multiple sources synchronously, at very high speed and precision. The fund of experience in vehicle testing is key to provide customized solutions for the challenges of automated vehicle testing.
- Calibration of ADAS functionalities

Mapping and positioning

- Generation, validation and real-time update of 3D mapping data
- Accuracy validation of positioning systems considering diverse environmental influences

Mobility

- Coexistence of conventional and highly automated vehicles in various scenarios (varying penetration rate of highly automated vehicles) in different vehicle maneuvers and/or use cases for impact assessment for these scenarios, i.e. by means of KPIs (travel time, traffic flow capacity, etc.)
- Floating car/probe vehicle data for the identification of hot spots; measurement and analysis of road infrastructure data based on LIDAR and stereo vision cameras, 3D road modelling for virtual vehicle testing, Road safety assessment and risk analysis.
- Traffic control automation and cooperative, connected driving

Human-Machine-Interface

- Analysis of human-machine interfaces regarding distraction and attention
- Design of novel in-car interaction approaches

Experience in different application domains

- Aerospace (primary flight control, power distribution systems, cabin pressure control, airconditioning, engine control, é), automotive (ADAS and automated driving, é), off-highway (agricultural machines, cranes, special vehicles incl. firefighting apparatus, ..), industrial applications (windpower plants and turbine control, é) and space (data backbone for ORION, é)

2.3.3.3 **Relevant products, procedures and services**

Tools and methods

- Tool suite for model-based test case generation for behaviour (embedded control) testing, supporting various modelling languages
- Tool set for coverage-oriented robustness testing of vision algorithms against optical challenges such as textures, or low contrast
- FMVEA method / tool for safety & security co-analysis of embedded CPS
- Workflow engine for analysis, certification and testing, supporting automotive, rail and generic safety and security standards

Semiconductors, ICs

- Semiconductors / power electronics for mobility application in cars, trucks, trains and airplanes
- ICs for automated braking assistants

Sensors / Sensor systems

- Touchless position sensing products (capacitive, inductive, hall)
- Sensor systems for assisted and automated driving
- Multi-channel radar sensors with range-angle-Doppler measurement capabilities at frequencies from 1 GHz to above 100 GHz
- Optical sensors for presence, colour and gesture detection.
- Real-time optical stereo camera based 3D reconstruction for autonomous navigation in unknown environments.
- Bio-sensing and spectral sensing

Connectivity and Infrastructure

- V2X in-vehicle equipment: V2X evaluation kits, planned: V2X radio modules and complete ex-works V2X vehicle ITS stations, V2X retrofit and aftermarket units
- V2X roadside ITS Stations, V2X central ITS stations and applications
- ITS installations for testing 5.9 GHz cooperative systems
- Interface from X2V traffic control center systems to traffic cloud services
- Simple tracking realtime application for managing traffic lights and passenger information
- Electrical systems, signaling and communications technology, as well as centralized control units.
- Simulation tool for mixed traffic situations; Multi-criteria routing tool

Measurement / performance of sensors and communication systems

- Investigations and certificates in relation to radar system performance and interferences
- Real-time wave propagation emulation and performance test of wireless communication systems (5G and 802.11p)
- Microwave and mm-wave measurement services
- Validation of RF sensor based systems considering atmospheric influences

Data logging, network, middleware and software components

- Flexible data logging systems for raw-data collection in application-oriented scenarios
- Networking components for TTEthernet and deterministic Ethernet
- Middleware and software components and platforms for safety relelevant data communication and controls

Development, Functional Integration and Testing of ADAS and ADF

- Advanced algorithm development of ADAS functionalities
- Functional integration demands for ADAS & ADF
- Concepts for functional integration of advanced driver assistance systems (ADAS) & partially / fully automated driving functions (ADF)
- Concepts for evaluation and virtual validation
- Testing strategies (especially for ADF)
- Automatic detection and objective evaluation of basic ADAS/ADF functions
- Test and evaluation systems for ADAS such as ACC, FCW, AEB, LKA etc. capable of wirelessly exchanging data between multiple moving vehicles
- Subsystem test benches/HiL for ADAS

ADAS solutions

- Optical camera surveillance solution for cars with real-time image processing and video transmission to a smartphone based control application

- Advanced optical driver assistance system for collision prevention for tramways
- ADAS collision avoidance System for tramways

Engineering and Consulting Services

- Engineering services for calibration and testing of ADAS functionalities
- Consulting services in the areas of hardware/software co-design and verification, system-on-chip design, FPGA & ASIC design, embedded systems software design, model checking & formal verification, simulation, test & diagnosis, electronic design automation & tools, automotive & control networks, wireless & ad hoc ne-works, real time & distributed system
- Concepts and engineering of ADAS for new OEMs in emerging markets, engineering and validation for established OEMs

User Centred Design

- User centred and participatory design for vehicles of the future
- Interaction Design
- Usability and user experience evaluation techniques

Test Tracks

- Predefined test tracks with specific maneuver catalogues and measurement equipment
- Living lab for V2X communication on real highways

2.4 Expected Impact

One of the megatrends in the mobility area is certainly the evolution from ADAS (advanced driver assystant systems) to (semi)automated driving vehicles. The expected impact on optimized energy consumption, reduced emissions, increased active and passive safety and comfort are very well known and evident.

Several states in the US have passed legislation permitting the operation of high to fully automated vehicles (within defined environments). Hence, key OEMs view North America as a launching pad for active participants keen on making market advancements.

Many global OEMs are working on automated vehicle demonstrators. German luxury automotive OEMs will be introducing conditionally automated vehicles in the market within the next three to five years

The automated driving segment is highly integrated due to the high quality and safety requirements of auto manufacturers. Auto manufacturers integrate electronic components and systems very early in their product development roadmaps and will favour stability in their supply chain.

In this context, semiconductors and related electronic components and systems play an indispensible role as enablers for automated driving. In terms of categories of semiconductors, strongest growth is usually expected in sensors, analog and discrete (especially power) components. Autonomous vehicles however face very complex technological and legislative challenges. Austria is well prepared and has leading players to drive the increasing penetration of automated driving functions, electric and hybrid vehicles.

Automated driving activities are strategic activities in the US and Japan. One reason for this is official permission to let autonomous cars drive on roads in certain regions. Recognizing this trend, EU politics is about to start granting such permissions, to avoid that Europe loses competitiveness in this fundamental future technology.

Austria is a country with a traditionally strong supply industry for the automotive industry as well ICT including hardware and software.

Present examples for Austrian contributions in global markets of AAV show that Austrian industry is in a good starting position and that there is large potential for substantial growth.

- Recent statistics ñAutoland Österreichò based on inputs from Statistics Austria and the Fachverband der Fahrzeugindustrie show impressively the importance of the automotive industry in Austria; Close to 250,000 vehicles and 2.2 million engines and gearboxes are produced per year in Austria. The turnover of this sector is reported to be around 43 billion Euros per year and during the last 25 years accumulated investments of approximately 8.4 billion Euros have been made. Around 450,000 jobs are directly or indirectly assigned to the vehicle sector in Austria.
- The study ñElectronics-based systems in Austria, facts and figuresò (see also Section 2.3.1) initiated by bmvit reports impressive figures of EBS in Austria. Almost 510,000 employees and researchers generate a turnover of close to 170 billion Euros in Austria. The emerging market of automated driving will significantly contribute to not just keep but to further increase these figures, underlining the

huge importance of EBS research and industry in Austria.

- ADAS for tramways: Bombardier Transportation Austria and AIT Austrian Institute of Technology are introducing an advanced driver assistance system for trams. It is the first such collision prevention system that has been developed under explicit consideration of the special requirements of light rail vehicles in mixed traffic. The technology represents an important basis for further levels of automation. This development gains global impact in the sector since Bombardier is among the major distributors of light rail vehicles world-wide.
- Concepts like ñTram on demandò in smaller urban environments or around regional branch railway lines require highly or fully automated rail vehicles and a management system on top of it. Austrian industry could be leading in this area. Some research projects and prototype tests have already taken place.
- Austrian chip manufacturer AMS acquired CMOSIS, a leading supplier of innvotive area scan CMOS image sensors. Progress in image sensor technology is an important driver for better perception systems required for autonomous systems.

Therefore it is essential for Austria to play an important role in Europe in this field to expand its position and to establish new business opportunities.

The representative organizations from industry research centers and academia expect the following impact:

- Common agreed approach for these activities
- Establishing of value chain or partial supply chain
- Strengthening international cooperation in R&D projects in particular in Europe
- Better basis for representing Austrian actors in the various committees in Europe, such as ARTEMIS, EPoSS, and ERTRAC/EGVI
- Projects of common European interest
- Allocation of a specific budget in Austria for these activities
- Establishing test areas for SAE level 3 tests in real driving conditions followed by level 5 test regulation
- Investing also in needed infrastructure for R&D
- Ensuring high user acceptance of HMI in automated vehicles

3 Applications

3.1 Applications in automotive on-road vehicles

The 2015 version of the multi-annual strategic research and innovation agenda from the European joint-undertaking ECSEL (*ECSEL MASRIA*) states:

Significant breakthroughs have been made in advanced driver assistance systems by European vehicle manufactures and vehicle suppliers recently. In order to swiftly proceed towards highly automated driving and flying, where the system relieves the driver from steering, accelerating and monitoring of the vehicle environment, the following three steps can be foreseen in the automotive domain (see also [1], *similar steps exist for the other domains in the mobility sector):*

1. *By 2020, conditional automated driving (SAE Level 3, see* Figure 2*) is expected to be available in low speed and less complex driving environments, e.g. in parking lots and in traffic jam situations on one-way motorways.*
2. *By 2025, conditional automated driving is expected to be available at higher speeds in environments with limited complexity, e.g. on highways.*
3. *By 2030, (conditional) automated driving is expected to be available in most complex traffic situations, i.e. in cities.*

Technological challenges in automated cars:

In closed and secured environments (e.g. factory floor, new city areas with dedicated infrastructure, precision farming, etc.), a revolutionary scenario to introduce automated vehicles without intermediate steps is likely to be proposed. Such vehicles with different levels of automation will be built on advanced systems for driver assistance, cooperative systems, and driver status monitoring as well as environment perception. Systems will be validated under virtual, semi-virtual and real world conditions. This requires dependable solutions for advanced sensors and actuators, data fusion, efficient use of connectivity, human interaction technologies, CPS, and (real-time) simulation concepts.

Secure and reliable communication networks, data links among vehicles as well as between humans, vehicles and infrastructure will be fundamental for traffic management systems. This will allow cooperative decision making in vehicle guidance and benefit from high performance computing systems. Technology transfer to and from robotics and aeronautics is an essential part of the development process, and the creation of regulatory frameworks as well as in-vehicle standardization has to go hand in hand with technology development.

Highly automated and autonomous cars are the next major technology field and challenge enabling a huge number of new applications, business models and major commercial opportunities for European high-tech companies in automotive industry sectors. Recent studies have identified an estimated annual market value for autonomous systems in transport (automotive, air, rail, and maritime) of 82 billion ú for the UK market only[15]. The global market for partially and fully automated vehicles is expected to grow from around \$42B in 2025 to \$77B in 2035[16]. These numbers show the vast potential of this industry and the capability of the European industry to be at the forefront of automated vehicle development and deployment. Due to this high market potential, technological giants such as Google and Apple as well as large industrial conglomerates such as Rio Tinto are investing heavily in the automated vehicle domain. This can lead to the development of technologies that represent a threat to well established European industries.

It is imperative for Europe to compete strongly in view of such technological and tremendously funded business rivals. A key factor for European automated vehicle leadership resides in its ability to manufacture highest quality vehicles at competitive costs. Automated vehicle applications and benefits are countless and we are only starting to understand the new markets, business models and products of this disruptive technology.

Many technological challenges offer opportunities for the Austrian industry and academia to take advantage of their excellent knowledge. The challenges comprise:

- Development of reliable and secure communication architectures for automated vehicles
- Development of connected macro architectures consisting of automated vehicles, traffic management centres and roadside infrastructure

[15] Trotta, F., Autonomous Systems: Opportunities and Challenges for the UK, Knowledge Transfer Network, April 2014, Available at https://connect.innovateuk.org/documents/3299324/6049173/Autonomous+Systems+Report.pdf/d05a4cd6-fa91-4f4c-99b3-08b672dd967c; Accessed February 2016.

[16] Boston Consulting Group: The Road to Autonomous Driving, http://de.slideshare.net/TheBostonConsultingGroup/the-road-to-autonomous-driving, January 8 2015; Accessed February 2016.

- Development of reliable, extendable and maintainable software platforms and algorithms for automated vehicles
- Development of reliable, extendable services related to and supporting autonomous and automated driving
- Development of cost-effective, reliable hardware platforms for control units which are the heart of automated vehicles
- Development of new sensors to create an accurate image of the outside environment for automated vehicles under any environmental conditions as well as their simulation models and test environments
- Development of reliable scene understanding capabilities, exploiting all available information from sensors, communication, and the past for enabling safe decision planning and action control.
- Development of fully reliable real-time high performance in-vehicle communication systems to cope with the exponential increase of data from the many sensors in automated vehicles
- New validation and verification methods and tools to cope with the diffiiculty of demonstrating and proving the reliability, safety and robustness of automated vehicles in all conceivable situations, i.e. in all possible traffic situations under all potential road and weather conditions.
- Development of HMI solutions that are highly accepted among users

This collection of issues has been identified by ERTRAC as a key challenge for the automotive industry and is today the main roadblock for product homologation and certification and thus commercialization of many new automated driving functions. Recent scientific publications from the automotive sector predict that more than 100 million kilometers of road driving would be required for the thorough validation of an automated car.

Only if these extensive tests have been performed will it be statistically proven that the automated vehicle is as safe as a manually driven car. Taking further into account the high number of vehicle variants and software versions, it becomes obvious that new approaches are required to validate electronics, components and systems for automated cars within a reasonable time period at reasonable costs.

The Austrian industry as well as academia suggest a lighthouse project(s) to develop prototype vehicles with various automation functions up to a fully automated vehicle. These prototype vehicles shall be tested in virtual test environments as well in Austrian road testing areas (discussed in the working groups of the Automatisierungsgipfel organized by bmvit).

Candidates such as the EcoAT Living Lab (Vienna) and other sites are currently being discussed as Austrian road testing areas for automated driving by the ASFiNAG management.

As stated in the A3PS roadmap [3], besides public roads particular testing areas will be needed, where especially bad road and weather conditions in a complicated mixed traffic environment can be tested in detail. Such testing areas shall include rural roads, city areas, high-speed areas as well as multilane roads where both vehicle and infrastructure technologies can be tested in a mixed vehicle environment. These traffic environments also include automated vehicles, non-automated vehicles, trucks, bicycles, dummy pedestrians, dummy animals, construction and artificial obstacles. Demonstration of dependability, i.e. safety, security, integrity, availability, reliability and maintainability of automated driving vehicles will be of great importance (see also Section 4.1, TF_5: Applications & Field tests). In addition to this, having a cross-border testing area is of high importance to demonstrate the interoperability of solutions in different countries.

3.2 Applications in off-road equipment

Based on the successes and the progress made in the automotive on road vehicle domain (interpreted as vehicles known as passenger cars, thus trucks and busses etc. are not included in the considerations related to automotive on road vehicles) numerous industrial areas subsumed under the acronym of ñoff road equipmentò have indicated increasing interest in migrating technologies from the automotive sector to their domains with respect to autonomous operation. In more detail, this applies to the agricultural sector, any kind of forest machines such as forwarders and harvesters, heavy duty machines such as construction and mining equipment, trucks, community vehicles such as busses, airport vehicles of any kind, and vehicles used for firefighting, garbage collection, disaster management and many more uses. Other applications may even range up to transport, production and service tasks in/on industrial premises, subsumed under robots and ñIndustrie 4.0ò.

It looks rather straightforward to simply install electronic control units (ECU) developed for application in the automotive sector in another domainôs applications, but a closer look often reveals the contrary. For example, infrastructure in road traffic provides roads on a flat and solid ground, traffic signs, driving lanes and lane marks, maps and radio traffic services enabling on-board 2D-camera systems to support detailed steering information in addition to the GPS information. Radar sensors are well suited to detect looming metallic obstacles (other vehicles).

Typical environments in off-road applications are much more unstructured and harsh. Considering a scenario for autonomous agricultural machines with uneven soil where dust and high standing crops are partially blocking the front view will result in very different requirements on the sensor system to be able to create a generic (3D-) model of the surroundings of an autonomous machine. A particular challenge in many applications lies in the fact that mobile machines often manipulate their own environment (harvester cuts grain, excavator shovels material, etc.), which is a very challenging condition for perception systems that must safely detect relevant obstacles, endangered persons or even an abyss. On the other hand speed is significantly lower in almost all off-road applications.

Thus there is a demand for developing other methods and different sensors to deliver relevant control data for autonomous operation.

However, the off-road application field offers interesting chances for concrete application in the near future, once a sufficient level of technical maturity is reached:

- Off-road environments can be more easily arranged as closed areas with restricted access to humans, other vehicles or large animals, thereby imposing different (actually lower) requirements for safety regulations and homologation of autonomous systems.

- The tasks of mobile machines can be less complex, because often there might be no need to interact with other moving objects.

- Some working environments exhibit high risk for health and life for the humans who have been manually operating machines under harsh and sometimes dangerous operational or environmental conditions. Automating such machines might receive additional support from society and the authorities.

Application example 1: Farming

The agricultural sector in Western and Central Europe is subject to an ongoing structural change. There is still a strong need for an increase of mechanisation and automation in farming. Ever increasing machine sizes will reach their limits in the small structures typical to the agriculture and landscape in Austria and many other countries: a remedy might be driverless tractors and harvesters.

The desired goal is also related to a detailed management and autonomous operation of fleets of machines cooperating autonomously. Thus the range of autonomous operation functions can significantly surpass the functionality of navigating the machine alongside a virtual pre-programmed track. (a) Intercommunication among the fleet: the fleet of machines (e.g., harvesters) must be coordinated to drive in a ñswarmò and work on tracks that are sufficiently offset in order to avoid working on parts of the field that were already harvested by the neigbouring machine. Thus they need to communicate among each other to harmonize their trajectories. (b) Communication with other fleets: a fleet of harvesters might need to communicate with a second fleet: the tractors collecting the harvested crops from the harvester and delivering them to a storage point. Such communication needs to include autonomous commands in order to start loading, stop loading etc. to be able to forward the harvested crops to a storage point. (c) In conjunction with classic goals of ñsmart farmingò, a third fleet might be useful: unmanned aerial vehicles (UAVs), providing a birdôs-eye view for detecting the status of soil, plants and weeds and also obstacles such as stones or holes that might cause damage to the implements. In addition, animals or even humans (children) may be in the machineôs trajectory and may be invisible to an onboard sensor system. Thus such information exchange will also be required in order to assure proper operation.

Application example 2: Airport Firefighting and Service Vehicles

At modern airports a dedicated and limited area is used by a huge fleet of vehicles ranging from baggage transporters, passenger busses, gangway machines, catering trucks, fueling trucks, follow me cars etc. Since the tracks that are offered are clearly defined, autonomous driving equipment would be of high value. However, it must be guaranteed that no persons or aircraft, other equipment & vehicles are endangered, regardless of the weather conditions (e.g. fog!). Eliminating drivers would save a lot of money and dispense with a monotonous job. However, different control mechanisms would be required in order to specialize the vehicles for autonomous airport operation.

Application example 3: Autonomous Systems in Production Environments, Mining and Construction sites

Autonomous vehicles for transport and service tasks in/on industrial premises, in logistics when loading/unloading or distributing goods of all kinds, in particularly structured environments or under particular operational conditions can further increase productivity and competitiveness of factories and optimize multimodal transport on a regional or global scale.

On mining and construction sites there are already real-world examples of successful applications of autonomously operated vehicles. A next task might be transferring such technologies e.g. to machines and construction sites of a smaller scale

Application example 4: Disaster Management

Environmental disasters such as floods, avalanches, landslides, earthquakes, or forest fires not only threaten the lives of directly affected humans and cause environmental damages of enormous costs, they also endanger emergency crews, firefighters, and all other helpers. The use of UAVs or other automated vehicles that can detect entrapped or buried persons, or off-road machines that can, e.g., help to stabilize landslides or buildings in danger of collapsing would significantly reduce the risks for rescue teams.

A related topic is dangerous operations in mountainous regions, e.g. for establishing avalanche barriers on steep slopes, an issue particularly relevant for Austria.

Application example 5: Maritime Applications

Providing solutions for autonomous maneuver-ing of large ships would reduce the need for external pilots generally used in complex harbours. Obviously, the requirements for maritime applications are somewhat different than for land vehicles.The advantage of autonomy in maritime applications is also obvious since a lot of damage to vessels and surrounding constructions is caused by humans and errors in navigation. Eliminating this threat is largely welcomed by shipping companies.

These examples show that there are many potentially useful applications besides automotive on road use cases. On the other side, different equipment will be required that needs to be developed separately, even if making use of some of the results and achievements gained in the area of autonomous operation for automotive on-road vehicles. In addition to the ñstraight forwardò insights, different standards need to be achieved when different application areas are considered. Safety as well as security aspects might significantly differ or be more or less strict for different applications.

3.3 Applications in mobility infrastructure

Highly or fully automated vehicles covering different transport systems (automotive, rail, ship and aircraft) will result in optimization with respect to sustainable transport (energy, environmental impact etc.) on a higher, more comprehensive level than just taking into account a single transport mode in fulfilling the task of moving people and goods on a regional or even wider level. This includes highly automated traffic control, logistics, communication, cloud computing and services, situation-aware self-learning of the transport system (vehicles and infrastructure).

This not only involves the big players in producing and operating vehicles, communication means and road/rail infrastructure but also industry in the database business, cloud service business, intensive logistics software and systems business. This opens additional markets beyond the classical businesses and markets which are considered in most cases when discussing automated vehicle challenges. It implies huge additional efforts in R&D&I and addresses societal, environnmental and political decisions in the European as well as on a global scale.

The role of a reliable mobility infrastructure will be of high importance for automated driving. The European Roadmap Smart Systems for Automated Driving of 2015 [6] states that: ñEven though creating of a dedicated vehicle communication infrastructure is not deemed necessary for AD, it can accelerate it, and it is also a prerequisite for application in urban areas.ò and ñBesides, from the DOT perspective, the potentials of automation can only be achieved if vehicles are seamlessly connected to infrastructure.ò

The main challenges for the mobility infrastructure of tomorrow are:

- Wireless secure sensor connections to infrastructure
- Dynamic mapping
- Ubiquitous position
- Reliability in critical situations

3.4 Applications in aerospace

Compared to on-road vehicles and off-road-equipment, the aerospace sector in principle is already very advanced. Aircraft generally have already been automated to a high degree already for many years. Most if not all control functions required for flight already use digital control electronics which have replaced the pure mechanical systems as a state of the art. Automatic pilots, landing support and many other systems support pilots in their daily work in the cockpits. One can almost say that aircraft are already capable of close to autonomous flight today.

However, another strongly growing group of aeronautic traffic participants is showing up: the UAVs and drones. UAVs are meant to fly close to or fully autonomously and similar performance will be expected from drones, even if they are probably not meant to operate in the same airspace as aeronautic traffic today (general and commercial aviation). This challenges the aerospace application domain in a similar way as the automotive sector, where mixed traffic is to be assumed. UAVs and drones need to become significantly safer to perform all decisions to merge seamlessly into todayôs air traffic without endangering or unintendedly influencing other aeronautic traffic due to their autonomous control. Regulations for civil aviation must be respected and processes must be ensured even if autonomous control is considered and no human supervision is available as a ñfall back layerò.

This requires numerous developments in both software and hardware with respect to control units and flight control and mission control computers. Additionally, regulations (a legal framework) need to be developed in order to allow autonomously flying objects to maneuver in the public airspace used by general aviation, commercial aviation and ï in the next consequence - UAVs and drones (even if regulations are not considered to be part of this initiative).

In case UAVs and drones will at least partly use the same airspace, measures must be put in place that guarantee proper control in a shared airspace. Open questions range from:

1) Autonomous take-off scenario

Using the same airports as i.e. commercial aircraft the UAV needs to allow influence of ground control and the tower to use the same facilities. The UAV needs to respect the same procedures as other aircraft with the difference that there is no pilot available and it has to interpret and execute the tower and ground control commands automatically without human supervision and at least as reliably as trained pilots.

2) Autonomous approach scenario

The UAV will have to respect the tower commands and will have to execute them in the same way as commercial pilots do, just controlled automatically. They will have to que up appropriately, fly in holdings if requested and will have to follow instructions from the tower automatically.

3) Autonomous landing scenario

Again the commands from the tower need to be fully respected and the automated functions need to be capable of interpreting tower commands in the same manner as pilots do.

4) Autonomous flight scenario

During flight, similar requirements will have to be respected as for the other scenarios. In addition, the UAV will have to conduct all changes of control responsibility of the ATM stations in different countries autonomously and will also have to fully respect the commands in order not to endanger other traffic (register and sign-off procedures).

5) Avionics

With increasing states of autonomy, requirements for assistance systems will also increase. Thus, technologies are required in order to meet advanced safety functions to allow safe navigation and flight.

6) Visual Perception

The small size, low cost and easy handling of advanced UAVs rapidly foster their applications and development. To perform productive activities, it is important that the aircraft maintains stability in the air (avoiding collisions as well avoiding unnecessary manoeuvres) which requires perception in the environment such as localization, and environmental sensing and perception (object and situation identification).

7) Safety Issues

Operating UAVs in a restricted or civil airspace requires technical approval. Therefore the competence is divided between national and European responsibilities. Harmonization would be required here.

These examples for developments needed to enable the participation of UAVs and drones in the same airspace as general and commercial aviation demonstrate the depth of development and design necessary to broadly provide UAV functionality. Application areas were already shown by the Amazon hype for delivering their goods via autonomous drones that would navigate by means of GPS and address as input parameters. However, practical attempts have impressively proven that there is still much be done prior to accepting such technology in public spaces.

3.5 Applications in railways

Railways have a significant share of the overall transportation volume of passengers and goods. The various kinds of rail vehicles, ranging from high speed trains and regional branch trains to urban light rail systems, metros and tramways all have a well-established application range.

Vehicle automation in the railway domain can be classified in two different fields of application: urban rail and main line systems. The difference between urban rail and main line systems stems mainly from the fact that urban rail systems usually operate on a closed railway network (i.e. there arenôt any level crossings and the tracks are enclosed and used exclusively by trains that belong to the urban rail operator). Also, the rail topology is much simpler in urban rail.

The main focus in **urban rail** is increasing the degree of automation in metro systems. There are various degrees of automation, or Grades of Automation (GoA) which are defined according to which basic functions of train operation are under responsibility of staff, and which are the responsibility of the system itself. For example, a GoA 0 would correspond to on-sight operation, like a tram running on street traffic. GoA 4 would refer to a system in which vehicles run fully automatically without any operating staff aboard. This mandates an Automatic Train Control (ATC), which automatically performs normal signaler operations such as route setting and train regulation. There is no driver, and no staff assigned to accompany the train, corresponding to a GoA4. If present, staff is assigned for passenger comfort.

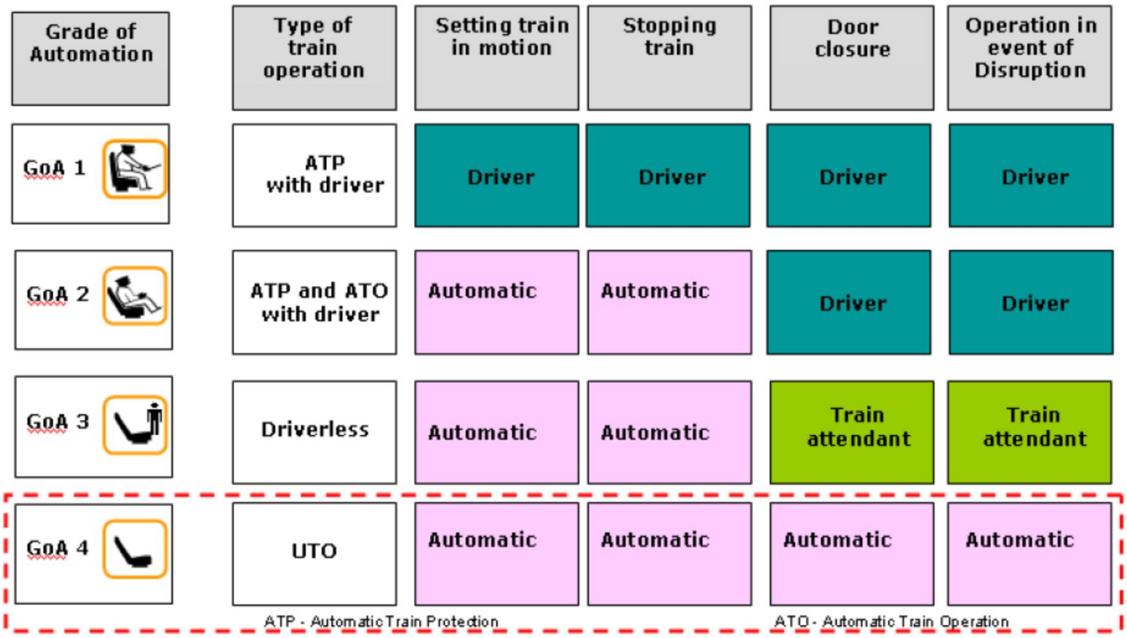

Figure 9: Grades of Automation in urban rail [10]

Todayôs regulations allow (in most cases) autonomously operated train systems only on tracks that have a physical fencing that prevents any access to the tracks. Such systems can maintain a very low risk for collisions with obstacles, and therefore, they need not be equipped with collision prevention systems based on extensive sensor systems. Such systems are well known as ñpeople moversò at airports. Also, some underground trains are operated driverless, in most cases with closed platforms where doors open only when the train doors behind them are opened, like in an elevator. Another example for driverless operated trains is the London Docklands Light Railway, where the entire concept was driven by minimizing the staff necessary for operation.

In many cases, such a physical fencing would either be not economically viable (e.g. for regional branch lines), or it would be simply unfeasible in mixed traffic areas (tramways). Other possible application scenarios are based on concepts with rather small, self-driving train cabinets that operate more or less ñon demandò, in an analogy to elevators. All these types of transportation systems are potential subjects for advanced technologies for autonomous operation. Actually, there are traffic modalities that are somehow in between road vehicles and rail-bound systems, namely urban buses and, especially, electrically driven trolley-buses.

We consider on board devices for sensing the environment in order to detect and avoid any obstacles as one of the crucial technological elements that are required to enable autonomous operation of such vehicles. Today, we see first OEMs announcing collision prevention systems for tramways. Such systems are designed to act as driver assistance systems, but in the future, similar concepts will also be part of the technical equipment required by driverless trains operating in ñopenò environments.

Similar assistance systems are becoming more and more common in the automotive area.However, the technical conditions and requirements are significantly different for cars and, e.g., trams:

- Trams brake at much lower levels of deceleration, which means that at equal speed the rail vehicle requires much longer braking distances, which in turn requires farther reaching 3D sensors, which are partially not yet available.
- Emergency braking in trams causes a significant risk of injury for the passengers. Automated braking systems on trams are therefore more critical in terms of false alarms or unnecessary emergency braking.
- The fact that trams are rail-bound seems to be an easement for realising automation, because steering would not be an issue. But in turn, it also removes the possibility of avoiding obstacles by means of steering manoeuvers.
- Regional (local) trains on secondary or tertiary railway lines operate in a somewhat ñopenò environment, with level crossings and the possibility that persons or large animals cross the tracks. On

the other hand many objects, particularly overhead line masts in curves, are in line of sight but are not obstacles requiring action. A combination of detailed maps with technologies for scene understanding and collision avoidance, together with GPS train positioning will be an efficient means to automate this type of rail traffic, which will not implement ETCS.

- Validation, verification and certification of systems mentioned above, particularly with respect to safety, reliability and cybersecurity and robust vision and perception, will be an important challenge.

All these issues add to the assumption that effective and reliable obstacle detection systems for trams need to be particularly anticipatory. In the long run, this can only be achieved by incorporating concepts of artificial intelligence, highly sophisticated capabilities for object classification and scene understanding which are simply not yet available.For **main line systems** the European Train Control System (ETCS) is a signaling, control and train protection system designed to replace the many incompatible safety systems currently used by European railways, especially on high-speed lines by using standard trackside equipment and a standard controller within the train cab. ETCS currently supports three levels: Level 1 is a cab signaling system that can be superimposed on the existing signaling system, leaving the fixed signal system in place. Level 2 is a digital radio-based system, where movement authority and other signal aspects are displayed in the cab for the driver. So far ETCS is used up to Level 2 in the field.

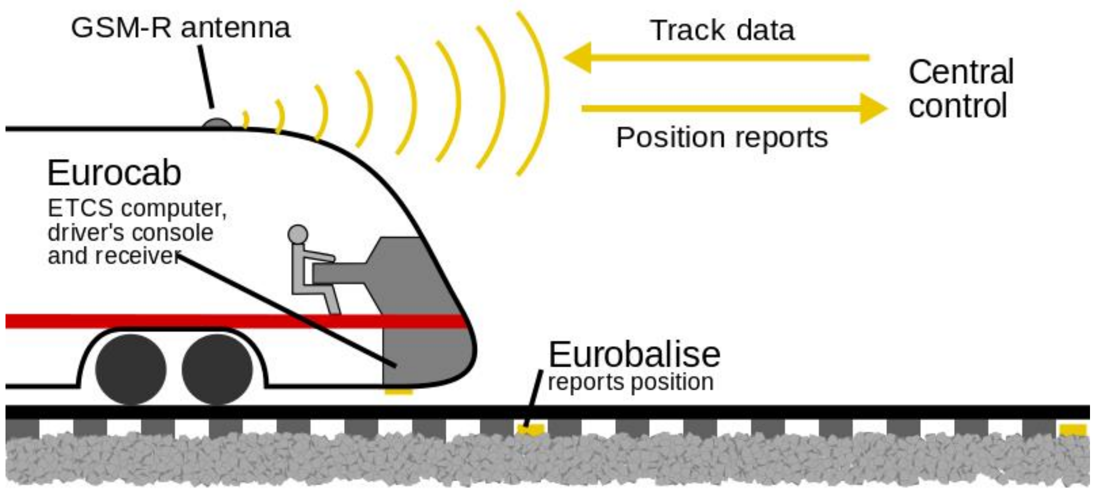

Figure 10: ETCS Level 3 [11]

With Level 3, ETCS goes beyond pure train protection functionality with the implementation of full radio-based train spacing. Fixed train detection devices are no longer required. Trains find their position themselves by means of positioning beacons and via sensors (axle transducers, accelerometer and radar) and must also be capable of determining train integrity on board to the very highest degree of reliability. By transmitting the positioning signal to the radio block center, it is always possible to determine which point on the route the train has safely cleared. The following train can be granted another movement authority up to this point. The route is thus no longer cleared in fixed track sections. In this respect Level 3 departs from classic operation with fixed intervals: given sufficiently short positioning intervals, continuous line-clear authorization is achieved and train headways come close to the principle of operation with absolute braking distance spacing (ñmoving blockò).

ETCS Level 3 is currently under development. Solutions for reliable train integrity supervision are highly complex and are hardly suitable for transfer to older models of freight rolling stock. Also, an ñEnd-of-train deviceò will be needed in order to safely guarantee, that the complete train is still within its moving block, which was traditionally done by trackside equipment.

In order to further advance train autonomous positioning, instead of using fixeddata balises to detect train location there may be "virtual balises" based on satellite navigation and differential GPS. The introduction depends on the future functionality of the EGNOS-supported Galileo satellite system. The Shift²Rail project will integrate Galileo satellites as soon as they come operational to test the EGNOS services, providing "virtual balises" that meet SIL4 safety of life criteria.

Starting at Level 2, ETCS enables the use of automated train operation (ATO) in main line systems, as information is moved from trackside equipment to radio-based on-board systems which can react to state changes like signal switches appropriately.

To make rail automation fully functional on main lines, considerable research effort is still required, as outlined above. For Austria and Austrian industry and research in this sector it is most important to achieve (by development, validation, verification and certification) the following on the highest safety integrity level:

a) train integrity
b) train autonomous positioning

The interest and participation of Austrian industry and research is envisaged in all of the mentioned technology elements, and a high level of economic and innovation potential could be realized.

3.6 Applications for waterways

The state-of-the-art of automated navigation on inland waterways is by far less advanced than automated driving in other modes of transport. Vessels on inland waterways have a rather long reaction time before steering activities show an impact.They cannot simply stop on a stable position without being connected to shore or ground, they have limited freedom for manoeuvres and the waterway infrastructure (in particular in free-flowing sections of rivers) is changing continuously (e.g. the water level) and has important dynamics (the flow velocity but also currents) which are not directly visible but change according to the circumstances (e.g. water level, operation of hydropower plants, actual morphology of the riverbed). Local experience of the shipmaster still is an unrivalled asset for safe inland navigation.

Therefore, as a first step, automated nautical assistance to the shipmaster is under investigation, without putting too much emphasis on truly automated sailing. Current research on the European level focusses on the collection of infrastructure data by collecting actual data from a large number of sailing vessels. At the same time guidance systems ("Automatische Bahnführungssysteme") become available which, under certain circumstances, help keep the vessel on the defined fairway unless special manoeuvres are required. Their usefulness and their impact on safety is subject to a running debate.

The challenges of the years to come for automation of inland navigation are

- in collection of actual reliable infrastructure data,
- interpretation of infrastructure data in central and embedded systems and
- the translation of the future digital knowledge about current infrastructure status into safe steering actions for vessels.

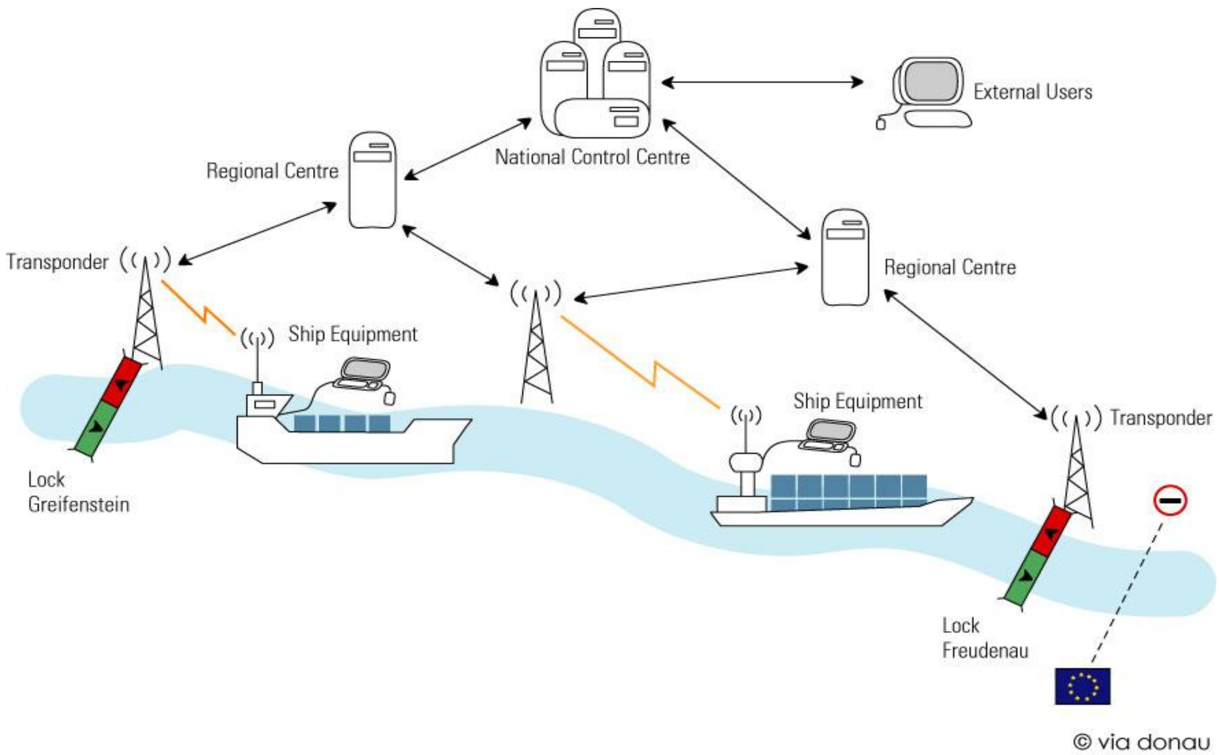

Figure 11: Automated navigation on inland waterways (Danube river, Lower Austria)

4 Austrian RDI Roadmap for Automated Vehicles

4.1 Task fields of activities / RDI topics

Five main task fields of activities (TF) have been identified as highly relevant for Austrian industry and thus constitute the backbone of the Austrian RDI Roadmap ñAutomated Vehiclesò: TF_1 System architecture, TF_2 Hardware, Sensors, Actuators, Connectivity, TF_3 Embedded SW & Cyber-Physical Systems, TF_4 Integration, V&V, and Field Tests, and TF_5 ADAS Applications. These task fields were further divided into sub-task fields / RDI topics (e.g. TF_1.1) and are described in detail below.

TF_1: System architecture

TF_1.1: Architectures

- Micro architectures considering HW, SW, middleware, etc. for fail-safe and fail-operational performance (redundancy concepts) based on multi/many-core systems
- Systems-of-Systems, macro architectures, and networks
- Systems-of-Systems, macro / X2V business process systems, complete data loop FCD/xFCD data from vehicles to traffic control centers, verification and data aggregation in traffic control centers, traffic control center interface to traffic clouds, broadcast from traffic control center to vehicles
- Qualification and V&V of middleware and platforms

TF_1.2: Tools and methods

- Development methods for the design of automated system of systems (e.g. co-simulation, simulation, co-design, tool-chains, analysis tools, scenario evaluation tools, driving style & driving quality evaluation)
- Managing enormous data quantities and complexity in recording and storing data during testing of automated vehicles (sensors, in-vehicle networks, state variables, etc.), cloud storage - data logging, interactive visual steering and analysis of large simulation ensembles
- Black box recording for automated vehicles
- Tools and methods for V&V
- Tools and methods for test generation

TF_1.3: Dependability, safety and security

- Dependability and interoperability concepts
- Safety and security requirements and concepts including data correctness and integrity
- Control unit HW for dependability
- Middleware and software for dependability
- Support of fail-operational performance, resilience, threat mitigation and prevention of intrusion for systems and system-of-systems in automated vehicle applications
- Privacy
- Integrability into legacy systems

TF_2: Hardware, Sensors, Actuators, Connectivity

TF_2.1: Hardware platform for automated vehicles

- (Domain-specific) hardware architecture and platform for partially and highly automated / autonomous vehicles (AAV)
- Development and target HW platforms
- HW safety and security
- HW abstraction for AAV

TF_2.2: Sensors & perception

- Sensors and methods for sensor development for AAV (e.g. LIDAR, radar, video, ultrasonic, etc.), high integration of sensors, robustness, auto-calibration and re-adjustment of sensors, diagnostics, environmental awareness algorithms and systems, sensor fusion and comprehension/capturing of scenarios, vehicle self-positioning and trajectory prediction (high precision and/or independent of GPS/GNSS), modelling of sensor signals, characterization and simulation models of sensors for AAV
- Migration, update/upgrade, maintainability, behavioural models for situational awareness

TF_2.3: V2x Connectivity

- Vehicle to X communication, connectivity to IoT and Cloud, interoperability, low latency (radio systems, RT-capable reproducible performance, higher bandwidth, 4G/5G/G5/WAVE- hybrid solutions and their interoperability, communication to vulnerable road users, standardization of V2X communication), LTE rail

- X2V business process systems operating models
- X2V processes for dynamic HD map rollout, backend fusion and feedback loop from vehicles

TF_2.4: Stimuli

- Sensor stimulation for AAV, communication for test purposes

TF_2.5: Traffic management HW platform

- Sensors for traffic management platform
- Cost-efficient competitive positioning solutions for
  - Intersection management
  - Capacity management
  - V2I & V2V cooperation

TF_2.6: Environmental design

- Street design, (intelligent) traffic signs, weather conditions, harsh environment etc.

TF 3: (Embedded) SW & Cyber-Physical Systems

TF_3.1: Traffic management SW platform

- Traffic management SW platform
- Cost-efficient competitive positioning solutions:
  - Intersection management
  - Capacity management and infrastructure-based maneuver planning
  - V2I & V2V cooperation
- (Multi-modal) route optimization logistics (Fuel consumption/time/logistics, platooning, combination with IoT)
- Cross-modal billing
- Incident management

TF_3.2: Embedded SW, Sensor data fusion

- Cognitive in-vehicle data mining and processing, low level sensor fusion, reliable platform SW / middleware for multicore AAV systems, reconfiguration, AAV run-time environment

TF_3.3: Environmental awareness, Control

- High level sensor data fusion, RT environment modelling, embedded robust mixed critical / safety relevant control functions for AAV (model predictive, self-learning, adaptive, distributed control, stochastic control...)
- SW elements for safety
- Fail-operational performance

TF_3.4: HMI and user acceptance

- Modelling of drivers and driving styles; detection of driving styles, detection of driving behavior of AAV, intuitive and adaptive HMI for AAV
- Measures to increase acceptance of AAVs (in particular in mixed traffic scenarios and concerning other road users)
- Behavioural models for situational awareness/prediction
- HMI design to ensure high user acceptance
- Testbed to measure HMI distraction aspects for AAVs

TF_3.5: Virtual environment, perception, driving strategy, path planning

- Scenario detection and interpretation (semantic interpretation, probabilities & plausibilities, risk assessment and classification), RT environment simulation (multi-dimensional), path planning (e.g. for different driving styles), decision making/reasoning with incomplete knowledge / ethical considerations

TF_4: Integration, V&V

TF_4.1: Test scenarios, Verification & Validation, and virtual testing

- Test scenario definition, automated test scenario execution, automated test case generation
- (Virtual) test environments for AAV, accidents databases to extract virtual test cases, test cases in different environmental conditions, digitalization (tagging), 3D-reconstruction using photogrammetric algorithms, ensure realistic models which have "sufficient" variability
- Incremental SW qualification
- Robustness and interference testbed for AAV sensor systems, validation procedures for AAVs, fault injection
- Test methods and tools for traffic management systems, modelling of real road sections and the necessary infrastructure and provision for virtual simulation environments, built-in self-test mechanisms (HW, SW), safety and security issues, stereoscopic visualization mechanisms
- Standardization and certification
- Test design to combine simulation and physical testing
- Manoeuvre catalogue development for realistic, reproducible test scenarios

- Technical and operative on-road / end-to-end integration of systems and services for automated driving

TF_4.2: Security and Cost-Benefit Analysis

- Security
- Tradeoff of infrastructure costs to additional value for end users

TF_5: Applications & Field tests

TF_5.1: Automotive domain - *Prototype of connected vehicle(s)*

- Prototypes of connected vehicles and their ITS infrastructure
- Field tests and prototype for Austrian fleet demonstrator for ITS supporting connected vehicles and infrastructure to vehicle communication (V2X, X2V) and in its usage
- Test track / living lab for automated driving under real road conditions

TF_5.2: Automotive domain - *Prototype of automated vehicle(s)*

- Prototype for Austrian demonstrator automated car using available Austrian technology wherever possible

TF_5.3: Off-road vehicle domain

- Prototype for Austrian demonstrator automated off-road (agricultural) vehicle using available Austrian technology wherever possible

TF_5.4: Aerospace domain

- Prototype for Austrian demonstrator automated UAV using available Austrian technology wherever possible

TF_5.5: Rail domain

- Prototype for Austrian demonstrator automated train and tram using available Austrian technology wherever possible

TF_5.5: Waterway domain

- Prototype for Austrian demonstrator for inland waterway applications using available Austrian technology wherever possible

4.2 Timeline and relation of main RDI topics to national and European funding programmes

4.2.1 Timeline for different levels of automation

Figure 10 shows the different timelines for different levels of automation in various application domains: Automotive (passenger cars, commercial vehicles, offrroad vehicles), rail, aerospace (large aircraft, drones) and maritime. For the automotive and the rail domains, established scales in common use could be applied: SAE levels (see Figure 1) and Grades of Automation (see Figure 8). For the aerospace and the maritime domains, distinct scales had to be defined. All levels of automation were associated with technology readiness levels (TRLs).

	TRL Level	TRL 4-8	TRL 2-8	TRL 1-8		
	Automation Level	SAE3 / GoA2 / AL3 / ML3	SAE4 / GoA3 / AL4 / ML4	SAE5 / GoA4 / AL5 / ML5		
Domain	**Level source**				**Reference**	**Comment**
Automotive Passenger Car	SAE	2016-2020	2017-2026	2019-2030	ERTRAC Roadmap	
Automotive Commercial Vehicles	SAE	2016-2020	2016-2025	2018-2026	ERTRAC Roadmap	
Offroad	SAE	2016-2020	2016-2030	2018-2028	estimated	
Rail	GOA	2016 - 2020	2020 - 2025	2025 - 2030	estimated; based on ETCS Level 3 publications	In isolated environments (people movers, metros) partially in use already, in open environments as indicated
Aerospace Large Aircraft	AL	already in use	already in use	2025 - 2030	estimated	Landing / Take-off automated, autopilots available, pilot still in command despite remote controlled flights are daily practice
Aerospace Drones	AL	already in use	2016 - 2025	2025 - 2040	estimated	Manually controlled UAVs available, partly automated drones will come soon like for AMAZON (they will not interfere with other airtraffic) automated flight with non human control will take quite a time.
Maritime / Waterways	ML	already in use	2020 - 2035	2035 - 2050	estimated	

SAE	SAE Levels of automated driving
GOA	Grades of automation
AL	3 ... manually remote controlled, 4 ... partially automated, 5 ... fully automated
ML	3 ... manually on-board controlled, 4 ... partially automated, 5 ... fully automated

Figure 12: Timelines for levels of automation timelines in different application domains.

Comment concerning waterways: RIS (River Information Services) provide on-board V2X communication, routing and tracking information today. Automated steering will be possible in sections with low traffic and/or sufficient space for maneuvering whereas in narrow space or dense traffic some manual intervention may be necessary also in the long run.

4.2.2 Relation of main RDI topics to national and European funding programmes

Figure 12 shows a basic mapping of the main subtask fields (RDI topics) identified to existing national and European funding programmes where these topics are also of relevance. ñUCò denotes specific relevance of Use Cases and Demonstrators there.

Besides this, the Austrian Automated Vehicles community would like to propose a new Austrian flagship programme ñAutomated Drivingò. This programme shall focus on large-volume, highly visible research and demonstration projects to promote the visibility of automated vehicles and to significantly strengthen Austria as a business location.

It should be noted that the mapping of task fields and sub-task fields (RDI topics) to European calls shown in Figure 13 reflects the joint vision of the Core Team of the present roadmap, the bmvit and FFG.

		National			European			
	Sub-task field (RDI topics)	**ICT**	**Mobility**	**Austrian flagship programme AD**	**ICT (Information & Communication Technologies)**	**ART (Automated Road Transport)**	**IoT (Internet of Things)**	**ECSEL**
TF_1: System architecture, Tools & Methods	Architectures	x	x		x			x
	Tools and methods	x	x	x	x			x
	Dependability, safety and security	x	x		x	x	x	x
TF 2: Hardware, Sensors, Actuators, Connectivity	Hardware platform for automated vehicles	x					x	x
	Sensors & perception	x	x					x
	V2x Connectivity	x	x	x		x	x	x
	Stimuli	x				x	x	x
	Traffic management HW platform	x	x			x		UC
	Environmental design	x	x			x		
TF 3: (Embedded) SW & Cyber-Physical Systems	Traffic management SW platform	x	x		x	x		x
	Embedded SW, Sensor data fusion	x			x	x	x	x
	Environmental awareness, Control	x	x		x	x		x
	HMI and user acceptenance	x	x			x	x	UC
	Virtual environment, perception, driving strategy, path planning	x	x		x	x		UC
TF 4: Integration, V&V	Test scenarios, Verification & Validation, Virtual testing	x	x			x	x	x
	Security and Cost-Benefit Analysis	x	x					UC
TF 5: Applications & Field tests	Automotive domain - prototype of connected vehicle(s)			UC		x	x	x
	Automotive domain - prototype of automated vehicle(s)			UC		UC	x	UC
	Off-road vehicle domain			UC			x	UC
	Aerospace domain			UC				UC
	Rail domain			UC				UC
	Waterway domain			UC				UC

UC = Use Case / Demonstrators

Figure 13: Relation of main RDI topics to national and European funding programmes

5 Appendices

In the following Appendices, first, the overall procedure of the roadmap development is described (see Section 5.1). This includes the structure and the analysis of the basic questionnaires sent out to and received from the Austrian partner community, the two public workshops held in Vienna at the end of 2015 and at the beginning of 2016, and the main consolidation and harmonization process primarily carried out by the Core Team and mainly based on the inputs and results from the public workshops and questionnaires. The series of Appendices is complemented by a Table of Figures, a Bibliography and a Table of Abbreviations and Acronyms (see Sections 5.2, 5.3, and 5.4).

5.1 Procedure of roadmap development

The development of the Austrian RDI Roadmap for ñAutomated Vehiclesò is based on a Support Action commissioned by the Austrian Ministry for Transport, Innovation and Technology (bmvit) to assess the need for research in Austria in this area and eventually to ensure the success of Austrian industry and "academia".

Therefore, experts were invited from the Austrian communities in the fields of mobility, ICT and robotics to cooperate in the creation of a common roadmap for the Austrian contribution to the establishment of a "European Platform for leadership in automated vehicles".

To efficiently cope with the task of creating such a roadmap, a Core Team was established consisting of highly qualified experts in the fields of automated vehicles and automated driving from the following companies and organizations:

- AVL (Lead of Core Team)
- A3PS
- AIT
- AustriaTech
- IESTA (Support and coordination of roadmap creation)
- Infineon
- TTTech
- and VIRTUAL VEHICLE

In close cooperation with bmvit, the Core Team was responsible for defining and driving the overall development procedure. This includes thorough analysis of existing European and other Austrian roadmaps, design and execution of public workshops (see below), basic overall consolidation and harmonization of partner inputs (see below) in face-to-face meetings, as well as basic definition of the final roadmap document.

This was accompanied by several dedicated meetings between representatives of bmvit and the Core Team, where the focal points, priorities and details of the roadmap were thoroughly discussed and adapted, and a presentation to the international advisory board of the Austrian support program ñICT of the futureò.

To achieve broad, but focused participation, basic information about the Austrian Roadmap ï including the motivation, goals and timeline - was sent to all members of ECSEL Austria, A3PS (Austrian agency for alternative propulsion systems), Digital Networked Data platform, AAL Austria (Ambient Assisted Living innovation platform), GMAR (Austrian platform for measurement, automation and robotics technology), OCG (Austrian Computer Society), and IoT Vienna, in an early stage. In the course of the roadmap development additional partners were identified, who were then contacted accordingly.

In addition, several public events organized by members companies and organizations of the Core Team were used to promote the roadmap creation and to inform and attract relevant Austrian partners:

- ECSEL Austria conference ñElectronic- & Software-based Systems in Europeò, 23-Nov-2015, Vienna
- ITS Austria Conference 2015 ĂDigital in Motion ï Transforming Mobilityñ, 23/24-Nov-2015, Vienna
- General Information Webex, 16-Nov-2015. November 2015

To efficiently collect information, i) a basic questionnaire (see below) and ii) a template regarding state-of-the-art, areas of excellence, as well as current and planned products, procedures and services in the area of automated vehicles, were circulated among interested Austrian partners. This was substantially supported by the inputs directly gained at the public workshops (see below).

The consolidated and harmonized results of these inputs (see below) constitute the backbone of this roadmap: Section 4 ñAustrian RDI Roadmap for Automated Vehiclesò, and the related process is described in detail below.

In addition to this, for basic orientation purposes the individual task fields and sub-task fields identified in the roadmap creation procedure eventually were assigned to the goals of the Austrian funding schemes ñICT of the Futureò and ñMobility of the Futureò as well as to European funding schemes in the framework of Horizon 2020.

5.1.1 Appendix: Questionnaires

In preparation for the first workshop (see section on workshops below), Austrian companies and research organizations in ICT, mobility and robotics were asked to fill in a specific questionnaire.

Also a direct link at the website of the bmvit was available for direct download of the questionnaire (https://www.bmvit.gv.at/innovation/aktuell/downloadsaktuell/fragebogen_roadmap_automated_vehicles.docx).

The questionnaire was derived from a comprehensive system view concerning automated vehicles / driving (s. Figure 14).

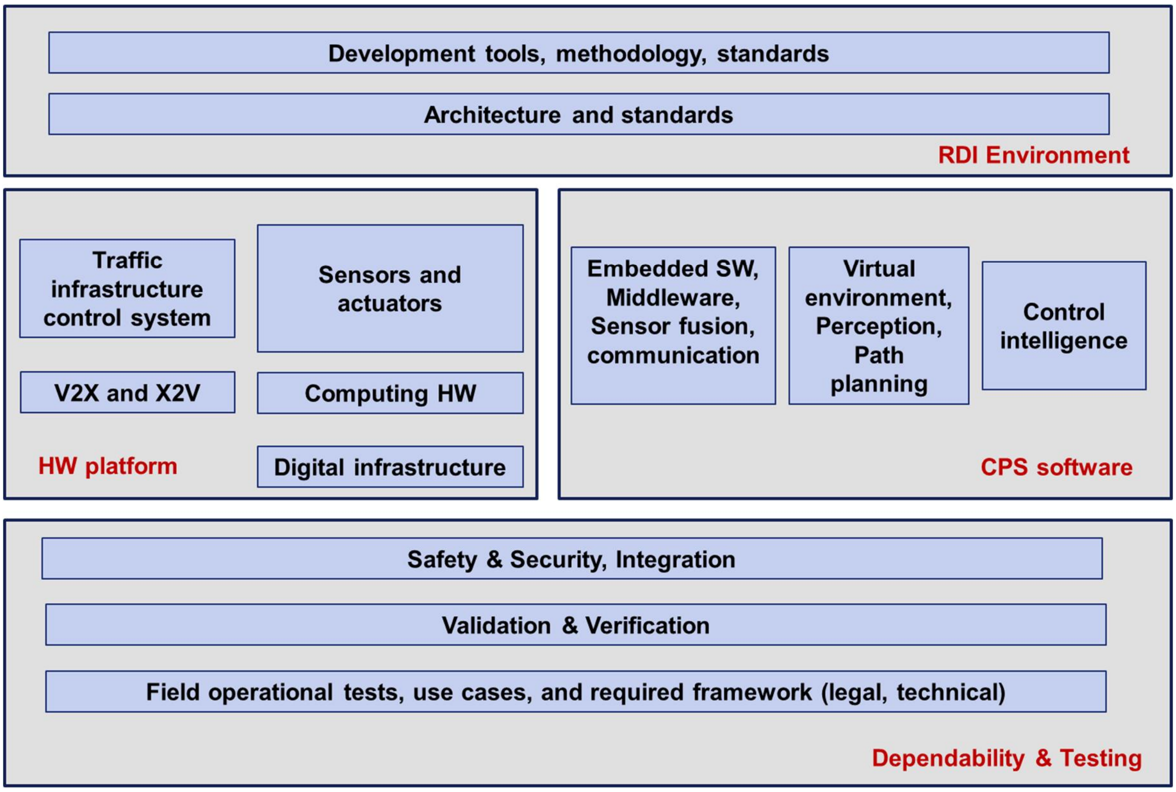

Figure 14: Comprehensive system view concerning Automated Vehicles / Driving as a base for the Questionnaire

The questionnaire consisted of two major parts: i) specific activity fields (AF), which the participating Austrian companies and organizations will operate in, and ii) planned R&D topics with a related timeframe.

The first part was comprised of the following activity fields and related topics, which could be selected by the partners:

- AF_1 ñDevelopment tools and methods" comprising architectures and standards, and tools and methods
- AF_2 "Hardware, sensors / actuators, Connectivity" comprising traffic control platforms, sensors, actuators, connectivity, and HW platforms
- AF_3: "Embedded SW / cyber-physical systems" comprising embedded SW and sensor data fusion, V2x, control, as well as virtual environments, perception and path planning
- AF_4 "Integration, testing, field testing" comprising safety / security, integration, validation, and field tests
- AF_5 "Other topicsò (optional) comprising topics not covered by AF_1 to AF_4

In the second part, planned research and development issues should be described by the partners:

- R&D project idea
- Corresponding project duration
- Perioddhuring which the planned project should start
- Estimated project costs
- Project focus on the following Austrian support programs (one or both):

- ICT of the future
- Mobility of the future

A thorough analysis of all the questionnaires returned gives the following overall results:

- The activity fields were ranked as follows according to the number of partners interested in a specific field: AF_2 (85%), AF_3 (77%), AF_4 (69%), AF_1 (62%), AF_5 (31%).
- However, the specific percentage between industrial and research partners was different: AF_2 (81% vs. 90%), AF_3 (69% vs. 90%), AF_4 (69% vs. 70%), AF_1 (63% vs. 60%), AF_5 (19% vs. 50%)
- Concerning AF_2, industrial partners were mainly interested in connectivity and sensors, whereas research partners were mainly interested in sensors
- Concerning AF_3, industrial partners were quite equally interested in all topics mentioned, the same holds for the research partners
- Concerning AF_4, industrial partners were quite equally interested in all topics mentioned, whereas research partners were mainly interested in safety / security and validation (V&V)
- Concerning AF_1, industrial partners were were quite equally interested in all topics mentioned, whereas research partners were mainly interested in tools and methods
- Concerning AF_5, quite specific topics were mentioned by a few industrial partners, whereas topics mentioned by numerous research partners were broader
- More than 50 project ideas were provided from both industrial and research partners
- Almost all project ideas have a topical range which only can be reasonably covered by combining both Austrian support programs, ICT of the future and Mobility of the future

5.1.2 Appendix: Workshops

Numerous Austrian companies, organizations and experts in ICT, mobility and robotics, interested in contributing to the ñAustrian RDI Roadmap for Automated Vehiclesò participated in two publicly accessible workshops.

1st Workshop, 24-Nov-2015, TechGate Vienna

The aim of the first workshop was to collect specific areas of activity in the field of automated vehicles, where Austrian companies, non-university R&D organizations and universities would like to make contributions.

The workshop was held in the course of the ITS Austria Conference 2015, starting with a special interest session on automatization, where the basic goals and objectives were presented to all participants, followed a first analysis of results from the questionnaires received.

The actual workshop was organized in 4 topical workgroups: ñDevelopment Tools and Methodsò, ñEmbedded SW / Cyber-Physical Systemsò, ñHardware, Sensors/Actuators, and Connectivityò, and ñIntegration, V&V, Field testsò. There, based on a collection of topics prepared by the workgroup leaders using existing Austrian and European roadmaps, contributions and additional topics from all the participants were collected, clustered, and provided with a related timeline relevant for R&D&I activities. Additional partners to be invited to contribute to the roadmap were identified. The results were presented by the workgroup leaders in a final plenary session.

2nd Workshop, 19-Jan-2016, TechGate Vienna

The aim of the second workshop was to thoroughly review the roadmap document prepared by the Core Team.

After a detailed presentation of the activities carried out since the first workshop including the process of consolidation and harmonization (see below), the basic roadmap structure and available contents, 4 workgroups were formed to review the latest version of the roadmap document. By this, missing items and topics as well as missing partners were identified, timelines for the different task fields of activity were aligned, and intended future products, procedures or services of the participating companies and research organizations in the area of automated vehicles were checked for their consistency with the existing roadmap.

The results were presented by the workgroup leaders in a plenary session, and finally the Austrian roadmap was approved by all the participants.

5.1.3 Appendix: Consolidation and Harmonization

The process of consolidation and harmonization was primarily carried out by the Core Team, and was mainly based on the inputs and results from the public workshops and the questionnaires.

In a first step, all the detailed inputs received in the first workshop and from the questionnaires were clustered, duplications were sorted out and overlaps were consolidated. Based on this, superordinate task fields and sub-task fields were derived, which all the consolidated inputs were assigned to.

In a second step, task fields and sub-task fields were eliminated if they were not of keen interest to the industrial partners. This is due to the fact that the Austrian RDI Roadmap for Automated Vehicles shall be focused on the needs of Austrian industry. Then the descriptions of the sub-task fields were diligently re-formulated and harmonized by the Core Team.

Additional Austrian partners identified in this process but not yet involved in the roadmap process were asked to provide additional input.

The updated roadmap document together with all task fields and sub-task fields including detailed descriptions was made available to the whole Austrian partner community for the second workshop.

After the second workshop, all the results from the workgroups were consolidated and harmonized again by the Core Team. Work focused on aligned wording and timelines, on approaching additionally identified partners, as well as on assignment of task fields and sub-task fields to different industrial domains, to the detailed categories of the Austrian funding tracks ñICT of the futureò and ñMobility of the futureò, and to European funding schemes.

After overall harmonization and consolidation, a mature draft of the Austrian roadmap was made available to the whole community participating in and contributing to this document for a final check and feedback.

5.2 Table of Figures

5.3 Bibliography

[1] ERTRAC, ñERTRAC Roadmap Automated Driving,ò ERTRAC, July 2015. [Online]. Available: http://www.ertrac.org/uploads/documentsearch/id38/ERTRAC_Automated-Driving-2015.pdf. [Accessed 31 July 2015].

[2] H. Winner, S. Hakuli und G. Wolf, Handbuch Fahrerassistenzsysteme: Grundlagen, Komponenten und Systeme für aktive Sicherheit und Komfort, Vieweg+Teubner, 2011.

[3] A3PS, ĂAustrian Eco-Mobility Roadmap 2025plus,ñ A3PS, Vienna, 2016.

[4] J. C. G. B. L. H. W. M. Maurer, Autonomes Fahren ï technische, rechtliche und gesellschaftliche Aspekte (German), Open Access Hrsg., Springer Vieweg, 2015.

[5] M. H. D. Watzenig, Automated driving ï safer and more efficient future driving, Springer, 2016 (in press)..

[6] EPoSS, Roadmap on smart systems for automated driving, 2015: European technology platform on smart systems integration (EPoSS).

[7] EURO NCAP, 2020 roadmap, European new car assessment programme (EURO NCAP), June 2014.

[8] A. Greenberg, Markey car security report, February 2015.

[9] International Transport Forum at OECD, Automated and autonomous driving ï regulation under uncertainty, Corporate Partnership Board Report.

[10] I. A. o. P. Transport, ĂA global bid for automation: UITP Observatory of Automated Metros confirms sustained growth rates for the coming years,ñ 2012.

[11] Wikipedia, ñEuropean Train Control System,ò [Online]. Available: https://en.wikipedia.org/wiki/European_Train_Control_System. [Accessed 14 01 2016].

5.4 Table of Abbreviations & Acronyms

Abbreviation / Acronym	**Long**
4G	4th Generation
5G	5th Generation
A3PS	Austrian Association for Advanced Propulsion Systems
AAL	Ambient Assisted Living
AAV	Automated / Autonomous Vehicle
ABS	Antilock Braking System
ACC	Adaptive Cruise Control
AD	Automated Driving
ADF	Automated Driving Function
ADAS	Advanced Driver Assistance Systems
AEB	Automatic Emergency Brake
AENEAS	Association for European NanoElectronics ActivitieS
ART	Automated Road Transport
ARTEMIS	Advanced Research & Technology for EMbedded Intelligence and Systems
ASIC	Application-Specific Integrated Circuit
ATC	Automatic Train Control
ATM	Air Traffic Management
ATO	Automatic Train Operation
ATP	Automatic Train Protection
BMS	Battery Management System
bmvit	Federal Ministry for Transport, Innovation and Technology (Austria)
C2X	Car to X communication
CAN	Controller Area Network
CAS	Collision Avoidance System
CEN	Comité Européen de Normalisation
CMOSIS	Complementary metal-oxide-semiconductor Image Sensor
CPS	Cyber-Physical System
DC	Direct Current
DNS	Domain Name Service
DOT	Department of Transport (U.S.)
DSRC	Dedicated Short Range Communication
DTA	Driveability Testing Alliance
EBS	Electonics-Based Systems
EC	European Commission
ECE	Economic Commission for Europe
ECU	Electronic Control Unit
ECSEL	Electronic Components and Systems for European Leadership
EGNOS	European Geostationary Navigation Overlay Service
EPoSS	European technology Platform on Smart Systems Integration
ERTRAC	European Road Transport Research Advisory Council
ESC	Electronic Stability Controll

Abbreviation / Acronym	**Long**
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
EU	European Union
FCD	Floating Car Data
FCW	Forward Collision Warning
FFG	Austrian Research Promotion Agency
FMVEA	Failure Mode, Vulnerabilities and Effect Analysis
FPGA	Field Programmable Gate Array
G5	ETSI ITS G5 communciation standard for cooperative ITS, operating in the 5 GHz band
GHz	GigaHertz
GoA	Grade of Automation
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HW	HardWare
IC	Integrated Circuit
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IR	InfraRed
ISO	International Standardization Organization
IT	Information Technology
ITS	Intelligent Transport System
JU	Joint Undertaking
KPI	Key Performance Indicator
LCA	Lane Change Assist
LDW	Lane Departure Warning
LIDAR	LIght Detection And Ranging
LKA	Lane Keeping Assist
LTE	Long Term Evolution
M2M	Machine to Machine
MASRIA	Multi Annual Strategic Research and Innovation Agenda
MEMS	MicroElectroMechanical Systems
MOEMS	Micro-Opto-Electro-Mechanical Systems
MoMuT	Model-based Mutation Testing
NCAP	European New Car Assessment Programme
NHTSA	National Highway Traffic Safety Administration (U.S.)
OEM	Original Equipment Manufacturer
OFDM	Orthogonal frequency-division multiplexing
PA	Park Assist
PDC	Park Distance Control
PPP	Public-Private Partnership
R&D	Research & Development
RDI	Research & Development & Innovation

Abbreviation / Acronym	**Long**
RFID	Radio-Frequency IDentification
RT	Real-Time
SAE	Society of Automotive Engineers
SMC	Smart Mobility Concepts
SMEs	Small and Medium-sized Enterprises
SoC	State of Charge
SoH	State of Health
SoP	Start of Production
SW	SoftWare
SWOT	Strengths, Weaknesses, Opportunities, Threats
sSDLC	secure Software Development LifeCycles
TLS	Transport Layer Security
TRL	Technoloy Readiness Level
UTO	Unmanned Train Operation
UAV	Unmanned Aerial Vehicle
UAV	Unmanned Autonomous Vehicle
V&V	Validation & Verification
V2I	Vehicle to Infrastructure communication
V2V	Vehicle to Vehicle communication
V2X	Vehicle to X communication
VHDL	Very High Speed Integrated Circuit Hardware Description Language
VITRO	Vision Testing for Robustness
WAVE	Wireless Access in Vehicular Environments
WEFACT	Workflow Engine For Analysis, Certification and Test
X2V	X to Vehicle communication
xFCD	eXtended Floating Car Data