Roadmap

Automation in Road Transport

iMobility Forum

Version 1.0
May 2013

Justification

This document concludes the first year of the Working Group Automation in Road Transport and provides the reader with a first roadmap for enhanced automation in the road transport sector.

The Working Group was created under the iMobility Forum after the successful workshop organized by the European Commission, DG INFSO in October 2011. This workshop commenced the three SMART studies, executed in 2011 for the European Commission, DG INFSO specifically focusing on automation, the future of internet and the connected car and during the workshop a clear need was identified to further discuss and guide the research, development and deployment of automation for road traffic and road transport systems.

The Working Group has met in total 6 times this year with the aim to define this first roadmap. This roadmap was also discussed and aligned with other Working Groups under the iMobility Forum like the I&R Working Group and the Legal Working Group. We would like to thanks all participants of the working group meetings for their effort and input to this document.

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Contents

Tabel of figures

1 Summary

Highly or full automation will contribute to the enhancement of traffic safety by reducing the driver‘s workload, in terms of driving, and minimizing the human errors and incidents due to driver distraction or reduced vigilance. Another important impact will be the reduction of congestion, mainly in urban areas and on motorways by optimising driving styles, minimizing speed variations and avoiding cases of stop and go. This will reduce vehicle emissions and fuel consumption per kilometre driven and will therefore have a positive impact on the environment.

Driving highly or fully automated on public highways could become acceptable within the next ten to fifteen years, once thorny legal issues have been sorted out. The complexity of automated driving in urban areas is particularly challenging and requires additional technological development in order to make the cars extremely safe.

This document explains the research needs in the area and connects them to its possible benefits and an implementation roadmap. Due to time restrictions automation in dedicated areas has not been included.

2 Introduction

The Working Group Automation in Road Transport was created under the iMobility Forum after the successful workshop organized by the European Commission, DG INFSO in October 2011. This workshop commenced the three SMART studies[1], executed in 2011 for the European Commission, DG INFSO specifically focusing on automation, the future of internet and the connected car and during the workshop a clear need was identified to discuss further and guide the research, development and deployment of automation for road traffic and road transport systems.

The mission of the working group on Automation in Road Transport[2] is to identify how automation and its subsequent applications can help to improve efficient, clean, safe and reliable road transport now and in the future and what is needed to foster deployment and implementation. To be more specific the working group focussed its activities on the common agreement on developing one or more **roadmaps** for future developments in the area of automation in road transport.

The process that led to this document basically consisted of the following steps:

1. Define the issues in the mobility domain that need to be solved;
2. Define a set of functions or applications that can help to do so including the value proposition and a clear and SMART description of these functions;
3. Map the functions with a clear value proposition to create a subset that covers all levels of automation;
4. Define the research needs and state of the art on specific topics needed to reach implementation or piloting of these functions.

Figure 1: approach defining roadmap

The final deliverable of the working group is at first the roadmap document and recommendations for future research.

[1] *European Commission, SMART 2010/0064: "Definition of necessary vehicle and infrastructure systems for Automated Driving"*

[2] *As laid down in the agreed Terms of Reference, dated 09-05-2012*

This document will start with a short introduction in automation and the definitions for levels of automation (§2.1). In chapter 3 we will focus on the expectations and the approach that was chosen focussing on specific impact areas and concept areas. In chapter 4 we continue with challenges and prospects for automation including a description of the State of the Art, the research needs and the key applications and milestones. In chapter 5 we will finally come to the roadmaps itself and the recommendations.

2.1 Definitions of Automation levels

For a clear understanding of automation in road transport some definitions are needed to enable a common understanding. Automation in this document refers to the transport system as a whole and all of its components (vehicles, drivers, users, road based infrastructure, information systems and applications to name the most important). The further deployment of automation in road transport will be a shared responsibility among the actors namely infrastructure operators and automotive industry. Indeed, the infrastructure will need to follow requirements in order to be qualified as "HAD friendly" or "HAD compliant".[3]

Automation is often used to define something to be "smart", in which automation takes over control from humans in order to do the right thing in complex events or circumstances. Automation can in addition also prove valuable in non-complex circumstances and it is not necessarily the one or the other. Concepts where driver and automation can control a vehicle together, cooperatively have proven very successful and intuitive, such as in the German H-Mode Project. An extended study performed by BASt[4] explored the impact of automation, the various levels of automation and the legal implications. From the beginning it was apparent that is exploring the landscape of automation there is a need for a common ground in terminology and taxonomy. Therefor we used these definitions form BASt in the working group as well as in this document. A more detailed overview of taxonomy for automation can be found in a presentation form Steven Shladover for the Taxonomy Working Group[5].

Definitions	Descriptions
Driver Only	Human driver executes manual driving task
Driver Assistance	The driver permanently controls either longitudinal or lateral control. The other task can be automated to a certain extent by the assistance system.
Partial automation	The system takes over longitudinal and lateral control, the driver shall permanently monitor the system and shall be prepared to take over control at any time.
High Automation	The system takes over longitudinal and lateral control; the driver

[3] Highly Automated Driving

[4] From Gasser, T, D. Westhoff, (2012) BASt-study: Definitions of Automation and Legal Issues in Germany and from "Gasser, T., Arzt, C., Ayoubi, M., Bartels, A., Bürkle, L., Eier, J., Flemisch, F., Häcker, D., Hesse, T., Huber, W., Lotz, C., Mauer, M., Ruth-Schumacher, S., Schwarz, J., Vogt, W. (January 2012): Legal consequences of increasing vehicle automation (Rechtsfolgen zunehmender Fahrzeugautomatisierung). In: Berichte der Bundesanstalt für Strassenwesen, Fahrzeugtechnik Issue F83. In German."

[5] From Shladover, S.E. (2012) University of California PATH Program, Automated Vehicles: Terminology and Taxonomy

	must no longer permanently monitor the system. In case of a take-over request, the driver must take-over control with a certain time buffer
Full Automation	The system takes over longitudinal and lateral control completely and permanently. In case of a take-over request that is not carried out, the system will return to the minimal risk condition by itself.

Figure 2: levels of automation

From various discussions and previous research the relevance of defining specific levels of automation is most applicable for vehicles and drivers. The reason for this lies in the fact, that automated control has severe implications on the legal and liability aspects. Nevertheless when we speak of for example partial automation this applies as much for the driver as for an operator or any other user of the transport system. For the ease of understanding the above summary of the various levels of automation uses the driver as an example.

Finally in this document the term high automation does not always strictly refer to the definition above but includes also partial automation.

3 Expectations and Approaches

The economic development and competitiveness of Europe depends on an effective and efficient transport and logistics system. The mobility of people and the flow of goods to, from and within Europe must be cost efficient and at the same time safe and environmentally sustainable. A holistic system approach is needed to achieve this.

According to data from the 2011 United Nations World Urbanisation Prospects report, urban populations will grow by roughly 2.6 billion over the next 40 years, while 70% of the world's population will live in cities by 2050. To support this growth, the concept of smart cities is stressed in various studies such as those released by Frost & Sullivan[6] and SAP and was also put forward in the Intelligent Infrastructures Futures Foresight Study of the University of Newcastle commissioned by the Foresight programme[7] in addition to being addressed by the European Smart Cities project.

One of several concepts relevant to smart cities, the concept of smart mobility promotes more efficient and intelligent transportation systems—effectively leveraging networks to ensure more efficient movement of vehicles, people, and goods, thus reducing gridlock; and promoting new 'social' attitudes. This might include smart cities, smart transportation hubs and smart corridors.

In general, the term "'smart" is applied to technical solutions based on ICT as an enabler for changing the organization of the ways in which we interact with others. A commonly used definition of smart states that it refers to: "operating with minimum of human intervention, using automatic control aimed at doing the right thing in a wide variety of complicated circumstances"

The expected result is a convergence of all technologies and approaches to take on the "smart" way of operating in order to drive sustainability.

The concept of increasingly automated control as a substitute for human control and intervention is the subject of this document, where automation refers to the application in the whole transport system and is not limited to vehicles only. The concept of highly automated vehicles though, is a very important aspect in this respect.

[6] http://www.google.nl/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=2&ved=0CDkQFjAB&url=http%3A%2F%2Fwww.frost.com%2Fprod%2Fservlet%2Fcpo%2F213428721.pdf&ei=cjB-UfyBEMWY1AW1z4CgCQ&usg=AFQjCNFYA4d614dZqgHh7iocEPoa8VWFPQ&sig2=5gFz6ZQO5Mdm7W1-hNnerA

[7] www.foresight.gov.uk

3.1 Impact areas

3.1.1 Mobility

Consider for a moment how we lived and worked 20 years ago.. In the 1990's mobile phones were not common, the internet and email was still something that was being developed and few cars were equipped with cruise control. Since then, ICT has been at become the backbone of our daily live and it's generally accepted that the future will be highly influenced by a few megatrends. These can be general and more societal oriented such as ageing and fragmentation, fading borders, environmental sustainability and the network society but also more specific megatrends like energy transition, smart infrastructures etc. These megatrends are expected to become part of our daily lives in about 10-15 years. The next so called "Einstein generation" or “generation Y” will then require technologies, networks and services which will be developed from the new, innovative ideas thought of today. On the other hand, previous generations will live longer, have changing mobility needs and inherent safety and comfort related hazards. These factors all combined will influence the demand on transport and thus on quality of life. Some examples of the impact on mobility in general and quality of life are accessibility to enhanced personalized public transport, automated servicing (car repositioning) but also on the way we design and build our urban areas where for example urban platoons can be foreseen not conflicting traffic of VRU's.

3.1.2 Environmental sustainability:

In March 2011 the European Commission adopted the White Paper - Roadmap to a Single European Transport Area 2, which proposes a series of policy measures to achieve the 60% GHG emissions reduction goal to 2050 compared to 1990 levels. For the transport sector, this translates to a reduction in GHG emission to around 20% below their 2008 level. At the same time the mobility demand will continue to increase.

The driver has an important influence over fuel efficiency. With an optimal driving style, the average driver could improve their fuel efficiency by around 10-15 %. Today, driver coaching systems are on the market and should have reached full maturity around 2015-17. To exploit the full potential of energy efficient transportation it is necessary to make the transition from driver coaching to automated energy efficient longitudinal vehicle control. Based on current advances in enhanced automated driving the next step can now be taken where the driver's impact on fuel efficiency performance is reduced in combination with optimising the vehicle's internal energy management systems. So the driver is still in charge and can always overrule the system. It is estimated that widespread implementation of this feature could produce a fuel efficiency improvement of around 20% in road transport.

3.1.3 Traffic efficiency

Congestion is more than a nuisance for road users; it also results in an enormous waste of fuel and productivity. Many manufacturing processes depend on just-in-time deliveries and free flow transport for efficient production. Congestion costs the EU economy more than 1%

of GDP. To reduce it, the EU needs more efficient transport and logistics, better infrastructure and the ability to optimise road capacity use. Automation will improve the maximum capacity in the road transport network by deploying technological developments like Intelligent Transport Systems advanced logistics transport planning and slot management for resilient supply chains and better suited solutions for modal shift.

3.1.4 Road safety

The Commission has adopted an ambitious Road Safety Programme which aims to cut road deaths in Europe between 2011 and 2020 together with a vision to move close to zero fatalities in road transport by 2050. Key figures for 2011 are:

- In 2011, more than 30,000 people died on the roads of the European Union;
- For every death on Europe's roads there are an estimated 4 permanently disabling injuries such as damage to the brain or spinal cord, 8 serious injuries and 50 minor injuries.

Moreover, 95% of the accidents are human error related. The need to increase traffic safety by reducing such accidents as well as maximising the comfort of the driver while driving also supports the research findings towards systems which enable increased automated driving at different levels. Automated driving at different levels has the potential to reduce such accident by eliminating the human factor. On the other hand, increased automation at the vehicle level, brings new challenges especially for interaction with other traffic participants like vulnerable road users.

3.2 Concept Areas

This section details the key concept areas for automation.

3.2.1 Towards fully automated vehicles (Self-Operating)

Highly, partial or full automation will contribute to the enhancement of traffic safety by reducing the driver‘s workload, in terms of driving, and minimizing human errors and incidents due to driver distraction or reduced vigilance.

The driver has an important impact on safety and efficiency. 95% of the road accidents are human error related. Automated driving at different levels has the potential to reduce such accidents by eliminating the human factor. On the efficiency side there is up to 20% difference between the worst driver behaviour and an optimal one. Driver coaching systems for efficiency are on the market and should have reached full maturity by around 2015-17. However, these advisory systems cannot guarantee improved efficiency because the driver is still in control. Based on current advances in automated driving the next step can now be taken where the driver’s impact on the performance is reduced or eliminated in combination with optimising the vehicle’s internal energy management systems. This would optimise performance resulting in optimal fuel efficiency. In parallel, driver coaching systems advancements should continue.

Another important impact will be the reduction of congestion, mainly in urban areas and on motorways by ensuring optimal driving, minimizing speed variations and avoiding cases of stop and go. This will – assuming that there will not be an increase in demand - reduce vehicle emissions and fuel consumption per kilometre driven and will therefore have a positive impact on the environment.

From a technical point of view, current technology for highly automated driving in controlled environments is quite mature and can be achieved without V2x communication. However, further research and enhancements of existing prototypes and systems are needed in order to succeed in mixed traffic scenarios and real driving conditions. One very important enabler is the capability to perceive the traffic environment in a very accurate real time and integrated manner.

To achieve this enhanced perception vehicles can be equipped with numerous sensors such as radars, cameras and perhaps even laser scanners to monitor the complete surroundings of the vehicle. At the same time other components such as highly accurate and dynamically updated maps and very accurate positioning systems are needed. To reduce costs, to increase synergies and to increase the accuracy, robustness and functionality of systems, advanced signal processing and data fusion techniques should be investigated and applied.

The research area of cognition and human factors is essential since partially and highly automated driving still includes the human driver at least in certain phases. Hence, the system behaviour and HMI must take into account the role of the driver in highly automated vehicles and an appropriate interaction design should be tailored to the driver's needs. In addition research on the perception, expectations and anticipation of other traffic participants when encountered with high or full automated vehicles or transport systems is needed. System perception and vehicle behaviour with regard to PTW and VRU's need to be covered due to potential shifts in concepts of operations for mobility and transport systems in the future when high levels of automation are being applied in combination with traditional uses.

Finally, legal and regulatory frameworks for automated driving need to be developed in order to enable large scale deployment.

3.2.2 *Safe & efficient cooperative driving*

With cooperative systems, vehicle efficiency and safety can be improved both in highway and urban driving situations. The penetration rate of the system (i.e. of in-vehicle cooperative communication platforms within the total population of vehicles) is an important factor to achieve the potential gains. However, limited penetration can give significant improvement (e.g. platooning or additional back-office information).
Platoons present an opportunity to both improve traffic efficiency and safety of vehicles on highway driving. However, for platoons to be viable there should be minimal impact on

supporting infrastructure, implying that platoons will operate on unmodified public motorways.

The efficiency gains of platooning are both on vehicle level due to reduced aerodynamic drag and reduced road congestion. Results from the SARTRE project show that fuel consumption decreases by about 8% for the the lead truck and by about 14% for the following trucks when in a platoon travelling at 85 km/h and with a following distance of 6m. The efficiency improvement is due to an overall improvement in the aerodynamics of the platoon vehicles as a system.
The typical maximum capacity of a highway today is about 2200 vehicles/hour/lane. Due to vehicle speed variations, so called shockwaves will be created when this capacity is exceeded, resulting in significantly reduced throughput. With platooning, the vehicle following gaps and the speed variations can be reduced. Traffic flow simulations indicate that with full penetration of CACC, highway capacity can be doubled but significant improvements are also seen in mixed traffic scenarios (i.e. a vehicle population including platoons and unequipped vehicles).

By using the full potential of intelligent traffic management systems, where the vehicle is a connected part with a high degree of automation, it is estimated that traffic congestion can be reduced by about 50%, there will be 8% fewer traffic accidents and a 5% reduction in CO_2 emissions and fuel consumption[8] in urban situations.

Cooperative highly automated driving offers significant potential benefits if combined with traffic management, especially within urban environments. Traffic management can then intervene cooperatively at different levels of the driving task, such as navigation or vehicle guidance, its intervention can range from purely informative systems to direct influence on the vehicle motion, and it could influence the availability and selection of a certain automation level within the vehicle. Assumptions for in-car speed advice based on previous studies on the effect and impact of road based variable message signs on traffic jam queue lengths, might indicate potential reductions in vehicle loss hours of 10-15% and significant CO_2 reduction which are supported by the results of the Dutch Dynamax-in-car tests and the adaptive green wave project Contrast on the Eindhoven-Helmond corridor.

3.2.3 Active Safety

Today, several types of safety warning systems exist on the market, primarily in premium segment vehicles. Recently, vehicle manufacturers took the next step to further enhance safety by introducing systems like Automatic Emergency Braking which autonomously takes control over the brakes when necessary to mitigate rear-end collisions or avoid collisions with vulnerable road users. These systems are now available for premium, mid-size and compact cars. In the near future, active safety will be increasingly deployed in lower-cost segments. To achieve this, research needs to be directed at systems with multiple functions, with high accuracy / reliability, and reduced cost.

[8] TNO report 2008-D_R0996/A: “Smarter and better – the benefits of intelligent traffic”

Deployment in heavy goods vehicles and buses will be accelerated by 2013/2015 legal requirements on mandatory CMbB (Collision Mitigation by Braking) and LDW (Lane Departure Warning) systems. On the sensor side, accuracy and reliability will be further enhanced, in particular regarding the detection of vulnerable road users. Moreover, in the near future, short-range communication technologies (V2V, V2I) will function as additional sensors. In combination with digital maps and e-Horizon, this will substantially enhance the robustness and predictive capacity of today's warning systems, thus minimizing false warnings and enabling automatic intervention across a wider range of scenarios. Enhanced predictive capabilities are also essential for systems supporting green driving, so synergies between those two application areas may be exploited.

4 Challenges and Prospects for Automation

4.1 State of the Art

Considering automation for the whole transport system we see developments at the individual component level - like vehicles, traffic management systems - with of course interaction with the user / driver and at the interaction level, like cooperative systems using V2X communication. The pace of developments and deployment of new advanced technologies which aim for automation of the human intervention or control is the highest at the individual vehicle level. At the road infrastructure level, some systems are already automated (like Automated Incident Detection (AID) but often a human operator is in full control due to safety requirements.

At the most advanced vehicle level, both in Europe and the U.S. there are prototype vehicles driving automatically both in urban and in highway environment. So from a technical point of view, current technology for highly automated driving in controlled environments is quite mature. These vehicles use state-of-the-art sensors (radar, lidar, GPS and camera vision systems) combined with high accuracy maps so the on-board systems can interpret the information to identify appropriate navigation paths, as well as obstacles and relevant signage. Still, for these prototypes the driver must always be ready to take over – these are partial automation systems.

Other applications of partial automation like platooning or cooperative traffic systems are also quite advanced and mature from a technical point of view and are being tested and assessed on their impact in various field operational tests across Europe, the US and Japan.

Further research and enhancements of existing prototypes and systems are needed in order to succeed real driving conditions and allowing a specific time buffer for driver take-over. This would mean a transition takes place from partial automated driving to highly automated driving.

4.2 Legal aspects

Legal and regulatory frameworks in Europe states the driver always must be in full control of the vehicle making highly automated systems illegal. In order to enable the deployment of automated vehicles the legal and regulatory frameworks need to be developed. Currently, some envisioned functionalities are not yet covered by laws and standards. Questions still arise, for example with respect to:

- Liability law (what kind of changes in liability law might be necessary? What kind of responsibility has to be taken by automation and therefore perhaps by OEMs? Which requirements are there for partially and highly automated vehicles not to create problems for OEMs in terms of liability - how to ensure that the driver has correct expectations and foreseeable misuse is prevented where necessary for instance through driver monitoring, and that driver ability in his required tasks is not degraded by system design.)

- Regulatory law (how might regulatory law have to be changed to allow highly automated driving?)
- Standardisation (to define common standards for partially or highly automated driving to ensure that the driver is able to change cars and still safely operate them.)
- Certification and verification (to define processes and tests to apply to highly automated vehicles)

In other fields where automation has been applied to a much larger extend like robotics, standards are already available. These can be used as a reference for the need for new standards in the area of road transport automation

4.3 Research areas

Further research is necessary in order to exploit fully the potential benefits of automation in road transport in a manner that is safe, understandable and acceptable to the driver and other stakeholders. Areas for research include:

4.3.1 Perception

One very important enabler for reliable and safe automated driving is the capability to perceive the traffic environment in a very accurate real-time and integrated manner. To achieve this enhanced perception the vehicle should be equipped with numerous sensors such as laser scanners, radars as well as (mono and stereo) cameras to monitor the complete surroundings of the vehicle as well as exploiting wireless V2X communication. To reduce costs and to increase synergies advanced signal processing and data fusion techniques should be investigated and applied. The special requirements of automated driving lead to increased needs for research and development in the area of perception. The following key areas (not exclusive) should be subject to further research and development:

- Reliable object recognition and tracking
- Situation awareness (including future path, manoeuvre identification)
- Highly accurate positioning (longitudinally and laterally to driving direction
- Accurate road representation
- Detection of free space
- Classification of objects
- Advanced fusion techniques
- Common Perception architecture
- Plug and Play concepts
- Quality assessment of perception systems as a further input for automation

4.3.2 *Vehicle automation*

Even though current technology for highly and fully automated driving in controlled environments is quite mature, further research and enhancements of existing prototypes and systems are needed in order to succeed in mixed traffic scenarios and real driving conditions. This also applies to the core of an automated vehicle, its automation, that consists of intelligent motion planning and control algorithms embedded in a robust and flexible system architecture.

New developments in the area of perception, human-machine interaction, cooperation with other traffic participants, cooperation with a traffic management and other ITS components as well as new actuator characteristics must be incorporated in the development of new planning and control algorithms. In addition, highly and fully automated driving requires a certain level of guaranteed safety (e.g. for liability reasons) regarding the planned manoeuvres and their execution. This requires further research in appropriate planning algorithms.

Therefore, the following key areas (not exclusive) should be subject to further research and development regarding manoeuvre and trajectory planning:

- Human compatible planning algorithms that enable an intuitive interaction and arbitration with the driver at navigation, guidance (manoeuvre) and stabilization (control) level and easy mode transitions (e.g. changing from assisted to partial, highly or fully automated driving)
- Cooperative planning algorithms for the interaction with other road users (vehicles, their automation and their drivers, pedestrians, cyclists, etc.) exploiting the potential of V2X communication
- Cooperative planning algorithms for the interaction with intelligent infrastructure components and a smart traffic management system
- Integration of navigational level with guidance (manoeuvre) (and stabilization) level, especially in cooperation with traffic management
- Integration of sensor (or map) uncertainties and actuator characteristics in planning algorithms
- Guaranteed safety of planned manoeuvres and trajectories. This includes e.g. guaranteeing the possibility of a minimum risk manoeuvre in failed take-over situations of the automation in emergency situations.
- Controllability of the execution (control) of planned manoeuvres

4.3.3 *Cognition and Human factors*

The research area of cognition and human factors is essential since partially and highly automated driving still include the human driver at least in certain phases. Hence, the system behaviour and HMI must take into account the role of the driver in partially and highly automated vehicles and an appropriate interaction design should be tailored to the driver’s needs.

To test this behaviour and ensure a certain overall performance of system and driver, human cognitive abilities must be taken into account and human factor evaluations are necessary, for example in the following areas:

- Situation awareness

- Driver behaviour and performance
- Effects of automated driving over a long period of time
- Interaction with automation in own vehicle (whether as intended or by design)
- Interactions with other road users (whether as intended or by design)
- Mode transitions (when and how to change from manual driving to partially or highly automated driving or back from fully automated emergency interventions to lower levels of automation)
- Mode confusion (relating to a certain aspect of the driver's situation awareness)
- Take-over ability (whether driver is able to take over in case of automation failure or non-availability at system limits when mode transition back to lower levels of automation is required)
- "Controllability"(whether false alarms, failures or system interventions are controllable by driver)

The research area of cooperation, interaction and HMI design is central to the development of highly automated and cooperative vehicles, since much of the success of such vehicles depends on the proper interaction between the various parties, such as between the human driver and the automation of his own car, the interaction (of these two) with other vehicles (of any degree of automation), with pedestrians and cyclists, and with infrastructure units such as intelligent intersections, lanes and/or traffic management centres. A proper interaction design is crucial especially when several parties have direct influence on the vehicle's movement. The interaction design should precede the detailed design of the human machine interface (such as inceptors, displays, acoustics) as well as the technical design of the automation and the usage of other technical capabilities such as V2X or X-by-Wire. Research in this area must always take into account the human cognitive abilities and includes:

- Definition of arbitration and interaction (rules, modalities, levels of driving task – multi-agent, decentralised decisions, etc.)
- Integration of functions (definition of overall concepts that group functions in terms of HMI)
- Definition of modes and transitions (manual, partially automated, highly automated, and emergency modes and the definition of the transitions in varying conditions and how to change from one mode to another)
- Merging of autonomous (vehicle based) sensors with cooperative data acquisition and validation
- HMI (Human Machine Interface) (design of visual, acoustic, haptic, and kinaesthetic elements for communication of system state, warnings, requests, and driver input)
- Human Machine Interaction strategies and concepts
- Design and development of Man-Machine Interfaces adapting to the cognitive and visual workload of operators working in a highly automated context.

4.3.4 Traffic Management

Highly automated driving offers even higher potential benefits if combined with traffic management, especially within urban environments. Traffic management can then "intervene" cooperatively at different levels of the driving task, such as navigation or vehicle guidance, its intervention can range from purely informative systems to influencing the vehicle motion by communicating advisory information or limiting certain levels of automation, and it could influence the availability and selection of a certain automation level within the vehicle. Here further research is necessary in order to exploit fully the potential in a manner that is safe, understandable and acceptable to the driver and other stakeholders. This area of research includes:

- Interaction of on-board-navigation with information from traffic management centre
- Open platformin the vehicles that enables additional information, such as dynamic traffic flow information, incident warning, road condition, weather condition, etc.
- Arbitration (negotiation between driver, on-board automation and traffic management centre)
- Distributed traffic management (tasks typically handled by a traffic management centre might be carried out by a network of highly automated vehicles, possibly supported by further information provided by sensors at intersections, etc.)
- Integration of navigational level with guidance (manoeuvre) level, (direct influence of traffic management on movement of vehicle or arbitration on choice of manoeuvre, for example the vehicles where the driver has chosen to temporarily hand over control to his automation could be rerouted and automatically follow alternative routes to achieve the given goal of avoiding congestion.)
- Supervision of automation by traffic management centres (an intelligent infrastructure could provide an additional safety layer by supervising the movement and status of highly automated vehicles and thereby increasing their reliability and possibly open wider application areas to highly automated driving)
- New logistics applications (highly automated driving (and its combination with traffic management) might enable new logistics concepts and business models to support the costs of such systems, such as allowing highly automated trucks exclusive or priority access to certain areas.)
- Support of multi- and intermodal mobility

4.3.5 Modelling

The research area of modelling plays an instrumental role in the development and evaluation of highly automated driving and its related applications. Especially if the driver can be modelled accurately enough, modelling can already be used during the development and design of highly automated vehicles, for example by testing certain assistance and automation functions and their HMI, first in simulations on driver models and iterating the design before studies with test persons are carried out. Models of both automation and driver and the interaction of several automations and drivers can help to predict and design even more complex cooperative systems. This also requires that sensors, e.g. radar, lidar, vision, GPS, and wireless communication that are used in the vehicles are accurately modelled in simulation. The effect on the overall traffic flow and the impact of highly automated vehicles, for example on congestion or emissions can be predicted and evaluated if valid models of the traffic flow exist. Next to simulation it is crucial that Hardware In the Loop (HIL) is the next logical step. Using HIL it will bridge the gap between simulation and practice. It also enables more realistic simulation on the short term. Hence this research area includes topics such as:

- Driver Behaviour
    - Cognitive processes relevant to driving
    - Reaction to Assistance
- Interaction
    - Driver vs. Automation
    - (Driver+Autom.) <-> Pedestrians
    - (Driver+Autom.) <-> (Driver+Autom.) <-> (Driver+Autom.)
- Sensor systems
    - Propagation of signals, such as radar and/or wireless communication
    - GPS, including obstruction and multi-path due to urban surroundings
- Traffic Flow
    - Highly automated vehicles
    - Mixed traffic
- HIL
    - Highly/fully automated vehicles tested in closed loop scenarios
    - Cooperative systems tested in closed loop scenarios
    - Driver interaction tested in closed loop scenarios

4.3.6 *Fail safe actuation of the automated vehicle*

Reliable and robust perception is necessary for automated vehicles to determine potential hazards and ensure safe driving from A to B. The next step is reliable and fail-safe actuation of the vehicle. In aviation safety integrity levels (SILs) are common and the system architecture is designed accordingly. Design of fail-safe architecture for automated driving according to Automotive SIL needs further exploration.
The design of fail-safe actuation is even more important in case X-by-wire technologies are used, such as steer-by-wire, which should be exploited to enable all degrees of freedom for an optimal human-machine interaction.
The fail safe actuation should be part of an overall concept for a robust and flexible system architecture, such that the appropriate dependability can achieved for the entire system, including sensors, software and actuators.

4.3.7 *Independent validation of automated systems*

And finally, when automated systems are ready for actually driving on the road, it is essential that these systems can be validated and/or certified by independent organisations to determine if the vehicle meets the required safety levels. For that, it is necessary to

- Determine necessary safety levels
- Design methodology to validate safety levels (of the system as a whole, i.e. the vehicle in all kinds of situations/scenarios in mixed traffic)
- Create/standardise test environment to perform validation

4.3.8 *Liability and legal aspects*

Although this is not a scientific research topic, all of the above research needs can be met, but are useless unless the legal and liability aspects are adjusted for the highly/fully automated driving case. A roadmap towards implementation of e.g. a legal framework is needed.

4.4 Development & deployment

An important aspect of innovation is the actual deployment and the development process prior to deployment. In contrast to the general accepted stages in innovation management, in most of the R&D projects we will start with the development prior or in parallel to the scoping and business case stages which will make it much more difficult to implement an innovative idea or concept successfully. At the basis of most successful innovation lies a detailed analysis of the areas of application and its stakeholders finally defining the business model and business case. In the roadmap for automation we tried to define the value proposition and business model for each and every selected function or application.

4.5 Key applications

In order to be able to define a comprehensive road map encompassing the whole spectrum of automation, use cases were selected that cover all levels of automation and find their application in all common scenarios (urban, highway and rural). These uses cases were mapped accordingly (see below).

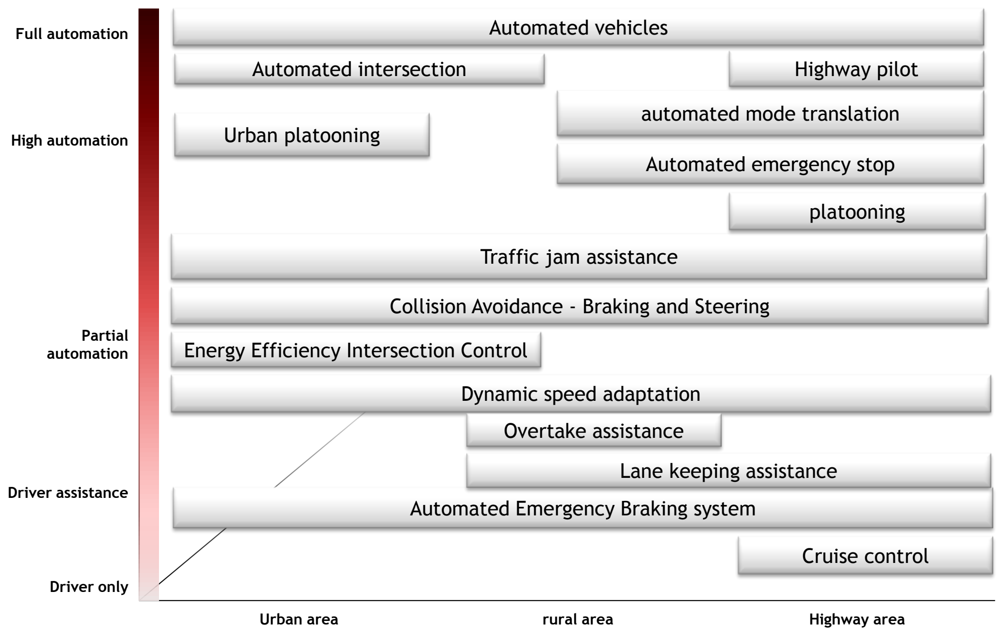

Figure 3: functional mapping of applications

4.5.1 Automated emergency stop

Scenario:	Highway + Rural
Function:	Automated emergency stop
Automation level	Full automation
Description:	Automatically bringing about a safe state with a minimum risk manoeuvre (e.g. lane change on emergency lane with subsequent vehicle stop) if driver drops out. The driver's status is monitored continuously. The function works without V2x communication.
Benefits:	Avoidance of dangerous situations caused by medical emergencies or drowsiness of the driver
Value proposition:	Private vehicles: willingness to pay

4.5.2 AEBS - Automatic Emergency Braking System

Scenario:	Highway, Rural & Urban
Function:	AEBS - Automatic Emergency Braking System
Automation level	Driver Assistance
Description:	AEB uses radar, laser, or video to sense an impending collision. The software then primes the brakes, or applies them if the situation is too far gone. The hope is that the safety tech will be particularly effective with front-end impacts, such as in heavy traffic. Besides stopping rear-ending crashes that clog up freeways, the required systems will also sense pedestrians in the roadway and apply the brakes before impact. The function works without V2x communication.
Benefits:	Avoidance of dangerous situations caused by inattention
Value proposition:	Private vehicles: willingness to pay Commercial: Business case on decreased accident costs

4.5.3 LKS - Lane Keeping Assist System

Scenario:	Highway & rural
Function:	Lane Keeping Assist System
Automation level	Driver Assistance
Description:	Active Lane Keeping Assistant System (LKAS) gives a smooth recommendation in the steering. The driver's decision takes priority at all times, but if no input is given the system follows the lane automatically. The function works without V2x communication.

Benefits:	Avoidance of dangerous situations caused by inattention
Value proposition:	Private vehicles: willingness to pay Commercial: Business case on decreased accident costs

4.5.4 CA-BS Collision Avoidance - Braking and Steering

Scenario:	Highway, Rural & Urban
Function:	CA-BS Collision Avoidance - Braking and Steering
Automation level	Partial automation
Description:	Extension of the automatic emergency braking system that also steer as a mean to avoid accidents. The function works without V2x communication.
Benefits:	Avoidance of dangerous situations caused by inattention
Value proposition:	Private vehicles: willingness to pay Commercial: Business case on decreased accident costs

4.5.5 Highway Pilot

Scenario:	Highway
Function:	Highway Pilot
Automation level	High automation
Description:	High automation in all conditions. Full automation in specific driving situations, fulfilling certain conditions. Example highway driving with low traffic and no exits. A Highway Pilot is a vehicle application which will support the driver on motorways and motorway similar roads with high level of automation in longitudinal and lateral control of the vehicle at speeds between 0 and 130 km/h (no technological limit). The systems should work without V2x communication Later versions would also include automated lane changes
Benefits:	Private vehicles: Comfort and improved safety where it supports the driver in monotonous traffic situations like long-distance driving which can lead to a lack of focus and increased accident risk. Specific secondary tasks are allowed.

	Commercial: Safety and efficiency Road Authorities: safety and efficiency
Value proposition:	Private vehicles: willingness to pay Commercial: Business case on increased efficiency

4.5.6 *Traffic Jam Assistant*

Scenario:	Urban, Rural & Highway
Function:	Traffic Jam Assistant
Automation level	Partial automation
Description:	The danger of getting into a traffic jam is present every day, in particular before a roadwork. Rush-hour traffic in the morning and in the evening is especially likely to cause a traffic jam and increases the accident risk even more. The driver gets annoyed by the stop & go and is pressed for time. Therefore, he pays less attention and needs assistance. The system can be seen as an extension of the ACC with Stop&Go functionality. The function controls the vehicle longitudinal and lateral to follow the traffic flow in low speeds (<30km) First without V2X, but V2X could lead shorter headways reducing congestion.
Benefits:	Safety: When driving in traffic jams space between vehicles is quite low and speed variations of vehicles in front happen quite fast, which augments the risk for rear-end collisions Comfort: can relax Efficiency (commercial vehicles): driver can work
Value proposition:	Private vehicles: Driver willingness to pay Commercial vehicles: efficiency, driver can work Road Authorities: efficiency, safety

4.5.7 *Energy Efficiency Intersection Control*

Scenario:	Urban Environment
Function:	Energy Efficiency Intersection Control
Automation level	Driver Assistance to partial automated
Description:	An adaptive urban traffic control system controls traffic lights and gives speed advices that the vehicle follow automatically. The driver has the possibility to override the advices. V2I communication is needed.

Benefits:	Less congestion and less total emission on a population of vehicles.
Value proposition:	Societal gain, need to be enforced with regulations Road Authorities

4.5.8 Dynamic Speed Adaptation

Scenario:	Urban Environment - Highway
Function:	Dynamic Speed Adaptation
Automation level	Partial automation
Description:	This function adapts the vehicle speed and the distance to other vehicle with input from the infrastructure, i.e. V2I communication is needed Works in combination with ACC and C-ACC.
Benefits:	Less congestion and higher safety
Value proposition:	Societal gain, need to be enforced with regulations

4.5.9 Overtake Assistance

Scenario:	Rural
Function:	Increased safety on rural roads, more comfort while overtaking and more awareness
Automation level	Driver assistance
Description:	Assisting in overtaking vehicles in rural scenario's by assessing the safe space or location for overtaking, taking into account speed of the vehicles including the vehicle to be overtaken. The function works without V2x communication.
Benefits:	Less accidents,
Value proposition:	Private vehicles: willingness to pay Commercial: Business case on decreased accident costs

4.5.10 Platooning

Scenario:	Highway
Function:	Platooning
Automation level	Highly automated
Description:	This function enables platooning in specific lane. The vehicle should be

	able to keep it position in the platoon with a fixed distance or fixed time difference from the front vehicle. The behaviour of the first vehicle (e.g. braking and steering) should be transmitted be V2V communication The function should also handle vehicle that wants to leave the platoon. Up scaling and deployment can be reached as follows: 1) Start with trucks as there is a strong financial incentive due to 10% to 15% fuel savings 2) Start with small platoons of only 2 trucks and co-operation with fleet-owners in high density truck area. 3) Start with a system where drivers are still in the following truck, for legal reasons 4) Setup an (open) fleet management system for trip matching between equipped trucks of different fleet owners
Benefits:	• Increased safety and comfort for the drivers. • Increased reliability • Reduced environmental impact due to less aerodynamic drag. • Reduced congestions due to better utilization of lane area.
Value proposition:	Truck: Increased fuel efficiency, see peloton business case, resulting in lower operational costs. Passenger: TBD

4.5.11 Automated intersection

Scenario:	Urban Environment
Function:	Automated intersection
Automation level	Full automation
Description:	Fully cooperative driving with adaptive speed control based on state estimation and state prediction in networks of intersections. Vehicles will communicate their directions / destinations, speed and position and will be fully controlled at intersection areas, creating small “urban platoons” crossing the intersection. The system combines infrastructure based state estimation with automated vehicle control. This use case will not take the interaction with VRU’s into consideration.
Benefits:	• Less investments in infrastructure based traffic equipment (including highly reduced maintenance costs) and seamless vehicle interactions; • More safety and efficiency in urban transport; • Options for prioritizing dedicated traffic users aimed at more sustainable traffic in urban areas.

Value proposition:	Societal benefits (reduced investments, increased control and safety); More comfort

4.5.12 *Urban platooning*

Scenario:	Urban Environment
Function:	Urban platooning
Automation level	High automation
Description:	Possible to have driverless cars following a lead vehicle. The function would support car sharing. One person can pick-up several vehicles.
Benefits:	One person can pick-up several vehicles.
Value proposition:	Business case from car pools or rental companies

4.5.13 *Automated mode Translation*

Scenario:	Highway
Function:	Automated mode translation
Automation level	High automation
Description:	Based on detailed situational awareness of the network an advice is communicated to the automated vehicles on the applicable safe level of automation and is changed according to the estimated changes in the network. This advice is based on the capacity, number of non-automated vehicles and is a safety level.
Benefits:	
Value proposition:	

4.6 Milestones

It is relevant to obtain and define target milestones in the three areas of interest for automation: safety, traffic flow and fuel efficiency. In other policy documents, studies and roadmaps specific milestones are already defined like the recent ERTRAC Roadmap. These references give us a guideline for the milestones directly linked to the development, implementation and uptake of automation in road transport but cannot automatically be copied because of differences in scope, definitions etc.

The Working group will take the second year (i.e. 2013) for coming up with specific milestones as a result of increased automation levels.

5 Roadmaps

Based upon the deduction in the previous chapters and paragraphs we drew 2 roadmaps, one for the highway scenario and one for the urban scenario. The roadmaps have a basic setup in which we discriminate between 3 phases with its subsequent TRL levels:

1. Technological research;
2. Piloting, large scale demonstrators;
3. Industrialisation

The roadmaps are setup in a way that they describe the sequence in which functions will be available or can become available. The next step then can be to see how certain scenarios might quicken or delay the development for deploying these functions. This might be scenarios like solving certain legal barriers or the restricted availability of low cost sensors or regulatory frameworks on sustainable solutions.

5.1 Highway

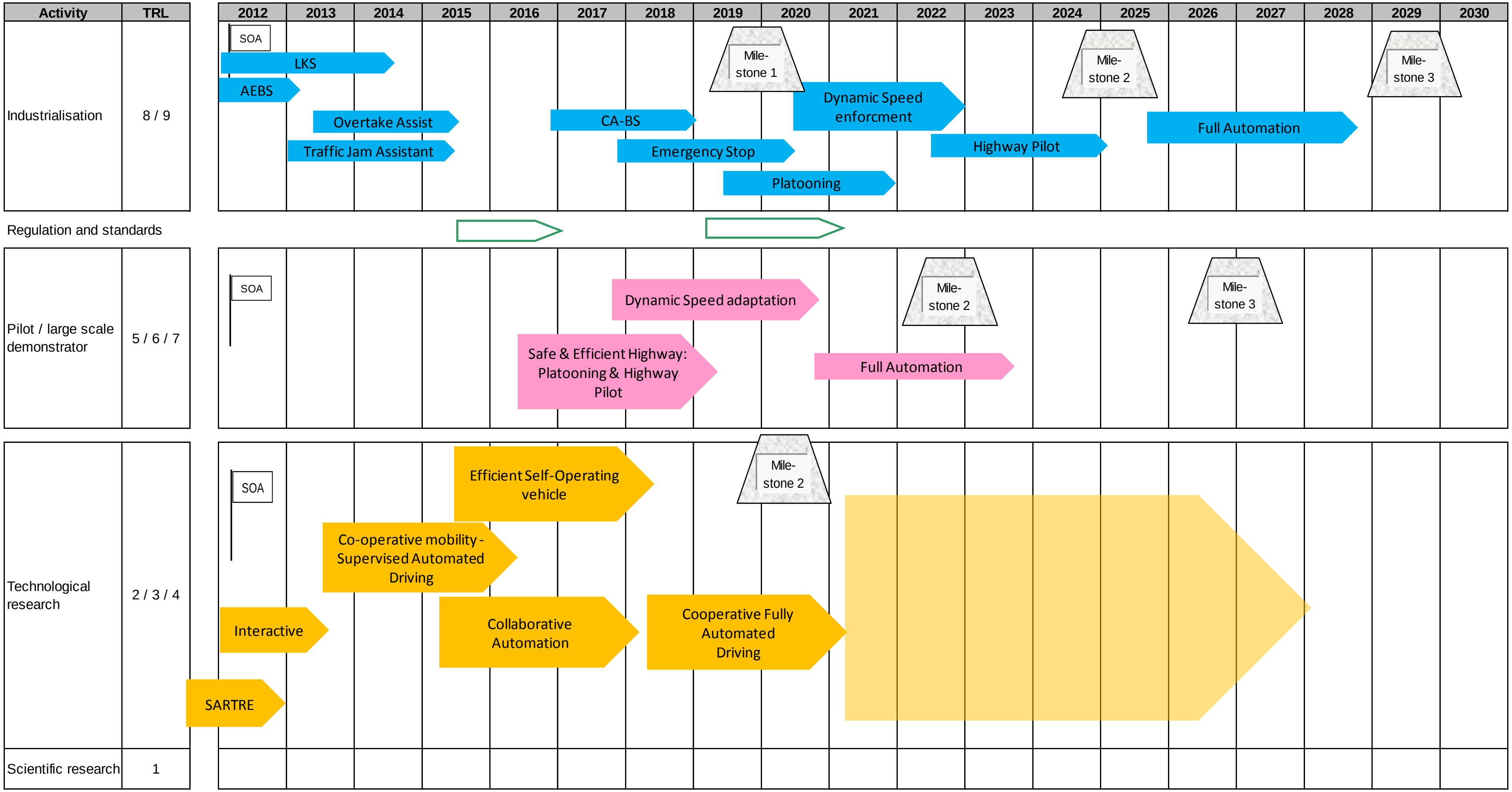

Figure 4: highway roadmap

Roadmap – Automation

5.2 Urban

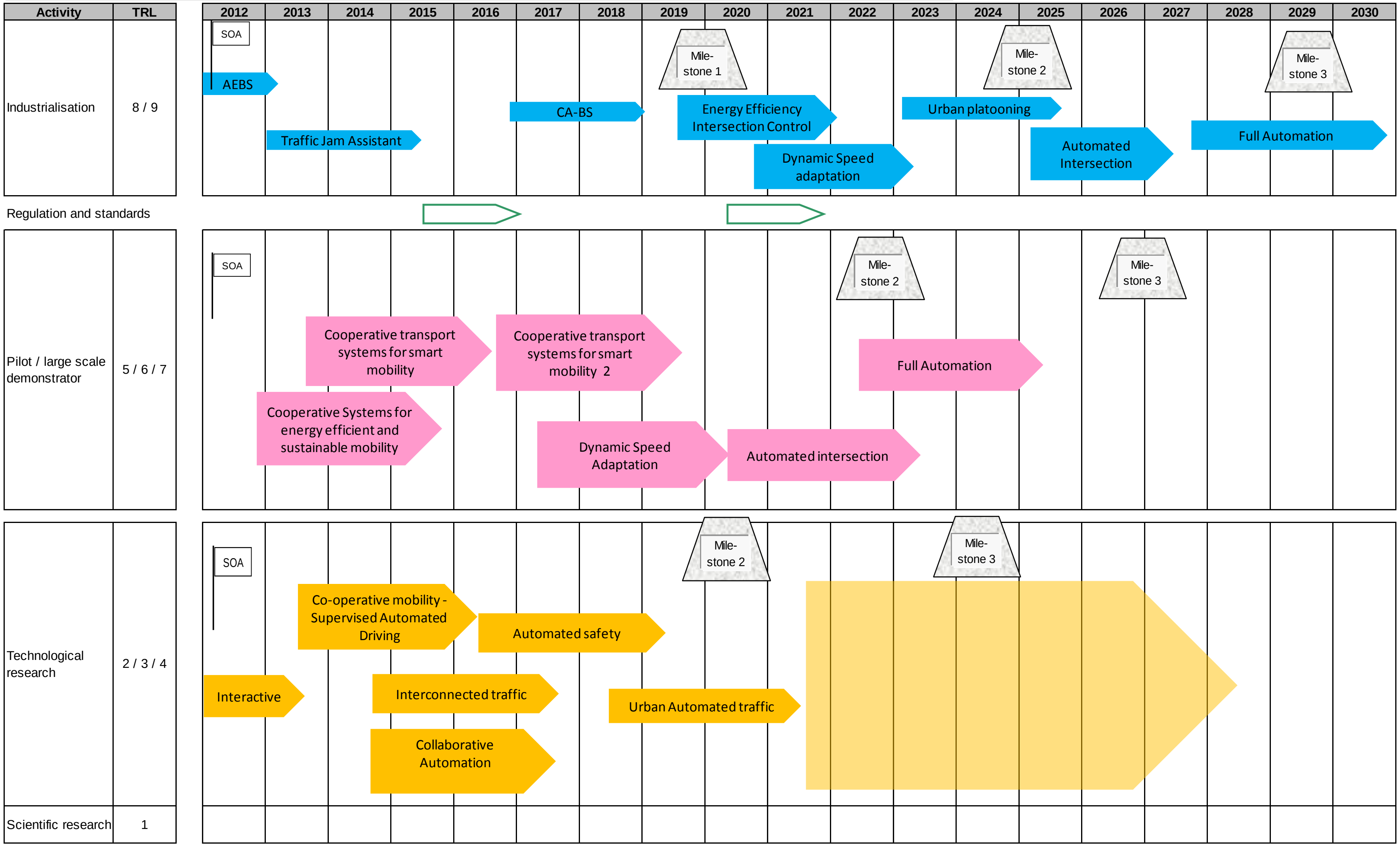

Figure 5: Urban roadmap

5.3 Recommendation of Research & Innovation activities

5.3.1 Efficient Self-Operating Vehicles

Contents and scope:

Based on the result from earlier initiatives, automation can be connected to the operation to guarantee an optimal efficiency limiting the driver impact on performances
Develop concepts and methods for the continuous assessment of the integrity of the complete driving situation in autonomous driving with the goal of timely reactivation of human attention and action.
Research should include:

- From driver controlled (partly -automated) driving to highly automated driving;
- Developing the technological components, data fusion and situation analysis methods in a functional architecture enabling safe highly and fully automated driving;
- Develop criticality measures for judging the complexity and manageability of traffic, weather, road, vehicle etc. conditions with respect to the proven skills of the automated system;
- Develop failure tolerant system architectures for highly and fully automated systems
- Defining and validating methods for the validation of system robustness and safety, proposing a code of practice for the safe design and validation of systems;
- Develop methods for robust driver state assessment for partly automated (driver has to be attentive) and highly automated (driver may not sleep) systems;
- Proving the impact of different levels of automation in driving and in traffic safety and efficiency;
- Preparing social acceptance for automation risk;
- Preparing legal aspects and requirements for registration, regulation, liability, code of behaviour for semi or highly automated and autonomous driving within EU- 27 and cross its boarders;
- Defining requirements and methods for testing, approval and real life safety impact of highly and fully automated low and high-speed driving (how to do it with a common acceptance by the society);
- 360° environmental detection, understanding and task planning with n seconds time horizon, strengthen methods to guarantee stable vehicle dynamics in the needed physical borderline and with needed accuracy (longitudinal and lateral control);
- Understanding technical aspects of the increasing proportion of automation in manoeuvring like flight path and trajectory decision for safe manoeuvres;
- Proving the driver's capability to take over vehicle control in an appropriate manner at take over request of partly and highly automated systems.

5.3.2 Collaborative Automation

Automation of driving requires collaboration between the driver and the automated- and connected vehicle systems. Automation can provide a more comfortable, efficient, productive, and safer driving experience. Development in driver-automation interaction is needed in the following areas:

- Partially and highly automated vehicle systems must be engineered to act in harmony with driver expectations and be resilient to system- and driver failures. Information, warning, intervention, and automation strategies must be further developed;
- Estimation of the driver's readiness to take control in automated driving situations
  - Assess different concepts for driver attention monitoring and reactivation
  - Develop criticality measures for judging the complexity and manageability of the situation (traffic, weather, road, vehicle,…) w.r.t. the proven skills of the system;
  - Design methods for early identification of upcoming situations with need of human action including statistical assessment of the effectiveness of such methods;
- Timely transitions and reactivation of human attention and action must be handled within safe driving performance limits in complex situations;
- Develop methods and conduct studies for the assessment of various types of HMI and system phasing in/out for the transfer of control between the system end the driver;
- Driver-vehicle-environment assessment, especially driver monitoring, is needed to keep the driver in the control loop despite monotonies, complex decision making, or short reaction times;
- Understanding HMI to define a "reference model for the driver" for the different levels of automation strategies from highly automated (low and high speed driving) to full automated driving (performance and limits in complex situations; hand-over; requests to keep the driver in the control loop in the field of monotonies and complex decision making or short reaction times; measures of "risks in driving situations" that drivers are willing to accept).

5.3.3 Cooperative Fully Automated Driving

- Develop methods and tools for the simulation of vehicle behaviour and traffic properties at various scales, that would allow to assess the impact and benefit of automated driving systems with various levels of coverage and fitment rate of the vehicle fleet;
- Extension and improvement of communication means and protocols supporting increased levels of automated vehicle control and safety;

5.3.4 Interconnected traffic

Contents and scope: The aim to show the full benefit of cooperative systems and automation in urban environment especially focusing on the vehicle-infrastructure functionality. Key areas:

- Traffic management system optimizing for mix of cooperative and standard vehicles.
- Dependability and security of information flow between vehicles e.g how can timing be accurately predicted in those systems;

- How to improve today's restraint systems if information on other cars or objects were at hand. Research how knowledge of mass, velocity, trajectory could benefit both participants in an integrated safety approach;
- Extension and improvement of communication means and protocols supporting increased levels of safety integration;
- Develop methods and tools for the simulation of vehicle behaviour and traffic properties at various scales, that would allow to assess the impact and benefit of automated driving systems with various levels of coverage and fitment rate of the vehicle fleet.

5.3.5 *Automated Safety*

Contents and scope: Full urban safety, including VRU

- Understand with what degree of reliability is needed in the information for safety systems, e.g. is the communication information so reliable so an airbag can be deployed in advance for maximum protection?
- Defining and validating methods for the validation of system robustness and safety, proposing a code of practice for the safe design and validation of systems. Specify the content and implement a unified;
- Accidentology database covering Europe with a detailed content suitable to identify priorities and to assess the benefit of future automatic safety systems.

5.3.6 *Urban Automated traffic*

Contents and scope:

- Development of systems allowing safe and smooth coordination of various types of transportation means in cities (automated / non-automated, public / individual…);
- Regulatory and business approaches to implement efficient means for cooperative safety encompassing Vulnerable Road Users.

5.4 Recommendation on large scale demonstrators

5.4.1 *Safe & Efficient Highway: Platooning & Highway Pilot*

Large scale demonstrator on safe and efficient highway driving based on platooning and highway pilot. Key result is to validate impact and to overcome deployment issues;

5.4.2 *Dynamic Speed adaptation*

Large scale demonstrator on dynamic speed adaptation. Key result is to validate impact and to overcome deployment issues;

5.4.3 *Full Automation (highway)*

To be written in a future version of the document

5.4.4 *Cooperative transport systems for smart mobility 2*
Large scale demonstrator following up the CIP planned for WP 2013;

5.4.5 *Automated intersection*
Large scale demonstrator on automated intersections. Key result is to validate impact and to overcome deployment issues

5.4.6 *Full Automation (urban)*
To be written in a future version of the document

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7 Acronyms and Abbreviations

CMbB	Crash Mitigation by Braking
LDW	Lane Departure Warning
LDS	active Lane Departure Support
AEBS	Advanced Emergency Braking System
AMI	Automatic Metering Infrastructure
APU	Auxiliary Power Unit
BRT	Bus Rapid Transit
EV	(Full) Electric Vehicle
GHG	Green House Gas
HCCI	Homogeneous Charge Compression Ignition
HDT	Heavy Duty Truck
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
ISO	International Standards Organisation
LEV	Light Electric Vehicle (like e-bikes, motorbikes and small cars)
OEM	Original Equipment Manufacturer
PHEV	Plug-In Hybrid Electric Vehicle
PTW	Power Two-Wheelers
R&D	Research and Development
RTD	Research and Technology Development
SAE	Society of Automotive Engineers
SUV	Sports Utility Vehicle
VRU	Vulnerable Road Users