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Physical and digital infrastructure for optimised ADAS performance

SUMMARY OF THE MAIN REPORT,
ORIGINALLY PUBLISHED IN DUTCH, MARCH 2021

INTRODUCTION

Our mobility is facing a new period of major changes, with traffic safety improvements remaining an important objective for governments as well as road maintenance and management authorities. A lot has been achieved in recent decades to improve infrastructure safety and influence road user behaviour. The automotive industry has also made huge advancements in vehicle safety. New vehicles are increasingly equipped with systems that assist human drivers in driving, including maintaining course, speed and distance. These driver assistance systems - Advanced Driver Assistance Systems (ADAS) - have a positive impact on traffic safety and make driving more comfortable and sustainable, if used correctly and safely and if they function well. Various ADAS will be mandatory in new passenger car models from 2022 and in all new cars from 2024.

Realising the positive impact of ADAS is a multi-disciplinary, collective task for automotive parties, legislators and road maintenance and management authorities. It is important for road maintenance and management authorities to know how they can make infrastructure future-proof in view of the rapid rise in smart vehicles and developments relating to mobility data digitisation, as well as how they can manage newly introduced risks. Which options are there from the current and future infrastructure to support the safe and correct performance of smart vehicles and which steps can be taken to work towards this and to improve traffic safety?

Royal HaskoningDHV was commissioned by the National Traffic Management Board (LVMB), in which the Netherlands' largest road maintenance and management authorities collaborate at national, regional and municipal level, to research the need for action and changes relating to guidelines, infrastructure and cooperation between road authorities, the car industry and other important stakeholders. The survey covered two main questions:

Research question 1: 'To what extent do the current speed limit sign guidelines need to be adjusted to ensure that ADAS can detect and read these?'
This question mainly relates to understanding whether the location, visibility and interpretability of various types of speed limit signs need to change to improve detection by traffic sign recognition systems and the performance of Intelligent Speed Assistance (ISA). The basic principle is that traffic signs should always remain clear for human road users.

Research question 2: 'How can we use the physical and digital infrastructure in a uniform way to optimise ADAS performance?'
More insight is needed into infrastructure characteristics that can impact safe and correct ADAS performance, including physical (road design and layout) and digital infrastructure (for example focused on communications and positioning/maps). The objective is to identify measures to support the safe use of ADAS, while guaranteeing and, where possible, improving traffic safety for drivers who drive without assistance.

Basic principles

TWO WAYS TO ALIGN INFRASTRUCTURE AND ADAS

Safe and correct ADAS performance largely depends on the Operational Design Domain (ODD)[1], also known as 'the operational area'; the situations and conditions within which ADAS is intended to perform well. These kinds of conditions are determined by environmental, geographic and time limitations and/or the requirement for the presence or absence of certain traffic or road features.

Every ADAS has its own ODD, which can vary as ADAS are different systems with different specifications. The larger the ODD, the greater the ADAS contributes to traffic safety. As soon as the vehicle ends up in a situation that falls outside these defined conditions, the ADAS will not perform or will perform poorly. Figure 1 illustrates this. When the vehicle is in a situation outside this ODD we refer to a 'fallback situation': the ADAS will automatically deactivate or the driver must take into account that the relevant ADAS driver assistance functions will fail entirely or partially. These gaps in the ODD reduce system predictability and reliability and increase the driver's task load when driving. This results in potential new risks instead of the intended traffic safety improvements. Functionality disappointments also make ADAS less attractive for consumers.

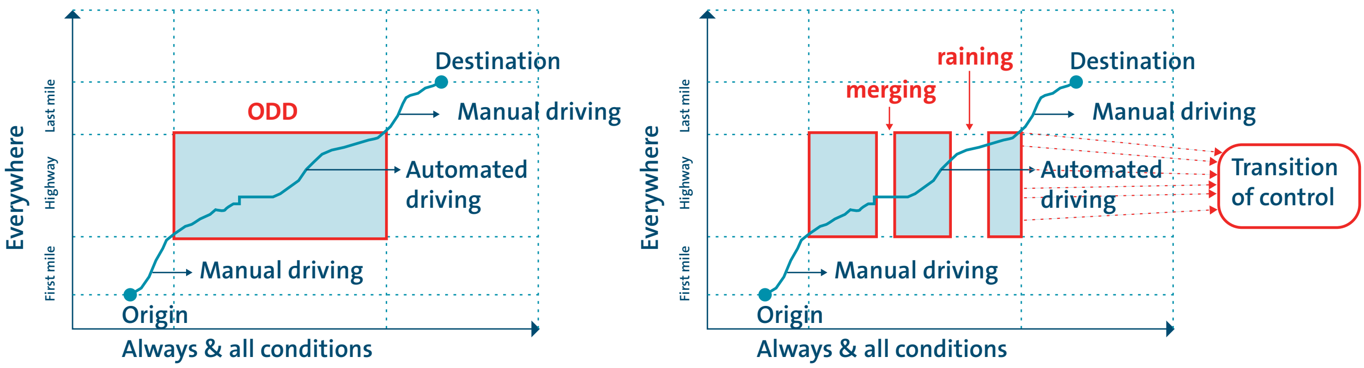


Figure 1: Location and time dependent factors caused gaps in the operational area of ADAS. (Source: Rijkswaterstaat)

There are two ways to improve ODD:

1. Remove or reduce gaps in the existing ODD: these gaps relate to conditions, traffic situations and road segments (location & time dependent factors) where the systems do not work (including the failure of Lane Keep Assist [LKA] due to lane markings being insufficiently visible).
2. Expansion of the existing ODD: as ADAS is currently largely but not entirely operational on highways and provincial roads, this expansion mainly relates to the lower speed road categories, often at the start and the end of a longer journey, such as access roads and municipal roads. Vehicle manufacturers have an important role here to tailor ADAS functionalities to frequently occurring and challenging traffic situations, such as interactions with cyclists and pedestrians. As long as this is not the case, road authorities' role in supporting the operation of the systems on these types of roads will be more limited than on the higher speed road categories.

We can conclude from this that removing or reducing gaps in the existing ODD will be more useful for road authorities than expanding the current ODD to other road types.

Scope

The study focused on vehicles that are equipped with driver assistance systems that fall within SAE levels 1 & 2, including anticipated developments[2]. The focus was on the types of driving task where the vehicle system assists the driver, rather than on the 'strict' definition of the **SAE levels**. This study included both lateral (lane keeping) as well as longitudinal (ISA and ACC) driver assistance functions. Regarding road types, this survey considered through roads (motorways and main urban and rural roads), urban corridors (arteries with optimized traffic flow)[3] and distributor roads.

1 ODD defines 'all conditions under which the driver assistance system (or parts of this) is designed to perform correctly, including (but not limited to) restrictions relating to weather conditions, geographic characteristics and times and/or the presence or absence of certain traffic or road features.' (SAE International, 2018)

2 Smart Vehicles Fact Sheet and background report '2019 Developments and figures for fleet safety and comfort systems', RWS

3 This additional specification within the urban road category was chosen as the various road user numbers are lower on these urban corridors, which makes the use of smart vehicles less complex.

Method

This study included an inventory of the infrastructural characteristics and conditions that contribute to safety and correct ADAS performance. Four types of road situations (straight road section, bends, junctions, on and off-ramps on motorways) were detailed to provide a structural image of how the systems function in various conditions (in increasing complexity). Aspects of existing guidelines that are not really geared for ADAS performance were also examined for longitudinal driver assistance functions via findings from practice tests and literature. We gained further insight on the latest developments and the interests of various involved stakeholders (automotive, road authorities, policy) by asking experts. These insights are used to recommend measures for modifications to both the physical and digital infrastructure and indicate the roles that various stakeholders have in the collective approach.

Scope
- Selection of road types
- Selection of road segments
- Selection of ADAS

Driving Tasks & Design Elements
- Analysis of driving tasks
- Inventory of design elements
- Relationship between driving tasks and design elements and urgency

Infrastructure requirements & guidelines
- Functional requirements for design elements
- Technical requirements for design elements
- Gaps in the current guidelines

Expert Interviews
- Automotive
- Road authorities/ operators
- Policy makers

Measures
- Physical/digital measures & adjustment of guidelines

Good physical infrastructure remains important, even in the digital future

ADAS for longitudinal driver assistance (ISA, ACC)

Literature research shows that accurate and clear speed regimes and good 'visibility' of the vehicle in front are critical conditions for longitudinal assistance. Repetition of information (positive redundancy) is also an important focus point and depends on the local traffic situation or conditions.

Empirical analysis of case studies within this survey demonstrated the functional and technical requirements on infrastructure elements for longitudinal control by ADAS. On the topic of *functional requirements*, it is important that infrastructure elements clarify: the traffic regulations, when a situation changes and what the changes demand of the driver/vehicle. Infrastructure should also be such that interaction between road users can be predicted and can take place in a safe way. Lastly, infrastructure must enable a vehicle equipped with ADAS to maintain a safe distance from other road users.

To satisfy these functional requirements, *technical requirements* for infrastructure have been determined: Traffic signs need optimal positioning and maintenance. The current guidelines relating to traffic signs do not take into account the requirements and operation of camera sensors usually used by ISA.

Current regulations and guidelines can be better geared for traffic sign recognition functioning.

The entire body of regulations and directives concerning rules of conduct, traffic signs and signage has been formulated for human drivers. Whereas human drivers can interpret the signs using insight and experience, in many cases vehicles cannot (yet). Some situations are also more complex for a vehicle system than for a human, such as the conditional information signs and regulatory signs (with implicit speed indication).

- **Current shortcomings in the ADAS ODD, caused by signage deficiencies, should be minimised. Traffic recognition systems should be taken into account when selecting, installing and maintaining signage. Use of signs that ADAS cannot interpret correctly must be avoided.**

- **The adapted guidelines must not lead to the road situation being less clear for human car drivers.**

The advantage of increasing clarity and uniformity and reducing complexity for traffic systems is that this also increases road situation clarity for human car drivers. Avoiding conflicting and/or conditional information where possible is beneficial for both. Vehicle systems also generally benefit from digital solutions relating to the digital on-board map, for example. Considerable efforts are also needed for this from the 'digital road authority'.

Public lighting is also relevant as this can impact camera sensor traffic sign detection. Consideration frameworks for installing and siting public lighting currently do not take ADAS into account. This can for example result in cameras being 'blinded' when detecting traffic signs which can lead to traffic signs not being detected.

Interviews with automotive industry and road authority experts showed that speed limit signs will continue to play an important role both in the short and long term.

'There is a considerable need for uniformity and international alignment with respect to symbols on traffic signs'

Road authorities and European Road Federation (ERF)

'The already existing traffic signs must be maintained and adapted in accordance with guidelines'

Automotive parties

'ISA functionality: information signs and conditional speed limit signs are currently the greatest problem - no system can interpret these correctly right now'

Road authorities and European Road Federation (ERF)

ADAS for lane keep assist (LKA)

Critical conditions for the safe working of lateral systems include 'visibility' of lane markings and sufficient contrast between the lane markings and the road surface. Lane width (recent studies indicate a minimum value of 2.7m) is also decisive for lateral system performance.

Regarding *functional requirements* for lane keep assist, it is important that infrastructure elements clarify the traffic regulations for the system/vehicle and the route to be followed. Functional requirements are translated into the following *technical requirements*: lane marking, lane width and installing and maintaining public lighting according to guidelines. To guarantee that the system detects lane marking and that the vehicles follow the defined route, it is important that lane markings are installed and maintained according to authorised design guidelines. Good marking contrast and reflection capacity are also important. Lastly, all requirements relate to both permanent and temporary markings. Conflicting information (e.g. ghost markings) should be avoided where possible.

'OEMs do not want to be dependent of infrastructure; they do not want to wait until infra is ready for the systems. They want to ensure that the systems are independent of external factors, but infrastructure is important'

Road authorities and European Road Federation (ERF)

'Without optics, the vehicle will not stay within the lines. For vehicles driving now, good lines are the most important'

Automotive parties

Recommendations

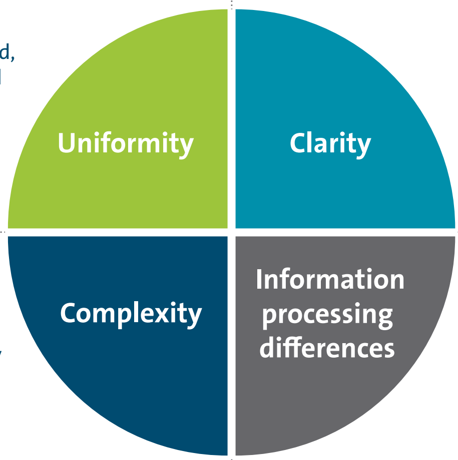
For an 'Integrated Safe System Approach' it is important that all stakeholders (from the people-vehicle-road domains), work in parallel and collectively on safe implementation of ADAS in the short term[4]. This survey has resulted in a series of recommendations for potential or other adaptation and improvement of the physical and digital infrastructure, taking into account relevant developments and their effects on the automotive industry, motorist and other road users. The recommendations are described in the form of measures and research questions that form a good basis and starting point for future action and research.

Measures

The proposed measures are related to various basic principles. Uniformity, clarity and reduction of complexity are the starting points. Measures that follow these principles have a beneficial impact on ADAS performance as well as on human drivers without ADAS. It is also important to recognise that in-car sensors and software do not work in the same way as human perception and how data are processed in the brain.

- Important for both the ecognizability of situations by the human driver and by the ADAS
- The way in which this uniformity is applied, is important for the effects on human and vehicle driving behaviour

- In road design (traffic signs, lane markings, etc.)



- Reduction of complexity that is created by e.g. conditional traffic signs

- A system detects and processes differently from humans, guidelines should take this into account
- Human drivers gain a general understanding of the traffic situation, and this is not limited to the detection of a single traffic sign; however, this is often the case with ADAS
- The experience and cognitive skills of human drivers lead to an experience-based interaction between them and the infrastructure; this is not yet the case, or only to a limited extent, with ADAS

Increase ADAS potential with a multi-disciplinary approach

The recommended measures focus on physical and digital infrastructure, the relationship between driver and vehicle, vehicle technology and policy. An 'Integrated Safe System Approach' is recommended when addressing the measures, in which parties from various domains, such as the legislator, road authorities, vehicle testing and approval body (RDW), human factors, CBR, OEMs and suppliers each take on tasks according to their role and coordinate with each other. Table 1 presents an overview of the most important measures, which states the planning horizon and the stakeholders that should be involved first.

4 https://www.adasalliantie.nl

Table 1: Overview of most important potential measures, based on term and cooperating parties.

#	MEASURE	TERM	PARTY
Physical infrastructure - uniform, clear, interaction with ADAS			
1	Presence, type and quality of lane markings (intensify maintenance of lane markings; check for contrast and reflection; focus on difference between permanent and temporary markings)	Short*	Road maintenance and management authorities
2	Public lighting: assessment of location based on impact of marking and signage detectability (contrast/reflection)	Short	Road maintenance and management authorities
3	Assess lane width main distributor roads 80	Short	Road maintenance and management authorities - suppliers (for assessment)
4	More focus on installation and maintenance of signage & adjacent vegetation.	Short	Road maintenance and management authorities
5	Guideline update required on sign image quality standards.	Short	Road maintenance and management authorities - suppliers
6	More focus on the installation location in the guidelines, taking into account possible differences between driver and vehicle systems in relation to 'distance recognition' and 'distance adjustment'.	Short	Road maintenance and management authorities
7	Guidelines should be clear for various and/or conflicting traffic signs: prevent this where possible, but also prioritise: which sign should be followed in the event of diverse and/or conflicting signs?	Short	Road maintenance and management authorities
8	Current advice[5] on retro-reflection categories of signs must be more binding and incorporated in the guidelines.	Short	Road maintenance and management authorities
Digital infrastructure			
9	Expand digital maps and make these more detailed: positioning via GPS; communicate traffic regulations to vehicles via digital maps; add road attributes and conditional traffic information.	Short	OEMs - suppliers - road maintenance and management authorities
10	V2X communications: facilitate the exchange of information on such things as the presence of other road users and status information of roads/routes.	Long**	OEMs - suppliers - road maintenance and management authorities
11	V2V communication: facilitate exchange of information on such things as speed, location and manoeuvres in line with Data Task Force and CCAM to enable cooperative driving	Long	OEMs - suppliers - road maintenance and management authorities
12	Optimisation ADAS sensors: improve the detection capacity of various sensor technologies (camera, lidar, radar) particularly in unfavourable conditions	Short	OEMs- suppliers
13	Use other ADAS to compensate for the failure of systems	Short	OEMs - road user
14	Global Navigation Satellite System (GNSS) developments (increase accuracy; link route information to speed changes)	Short	Suppliers
Digital measures (not connected to infrastructure)			
15	Link digital maps to system HMI: clear control, understandable traffic information and vehicle/vehicle system status	Long	OEMs - suppliers - road maintenance and management authorities
16	Fallback on manual control via external controller	Long	OEMs - road users
17	Investigate the option of creating and displaying a traffic sign that announces the need to deactivate driver assistance systems in the upcoming road section/traffic situation	Short	OEMs - suppliers - road maintenance and management authorities
18	Traffic education and campaigns with a focus on driver responsibility, awareness of system limitations and correct information provision through aftersales	Short	Road maintenance and management authorities - Government
Other measures			
19	Road authorities develop as digital road authorities by, for example, presenting basic information in digital form and making automatic driving function support service levels clear digitally.	Short	Road maintenance and management authorities - Government
20	Communication times should be properly aligned	Short	Road maintenance and management authorities - OEMs - suppliers
21	Research possibilities of changes to MOT	Short	RDW - Government

* short = 0-5 years; ** long = 5-10 years

5 The features of retro-reflecting material should correspond at least with class I of the NEN 338 standard.

Research and development questions

The discussion relating to promising measures and role division/alignment between the involved stakeholders resulted in various research questions for the longer term and development questions for the short term (Table 2).

Table 2: A selection of the most important questions (from the international/European perspective)

General	
1	How often do 'fallback' situation anomalies occur?
2	How do the roles of physical and digital road authority interact? What does this mean for current functions, processes, roles and what will the new role division be?
Physical infrastructure	
1	To what extent is reflection class (III), which is currently used on traffic signs, suitable for vehicle cameras? For example, is reflection too high in some lighting conditions and does this result in cameras being 'blinded'?
2	What are suitable image quality standards to ensure vehicle camera systems detect traffic signs?
3	Can vehicle systems recognise a traffic sign earlier/later than human drivers? How long does the system need to take a decision and how rapidly does the system adjust the vehicle behaviour?
4	To what extent can ISA and traffic recognition systems (TSR) detect information signs and respond correctly to these?
5	How effective is an 'ADAS off' traffic sign when approaching a traffic situation outside the ODD (e.g. roadworks)?
6	To what extent must permanent markings and temporary markings differ in reflectivity and contrast to enable correct LKA detection?
7	What would the impact be of detection of advisory speed signs by ADAS? To what extent is this detection on the agenda of OEMs and suppliers?
Digital infrastructure	
1	What could the role of V2V be in situations where driver assistance functions fail entirely or partially?
2	Positioning via GPS/GNSS: what are the developments with respect to signal precision and how can signal availability/reliability be guaranteed.
3	What is the situation regarding communication network availability/reliability in the short and longer term and how will privacy and security aspects of data exchange be guaranteed?

Discussion

Many of the above recommended measures and research questions are of an international nature. It is useful to scale up the scope of the current project to European level, linking to the broader international context (the level at which ADAS developments take place). For effective development of measures it is useful to connect with ongoing international research and initiatives. This will improve investigations into how progress can be made for both individual countries and internationally. At international level more specific guidelines can be derived that also help form a basis for a public-private debate on further developments, implementation and increasing ADAS returns, Connected Driving and vehicles with increasing levels of automation in the longer term.

Lastly, it is important to note that adaptations to roads can never match the pace of new vehicle technological developments. This is due to infrastructure's long-term and expensive replacement cycles. This means that adaptations in infrastructure almost always lag behind automotive developments. However, for the short cyclical management and maintenance process, there are good options to use minor infrastructural measures (as mentioned in this document) to improve ADAS functioning in the short term. Digital infrastructure is better able to match the tempo of automotive developments than physical infrastructure and this also aligns with the development steps that road authorities are currently taking on the route to becoming a 'digital road authority'. It is also important that, among the road authorities, there is good coordination between policy makers and implementers, in terms of the possibilities and limitations of new technological developments and how road authorities can put these into practice.

This study has been commissioned by LVMB

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