CEDR Transnational Road Research Programme
Call 2017: Automation

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MANTRA

MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business

D2.1 Vehicle fleet penetrations and ODD coverage of NRA-relevant automation functions up to 2040

Deliverable 2.1 Version 1.0

Start date of project: 01/09/18 End date of project: 31/08/20

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Glossary of Terms

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
aFAS	aFas is the German acronym for driverless safety trailers
AI	Artificial Intelligence
BaU	Business as Usual
B/C	Benefit/Cost ratio
CACC	Cooperative Adaptive Cruise Control
CAD	Connected and Automated Driving
CBA	Cost Benefit Analysis
ENPV	Expected Net Present Value
ERTRAC	European Road Transport Research Advisory Council
ISAD	Infrastructure support levels for cooperative connected automated driving
MANTRA	Project Acronym: Making full use of Automation for National Transport and Road Authorities – NRA Core Business
NRA	National Road Authority
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
PDO	Property Damage Only accidents
STEEPLE	Social, Technology, Economic, Environmental, Political, Legal, Ethical analysis
V2V, V2I	Vehicle-to-Vehicle, Vehicle-to-Infrastructure communications
VMS	Variable Message Sign

1 Introduction

MANTRA is an acronym for "Making full use of Automation for National Transport and Road Authorities – NRA Core Business". MANTRA responds to the questions posed as CEDR Automation Call 2017 Topic A: How will automation change the core business of NRA's, by answering the following questions:

- What are the influences of automation on the core business in relation to road safety, traffic efficiency, the environment, customer service, maintenance and construction processes?
- How will the current core business on operations & services, planning & building and ICT change in the future?

This first MANTRA deliverable D2.1 Vehicle fleet penetrations and ODD coverage of NRA-relevant automation functions up to 2040 provides input for work in other MANTRA work packages (see figure 1):

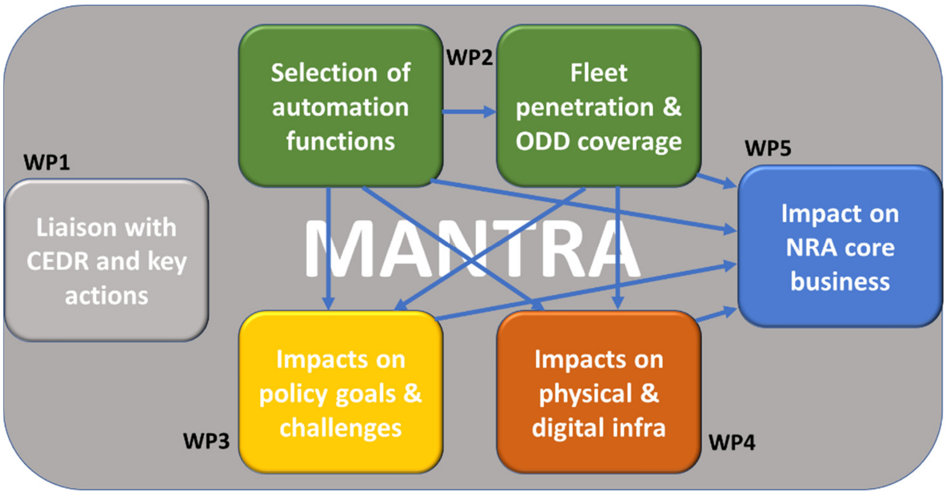

Figure 3. *Summary of MANTRA work packages, the main tasks and their links.*

This first MANTRA deliverable D2.1 Vehicle fleet penetrations and ODD coverage of NRA-relevant automation functions up to 2040 was internally reviewed and feedback was provided between February 1st, 2019 and March 7, 2019 (two telcos with PEB contacts; CEDR CAD group and PEB meeting Tallinn). Results were presented at the CEDR CAD meeting in Tallinn. PEB suggestions for clarification between March 2019 and June 2019 are all integrated – so the status is accepted by PEB. In a regular PEB telco early in September 2019 it was suggested to freeze the document after the MANTRA workshop in Vienna, September 10, 2019 as version D2.1 V 1.0. Only after all MANTRA deliverables are handed in there might be a version 2.0 integrating all further newly emerging details on ODDs or clarifications towards other publications.

This version fully integrates input and feedback from Wolfgang Schildorfer, Merja Penttinen, Elina Aittoniemi (VTT), Jacqueline Erhart (Asfinag), Pirkko Rämä as well as discussion input from CAD group miniworkshop in Vienna and CAD group meeting in Oslo and Tallinn and preparatory files for the ERTRAC roadmap meeting. We also received and fully integrated feedback and suggestions including bilateral communication during two ARCADE workshops in Brussels (February and April) and EC's 5G Strategic Deployment Agenda (SDA) for CAM (Connected and Automated Mobility) for the period 2021-2027.

Next steps in work packages 2, 3 and 4 focus on the safety, efficiency and environmental impacts of connected automated driving utilizing the vehicle and ODD coverage predictions, based on the likely changes in mobility and driver / traffic behaviour of road users. The work continues by assessing for each of the selected functions how the function together with connectivity affects the physical and digital road infrastructure as well as the communication infrastructure, due to a) the need to make changes to the infrastructure to provide the required ODD to facilitate connected and automated driving, b) the automated function's operation itself, and c) the possibility to improve infrastructure related operations as a result from utilizing automated functions or new data provided by these functions. This will also cover the legal framework and affected technical standards, and any needs to make changes in them. The work concludes by mapping the socio-economic, infrastructure and other impacts of the selected functions against the core business areas of the road operators. In addition, the work will contain a comprehensive assessment of the impact of the total change in NRA core business due to connectivity and automation in combination with digitalization, electrification, urbanization, servitization and other megatrends. While national priorities concerning core business emphasis and automation functions vary, MANTRA applies a European transnational approach to facilitate the utilization of the results for all CEDR members. The MANTRA consortium not only represents a variety of European countries but is in addition a well-balanced mix of renowned research institutes providing the scientific foundation and experienced ITS/road operations advisors adding the practical flavour. It is excellently suited to carry out the project with high expertise on connected and automated driving as well as ITS related research and wide experience in NRA core business processes, and also in CEDR cooperation.

The logic behind three ongoing connected research assignments in this CEDR automation call is illustrated by the following chart: (Harrer et al 2017):

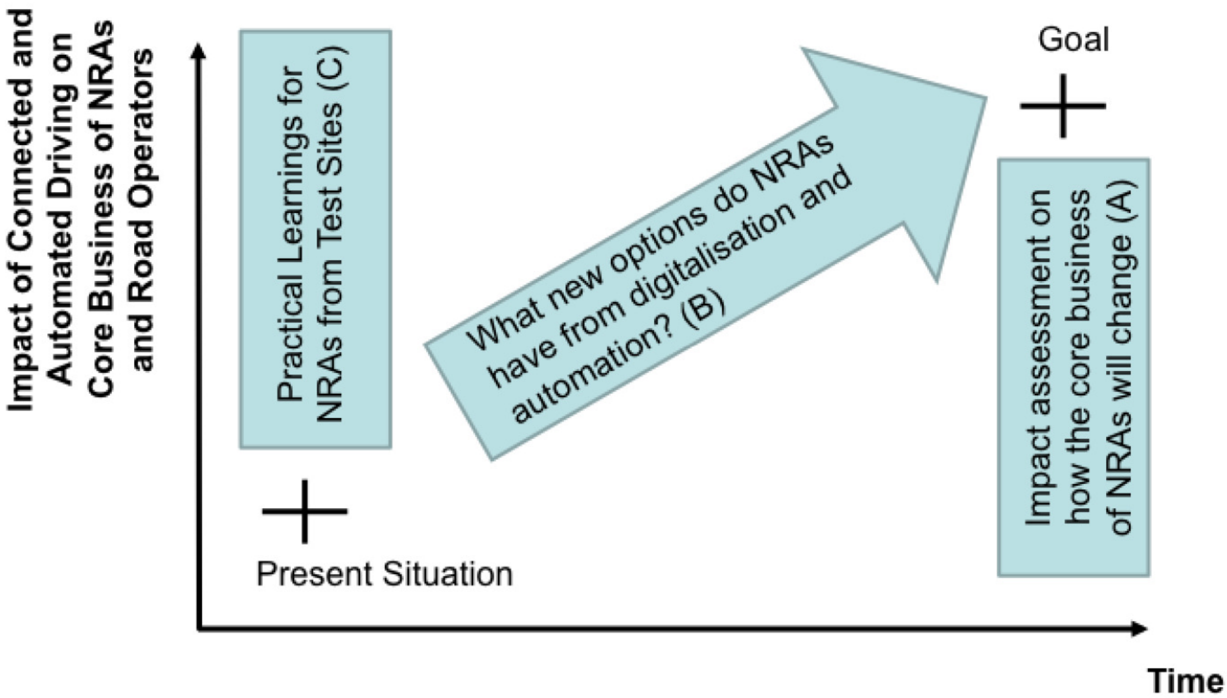

Figure 2. *Context for CEDR automation call 2017 (Harrer et al. 2017* DORN CEDR automation call. (chart illustrating the logic behind three connected research assignments / the three projects – with MANTRA being the one on the right side*).*

2 Relevance to road authorities and operators

Automation functions will find its way into real-world road-based mobilities. The question is how to effectively discuss and prepare for these issues and this transition phase within NRAs' management layers. Today's solutions can quickly become the problem in a tomorrow with automation functions. Geißler emphasized the correlation between ISAD and ODDs (Geißler 2019). Dialogue between road authorities and vehicle manufacturers is needed. This change management process needs alignment with ongoing C-ITS deployment activities. Van Dam emphasized the need to quantify the value capture from automation functions for road operators before investment decisions at NRAs can be discussed (van Dam 2019).

This first deliverable from MANTRA provides several elements and concepts to shape managerial preparation:

- four priority use cases for AV, (Highway autopilot including highway convoy (L4) – 1 as 1st phase; Highly automated (freight) vehicles on open roads (L4); Commercial driverless vehicles (L4) as taxi services; Driverless maintenance and road works vehicles (L4)
- Operational Design Domains (ODDs) for the use cases, including the road operator attempts to categorise their physical and digital infrastructures in support to them
- estimated ODD coverages for automation functions up to 2040
- a set of fleet penetration rates for these priority use cases and
- a first discussion on limitations of this approach to discussing an open future.

Fleet penetration rates for four priority use cases provide tools for preparing internal discussions concerning real-world take up of new vehicles and new services. This input on penetration rates is to help anticipate lead times, public discussions and co-dependent investment cycles.

This current period of dynamically evolving ideas about future automated mobilities has seen competitive signalling both from established OEMs as well as from new players striving for investment rounds and public attention. Some stakeholders maintain that we will see higher levels of automation in commercially valid services by 2020 while others seem fully convinced that this cannot validly be done prior to 2040. This document is a first input for both the NRAs as well as next WPs in MANTRA.

This all helps better understand how an information layer from AV comes as a "third element" between physical infrastructure and automated vehicles and how these "three layers" are challenging and shaping established processes with road operators.

MANTRA responds to the questions posed as CEDR Automation Call 2017 Topic A (vertical block at the right hand side of the chart): How will automation change the core business of NRA’s, by answering the following questions:

- What are the influences of automation on the core business in relation to road safety, traffic efficiency, the environment, customer service, maintenance and construction processes?
- How will the current core business on operations & services, planning & building and ICT change in the future?

MANTRA started the work at a time of quick development of connected and automated driving, when numerous other projects, platforms and working groups in Europe and other parts of the world are working on slightly overlapping areas. Hence, MANTRA emphasizes close liaison towards other actions in the area, building on the consortium members’ own involvement in European and national projects as well as the experience working with NRAs. The liaison is especially close to CEDR CAD WG, the members of which are heavily involved in key European and international platforms and working groups. However even this close involvement cannot possibly eliminate external dynamics in terms of ODDs or in dynamically emerging connected and automated mobility services. Therefore input in this deliverable should not be mistaken as a forecast but rather as a pragmatically necessary starting point for any analytical work.

Feedback at two workshops during the Tallinn meeting on March 7, 2019 provided significant indication that for several road authorities, early identification of risks related to anticipated road capacity reduction from early forms of automated vehicles and assistive functions especially during the crucial peak hours would help effective preparation. Tolling infrastructure was highlighted as important to ODDs of all forms of truck automation (Harrer 2019). Among further candidates for proactive action from NRAs there is the issue of some critical interaction between ODDs for different use cases: e. g. currently safety trailers are not recognized by CACC in cases where they are positioned diagonally to a lane. This illustrates consequences from vehicle manufacturers providing rather narrow ODDs and eliminating tricky cases at least in early phases of commercial take-up.

3 The automation functions most relevant for road operators

The initial starting point was a set of candidate automation functions all based on the latest definitions in ERTRAC (2017) etc. In a mini-workshop held on August 31st 2018 with the CEDR CAD group and CEDR PEB at FFG premises in Vienna, Austria the following set of 15 candidate automation functions was discussed:

1 Highway Chauffeur (Level 3)

Conditional Automated Driving up to 130 km/h on motorways or motorway similar roads. From entrance to exit, on all lanes, including overtaking. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can at all times override or switch off the system. In case of a takeover request to the driver from the system, the driver has sufficient time reserve to orientate himself and take over the driving task. In case the driver does not take over, the system will go to a reduced risk condition, i.e. bring the vehicle to a safe stop.

2 Highway Autopilot including Highway Convoy (Level 4)

Highly Automated Driving up to 130 km/h on motorways or motorway similar roads from entrance to exit, on all lanes, including overtaking and lane change. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can at all times override or switch off the system. There are no requests from the system to the driver to take over when the system is in normal operation area (i.e. on the motorway). The system will go to a reduced risk condition, i.e. bring the vehicle to a safe stop. Depending on the deployment of cooperative systems, ad-hoc convoys could also be created if V2V communication is available.

3 Urban and Suburban Pilot (Level 4)

Highly Automated Driving up to limitation speed, in urban and suburban areas. The system can be activated by the driver on defined road segments, in all traffic conditions. The driver can at all time override or switch off the system

4 Highly automated freight vehicles in dedicated lanes/roads/areas (Level4)

Automated freight transport carriers on dedicated and controlled lanes/roads/areas and for potentially un-manned freight transport. Vehicles can be designed without cab for driver. Operation could be done during night in lower speed to save fuel.

5 Highly automated freight vehicles on open roads (Level4)

Automated freight transport carriers on public roads and for un-manned freight transport. Vehicles can be designed without cab for driver. Operation could be done during night in lower speed to save fuel

6 Automated Truck Platooning (Level 2)

This function enables platooning in both dedicated lane/road and on open roads in mixed traffic. The vehicle should be able to keep its position in the platoon with a safe distance between the vehicles. The driving behaviour of the leading vehicle is transmitted by V2V communication to the following vehicle taking vehicle characteristics into consideration, such as braking capacity, load. The function will also handle platooning management of forming, merging and dissolving platoons together with interaction with other road users and road infrastructure requirements.

7 Automated Bus Chauffeur (Level 3)

Conditional automated driving in traffic jam up to 60 km/h on motorways and highways. The system can be activated in case of a traffic jam scenario exists. It detects slow driving vehicles in front and then handles the vehicle both longitudinal and lateral. Later versions of this functionality could include lane change functionality. Driver must deliberately activate the system, but does not have to monitor the system constantly. Driver can at all times override of switch off the system.

8 Automated Buses on dedicated lane (Level 4)

The automated bus operates in dedicated bus lanes together with non-automated buses in normal city bus speed. Functions may include bus-trains, following and bus-stop automation for enhanced productivity, safety, traffic flow and network utilization.

9 Automated PRT/Shuttles on dedicated roads (Level 4)

The automated PRT/Shuttle drives in designated lanes / dedicated infrastructure, with a maximum speed of 40km/h. This may be combined with automated functions for enhanced safety, traffic flow and network utilization.

10 Automated Buses in Mixed Traffic (Level 4)

The automated bus operates in mixed traffic on open roads together in normal city traffic speed. Functions may include bus-trains, following and bus-stop automation for enhanced productivity, safety, traffic flow and network utilization.

11 Automated PRT/Shuttles in mixed traffic (Level 4)

The automated PRT/Shuttle drives in mixed traffic in same speed as other traffic.

12 Commercial driverless vehicles (L4) as taxi services

13 Driverless maintenance and road works vehicles (L4)

14 Automated traffic management systems (“EU EIP L4-5”)

15 Fleet management of L4 vehicles outside Operational Design Domain (ODD)

As one key outcome from the mini-workshop in Vienna it was agreed to use the following four as the basis for MANTRA. This decision process was also presented during the CEDR CAD group meeting in Oslo in November 2018:

> 2 Highway autopilot including highway convoy (L4) – 1 as 1st phase
>
> 5 Highly automated (freight) vehicles on open roads (L4)
>
> 12 Commercial driverless vehicles (L4) as taxi services
>
> 13 Driverless maintenance and road works vehicles (L4)

Some more detailed discussions on the four automated driving use cases resulted in some additional details on their specifications.

Automated emergency braking is considered to be a part of all use cases in the next decades.

Currently the robot taxis are planned as an urban street service only, but by 2040 this service will also cover other roads (ring roads, arterials, highways) around urban areas in order for the taxi service to provide door-to-door service. Cooperation between local and national traffic management is needed for the large area coverage. Likely, specific locations for safe pick-up and drop-off of passengers need to be allocated and designated to the robot taxis, perhaps to be shared with automated shuttles. For 24/7 services, robot taxis should also be able to deal with most weather and road surface conditions.

The exchange on higher levels of truck automation triggered some exchange on adequate processes and information requirements within road operators to adequately cope with these new opportunities and challenges. National differences on the approach exist currently. At the CEDR CAD group meeting in Stockholm June 2019 three initiatives on truck automation will present inputs to a next round of roadmapping on NRA levels.

In general, the terminology related to connected and automated driving is evolving. The globally used SAE (2018) definitions for levels of automation are updated regularly to clarify the role of automation and the role of human driver. Further, the technologies, sensors, and software for automated vehicles are evolving even at a quicker pace. Hence, the ERTRAC (2017) deployment and R&D&I roadmaps are regularly updated, with last update in 2019 Connected Automated Driving Roadmap Version: 8 Date: 08.03.2019 ERTRAC Working Group "Connectivity and Automated Driving".

4 Operational Design Domains

4.1 General on Operational Design Domain

Operational design domain (ODD) is a description of the specific operating conditions in which the automated driving system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/night time, etc.), prevailing traffic law and regulations, and other domain constraints. An ODD can be very limited: for instance, a single fixed route on low-speed public streets or private grounds (such as business parks) in temperate weather conditions during daylight hours. (Waymo 2017)

The ODD is relevant to all levels of automation except for 0 and 5 as shown in Table 1. Any automation use case of level 1-4 is usable only in its specific ODD.

Table 1. Relevance of Operational Design Domain for different automation levels (SAE 2018)

Level	Name	Narrative definition	*DDT*		*DDT fallback*	*ODD*
			Sustained lateral and longitudinal vehicle motion control	***OEDR***		
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems.*	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT.*	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system.*	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene.*	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene.*	*System*	*System*	*System*	**Unlimited**

The automated vehicles are deployed so that they consider the ODD and especially its ending. This is illustrated in Figure 33.

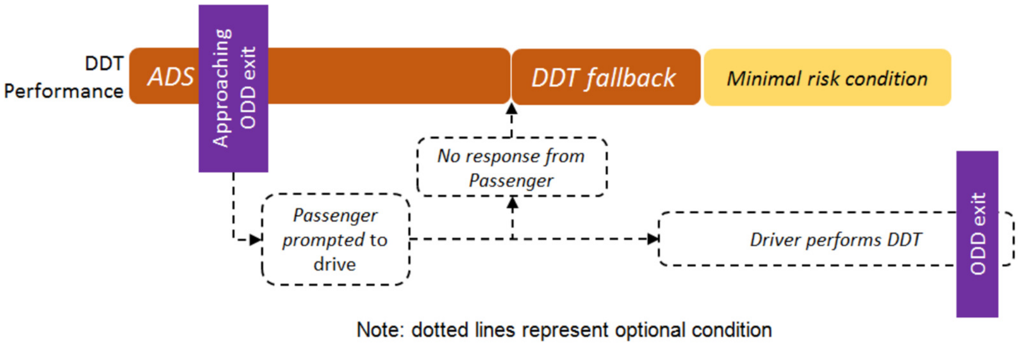

Figure 3. Performance of automated vehicle when approaching ODD exit. ADS = Automated Driving System; DDT = Dynamic Driving Task. (SAE 2018)

The automated driving system becomes aware of the impending exit from the ODD, and may prompt the fall-back ready user to take over the tasks of the driver. If there is no response from the passenger indicating takeover, the system initiates dynamic driving task fallback, and moves to a minimal risk condition. The characteristics of automated achievement of a minimal risk condition at level 4 will vary according to the type and extent of the system failure, the ODD for the automated driving system feature in question, and the specific operating conditions when the ODD exit occurs. It may entail automatically bringing the vehicle to a stop within its current travel path, or it may entail a more extensive manoeuvre designed to remove the vehicle from an active lane of traffic and/or to automatically return the vehicle to a dispatching facility. (SAE 2018)

For the user, it would likely be more comfortable the less often the control of the vehicle needs to be transferred between ADS and the driver (Figure 4). It is also likely that elimination of the transfer situations requires investments from the stakeholders responsible for the existence of the ODD in the specific situation. Hence, the continuity and length of the ODD play an important role for both the user and those responsible for maintaining the ODD.

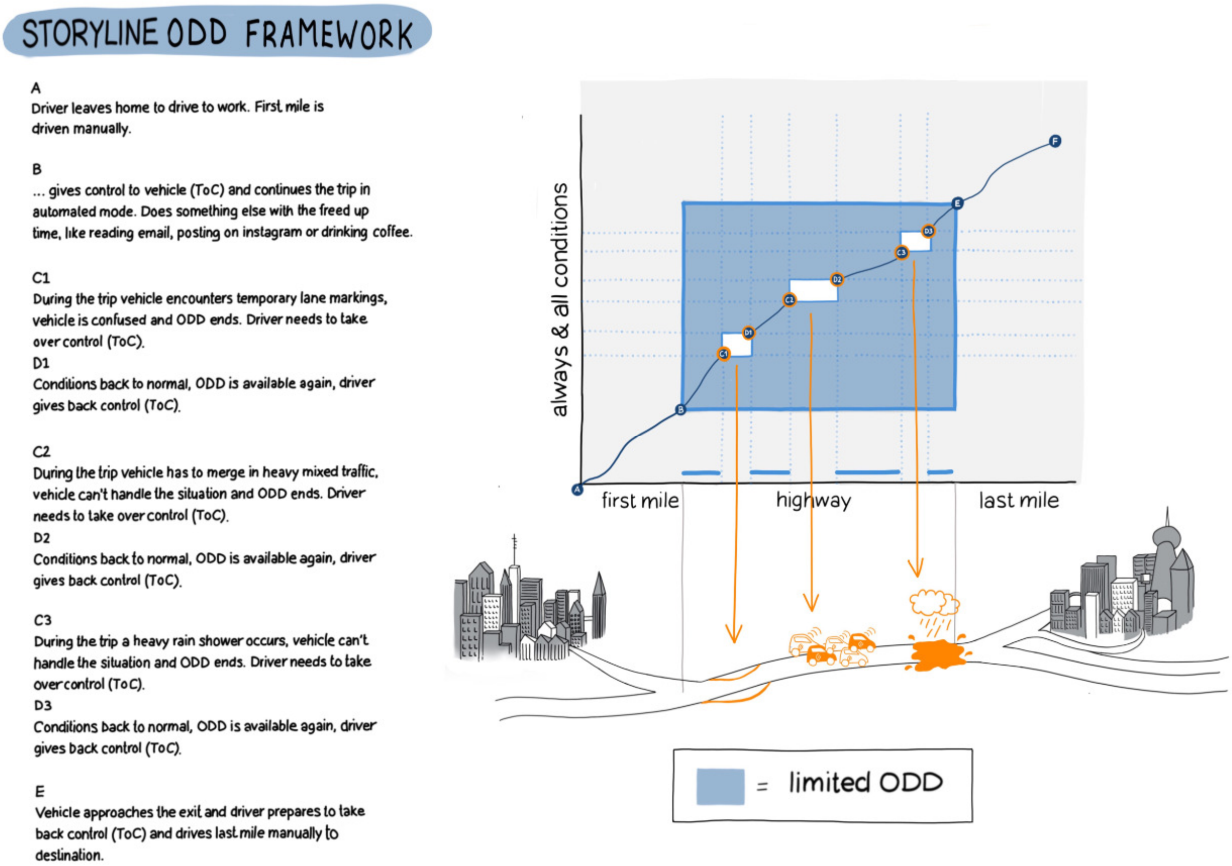

Figure 4. ODD-related needs for transition of control for highway autopilot (Alkim 2018)

The attributes of the ODD are directly connected to the way the automated driving system works. Figure 5 shows the example from General Motors.

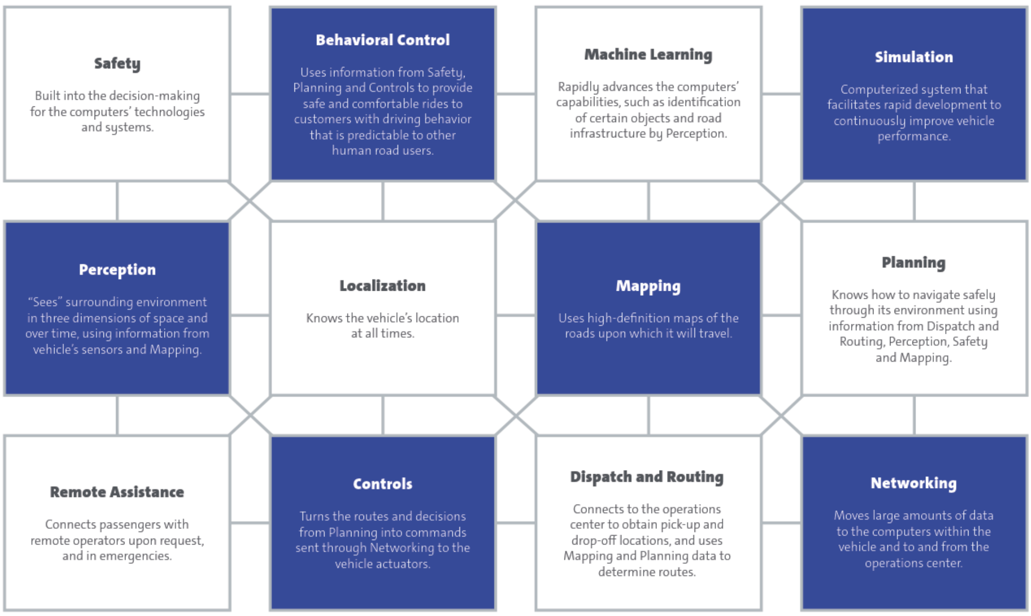

Figure 5. The building blocks of the automated driving system (General Motors 2018)

Perception, accurate positioning and mapping are evidently the key building blocks in the automated driving systems' architecture. See Figure 4 for the description of the different positioning solutions. The sensors and their range are essential especially with regard to the speed ranges possible (Schoettle 2017). Connectivity/networking to operations centres and real-time information are also important elements. All of these are also related to the vehicle's interaction with its environment, and thereby strongly connected to the ODD.

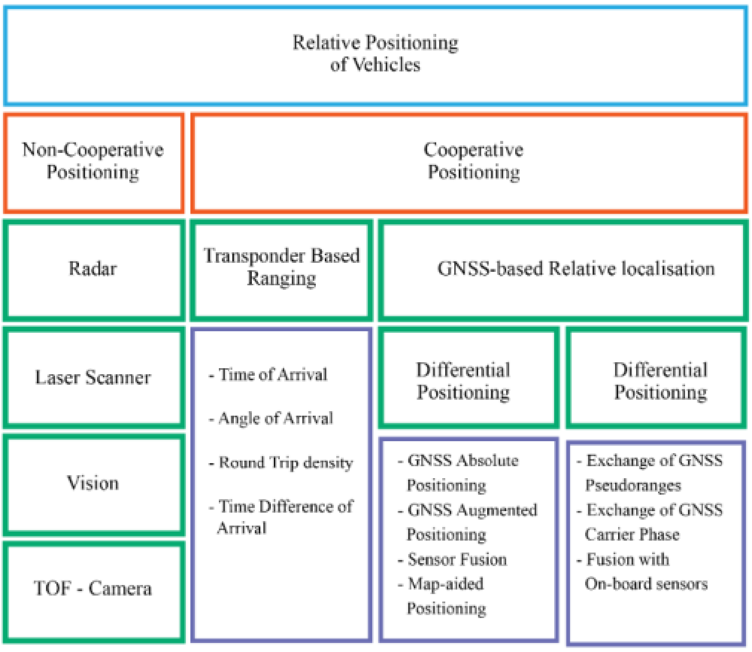

Figure 6. Vehicle positioning technologies. (Johnson & Rowland 2018)

Koopman & Fratrik (2019) also highlight the importance of perception, sensors and software involved in the concept of Object and Event Detection and Response (OEDR), which relates to operation within a defined ODD (NHTSA 2017). The term OEDR generally refers to the proper handling of external situations that the vehicle encounters, including perception, planning, and implementation of own-vehicle actions. In practice, the list of possible considerations can become surprisingly large. One factor that should be considered is the types of manoeuvres the vehicle itself initiates, typically having to do with navigation, such as entering and exiting a limited access roadway, initiating turns, changing lanes, and so on. A safety validation should also consider responses to and operation with system faults and limitations such as insufficient sensing capability and computational failures. A fault response might include continuing operation with normal capabilities by making use of installed redundancy, reduced capability, or transitioning the system to a safe state. Whichever strategy is chosen, a safety validation must ensure that fault detection and fault responses work properly. (Koopman & Fratrik 2019)

So far, automated driving use cases have been developed and piloted by various stakeholders without any real coordination. Hence, the stakeholders have made their own decisions concerning the sensor choice, connectivity, positioning options utilised and other factors determining the ODD with only the global, national, and local regulatory frameworks affecting their choices. At the same time, the stakeholders have not published any accurate information about their ODD details as long as the use cases are still not rolled out into the market. There are also proponents calling for more coordinated and interoperable manner to deploy automated driving. Alonso Raponso et al. (2017) recommend Coordinated Automated Road Transport. Their coordinated automated road transport is meant as an extension of the automated driving concept by adding communication capabilities that connect vehicles in between and with the infrastructure and adding a central coordination player to achieve the full potential of automated driving in terms of social, economic and environmental benefits. Such a coordinated approach would require an additional ODD layer, but on the other hand provide more harmonisation of the ODDs between the stakeholders. Shladover (2018) points out that in the SAE J3016 group, the ODD is specific to each individual driving automation system feature and can only be defined by the manufacturer of the system, based on the specific technological capabilities and limitations of that system.

So far, the manufacturers and/or designers of automated driving systems have only published ODDs for urban cars in their voluntary safety reports (Ford 2018, General Motors 2018, Waymo 2017) while only very recently first ODD descriptions for motorway systems have become available (Mercedes Benz 2019). For other use cases, we are forced to make assumptions on the ODD features of the five automated driving functionalities based on pilots, studies and expert views expressed in various working groups, articles or conferences. The assumed specification for the ODD of each chosen functionality (requirements for physical and digital infrastructure) is presented in the following section.

4.2 Possible ODD for each chosen functionality

It is up to the manufacturers of the system to specify the ODD for their automated driving system.

According to CEDR CAD WG discussions including L3Pilot consortium members, vehicles are customised at large, i.e. there is a strong product differentiation. ODDs for the same or similar functionality can differ between vehicle manufacturers, brands, makes and models. Depending on the value of the vehicle the technical realisation of the same or at least a similar functionality may differ (e.g. number and positioning of sensors). Moreover, ODDs will strongly evolve over time because of technical progress (sensor capabilities, computing power, sensor fusion algorithms etc.) and decreasing costs in a mass market.

For the purposes of this study, the ODD specifications are needed, however, to provide orientation about the big development lines to NRAs. The specifications below have been produced on the basis of available documents, reports and presentations as well as discussions in different fora and working groups.

Kulmala et al (2018) developed a list of ODD attributes, and the recent paper by Koopman & Fratrik (2019) does not contradict it. Thereby, this study also utilised that list (Table 7).

Table 2. ODD attributes (Kulmala et al. 2018)

ODD attribute	Physical / Digital infrastructure	Static / Dynamic
Road	Physical	Static
Speed range	Physical	Static
Shoulder or kerb	Physical	Static
Road markings	Physical	Static
Traffic signs	Physical	Static
Road furniture	Physical	Static
Traffic	-	Dynamic
Time	-	Dynamic
Weather conditions	-	Dynamic
HD map	Digital	Static
Satellite positioning	Digital	Static
Communication	Digital	Static
Information system	Digital	Static

Many attributes are related to infrastructure, mostly the physical infrastructure. Also aspects of the digital infrastructure are relevant for the ODDs.

Concerning the nature of the attributes, most of them are considered as static with regard to the availability of the service behind the attribute. In many cases, the service content itself can be quite dynamic – up-to-date information about a variable message sign from an information service provided in real time via the communications service to a vehicle accurately located just at the moment utilising a newly updated HD map.

4.3 ODDs in MANTRA

4.3.1 Highway autopilot including highway convoy (L4)

According to ERTRAC (2017), the highway autopilot including highway convoy provides automated driving up to 130 km/h on motorways or roads similar to motorway from entrance to exit, on all lanes, including overtaking and lane change. The driver must deliberately activate the system, but does not have to monitor the system constantly. The driver can at non-critical times override or switch off the system. There are no requests from the system to the driver to take over when the system is in normal operation area (i.e. on the motorway). The system will go to a reduced risk condition, i.e. bring the vehicle to a safe stop (e. g. in case of failure or malfunction). Depending on the deployment of cooperative systems, ad-hoc convoys could also be created if V2V communication is available.

The ODD-related requirements were originally identified for the use case in the C-ITS Platform's Physical and Digital Infrastructure Working Group (Kulmala et al., 2017), and then elaborated for MANTRA by the CEDR CAD WG in Oslo, November 2018. The result is shown in Table 3.

Table 3. ODD related requirements for highway autopilot (L4)

Highway autopilot incl highway convoy	
Road	Motorway or similar dual carriageways with separated driving directions, only on line sections not including toll plazas, ramps or intersections, but containing straight driving on weaving sections
Speed range	Up to 130 km/h; some systems do not work below 30-40 km/h; no restrictions 2030-
Shoulder or kerb	Safe stopping for a minimal risk condition requires a wide paved shoulder available for this purpose and not used for, e.g. hard-shoulder running. Safe refuges or shoulder areas similar to bus stops could be made available in case of narrow shoulders at intervals of e.g. 500 m on each carriageway
Road markings	Minimum quality of solid or dotted lines painted on the pavement if accurate lateral positioning is based on a camera detecting the location of the lane borders, and if the lines indicate traffic management information (e.g. no overtaking or lane change)
Traffic signs	Needed for vehicle to react to traffic control indicated by traffic signs along its trajectory to select appropriate speed or to take other required action. The sign content can be accessible via cloud, or tags and/or beacons attached to the sign [or as data inside the vehicle system (not necessarily in a cloud). could be just downloaded i.e. each time the car starts and then stored in the vehicle.]
Road furniture	Wireless radio beacons or physical landmarks possibly with sensor reflectors to support and increase positioning accuracy for AD vehicles. This is most valuable in tunnels and in totally open areas with no fixed objects nearby, or on sections with high likelihood of poor road weather conditions; or when some objects in the environment interfere with the vehicle's sensors.
Traffic	Not in incident situations with people on roadway, or other safety information cases like road work zones
Time	No specific requirements
Weather conditions	All conditions except for heavy rain or snowing, or road covered with thick layer of snow or water, or in some cases sun glare, heavy fog, or darkness without lighting, 2030- only most severe restrictions apply such as floods, thick snow, etc.
HD map	HD Map of minimum quality needed if the lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching.
Satellite positioning	Needed if the road position, lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations (e.g. RTK) and possibly also by landmarks on problem sections (tunnels, forests, ...) and conditions (weather).
Communi-cation	Needed for end of queue, lane change, and merge situations for negotiations among vehicles and for maintaining a local dynamic map. Short latency V2V communication is a necessity for highway convoy. V2I communication can be used to receive traffic management information in addition to real-time information.
Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances (SRTI) on the road ahead are needed for tactical decisions on route choice, lane selection and safe speed choice. Digital rules and regulations as well as a geofencing database are also

	needed.

The ODD specifications will likely not correspond to those in 2040 as the capability and price of the sensors and software in automated vehicles will likely improve considerably during the next 20 years, expected to increase greatly the coverage of the ODDs. It is, however, impossible to predict with reasonable accuracy the ODD of 2040. Thereby, MANTRA is using the ODD specification above, agreed in the CEDR CAD WG. This applies to all of the four automated driving use cases.

4.3.2 Highly automated (freight) vehicles on open roads (L4)

The ODD description here is based on literature as well as discussions with experts, and the CEDR Oslo CAD WG workshop. During the CEDR CAD WG meeting in Stockholm in June 2019 one focus upon automated freight vehicles on open roads is foreseen. One reviewer suggested to include here a brief mention of the highway-only drop-off-pick-up model by e.g. Embark: http://auvsilink.org/AVS2018/Plenary/940-1000_Wed_Rodriguez.pdf Although we anticipate additional dynamics with several road operators we have had to freeze this section for purposes of penetration rates as well as for work in work packages 3 and 4 in MANTRA. We suggest maintaining at least significant structural similarities in order to make preliminary results from MANTRA easier to digest at CEDR CAD group. The ODD requirements adapted to the common format are shown in

Table 4.

Among candidates for proactive action from NRAs towards automation there is the issue of some critical interaction between ODDs for different use cases: e. g. currently safety trailers are not recognized by CACC in cases where they are positioned diagonally to a lane. This illustrates consequences from vehicle manufacturers providing rather narrow ODDs and eliminating tricky cases at least in early phases of commercial take-up.

Table 4. ODD related requirements for highly automated (freight) vehicles on dedicated roads (L4)

Highly automated (freight) vehicles on open roads (L4)	
Road	Motorways or similar dual carriageways with separated driving directions and selected freight-relevant other roads also with single carriageway and on-coming traffic. Restrictions might apply for bridges or tunnels
Speed range	Up to 80 km/h
Shoulder	Safe stopping for a minimal risk condition requires a wide paved shoulder available for this purpose. Safe refuges or shoulder areas similar to bus stops but long enough for freight vehicles could be made available in case of narrow shoulders at intervals of e.g 500 m on each carriageway
Road markings	Solid or dotted lines painted on the pavement needed if the accurate lateral positioning solution is based on a camera detecting the location of the lane borders, and if the lines indicate traffic management information (e.g. separation of automated freight vehicle lane from other traffic lanes)
Traffic signs	Needed to indicate any lane use restrictions (automated freight vehicles/other vehicles), either static indicating the times of use or dynamic signs at sufficient intervals. Signs indicating use by automated freight vehicles.
Road furniture	Gantries for overhead lane control signs. Possible gates for entering and exiting the road used for automated freight vehicles, to be opened via V2X. V2X short-range communication beacons at sufficient intervals, and at least at both ends of road and at junctions. Wireless radio beacons or physical landmarks possibly with sensor reflectors can be used to support and increase positioning accuracy for AD vehicles. This is most valuable in tunnels and in totally open areas with no fixed objects nearby, or in poor road weather conditions. Some NRAs indicated crucial importance of tolling infrastructure with regard to ODDs of all forms of truck automation.
Traffic	No restrictions on motorways or similar dual carriageways. On other selected freight-relevant roads, only with low traffic volumes.
Time	No restrictions on motorways. On other roads, sufficiently low traffic volumes only during the night time hours.
Weather conditions	All conditions except for heavy rain or snowing, or road covered with thick layer of snow or water, or in some cases sun glare, heavy fog, or darkness without lighting, 2030- only most severe restrictions apply such as floods, thick snow, etc.
HD map	Needed if the lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching.
Satellite positioning	Needed if the road position, lane identification and accurate lateral lane positioning solution is based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations and possibly also by landmarks.
Communi-cation	V2V and V2I communication needed for vehicles to communicate for safety and to access the dedicated lane or road.
Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances on the road for tactical decisions. Currently CACCs would not recognize safety trailers if they are placed diagonally to the lane. Appropriate information/communication could provide a workaround.

4.3.3 Commercial driverless vehicles (L4) as taxi services

The automated taxi service operates without a human driver transporting passengers from their origin to their destination within the boundaries of a specific geographical area. The ODD specification is based on the Waymo's self-driving car concept (Waymo 2017).

Waymo's system includes three types of LiDAR developed in-house: a short-range LiDAR giving an uninterrupted view directly around it, a high-resolution mid-range LiDAR, and a long-range LiDAR that can see more than 200 m away. Their vision system also includes colour cameras designed to see the world in context, as a human would, but with a simultaneous 360-degree field of view to spot traffic lights, construction zones, school buses, and the flashing lights of emergency vehicles. The high-resolution cameras are designed to work well at long range, in daylight and low-light conditions. Waymo's radar has a continuous 360-degree view to track the speed of road users in front, behind and to both sides of the vehicle. Waymo vehicles also have a number of additional sensors, including an audio detection system to detect police and emergency vehicle sirens, and GPS to support the accurate positioning of the vehicle. (Waymo 2017)

Positioning is based on a 3D map built during mapping drives with test vehicles equipped with the vision sensors listed above. These maps contain also road types, the distance and dimensions of the road itself, and other topographical features. After that, the map is complemented with automated driving related important information that includes traffic control information such as the lengths of crosswalks, the locations of traffic lights, and relevant signage. The automated driving system can detect when a road has changed by cross-referencing the real-time sensor data with the on-board 3D map. If a change in the roadway (e.g., a collision up ahead that closes an intersection) is detected, the vehicle can re-route itself within the system's ODD and alert the operations center so that other vehicles in the fleet can avoid the area. In this case, the maps also provide feedback, and the maps can be updated accordingly. (Waymo 2017).

The Waymo ODD covers city streets in good as well as inclement weather, such as light to moderate rain, in both daytime and at night. (Waymo 2017).

Concerning the density of passenger pick-up/drop-off locations, the Finnish guidance (Tiehallinto 2003) recommends 300 m on low speed city streets and 600 m on high speed roads for bus stops. The requirements adapted to the common format are shown in

Table 5.

Table 5. ODD related requirements for commercial driverless vehicles (L4) as taxi services.

Commercial driverless vehicles as taxi services	
Road	Urban paved streets of good quality with not too complicated junctions; 2030- all urban roads including ring roads. motorways and any other road
Speed range	Up to 60 km/h; 2030- up to 80 km/h and then 100 km/h
Shoulder or kerb	Roadside parking space on streets, wide shoulders or refuges on other roads with 500 m intervals; Space needed for passenger hop-ons and -offs, likely clearly marked beside public transport terminals, public service, shopping and recreation areas, and elsewhere in cities at about 300 m intervals
Road markings	No specific requirements
Traffic signs	No specific requirements
Road furniture	Possible shelters and seats for waiting passengers facilitating existing public transport stops where possible
Traffic	Separation of pedestrian/bicycle paths
Time	No specific requirements
Weather conditions	No heavy precipitation, no ice nor snow on road, no fog/steam/smoke/dust hindering vision; 2030- only most severe restrictions apply such as floods, thick snow, etc.
HD Map	Needed as the lane identification and accurate lateral lane positioning solution is based on vision sensors (especially laser scanners) and satellite positioning with 3D HD map matching.
Satellite positioning	Needed to complement the vision sensor system supported by satellite positioning with 3D HD map matching.
Communication	At least 3G needed for V2I communications with operations centre, 4G or higher for remote control of vehicle. Possible short-range communication for communication in smart intersections.
Information system	Digital traffic rules and regulations, geofenced restrictions

4.3.4 Driverless maintenance and road works vehicles (L4)

4.3.4.1 **Specifics of this use case**

Although there exist some differences in the definition and focus of this use case (due its diverse sub-use cases) the general structure has been maintained in order to make preliminary results from MANTRA easier to digest and discuss at CEDR CAD WG.

Highway operation and maintenance works traditionally face the challenge to be carried out in an environment with high-speed traffic right next to it and therefore poses enormous safety hazards for the workers. Driverless maintenance vehicles have the potential to reduce this risk tremendously. It will still take time until all types of operation and maintenance works will be possible to be done by driverless vehicles. However there are quite a few use cases where the driverless vehicles could already provide safety and efficiency benefits in the near future. In particular for the initial simple use cases it will be necessary to have a human driver navigate the vehicle to its point of use and only as soon as it has arrived within its designated ODD the human driver can switch to an adjoined maintenance vehicle and let the maintenance vehicle go driverless. This particular example will be very valuable for any moving work zones where workers are needed on site to carry out the actual work anyway and where the driverless maintenance vehicle will act as the safety trailer/crash cushion.

As a further step and more advanced scenario the maintenance and road works vehicles are to carry out maintenance and road works operations without a human driver in the vehicle. In this advanced scenario it is, however, assumed that the vehicles are at all times connected to an operations centre, where the on-duty operator can take over remote control of the vehicle when and where needed.

In order to define ODDs in accordance with the standardized structure used in this report the driverless maintenance and road works vehicles will be divided into the sub-use cases described in the following chapters to allow for their differentiating purpose in road maintenance. Initially it is therefore important to understand the most common maintenance works to secondly identify which could potentially be carried out by driverless vehicles within this projects time horizon. As these already provide various types of sub-use-cases the analysis of Driverless Maintenance and Road Works Vehicles in this report will be limited to highways.

4.3.4.2 **Typical maintenance works**

The following are works and services which are believed to be necessary to achieve the best possible results with regard to the availability, reliability and sustainability of a highway. These services are essential to ensure the safety of the road users and for the proper management and communication of all incidents as well as of all planned maintenance works and to ascertain that the condition and status of the highway is maintained. Typical maintenance works include the following major work elements:

- Inspection of the Highway condition and inventory
- Safety Patrols and inspections
- Detailed visual inspections
- Maintenance and repair of the road elements and furniture
- Cleaning of road surface
- Cleaning and repair of noise barriers, signs and other road furniture
- Debris and litter collection (on highway and off highway)
- Road marking
- Maintenance and repair of road surface
- Maintenance and repair of structures
- Landscaping & grass cutting
- Incident management / Emergency responses potentially incl. rescue of broken down vehicles
- Traffic Management
- Environmental / Health and Safety Management

Significant elements of these works will still need to be carried out manually even in 2040. However, for quite a few of these tasks, driverless vehicles could perform the actual driving task.

4.3.4.3 Sub-use cases for driverless maintenance vehicles

The described maintenance works need to be carried out with different types of vehicles in varying situations. This results in varying ODD requirements if these vehicles are assumed to be driverless maintenance vehicles. The following sub-cases describe maintenance vehicle types/use cases relevant for this analysis.

Sub-use case 1: Safety trailer/Crash Cushion

A protective vehicle that is used to protect temporary or slow-moving mobile road works as well as clearing works after accidents from moving traffic. The crew of the protective vehicle which safeguards such works against moving traffic bears an increased accident risk.

The operation of a driverless (connected) automated protective vehicle which follows the actual maintenance vehicle, will reduce this risk. This sub-use case implies a structured operational environment and the number of situations which have to be perceived and considered for driving decisions are limited.

Sub-use case 2: Trucks for on-highway maintenance works in summer with regular operating speed

A number of on-highway maintenance works that are performed on dry ground conditions (mainly during summer) with an operating speed of up to 60 km/h within regular highway traffic flow. Works covered are for example regular visual inspections, sensor surface measurements, cleaning, etc.

Having these works performed by driverless vehicles would require advanced automation technology due to the necessary high accuracy and involved number of scenarios.

Sub-use case 3: Winter maintenance truck with regular operating speed

In countries with snowy/icy winters, the operational works around winter maintenance belong to most crucial task when it comes to providing safe roads. During the winter months, road operators in such countries require a high number of vehicles and drivers on stand-by, ready to start work 24/7. Winter maintenance works on highways are generally divided into preventive salting works performed at speeds of up to 60 km/h independent of snowfall and snow ploughing works performed at speeds of up to 45 km/h during and after snowfall.

Preventive winter maintenance are not much different from sub-use case 2 as speeds and road conditions are similar. However, for obvious reasons snow ploughing works cause a lot more challenges for an automated or even driverless vehicle as road markings are not visible and vehicle sensors are easily covered and malfunctioning. In terms of complexity, this is a very advanced sub-use case.

Sub-use case 4: Trucks for road shoulder works

Vehicles moving along the emergency lane, secured from the moving traffic by witches' huts and protective vehicles can perform various maintenance tasks. This could for example involve mowing, cutting trees or roadside cleaning works. These works have principally no interaction with moving traffic as they are protected by temporary lane closures and the impact on traffic flow is no different between an automated vehicle performing the works and a traditional manually driven vehicle. Safety benefits for operational workers currently driving these maintenance vehicles are evident as temporary lane closures are greater safety hazards.

The level of complexity for the tasks to be performed depend on the actual operational work. Mowing grass is rather uniform while cutting trees involves much more irregular movements. Already now, such works can partly be performed by remote-controlled mowers being operated by maintenance workers close by.

Sub-use case 5: Road works vehicles moving at regular speed

Some road works like refreshment of road markings or pavement surface treatments can be performed at relatively high speeds of up to 60 km/h. The requirements and complexity levels are basically the same as for sub-use case 2.

Sub-use case 6: Road works vehicles in construction work zones

One key element of road director's core business is highway construction. Nowadays the biggest share of construction works is not anymore new construction but rather refurbishments and lane-extensions under traffic. In this sub-use case the paver vehicle would work driverless in a closed off road works zone. The complexity of this use case is in the works to be performed not in the interaction with moving traffic. The benefits for policy goals of road directors need to be determined very much different to the other sub-use cases.

4.3.4.4 Selection of sub-use cases to be evaluated in detail

The described sub-use cases were presented to the CEDR CAD WG during their plenary meeting in Oslo on 6th November 2018. In the MANTRA project two of the above described sub-use cases will be described in detail and analysed regarding their impact on infrastructure needs, policy goals and core business of road director's.

In an open discussion the goal of the CEDR CAD WG became clear: to choose a "low hanging fruit", meaning a sub-use case which can provide high impacts on policy goals rather soon on the one hand and an advanced, complex sub-use case materializing probably only later in the time horizon up to 2040 on the other.

The collective result was to move on with the following sub-use cases:

- **Sub-use case 1 "Safety trailer":** The use case closest to deployment with relevant impact for all CEDR member states.
- **Sub-use case 3 "Winter maintenance truck":** A very complex use case which requires to think further ahead. Depending on the results in terms of impact on policy goals and whether this sub-use case is worth the effort early adaptions and preparations could be prepared ahead by road directors.

In the CEDR CAD WG these two sub-use cases were then discussed with the expert members in a break-out session defining the ODDs in line with the general structure based on an expert discussion.

4.3.4.5 ODD Description "Safety trailer"

The crucial part for the early deployment of an initial safety trailer is the general limitation of its ODD to the area of use, e.g. the mobile road works zone. It is still required that maintenance workers are driving the safety trailer to its point of use. This way the safety trailer does not need to be able to master complicated scenarios navigating through fast-moving highway traffic.

The ODD limitations for "Safety trailers" agreed upon during the break-out session are presented in Table 6.

Table 6. ODD related requirements for safety trailers.

Safety Trailer	
Road	Motorway or similar dual carriageways having a paved road shoulders not including toll plazas, ramps or intersections
Speed range	Standing or driving slowly to protect moving work zones with a maximum speed of 20 km/h
Shoulder or kerb	Initial deployment only on road shoulders, so wide shoulder required for early adoption
Road markings	Initial positioning of safety trailer through connectivity to vehicle ahead. For improved lateral positioning cameras are detecting road markings. Optimum functionality in areas with clearly visible solid or dotted lines painted on the pavement. For purely following tasks on the road shoulder no road marking requirements.
Traffic signs	Not needed. Vehicle either follows another vehicle and/or navigates along road marking.
Road furniture	No specific requirements. Wireless radio beacons or physical landmarks possibly with sensor reflectors can be used to support and increase positioning accuracy. This is most valuable in tunnels and in poor road weather conditions. However only if also used for other types of use cases, not required specifically for this one.
Traffic	No specific requirements
Time	No specific requirements
Weather conditions	All conditions, except for heavy rain or snowing, or road covered with any layer of snow or water.
HD Map	No specific requirements
Satellite positioning	Initial deployment on road shoulder: no satellite positioning required. Advanced version: enabling communication about its position required with land station (e.g. RTK) support accompanying the vision sensor system with 3D HD map matching to provide information to traffic management centre and in turn to road users through variable message signs/in-car navigational systems.
Communi-cation	CACC can provide information about position to traffic management centre for further information to road users. V2V communication with other maintenance vehicles, mobile road signs.
Information system	Real-time information of the location and operation of the vehicle to be disseminated to traffic centres and service providers, and finally to other road users; Digital rules and regulations

Currently Safety trailers are not recognized by CACC in cases where they are positioned diagonally to a lane. This illustrates consequences from vehicle manufacturers providing rather narrow ODDs and eliminating tricky cases at least in early phases of commercial take-up.

4.3.4.6 ODD Description “Winter maintenance truck”

As described earlier this use case involves driving in the, nowadays considered, most complicated ODD environments involving snow and tough conditions for visual sensors and cameras. The use case is therefore considered not as actually driverless but level 4 automation with a driver on board (in at least the leading vehicle in case of a winter maintenance platoon) to take over at intersections, road works zones, ramps, rest areas and other complex parts of the highway.

The ODD limitations for “Winter maintenance trucks” agreed upon during the break-out session are presented in Table 7.

Table 7. ODD related requirements for safety trailers.

Winter maintenance truck	
Road	Motorway or similar not including ramps or intersections. Not in toll plazas nor road work zones. Limited in areas of noise barriers, depending on height and type of noise barrier.
Speed range	Preventive salting works max. speed 60 km/h (no snowfall) and snow ploughing works max speed 45 km/h (during and after snowfall)
Shoulder or kerb	Safe stopping for a minimal risk condition requires a wide paved shoulder available for this purpose and not used for, e.g. hard-shoulder running. Safe refuges or shoulder areas (emergency bays) could be made available in case of narrow shoulders at intervals of e.g. 5000m on each carriageway
Road markings	Initial deployment preventive salting: An early adoption of this use case could be the use solely for preventive salting only therefore requiring solid or dotted lines painted on the pavement for accurate lateral positioning solution is based on a camera detecting the location of the lane borders Full deployment snow ploughing: No specific requirements
Traffic signs	No specific requirements
Road furniture	Wireless radio beacons or physical landmarks ideally with sensor reflectors necessary to be used to support and increase positioning accuracy for maintenance trucks.
Traffic	Initial adoption in low traffic volume only.
Time	No specific requirements
Weather conditions	Initial deployment preventive salting: Initially only when road marking is still visible. All conditions except snow or heavy rain. Full deployment snow ploughing: All conditions
HD Map	Needed for full use - lane identification and accurate lateral lane positioning based on satellite positioning with 3D HD map matching.
Satellite positioning	Needed for full use - road position, lane identification and accurate lateral lane positioning based on satellite positioning with 3D HD map matching. Satellite positioning accuracy is supported by land stations (e.g. RTK) and possibly also by landmarks.
Communi-cation	V2I communication to be used to receive traffic management information in addition to real-time information.
Information system	Real-time traffic information on incidents, roadworks, events, congestion and other disturbances on the road ahead are needed for tactical decisions on route choice, lane selection and coordinated take over procedure to operator.

4.4 Road operators and ODD

ODDs are important to road operators as the provision of the physical infrastructure related elements of ODDs are almost solely under the responsibility of the road operators. This also applies to the some digital infrastructure elements as well. Also traffic and weather condition aspects can be influenced by road operator actions such as traffic management and winter maintenance, respectively. The provision of ODDs can also be very costly, more than 10 billion euro for the European motorway network in the next ten years (CEDR 2018).

Some of the road operators have already discussed the infrastructure related elements of the ODDs. The concept of infrastructure support levels has been developed in INFRAMIX (Carreras et al. 2018) for cooperative connected automated driving as shown in Table 8.

Table 8. Infrastructure support levels for cooperative connected automated driving (Carreras et al. 2018).

	Level	Name	Description	Digital information provided to AVs: Digital map with static road signs	Digital information provided to AVs: VMS, warnings, incidents, weather	Digital information provided to AVs: Microscopic traffic situation	Digital information provided to AVs: Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				
Conventional infrastructure	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	X			
Digital infrastructure	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	X	X		
Digital infrastructure	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	X	X	X	
Digital infrastructure	A	Cooperative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	X	X	X	X

The support levels provide significant detail on the information system, and address the communication, maps, traffic signs, and road furniture aspects of the ODD as well. The concept will likely be detailed further in the future, and may need to be adapted and/or complemented with regard to specific automated driving use cases.

ISAD can neither substitute ODDs nor provide room for independent roadmapping. Geißler emphasized the correlation between ISAD and ODDs (Geißler 2019). Dialogue between road authorities and vehicle manufacturers is needed. This change management process needs alignment with ongoing C-ITS deployment activities. Van Dam emphasized the need to quantify the value capture from automation functions for road operators before investment decisions at NRAs can be discussed (Van Dam 2019).

The Swedish Transport Administration has also looked specifically at the information needs of automated vehicles, and classified the needs as the following (Zarghampour 2018 and 2019):

1. Road network
2. Barriers, signals, signs, rules, regulations
3. Temporary changes in 1. and 2.
4. Dynamic traffic information
5. Weather information

The Dutch Rijkswaterstaat is emphasising the need to ensure that the transport infrastructure is ready for connected and automated driving. They stress the need to accomplish this in close cooperation between road operators, automotive stakeholders, and the telecom sector. The ODDs need to be optimised with regard to both their benefits and their costs. With regard to the infrastructure, it is crucial to differentiate what is essential for the automated vehicles, and what is just nice to have. Furthermore, Dutch stakeholders are making efforts to determine what is the acceptable behaviour of automated vehicles when **inside** the ODD, proposed a driving licence for vehicles as a way to verify acceptable behaviour (Alkim 2018).

4.5 Estimated ODD coverages up to 2040

In this section we provide estimated ODD coverage of NRA-relevant automation functions up to 2040. The ODDs will evolve in line with sensor capabilities, software capabilities, complexity of interaction with rare contexts and public acceptance. For the purpose of the next activities in MANTRA work packages 3 and 4, and for fruitful discussion within NRAs, we here provide estimated ODD coverages up to 2040 for our priority use cases. This will be used as input to quantify the value capture from automation functions for road operators (Geißler 2019; Van Dam 2019). Presentation format is intended to follow the anticipated timeline from now / before 2020 until 2040. All focus use cases in MANTRA are anticipated to be implemented in rather wide ODDs before 2040.

Several key influences on our estimated ODD coverages up to 2040 have already been stated throughout chapter 4. Cooperation between local and national traffic management is needed for the large area coverage. Specific locations for safe pick-up and drop-off of passengers need to be allocated and designated to the robot taxis, perhaps to be shared with automated shuttles. Connectivity is considered an integral part for all of our priority use cases, however to a lesser degree for the safety trailer. So ODD coverage is anticipated to follow availability of connectivity / communication infrastructure. Significant co-dependence between connectivity / communication infrastructure and CCAD exists. Risk-rating and acceptance of incidents on roads is expected to evolve closely to ambitious targets towards mission zero. Some experts even see significant coevolution between investment in smart roads and CCAD. However, the concept of smart roads is anticipated to undergo significant changes until 2040. This has the potential of introducing another form of divide between European regions (from the financial capacity to spend on upgrading roads to smart roads). For some NRAs (explicitly mentioned by UK and Denmark at CEDR CAD meeting in Tallinn, March 2019) efficiency and efficiency-related risk mitigation are seen as priority issues in allowing automation functions to be used on their road networks. The road authorities are concerned about the likely reduction of capacity due to highly automated vehicles' "over-cautious" behaviour, and the impact of this especially during peak hours, when the traffic managers specifically strive to optimise traffic flow and maximise road throughput. Taking all this into consideration it is anticipated that ODD coverage for our priority use cases will mostly follow a hot spot approach.

Highway autopilot including highway convoy (L4)

ODDs for this use case are anticipated to follow the known trend in driver assistance services: premium cars will be the first with ODDs for Highway autopilot including highway convoy. Availability of CACC without higher level automation has the potential to further prepare the ground for future take-up. Basically, all existing highways between intersection areas are likely within the ODD for the highway autopilot from most vehicle manufacturers from the market entry. However some road operators might limit access to specific tunnels or specific bridges. For some NRAs (explicitly mentioned by UK and Denmark at CEDR CAD meeting in Tallinn, March 2019) efficiency and efficiency-related risk mitigation are seen as priority issues in allowing early automation functions to be used on their road networks. For several road operators' interest will be likely on safety critical hot spots. Easier forms of ODDs (good weather conditions; basic connectivity) are anticipated when the system enter the market, and the coverage will I grow in line with high quality positioning, connectivity and information systems becoming available. The Europe-wide ODDs will co-depend on public discussion of risk-mitigation (capacity loss), public discussion of motorized individual traffic, ambitious safety goals, ambitious air quality goals and some form of equality discourse. Highway autopilot including highway convoy has the potential to significantly contribute to air quality challenges in areas with continental climate. Therefore there is a possibility for a rather heterogeneous picture for individual European countries and individual road operators. On the other hand, motorways / highways are the simplest part of the road transport system in terms of road user interaction, and thereby the vehicle system’s ODD coverage will likely cover also the intersection areas as well as merging and exiting traffic in good weather conditions before 2030. Hence, we anticipate that larger parts of European highways will be covered by ODDs in good weather conditions until 2030. Depending on severe weather conditions and some anticipated increase in harsh weather events, the ODD may still be limited until mid-2030ies (compare winter maintenance and dependence on sensors).

Highly automated (freight) vehicles on open roads (L4)

Estimation of ODD coverage here is strongly influenced by political priorities and views on the role of truck-based traffic. The exchange on higher levels of truck automation during the CEDR CAD workshop in Oslo, 2018, triggered some exchange on adequate processes and information requirements within road operators to adequately cope with these new opportunities and challenges. This process is anticipated to be intensified at the CEDR CAD group meeting in Stockholm, in June 2019 – with three truck automation initiatives presenting their views as input for dialog and discussion at the CAD group level. National differences on the approach exist, at least currently. Some service providers maintain that they will bring higher forms of automated freight vehicles on highways to commercial deployment before 2030. Some even maintain the will simply follow all opportunities, where this form of operation becomes legal. To our knowledge, all (announced) deployment on public roads currently takes place outside Europe. However, this might involve some form of competitive signalling. Anticipated drivers for ODD coverage are anticipated gains in safety, air quality and driver shortage. As we focus here on L4 on open roads in Europe we see the hot spot approach starting with hub to hub services around harbours or between industrial plants on open roads with a focus upon specific highways avoiding interactions with complex situations by 2026. A wider ODD coverage will most probably deal with all highways / smart roads in good weather conditions well before 2040, with most adverse weather conditions likely covered by 2040. In Nordic countries, an important need for highly automated freight vehicles relates to two-lane rural roads with long time-critical goods transport chains operated throughout the year, one example being the >30 large trucks daily transporting fresh salmon from Northern Norway to Helsinki via E8 (more than 90% of length two-lane rural roads) and then by plane to Japan in strict time pressure of 36 hours for the whole chain. It is debatable whether this could be automated by 2040.

Commercial driverless vehicles (L4) as taxi services

Latest input from high-level safety experts (Schöneburg, 2019) suggests that early forms of commercial driverless vehicles as taxi services will take advantage of highly regionalised ODDs. These cars will learn specific public roads with little interaction with pedestrians or cyclists in a specific metropolitan area (e. g. business headquarters and airports or train stations). Therefore this should not be mistaken as generalised ODDs for all urban streets. This specific form of business taxis is anticipated to become available before 2025 in Europe and earlier in other regions. At the February 2019 ARCADE workshop it was anticipated that specific "knowledge" exchange on locally acceptable forms of Commercial driverless vehicles as taxi services might help to provide broader validity ("social networks for automated taxi functions").

For a more general form of robot taxis, even though a pilot robot taxi service was already started in late 2018 in the Phoenix area in the USA, some experts still doubted that such services would take long time to be allowed in Europe, and that the necessary door-to-door ODD coverage and capability would not be available until early 2030s. As a next step, robot taxis are planned as an urban street service only, but by 2040 this service is anticipated to also cover other roads (ring roads, arterials, highways) around urban areas in order for the taxi service to provide door-to-door service. These services are expected to be available by 2040 in all major cities of at least 0.5 million inhabitants in Europe. Cooperation between local and national traffic management is needed for the large area coverage. Likely, specific locations for safe pick-up and drop-off of passengers need to be allocated and designated to the robot taxis, perhaps to be shared with automated shuttles. For 24/7 services, robot taxis should also be able to deal with most weather and road surface conditions.

Driverless maintenance and road works vehicles (L4): Significant elements of these works will still need to be carried out manually even in 2040. However, for quite a few of these tasks, driverless vehicles could perform the actual driving task. Focusing on the selected maintenance sub-use case the following ODD coverage is expected:

Sub-use case 1: Safety trailer/Crash Cushion: Some automated roadworks trailer ODDs are anticipated to be around soon (successful proof of concept from aFAS project 2016 to 2019; time of commercial roll-out by MAN not yet decided. (Ulrich 2019)). As already stated above, driverless maintenance vehicles have the potential to significantly reduce safety risk from passing vehicles at higher speeds. Therefore, we anticipate first ODDs to focus on maintenance and road work zone protection on road shoulders of highways. Initial ODDs request a human driver to navigate the vehicle to an area where the ODD is fully covered. As soon as it has arrived within its designated ODD the human driver can switch to an adjoined maintenance vehicle and let the maintenance vehicle go driverless. It will still take time until a wider ODD for protection of various types of operation and maintenance work zones (on main lanes, combinations of work zones) will be possible to be done by driverless vehicles. The roll out of wider ODD scenarios extended to main lanes will be driven not only be the technical development but rather depends on legal adaptions for use of such work zone protections. The focus of early adopter NRAs will be on safety hot spots where the number of incidents are condensed. Risk-rating and acceptance of incidents is expected to evolve closely to ambitious targets towards mission zero and may vary depending on management priorities and ambitious public targets. ASFINAG and contractors at Dutch Rijkswaterstaat are anticipated to be pilot users of automated Safety trailer / Crash Cushion. In case of ASFINAG, by far the biggest share of accidents with safety trailers happens in only three locations of the whole network. In these locations a high share of heavy goods vehicles correlates with difficult road geometries. These would obviously be the locations for early adoption of safety trailers (Ulrich, 2019). However, one known unresolved issue comes from the interaction with automated functions at other trucks and vehicles. Currently Safety trailers are not recognized by CACC in cases where they are positioned diagonally to a lane. This illustrates consequences from vehicle manufacturers providing rather narrow ODDs and eliminating tricky cases at least in early phases of commercial take-up.

Sub-use case 3: Winter maintenance trucks with regular operating speed would profit from smart roads, high-accuracy digital maps and commercially available powerful sensors. The technology is expected to be widely used in zones of minimum interaction (e.g. airports, rest areas) first and depending on the experiences there, a step by step roll out in situations/areas with reduced interaction, low traffic volumes and clear road geometries. Doubts of the regulatory barriers and adverse weather capabilities pushed the Low scenario year for automated winter maintenance vehicles to 2030. The same ODD as for highway autopilot will be applicable at the minimum. In 2040, it is likely that the weather-related ODD restrictions will be much smaller than when the systems enter the market. Other main roads with 3D HD maps on road structures, accurate satellite positioning, and wireless broadband (5G+) will likely also provide the ODD for automated maintenance vehicles. However, this is beyond the scope of our study. Driverless Maintenance and Road Works Vehicles in this report will be limited to highways.

5 Vehicle fleet penetration of the automation functions up to 2040 in Europe

Assessment of vehicle fleet penetration of the automation functions generates the second key element for a consistent further work in MANTRA. Approach and assumptions have seen several interactions within MANTRA, with the CEDR CAD WG as well during steering group telcos and email interaction in January 2019. The MANTRA authors thank all contributors for sharing their questions and views. We anticipate some final feedback during the review period in February 2019.

5.1 Approach

To estimate the vehicle fleet and vehicle km penetration of the selected use cases in Europe in 2040, we needed to take the following steps:

1) determine the fleet related to the use case
2) find out the age distributions (by year) of the current vehicle fleet in Europe
3) determine the year of market introduction of the use case in Europe, i.e. the year in which a vehicle with the use case can be bought in Europe
4) determine the penetrations of the use case in new vehicles sold each year, called market penetration
5) determine the future vehicle sales and market development scenario
6) calculate the relative number of vehicles equipped with the use case in 2040 as a sum of vehicles equipped for each year since the market introduction to 2040
7) calculate the vehicle km or traffic flow penetration by vehicles equipped with the use case in 2040 as in previous step but now weighed with kilometres driven by vehicles of different age

The next sub-chapters describe the contents of these steps in more detail.

5.2 Fleets and markets up to 2040

Step 5) will determine the basics of the whole process, and that is why that needs to be considered first.

McKinsey&Company (2019) present predictions such as “robotaxis will become a cheaper mobility option than private vehicles in urban environments in 2030” and “in 2030, one car in ten sold could be a shared car”. Arbib and Seba (2017) predict that “by 2030, within 10 years of regulatory approval of autonomous vehicles (AVs), 95% of U.S. passenger miles traveled will be served by on-demand autonomous electric vehicles owned by fleets, not individuals, in a new business model we call “transport-as-a-service” (TaaS)”. If such predictions will become the reality in 2030, the size of the vehicle fleets and the vehicle markets will change in a fundamental manner, but the exact nature and magnitude of changes are extremely hard to predict, especially in the heterogeneous European markets.

On the other hand, so far the TaaS-like services have not resulted in major changes in vehicle sales nor indicated sustainable business cases. Hence, MANTRA assumes an evolutionary market development scenario, where changes take place gradually and the current status with regard to vehicles fleets and their age distributions where current distribution will remain stable over time or evolve only to some degree.

In MANTRA, the relevant fleets selected for the use cases were:

Highway chauffeur and autopilot:	cars
Automated freight vehicles:	heavy goods vehicles (HGV, weight > 3.5 tn)
Robot taxis:	taxis
Automated winter maintenance veh.:	winter maintenance vehicles (HGV)
Automated roadworks safety trailers:	lorries and tractors (Eurostat 2019)

For the estimates we decided to use two scenarios of Low and High. Low is the "business as usual" scenario, where the automated driving use cases are taken into use as in usual market economy, utilising solutions based on the utility or economic value to the customer or user. The High scenario assumes the acceleration of automated driving use cases via financial incentives such as reduced taxation or via regulatory actions, for instance by mandating automated driving in specific conditions.

5.3 Vehicle fleet age distributions

The vehicle fleet age distributions were available from Eurostat (2019) for cars, heavy goods vehicles, lorries and tractors for all EU countries except for Bulgaria, Greece, Romania and Slovakia. In addition, the distributions from Liechtenstein, Norway and Switzerland were utilised for the European figures. The figures for 2016 were the ones available in the beginning of 2019, and these were thereby used.

The distributions were available at Eurostat (2019) for the following age categories only:

- Less than 2 years
- From 2 to 5 years
- From 5 to 10 years
- From 10 to 20 years
- Other (20-)

As MANTRA estimations requires annual distributions, they were produced on the basis of the following rules: For the 0 and 1 year old cars (less than two years), the annual figures were divided similarly with those in Finland available from Kulmala et al. (2018). For the other age categories, the annual figures were calculated as a linear transformation (Y = a + bX), using the so far oldest year estimated from the previously studied age category as "a" and determining "b" by looking at the mean of the age category (number of vehicles/number of years in the category, used as "Y") and its distance in years ("X") from the "a" year. In addition, the distributions were smoothed to get more plausible distributions without drastic steps. The last category of 20 or more years was not used in the calculations, although its magnitude has an impact on the magnitude of the other figures in the distribution. The statistics from some countries likely have also vehicles of unknown age in the last age category, which might cause bias in the results. The impacts or such bias will, however, likely be quite small.

The taxi fleet's age distributions were not available from European statistics. Hence, the Finnish results of Kulmala et al. (2018) were used also for all Europe.

The vehicle age distributions utilised in MANTRA are shown in Figure 5. Taxis differ from the other vehicles in the way that many of the taxis are less than 3 years old, and due to the high vehicle kilometres driven during the three years, they likely are also crapped much younger than vehicles in private use.

It should be pointed out that the age distributions vary greatly between European countries based on their economic and vehicle taxation situations. The vehicle fleet is much younger in the well-off countries with low vehicle purchase tax, and much older in the poorer countries and those with high vehicle purchase tax. The figures also indicate that older vehicles are being exported from well-off countries with low vehicle purchase tax to other countries, explaining the differences between countries. Thereby the European fleet age distributions can differ considerably from national distributions.

The lorries and tractors are also vehicles, where some road haulage companies, perhaps especially the large ones, renew their fleets quickly after a few years, showing in the age curve. On the other hand, the road hauliers with only one or two vehicles may well keep the vehicle for many years. The European distribution is most even for the cars.

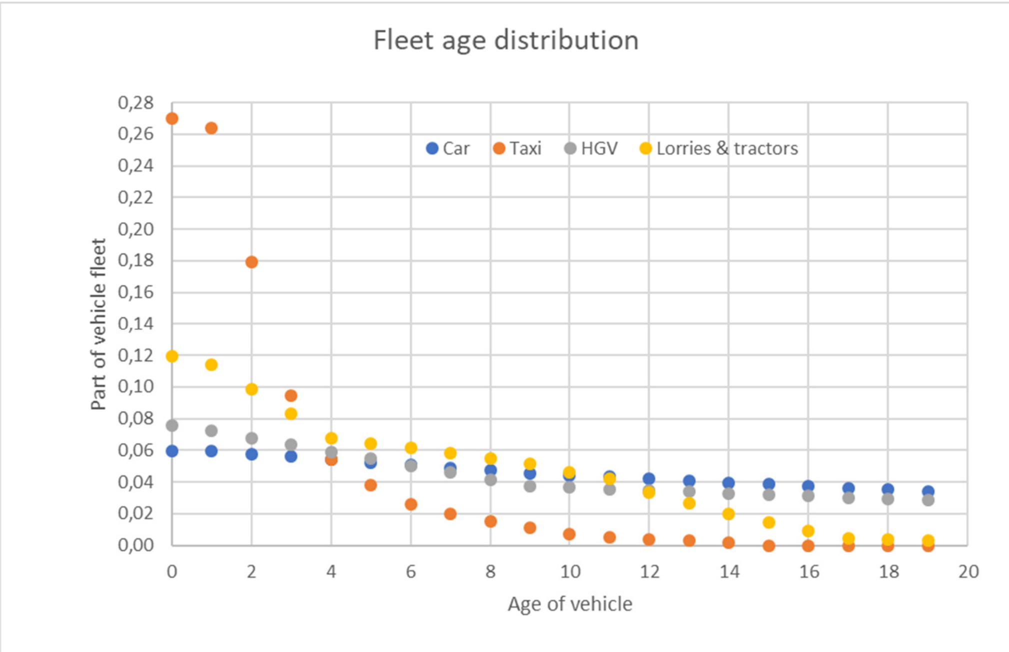

Figure 7. Vehicle fleet age distributions in Europe (2016).

MANTRA analyses require also estimations of the vehicle km penetrations. These are important with regard to the impacts of automated driving as the vehicle km penetrations actually reflect the traffic flow penetrations. To calculate the vehicle km penetrations, the additional information needed is the average annual vehicle kilometres driven for vehicles of different age, relative to the vehicle kms driven of new cars (less than one year old). For cars and heavy goods vehicles (including lorries and trucks), MANTRA utilised the estimates from eIMPACT (Wilmink et al. 2008). For taxis, the estimates of Kulmala et al. (2018) were used.

Figure 8 shows the relative vehicle kilometres driven be vehicles of different age.

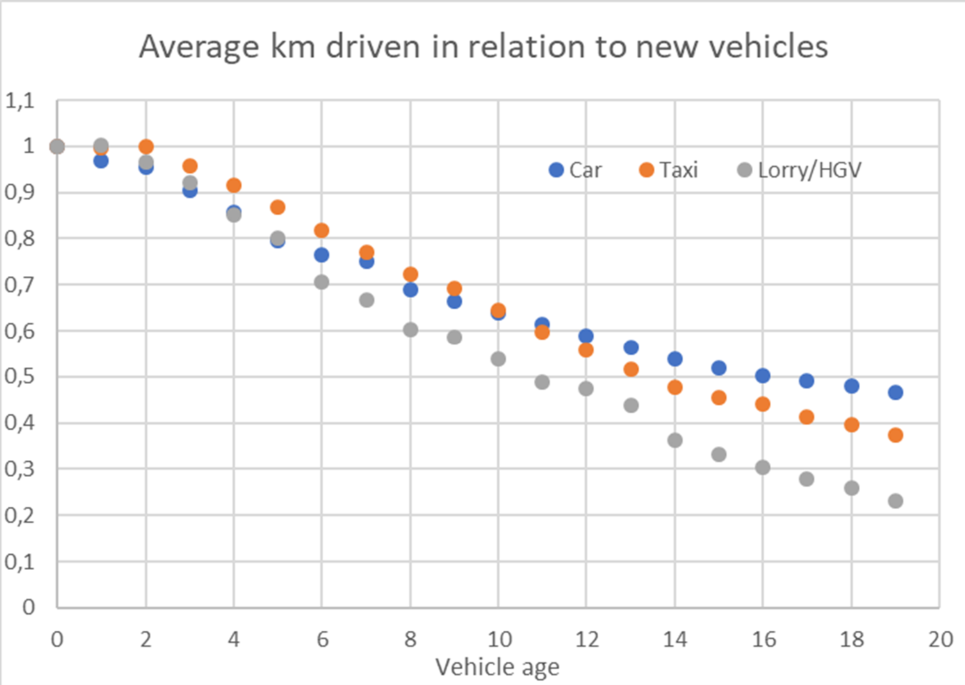

Figure 8. Average annual vehicle kms driven relative to those driven by new vehicles for cars, taxis and lorries and other heavy goods vehicles in Europe.

5.4 Market introductions

The market introductions of automation use cases are determined by expert assessment as no reliable data is available. Some researchers such as Chan (2017) have compiled data from the announcements for automotive and IT companies. ERTRAC (2017) predicted market introductions based on a common view of industry, road operator, authority and academia representatives with a research interest. Based mostly on the estimations of the latter, a workshop organised in August 2018 in Helsinki provided the Low and High estimates for six automated driving use cases as reported by Kulmala et al. 2018. These were used also for MANTRA as a starting point. On the basis of discussions in the MANTRA consortium involving also CEDR representatives, the years in Table 9 are used as the market introduction times for the use cases studied.

Table 9. market introduction years for the MANTRA use case in Low and High scenarios.

MANTRA Use case	High	Low
Highway chauffeur and autopilot	2021 2023	2021 2023
Automated freight vehicles	2025	2025
Robot taxis	2025	2032
Automated winter maintenance vehicles	2025	2030
Automated roadworks safety trailers	2023	2023

The Low and High values were the same for many use cases but not for all. For robot taxis, even though a pilot robot taxi service was already started in late 2018 in the Phoenix area in the USA, some experts still doubted that such services would take long time to be allowed in Europe, and that the necessary door-to-door ODD coverage and capability would not be available until early 2030s. Similar doubts of the regulatory barriers and adverse weather capabilities pushed the Low scenario year for automated winter maintenance vehicles to 2030.

5.5 Market penetration in new vehicles

The market penetration curves for highway autopilot, automated freight vehicles, robot taxis and winter maintenance vehicles were obtained from those of Kulmala et al. (2018). The automated roadworks trailer penetrations were indicated by Ulrich (2019). The market penetration of SAE level 3 highway chauffeur in new cars were assumed to be the following:

Year	Low %	High %
2021	0.2	0.4
2022	0.29	0.66
2023	0.4	1.05
2024	0.5	1.7
2025	0.6	1.75
2026	0.5	1.75
2027	0.2	0.4
2028-	0	0

This means that after 2027, the customers prefer the level 4 autopilot to to the level 3 chauffeur use case. The market penetrations for the highway chauffeur/autopilot use case are shown in Figure 10.

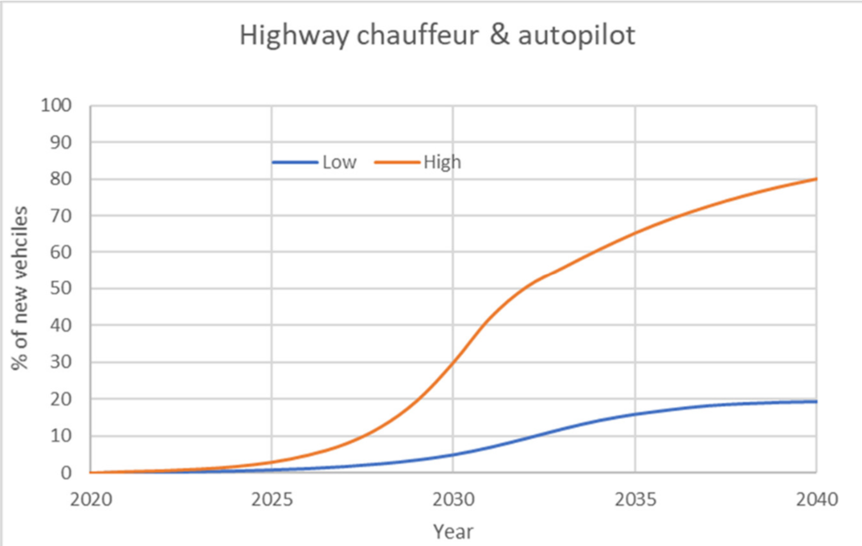

Figure 10. Penetration of highway chauffeur and autopilot in new cars sold in 2020-2040 in Europe in Low and High scenarios.

Similarly, the market penetrations of automated freight vehicles, robot taxis, automated winter maintenance vehicles, and automated road works safety trailers are presented in Figures 11-13.

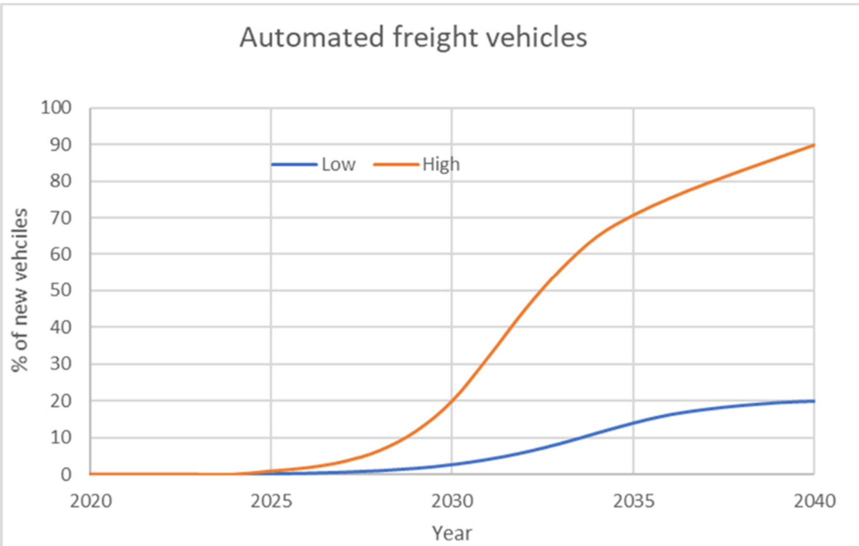

Figure 11. Penetration of automated freight vehicle use case in new HGVs sold in 2020-2040 in Europe in Low and High scenarios.

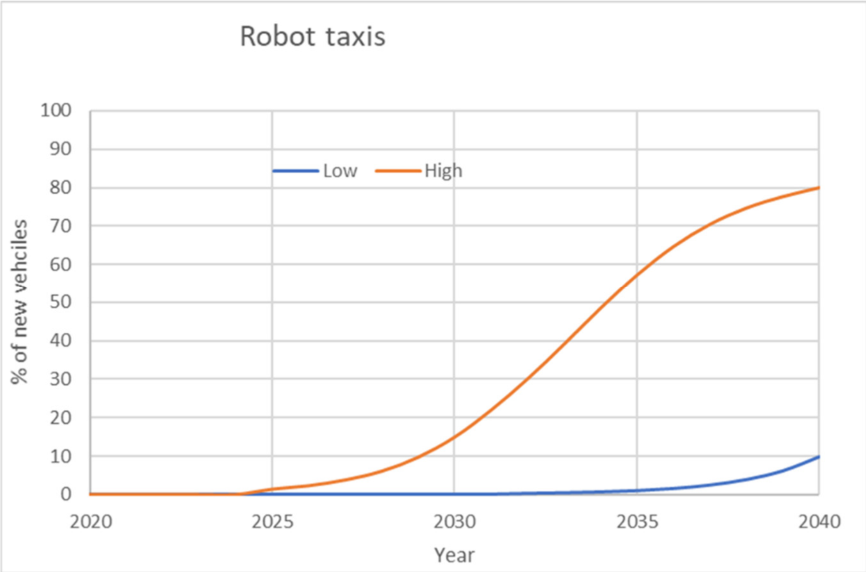

Figure 12. Penetration of robot taxis in new taxis sold in 2020-2040 in Europe in Low and High scenarios.

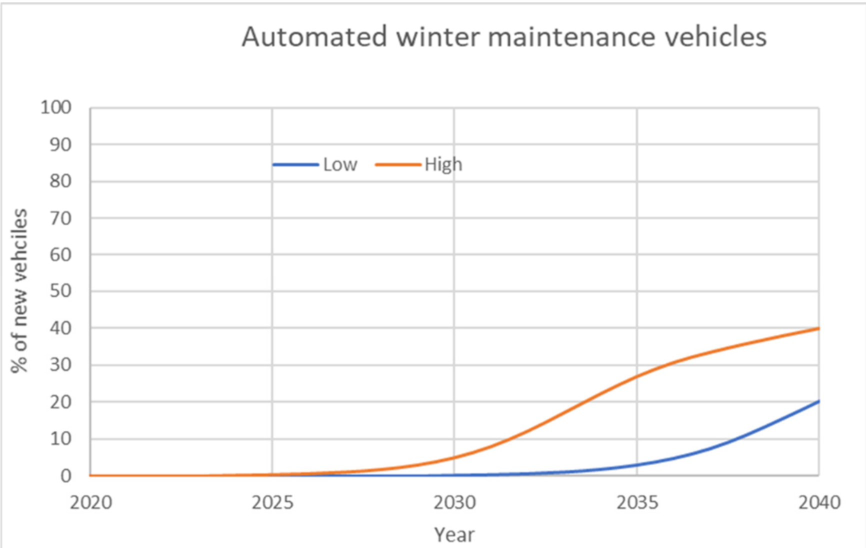

Figure 13. Penetration of automated winter maintenance vehicle use case in new maintenance HGVs sold in 2020-2040 in Europe in Low and High scenarios.

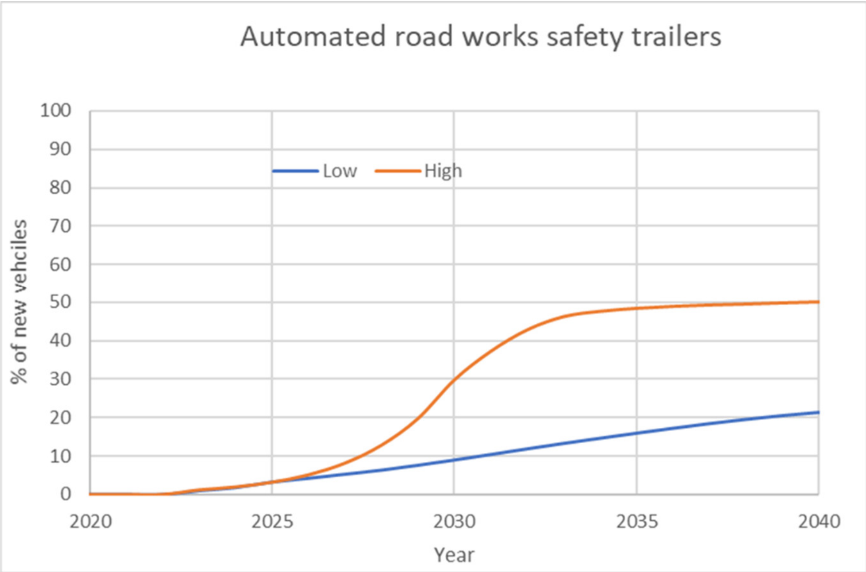

Figure 14. Penetration of automated road works safety trailers in new safety trailers sold in 2020-2040 in Europe in Low and High scenarios.

5.6 Fleet and vehicle km penetrations in 2030 and 2040

On the basis of the use case shares in new vehicles in 2020 and later, the number of vehicles equipped with each use case was calculated for the vehicle fleets in both 2030 and 2040 in Europe, in both Low and High scenarios. Next, the annual use case shares were weighed with the average distances in km driven by vehicles of different age, again in both 2030 and 2040, and Low and High scenario. the vehicle renewal rate was assumed to remain the same, although the prices of highly automated vehicles are likely higher than those of vehicles with lower automation levels.

The calculations resulted in the fleet and vehicle km penetrations shown in Tables 10 and 11.

Table 10. Vehicle fleet penetrations of the MANTRA use cases in Europe in 2030 and 2040 in Low and High scenarios.

MANTRA Use case	Fleet	Fleet penetration (%)			
		2030		2040	
		Low	High	Low	High
Highway chauffeur and autopilot	Cars	0.9	4.7	9.0	38.6
Automated freight vehicles	HGVs	0.5	3.2	8.7	42.6
Robot taxis	Taxis	0.0	8.2	5.4	70.8
Automated winter maintenance vehicles	Mainten. HGVs	0.0	0.9	4.5	16.8
Automated roadworks safety trailers	Safety trailers	2.6	5.7	11.0	30.0

Table 11. Vehicle km penetrations of the MANTRA use cases in European vehicle fleets in 2030 and 2040 in Low and High scenarios.

MANTRA Use case	Fleet	Vehicle km penetration (%)			
		2030		2040	
		Low	High	Low	High
Highway chauffeur and autopilot	Cars	1.3	6.6	11.1	47.2
Automated freight vehicles	HGVs	0.8	5.1	12.4	59.5
Robot taxis	Taxis	0.0	8.6	5.7	72.6
Automated winter maintenance vehicles	Mainten. HGVs	0.0	1.3	6.9	24.0
Automated roadworks safety trailers	Safety trailers	3.9	8.9	14.7	39.7

6 Limitations to work on ODD and penetration rates

Input and results from this deliverable should not be mistaken primarily as a forecast but rather as a pragmatically necessary starting point for further analytical work. Ex-ante ODDs will always deviate from ODDs from the perspective of established CAM services in 2030 and especially 2040. However for the purposes of take-up in MANTRA work packages 3 and 4 we need to freeze views as of February 2019.

The main limitation to ODD results concerns the continuous evolution of technologies, making the technical solutions more capable and at the same time more affordable. For ODD, these technologies are related mainly to sensing and software including AI. This means that in 2030 and especially 2040, the automated vehicles will be able to cover much larger part of the road network, traffic situations, and weather conditions than in 2020. However, the forecast of the detailed ODD in 2030 and 2040 is impossible today. By definition and in full consent with the CEDR PEB group and CEDR CAD group our ODDs focus on the four defined priority use cases. Therefore some road operator-related questions (e. g. difficult cases at traffic lights; pedestrian zones) have seen little attention, given the anticipated coverage outside the scope of this timing interval.

Concerning the penetration rates, the aggregated forecasts are based on an evolutionary approach to CAD where current distributions for mode choice, vehicle ownership, etc. will remain stable over time or evolve to some degree only.

Even if there is justification for a more revolutionary setup it is hard or almost impossible to make predictions on the timing of the tipping point (what year counts for widespread regulatory approval?). We dropped sounding out ways to provide some argument of microfoundation based on the RethinkX study (Arbib & Seba 2017) and argue that this would lead to totally different mobility patterns including penetration rates. However, whether MaaS/TaaS will break through even in the USA is under much debate.

The regulatory environment and cultural acceptance makes such a revolutionary approach more unlikely for Europe. There is some new McKinsey work (McKinsey & Company 2018), which adds some dose of industrial policy thinking to the competition between world markets. It goes way too far for the MANTRA topic at stake but it might be nevertheless interesting in the context.

We consider the following examples provide some flavour of what can change in the future and why:

One of the most dynamic forces in newest trucks in Europe is likely Girteka Logistics. They are said to have bought some 4000 brand new trucks in 2018. We validated the rumour „the most dynamic force“ with a team of truck OEM middle management in automation in December 2018 (joint Workshop Connecting Austria, Digitrans, truck OEM) December 11, 2018, Linz, Austria) and informally this judgement has been entirely confirmed. So other leading players will not observe introduction of automation functions by piloting stakeholders without any competitive reaction (e.g. also buying into the most competitive vehicles). This non evolutionary element could not be integrated into your modelling. The commercially successful / leading Austria-based fleet operators all have established a similar strategy. All trucks have ACC and are replaced every 2 years after 240.000 km. We validated this during a workshop (Ressort Green Logistics Austria – a subsection of Austrian Haulier Association), July 3, 2018) with the executives in charge of greening truck-based logistics (all maintain they change always after 2 years 240.000 kms). However, both globally as well as within Europe there have been entirely different approaches towards environmentally friendly trucks. It should also be remembered that the truck discarded after 2 years in some high-economy countries may well be used for many years by smaller road haulage companies, perhaps in low-economy European countries.

The context for adoption in the truck case in Europe is kind of different because there is some piggy-packing of other political issues (longer vehicles, heavier vehicles, etc). These differences and conflicts are known to road operators. But this impacts the attractiveness of the business model for new top of the line trucks and Europe-wide service providers. No wonder Mercedes announced higher levels of truck automation for the US only with trucks going 310.000 km per year and more and all this at higher speeds. (Aigner, 2018)

For the time being Mercedes, Volvo, Scania, IVECO and MAN have demonstrated severe hesitation towards bringing truck automation onto European roads (mostly for cultural reasons). This was also felt at the ARCADE workshop in Brussels on February 5/6, 2019, Breakout session 2. Freight Vehicles use cases (Mats Rosenquist, VOLVO). This is in line with Mercedes' latest competitive announcement to making this an American success story. Therefore, we anticipated a rather evolutionary approach without radical dynamics for Europe on what will actually be used / adopted in Europe.

The most dynamic force in taxi in Europe is probably yet unknown. There has been some rumour that Mercedes sold 100.000 automated S-class limousines to an unspecified (probably UBER) operator under the condition that these cars work fully operational driverless. Some informal clarification has maintained that this does not necessarily mean that these cars can go everywhere. They might undergo local learning and be used in local environments. Here the tricky thing comes in. Would you operate these in Dubai, and other locations where you have less of cultural resistance and administrative barriers? The single case is interesting for the same reason as Girteka. If UBER operates driverless taxi services with S-class Mercedes in any European metropolitan area all existing taxi fleet operators interested in the business segment (international corporations) would immediately switch if the can get hold of new cars. Naturally, the taxis discarded would likely be utilised as taxis or private vehicles by other operators and private persons elsewhere. Again, we decided to stay with an evolutionary approach and not to integrate this into our modelling.

CAD functions becoming available in middle class cars are anticipated to drive our evolutionary penetration model. And culturally in several European countries it is rather unclear whether penetration rates exclusively for the top of the line cars and customers would get public authorisation. To be blunt: "For checking your emails while commuting in your own driverless car" city authorities might be the unknown element in our adoption modelling. Therefore, we stayed with an evolutionary middle class feature penetration approach and avoided to integrate this on a European scale.

Concerning winter maintenance trucks, one European road operator operates 360 maintenance trucks, replaces them every 12 years and hence gets 20 new trucks each year. In terms of market availability, there was agreement that 2030 sounds like a reasonable entry date. However, interesting was that not the sensing and positioning in snowy conditions was considered most challenging but the salting logistics. Reportedly, there have been approaches to automating the salting logistics in Scandinavia, which have been ended and turned back to manual salting (decision by the driver) just recently as the amounts were just wrong (in particular on bridges, etc.) (Ulrich 2019).

With regard to safety trailers, the pilots on the German aFAS project are going very well. (aFAS website and MAN website; aFas is the German acronym for driverless safety trailers). However, MAN has not yet announced that they will bring safety trailers commercially to market. This supports our evolutionary market entry modelling. According to a head of operation (NRA), this operator has around 3-5 very critical areas, where 100% of the accidents (25-40 each year) where trucks crash into the regular safety trailers happen. Therefore this operator intends to buy 3-5 driverless safety trailers right away when they are available, to secure these areas. After that they probably wouldn't even replace all the regular ones with the self-driving ones as they will be a lot more expensive. In total this single operator has 43 operation centers, assuming that each of those has 2 safety trailers, we would have 5% right away. Obviously that's just one European road operators' opinion but it does support our penetration modelling and our background assumptions.

Strong recessions have a definite impact on the distributions. Investing in a new motor vehicle is a decision with major economic impact both for a private household and for a company, and for many, such a decision can be postponed if the economic outlook is doubtful, or even made earlier if it seems an economically clever thing to do due to vehicle tax increase etc. We decided to smooth the "economic" bumps out of the curves. These bumps would be due to a factor not related to the vehicle age as such but only to the extraordinary conditions of the specific years in question, because the distribution is to be used for prediction purposes, and the coincidence of having similar extraordinary conditions in the future are extremely difficult to forecast. If we are using the distributions to explain today's situation or that in the past, we would naturally never modify the distributions.

7 Conclusions

Input and results from this deliverable should not be mistaken as forecast but rather as a pragmatically necessary starting point for any analytical work. Ex-ante ODDs will always deviate from how ODDs will be seen from the perspective of established Cooperative automated mobility services in 2030. ODD is specific to each individual driving automation system feature and can only be defined by the manufacturer of the system, based on the specific technological capabilities and limitations of that system. However for the purposes of take-up in MANTRA work packages 3 and 4 we need to freeze views as of February 2019 (plus PEB and CAD WG feedback).

Automation will find its way into real-world road-based mobilities. This MANTRA deliverable 2.1 suggests discussing and preparing for these issues and this transition phase within road operators' management layers by means of five concepts / tools:

- four priority use cases for AV, (Highway autopilot including highway convoy (L4) – 1 as 1st phase; Highly automated (freight) vehicles on open roads (L4); Commercial driverless vehicles (L4) as taxi services; Driverless maintenance and road works vehicles (L4)
- Operational Design Domains (ODDs) for the use cases, including the road operator attempts to categorise their physical and digital infrastructures in support to them
- estimated ODD coverages up to 2040
- a set of fleet penetration rates for these priority use cases and
- a first discussion on limitations of this approach to discussing an open future.

The aggregated forecasts are based on an evolutionary approach to CAD where current distribution will remain stable over time or evolve to some degree. Even if there is justification for a more revolutionary setup it is hard or almost impossible to make predictions on the timing of the tipping point (what year counts for widespread regulatory approval?).

This all helps better understand how an information layer comes as a "third element" between physical infrastructure and automated vehicles and how these "three layers" are challenging and shaping established processes with road operators.

One important lesson has been that ex-ante ODDs will always deviate from ODDs from the perspective of established CAM services in 2040. This is due to technology development making the vehicle sensors and software much more capable but also considerable cheaper. However, for the purposes of take-up in MANTRA work packages 3 and 4 we need to freeze views as of February 2019.

Among candidates for proactive action from NRAs there is the issue of some critical interaction between ODDs for different use cases: e. g. currently safety trailers are not recognized by CACC in cases where they are positioned diagonally to a lane. This illustrates consequences from vehicle manufacturers providing rather narrow ODDs and eliminating tricky cases at least in early phases of commercial take-up.

The infrastructure support levels for connected and automated vehicles are related to the ODDs from the automotive industry. It is evident that the provision of infrastructure support and ODD by the road operators may require considerable investments, and this necessitate reliable quantification of the value capture from automation functions for the road operators. Hence, close and constructive dialogue between road authorities and vehicle manufacturers is needed. This change management process needs alignment with ongoing C-ITS deployment activities.

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