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Cooperative Automated Driving at Transition Areas

Jaap Vreeswijk[a]*, Anton Wijbenga[b], Julian Schindler[c]

[a,b]MAP traffic management B.V., Ptolemaeuslaan 54, 3528BP Utrecht, the Netherlands
[a]German Aerospace Center (DLR), Braunschweig, Germany

Abstract

When cooperative automated vehicles (CAVs) emerge on urban roads, there will be areas and situations where all levels of automation can be granted, and others where highly automated driving (AD) will not be allowed or not feasible. Complex environments, missing sensor inputs or temporary road configurations are examples of such situations and at these locations CAVs are expected to degrade their level of automation. Such geographic areas are referred to as 'Transition Areas' and presumably are associated with negative impacts on traffic safety and efficiency, in particular with mixed traffic fleets. The H2020 TransAID project is developing a digital infrastructure and dedicated traffic management strategies to assist CAVs in better anticipating to transition areas ahead, and preserve safe and smooth traffic flow. This contribution summarizes the project's guideline and roadmap for road authorities and/or service providers for dealing with automated driving in the urban environment in general and in transition areas specifically.

Keywords: automation, connectivity, infrastructure, transition of control, traffic management, guideline

* Corresponding author. Tel.: +31 6 4164 7985
E-mail address: jaap.vreeswijk@maptm.nl

1. Introduction

As the introduction of automated vehicles becomes feasible, even in urban areas, it will be necessary to investigate their impacts on traffic safety and efficiency. This is particularly true during the early stages of market introduction, where automated vehicles of various levels of automation, connected vehicles (able to communicate via V2X) and conventional vehicles will share the same roads.

There will be areas and situations on the road where high levels of automation can be granted, and others where it is not allowed or not possible due to, for example, missing sensor inputs, the complexity of the situation, etc. At those locations the so-called Operational Design Domain (ODD) of automated vehicles ends and vehicles may initiate a change of driving mode, thereby handover the control of the vehicle to the driver or perform a minimum risk manoeuvre (MRM). Hence, such locations are referred to as 'Transition Areas' (TAs).

The goal of TransAID is to gain insight into measures that mitigate the (possible) negative impact of unintended Transition of Control (ToC) (i.e. the handover) or MRMs on traffic flow and/or safety. Therefore measures have been developed with one of three goals:

1. **Prevent ToC or MRM**: Apply a solution type to a situation to prevent the ToC or MRM. The vehicle can maintain its automated driving state. As a result, the traffic flow is undisturbed.
2. **Manage or support ToC or MRM**: In some situations, a ToC or MRM might not be preventable and there is no time or space to do it elsewhere. The ToC or MRM can be managed (e.g. indicate a safe spot) and supported (e.g. inform surrounding vehicles to give way).
3. **Distribute (in time and space) ToC or MRM**: In situations where the problem is predictable, but despite the predictability ToC or MRM cannot be prevented, it is best to phase the ToC or MRM. That way, not all vehicles perform a ToC or MRM at the same time at the same place, but sequentially and distributed along the road, thereby minimizing the impact.

The measures are described in more detail in Wijbenga et al. (2018). To design infrastructure-assisted driving at transition areas, situations in which ToCs disturb traffic need to be identified and studied. Especially, why, when, and where exactly ToCs are triggered needs to be better understood. This mostly requires a better understanding of the constructs of the Operational Design Domain of automated vehicles.

The main purpose of this paper is to discuss different perspectives on the ODD of automated vehicles as well as measures – vehicle technology, (digital) infrastructure-related and otherwise – that facilitate automated driving and help preserving and extending the ODD. In addition, this paper summarizes a guideline and roadmap prepared by the TransAID project, which aims to support road authorities and/or service providers dealing with automated driving in the urban environment in general and in transition areas specifically.

2. Cooperative Automated Driving

One common desire across all stakeholders, both public and private, is to exploit the full benefits of connected and automated driving in terms of safety, efficiency and the impact on the environment. The global vision is that automated vehicles, connected vehicles and cooperative intelligent transport system (C-ITS), together, will lead to more sustainable mobility (i.e. zero road fatalities, optimal traffic flow, reduced emissions, reduced congestion and social inclusiveness). There are many views on possible development paths, likely roadmaps and intermediate phases. The European Commission has illustrated the path towards cooperative, connected and automated mobility as shown in the figure below (Barradas, 2018). What is interesting about this figure from the perspective of MAVEN are the labels 'negotiate' and 'orchestrate' which is literally what MAVEN use cases aim to achieve.

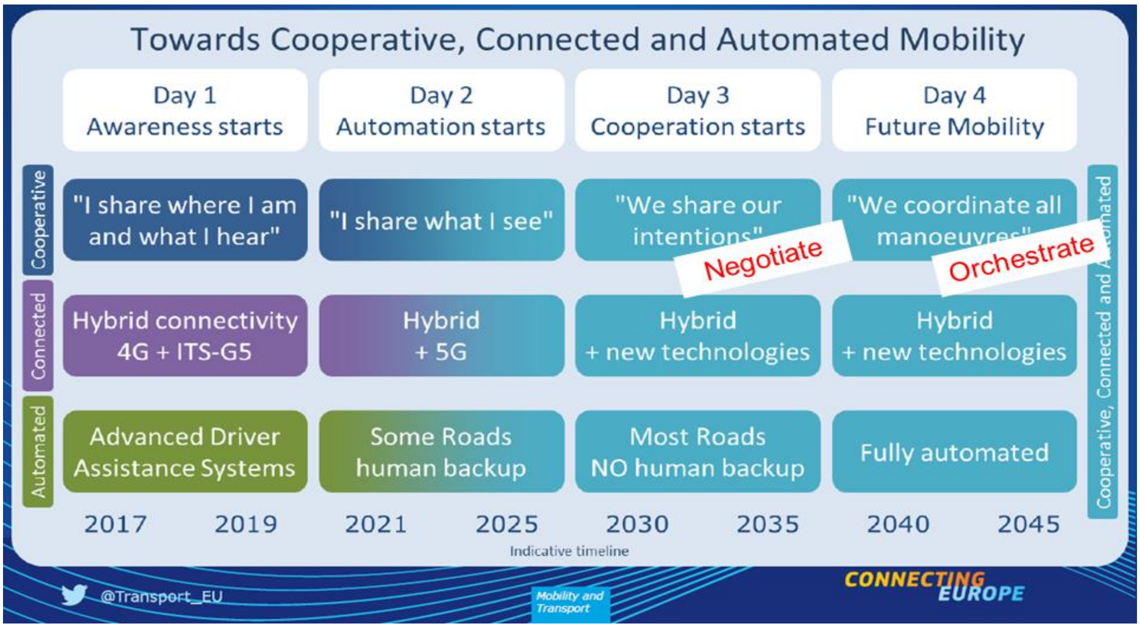

Fig. 1 path towards cooperative, connected and automated mobility

To better understand the framework of cooperative, connected and automated mobility, it is important to know the meaning of these terms, as they are often confused. Here we propose the following definitions (Andata, 2019).

- Autonomous Driving: autonomy means that one is able and allowed to make decisions independently and on one's own mind. In the case of autonomous driving a single vehicle can make its own driving decision independently.
- Automated Driving: automation deals about the execution of processes and procedures without human intervention. Hence automated driving implies driving without the intervention of human drivers.
- Connected Driving: in the case of connected driving, information is exchanged between automated as well as non-automated vehicles and other traffic participants and/or infrastructure in an automated way.
- Cooperative Driving: cooperative driving means, that single vehicles and drivers act cooperatively within traffic. This implies, that single traffic participants are coordinating their microscopic aims and actions in the light of improved overall macroscopic effects.

It is important to note that connected driving itself does not necessarily imply cooperative driving. Single traffic participants can theoretically use the additional information for their own individual advantage at the cost of others. Similarly, autonomous driving does not intrinsically cause improved traffic. If everybody decides on his own without a cooperative coordination with other traffic participants, then chaos and traffic collapses may be a consequence. Normally, autonomy is only appropriate in the case of low densities. Automated driving can lead to significant improvements in traffic, because cooperative behaviour can be enforced for robots much easier than for human beings. Robots follow their instructions much more precisely than humans, unless these are autonomous robots which decide to do differently.

3. Managing the Operational Design Domain

What is relevant about the expected benefits of cooperative, connected and automated driving and when they become available is the operational design domain (ODD) of automated vehicles. ODD is a description of the specific operating conditions in which the automated driving system is designed to properly and safely operate, including but not limited to roadway types, speed range, environmental conditions (including weather, daytime/night time), prevailing traffic law and regulations, and other domain constraints (SAE, 2018). Any automation use case of level 1-4 is usable only in its specific ODD. An ODD can be very limited, for instance a segregated road or a single fixed route on low-speed public streets. A graphical representation of the ODD with a storyline including the Transition of Control (ToC) process is shown in the figure below (STRIA, 2019).

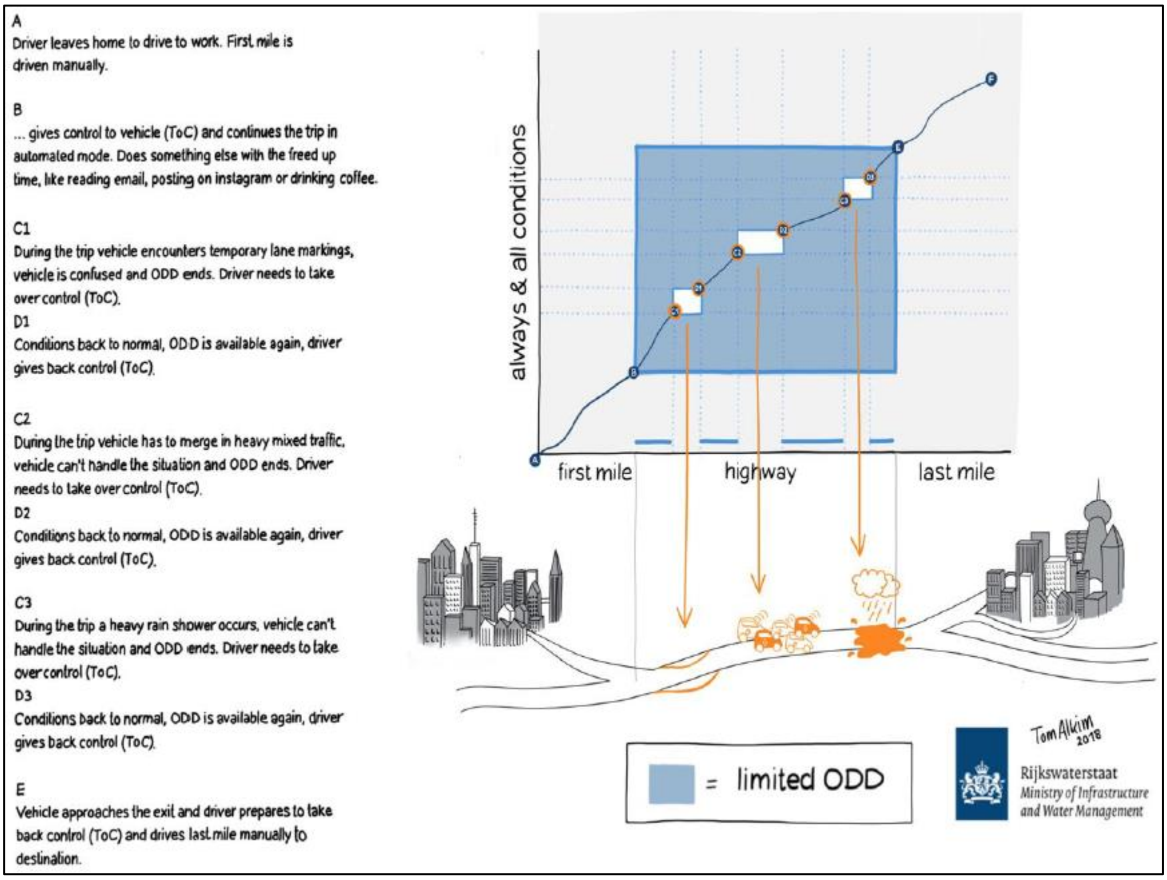

Fig. 2 visual representation of ODD

The attributes of the ODD are directly connected to the way the automated driving system works and the interaction with its environment. An important aspect to realise about the ODD is that there is not one stakeholder who can affect all specific conditions, let alone control them. Therefore, a vehicle manufacturer cannot guarantee that a level 4 vehicle can always drive in L4 mode, but only inside the ODD. And similarly, a road operator would not be able to offer a road on which a L4 vehicle can be guaranteed to drive in L4 mode because factors outside their control (such as adverse weather conditions) may prevent that. However, a mutual goal amongst stakeholders could be to 'manage' the ODD, making it as uninterrupted, stable and predictable as possible, in order to allow as much automated driving as possible thus maximising the potential benefits that are associated with it. This implies that actions by both vehicle manufacturers and public authorities can help to preserve and extend the ODD of automated vehicle geographically and temporally.

The above implies that the path from no automated to full automation, in fact has two dimensions: the increase of the automation level and the expansion of the use area as shown in the figure below.

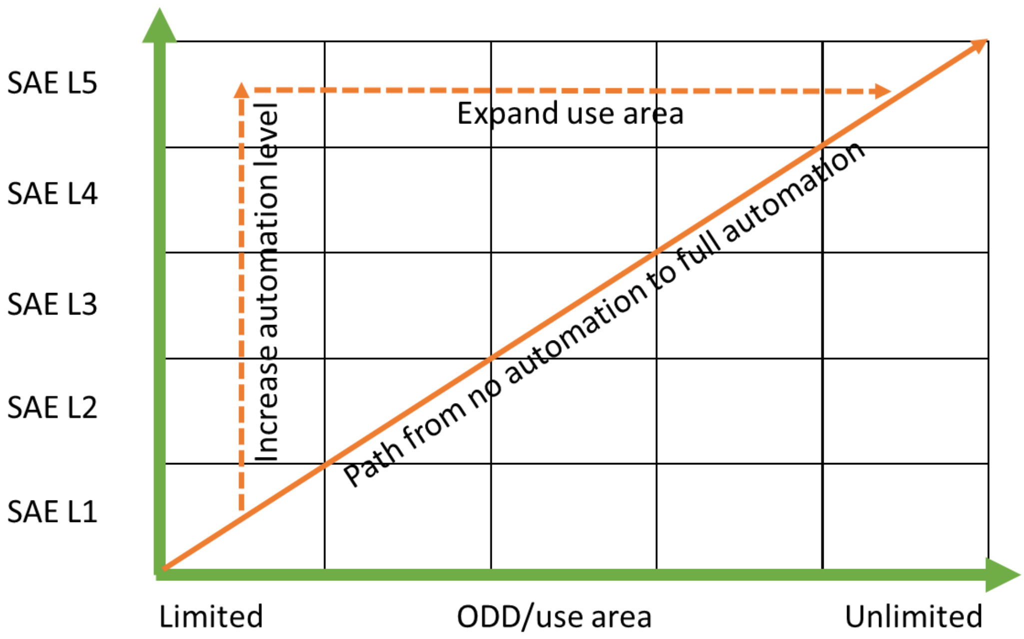

Fig. 3 automated levels versus the ODD use area

The central question related to this figure and the different stages it represents is: what attributes mark the boundaries of these stages, and what is needed to enable a transition to the next level?

4. Operating environment

To answer the above question, it is relevant to understand the differences between various operating environments and the how these affect the ability to deploy actual, operational, real world automated vehicle solutions within a reasonable timeframe. To appreciate the difference between controlled, semi-controlled and uncontrolled environments, four key areas need to be considered (Lohmann and Van der Zwaan, 2018):

- Speed: how fast is the vehicle moving and other vehicles in its vicinity? At lower speeds everything is always easier, especially when nearing intersections.
- Intersections: does the vehicle need to deal with cross traffic, other cars or vulnerable road users? Are the intersections on a grade? Is the traffic in them regulated, and if so, how much control is there over the traffic flow?
- Access: is the vehicle segregated in its own separate lane or pathway, or does it need to share the lane with other vehicles? How likely is it that there will be people or vehicles in the lane that are not supposed to be there? What other vehicles does the automated system need to share its lane with? Sharing part of the street infrastructure with a human-driven bus is much easier than with random traffic and pedestrians.
- Behaviour: how much control is there over how people use and interact with the system? Human nature dictates that people will always be disobedient and ignore traffic signals. Who are the users?

Differences in these four areas denote a continuous scale from fully controlled to uncontrolled environments. At one end of the scale is a people mover system operating on private premises along its own track or pathway. At the other, a fully autonomous driverless vehicle navigating busy city streets amongst other traffic. In this sense, car manufacturers and tech-giants talking about automated cars being deployed in the upcoming years (2020 - 2025) are talking about highways. A highway is an environment where all vehicles travel at approximately the same speed, have no at grade intersections, with access restricted to cars and behaviour being relatively similar. It is basically a semi-controlled environment and certainly very different from a city centre where cars, buses, bikes and pedestrians create an uncontrolled environment, which is much less predictable and more complex.

5. Infrastructure Support Levels for Automated driving (ISAD)

Another way of classification that builds upon the previous sections comes from the H2020 INFRAMIX project (INFRAMIX, 2019), which has developed a scheme similar to the SAE levels for automated vehicle capabilities, only then for digital infrastructure. The so-called Infrastructure Support Levels for Automated driving (ISAD) aims to classify and harmonize the capabilities of a road infrastructure to support and guide automated vehicles . What is particularly interesting is the interplay between the ODD, the SAE automation levels, the ISAD. Clearly they are related, but not interchangeable nor perfectly compatible. Again, for an holistic approach the involvement, collaboration and cooperation between relevant (inter)national parties involved in automated driving is required. Involved parties are e.g. different sectors in industry, utilities, infrastructure providers, academia, public authorities.

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

Fig. 4 Infrastructure Support Levels for Automated driving (ISAD)

6. Automation readiness

So how can public authorities prepare for automated driving? What can they do to facilitate, anticipate and/or regulate automated driving? Various initiatives have been trying to identify and structure possible actions that cities can take to progressively introduce automated driving. One of them is the H2020 CoEXist project (CoEXist, 2019), which has developed a CAV-ready framework for cities which proposes actions that cities can take to progressively introduce CAVs into their policy and planning processes . Three phases have been identified: (1) becoming CAV aware; (2) planning for automation (including defining measures), and (3) implementation of measures. A range of actions are proposed according to the three phases and considering different mobility aspects: policy, planning, infrastructure, capacity building and traffic management.

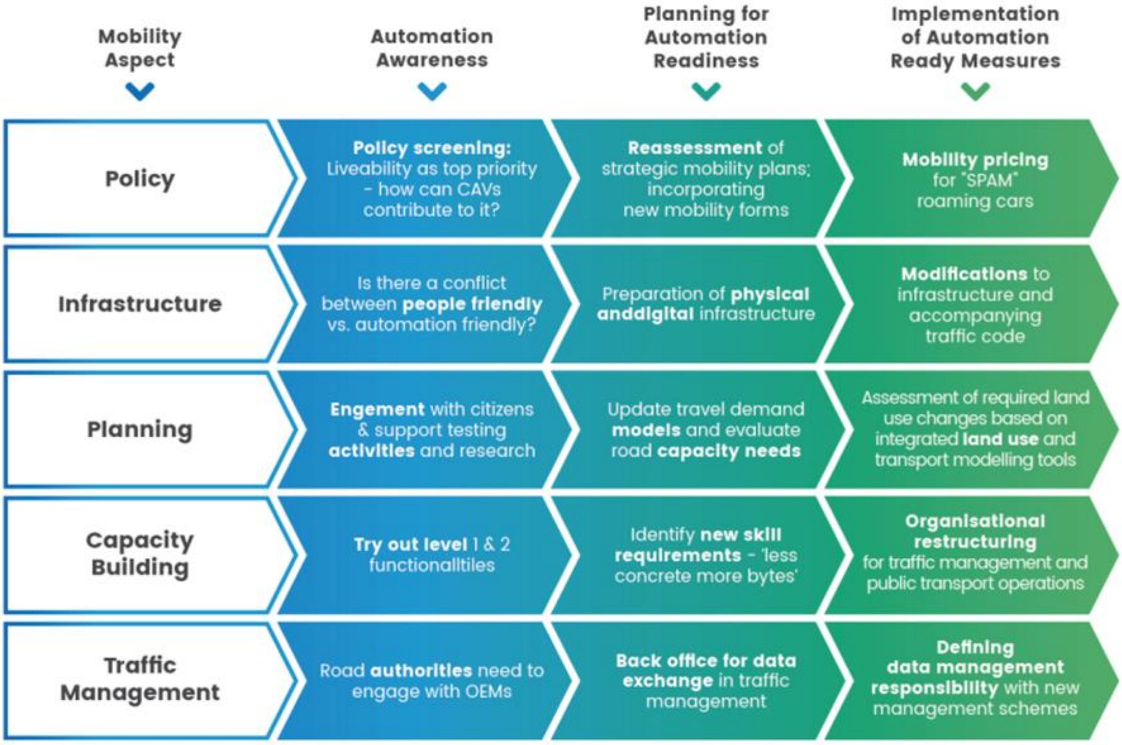

Fig. 5 Overview of three phases towards automation-readiness with examples of measures

7. Guideline for managing Transition Areas (and ODD)

The H2020 TransAID project is developing a digital infrastructure and dedicated traffic management strategies to assist CAVs in better anticipating the end of their ODD, i.e. to transition areas ahead, and preserve safe and smooth traffic flow.

The TransAID project will produce a 'how-to' guideline and roadmap for road authorities and/or service providers for dealing with automated driving in the urban environment in general and in Transition Areas specifically. It will contain concrete required activities and possible road infrastructure modifications that local authorities can undertake, to facilitate the introduction of automated driving. TransAID strives to describe how an intelligent and digital infrastructure can accommodate the introduction of automated driving, also when the entire spectrum from vulnerable road users to conventional vehicle to highly automated vehicles co-exist. The roadmap will include recommendations steps to be taken by policy-makers, OEM's, infrastructure systems providers, standards-development organizations among others. Technical, political, societal, institutional and organizational aspects will be considered.

Note to reviewer: the preparation of the guideline / roadmap is planned for autumn 2019 and will be preceded by a meta-analysis of simulation and field study results, and stakeholder consultation workshops. This work is done in close cooperation with other H2020-projects on this topic (e.g. those cited). The final version of this paper will include the results.

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