# Towards Safe and Efficient Driving through Vehicle Automation: The Dutch Automated Vehicle Initiative

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The automotive community is achieving substantial progress in the development of automated vehicles. But do we actually want automated vehicles and if so, how can we support their safe and legal introduction onto Dutch roads? The Dutch Automated Vehicle Initiative (DAVI) aims at the investigation, improvement, evaluation and demonstration of automated driving on public roads. DAVI is a collaboration between Delft University of Technology, Connekt, RDW, TNO, Toyota Motors Europe as well as many other Dutch and selected international partners. But, what is automated driving actually?

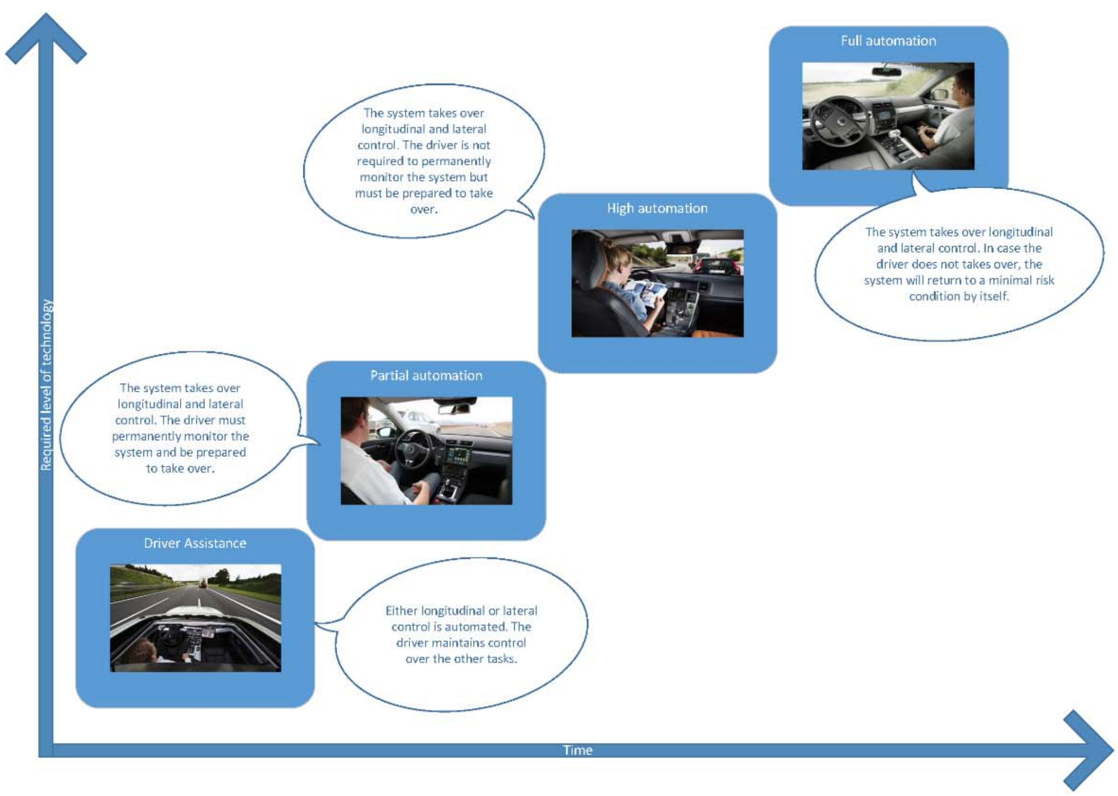


*Figure 1. A visual representation of the evolution of automated vehicles with respect to complexity of technology and time.*

## Vehicle automation: A definition

Many definitions of automated driving are currently in use (e.g., auto-pilot, autonomous vehicles, automatic vehicles, etc.). In the EU iMobility working group on Automation a definition was developed based on the level of automation and consequently the required (or remaining) role of the driver. In this context, we distinguish between driver assistance (i.e., ADAS), partial, high and full automation. In Fig. 1 these different concepts are explained along with the required level of technology. The different stages are overlapping in time and manually driven vehicles will be present in mixed traffic with automated vehicles with varying levels of automation. This is referred to as the penetration level, a critical factor in the beneficial introduction of automation.

## When will automated vehicles be introduced on public roads?

Currently we find ourselves in the stage of driver assistance (see Fig. 1). Many systems are already commercially available, such as Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA), Autonomous emergency breaking (AEBS) and Automated Parking or parking assist. Partial and high automation is a subject of intensive R & D projects, such as the HAVE-IT and SARTRE project in the EU and the Google or CMU car in the USA.

Fully automated experimental vehicles have already been developed in the DARPA challenges in the USA. Others, such as ECT and Rivium are already using automated vehicles based on dedicated and restricted infrastructures.

Although automated driving tests are presently being conducted world-wide, the question of when automation will be available in consumer vehicles still remains. In order to have automated vehicles drive safely and efficiently on public roads, numerous challenges have to be resolved. In this sense, DAVI aims at the investigation of automated driving on public roads in order to get insight into the requirements needed for safe and efficient driving as well as into the effects automated driving will have. But do we need automated vehicles at all?

## Does automated driving offer possibilities to improve the safety and efficiency of transportation?

Automated driving can be assumed to offer unique possibilities to improve traffic flow efficiency, traffic safety and reduce greenhouse gas emissions. In this context, the following improvements are envisaged:

1. Assuming the current levels of traffic flow, it seems realistic to expect that automated driving may reduce congestion by 50%. We envisage that this improvement follows from better anticipation towards the traffic conditions downstream, thereby reducing the probability of a traffic breakdown, and acceleration of the clearance of congestion by increasing the outflow from a queue. Vehicle to vehicle communication will provide additional benefits in the prevention of congestion and the management of traffic flow in the network.
2. Automated driving aims at a 100% reduction of accidents involving vehicles. Through advanced technology, automated vehicles will be able to detect and respond to hazards and vulnerable road users (i.e. cyclist, pedestrians etc) faster and more adequately than the human driver.

3. Automated driving is expected to improve energy efficiency by approximately 20% through efficient and precise speed control. The reduction in congestion also leads to an improvement in the energy efficiency through a reduction in the variation of speed. Finally, platooning with small time headways substantially improves energy efficiency through a reduction in the aerodynamic drag especially in LGV's (i.e. trucks etc).
4. Besides these benefits to society, automated driving will lead to an improved travel experience, as in fully automated vehicles drivers will have the freedom to spend their time on other activities during a long trip.

## Evaluating the possibilities through automation on public roads

Although an improvement in traffic flow efficiency, traffic safety and a reduction in greenhouse gas emissions can be expected, it has to be noted that the evidence is based on theoretical considerations and modelling studies of systems that bear similarities with automated vehicles.

Also, the relationship between traffic flow efficiency and automation of vehicles is far more complex than assumed in these theoretical considerations and modelling studies. For instance, human factors (i.e., the unpredictable human behaviour) may be assumed to lead to different system settings governing the car-following, lane choice and lane changing behaviour of the automated vehicles.

Finally, it can be assumed that automation is not an all or nothing phenomenon (see also Fig. 1). It can be expected that vehicles with different levels of automation will be present on the Dutch roads (ranging from manually driven vehicles to fully automated vehicles). Especially the presence of manually driven vehicles is interesting, as it is not yet known how these drivers will react to the presence of automated vehicles (for instance driving in between platoons etc.).

It is therefore crucial to determine the effects of automated vehicles in complex real world driving conditions.

## Important challenges of automated driving on public roads

The challenges that we will address can be divided into four different categories, namely:

1. Technological challenges;
2. Challenges related to human factors;
3. Traffic management challenges;
4. Traffic safety and legal challenges;

### Technological challenges

Automated vehicles should be sufficiently aware of the infrastructure and the other road users (this is referred to as situation awareness). Currently, sensing technologies are already capable of identifying other road users, obstacles, navigation paths, road signs and delineation. This was for example already demonstrated in the Intercontinental Challenge in which automated vehicles drove 13.000 km from Parma/Italy to Shanghai/China.

However, the reliability of sensing technology has to be quantified, and new methods for quantifying the reliability of sensing technology in various weather and traffic conditions are desperately needed. Furthermore, the reliability of sensing technologies has to be improved for real-life conditions. The technology should be sufficiently aware of the situation in case of for example complex traffic situations (i.e. driving through a city centre) and adverse weather conditions (i.e. snow, heavy rain, etc.).

Besides reliable sensing technologies, automation control strategies have to be developed. Current control strategies mainly focus on longitudinal control (e.g., Adaptive Cruise Control). Up to now, lateral control systems are predominantly advisory (i.e. Lane keep assist). In this context new automated control strategies have to be developed to deal with the different situations such as:

- Merging on highway;
- Overtaking on different roads;
- Lane changing;
- Manoeuvring through varying traffic (i.e. vehicles, cyclist, pedestrians).

## Human factors challenges

Besides the numerous challenges with regard to technology, important challenges related to human factors have to be resolved. Empirical evidence shows that automation has a substantial influence on human behaviour. With automation, the role of the human driver changes substantially. To be more precise, the role of the driver changes from being a manual controller of the vehicle to being a supervisor of the system. However, in case of partial and high automation, a capable driver is still required (i.e. he or she needs to resume manual control in the case of a sensor failure or in case of too complex traffic situations). In this context we need profound insight into the determinants of the quality of the interaction of the driver with the automated vehicle in case of real-life traffic conditions. Examples of these determinants are driver workload, situation awareness and vigilance. Up to now, the quality of these interactions have predominantly been researched using driving simulator studies.

Earlier we mentioned that the presence of automated vehicles may lead to changes in driving behaviour of the manually driven vehicles. It is not yet clear what these changes are and if they are at all present. In this context we need insight into the adaptation effects in driving behaviour of manually driven vehicles in relation to the presence of automated vehicles.

Finally, a very important human factors issue is user acceptance. Are drivers actually willing to give up direct control over their vehicle and under what conditions? If automation of vehicles is not accepted by the users and users refrain from using the technology, the impact of automation on traffic flow efficiency, traffic safety and energy efficiency is mitigated. It is, however, not yet clear to what extent users accept automation and what the determinants of user acceptance of automation are.

## Traffic management challenges

The advent of vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) in combination with automated vehicles offers a vast range of possibilities to increase traffic flow efficiency, traffic safety and reduce greenhouse gas emissions and energy consumption. Communication can enable sharing of information and can consequently be used to get information about the traffic situation, dynamic speed information, etc. Possible traffic management strategies using automated vehicles and communication are platooning and lane specific control. For example, platooning has been shown to be able to increase the steady state flow over 6000 veh/h, which is a substantial increase compared to normal traffic. Furthermore, previous research has shown that lanes are generally underutilized. Through lane specific control using automated vehicles an optimal distribution of the lanes can be attained. Finally, current traffic management measures often result in suboptimal performance since drivers disregard advice or comply imprecisely with the provided advice.

Up to now studies, on automated driving in relation to traffic management strategies have been performed using traffic flow simulations. In this context empirical on road verification of the efficiency of these strategies is duly needed.

## Traffic safety and legal challenges

As automation of vehicles aims at a 100% reduction of accidents involving vehicles, we need to actually quantify these benefits of automated driving on traffic safety before we can safely deploy automation in consumer vehicles. In this context it must be stated that even assuming 100% reliable sensing technology and safe control strategies human factors aspects may mitigate the safety benefits of automation. For instance, we already mentioned that automation is not an all or nothing phenomena. We envisage that vehicles with different levels of automation will mix with manually driven vehicles. Although generally automated vehicle technology is not distracted, doesn't sleep, can react faster and safer than a human driver, the human factor of the surrounding traffic remains. Insight into the human factors aspects of automated driving (for instance the adaptations in driving behaviour of manually driven vehicles following the presence of automated vehicles and possible transitions from automated to manual driving) will be needed to quantify the benefits of automated driving on traffic safety.

However, current methods to predict safety benefits are imprecise, as they ignore or simplify effects on human behaviour. We need to have automated vehicles drive on public roads in order to study and quantify effects of automation on behaviour.

Besides these challenges in relation to traffic safety many challenges with regard to legal aspects are present. A first legal challenge is type approval. In this sense the famous Geneva convention states that a driver should be able to monitor and control the operation of the vehicle. This means for instance for partially automated vehicles (e.g., through a combination of Adaptive Cruise Control with a Lane Keeping System) that drivers need to have a monitoring system which will turn off the systems by itself when it detects that a driver is distracted. In case of highly automated vehicles, the monitoring and control of the vehicle is shared between the vehicle and the driver. From a viewpoint of type approval there is therefore a need to legalize shared driving responsibility and also to implement procedures to test this.

Furthermore, the introduction of automated vehicles raises important challenges with regard to liability. Liability for material and immaterial damage caused with an automated vehicle may differ from the liability with manually driven vehicles. In case of partial automation, a driver may be assumed to be fully liable, while in case of high automation it may depend on the specific situation. In case of full automation the manufacturer might be liable. All these issues must be understood, assessed and addressed for automated vehicles to be legally on the road.

## The Dutch Automated Vehicle Initiative (DAVI)

In order to grasp the full potential of automated vehicles on Dutch roads it is time to investigate, improve and demonstrate automated driving on public roads, with automated vehicles sharing the road with manually driven vehicles. For this purpose, DAVI will develop automated vehicles equipped with all necessary technologies that enable the vehicle to drive in automated mode on public roads. DAVI focuses its effort on the aforementioned challenges and will bring the developed knowledge and technology to everyday life.

Since its inception in March 2013, DAVI rapidly gained momentum, aiming for a first public demonstration as well as the official launch of its R & D program at the Innovation Relay in Amsterdam on 12th November 2013.

## How is DAVI going to address the challenges?

In collaborative projects DAVI develops automated vehicles. These vehicles will be tested extensively on a test track, on a closed roads and in mixed traffic on public roads. The reliability of the technology will be quantified and improved under various driving conditions (e.g., various road and weather conditions, driving conditions with differing levels of complexity, etc.). Furthermore we aim to develop and extensively test new lateral control strategies (merging, lane changing, overtaking).

Human interaction with the automated vehicle, especially mode transitions (from automated to manual mode and vice versa) will be assessed systematically. The on-road assessment of these interactions will be pivotal in the development of human-machine-interfaces supporting for example the mode transitions. Furthermore, a substantial amount of attention will be paid to user acceptance. Finally, behavioural data will be used to develop and validate traffic flow models allowing for the approximation of the influence of automation in mixed traffic on traffic flow efficiency.

DAVI aims at bridging the gap between individual vehicle automation and traffic management. Using innovative real life experiments as well as simulations, we will evaluate different traffic management strategies for automated vehicles (such as platooning, lane specific control, optimization of route choice etc). In this context we aim to perform large scale traffic simulations to predict the effects of automation with varying penetration levels on traffic flow efficiency, safety and energy consumption.

Finally, DAVI aims to address the challenges with regard to automation in relation to the many legal aspects associated with the introduction of automated vehicles, in close cooperation with the applicable international working groups and projects. RDW, the Dutch vehicle approval authority will support the safety assessment of the automated vehicle, including the reliability assessment of sensing technology as well as behavioural effects of automation. RDW will use the experience gained in DAVI to co-develop type approval procedures for automated cars.