D5.4

Signalling for informing conventional vehicles

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Reviewer	Evangelos Mintsis	CRT
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Editor / Main author

Julian Schindler (DLR)

List of contributors

Xiaoyun Zhang (DYN)

Anton Wijbenga (MAP)

Evangelos Mintsis (CRT)

Dominic Lysander Herbig (DLR)

List of reviewers

Evangelos Mintsis (CRT)

Dissemination level:

■ PU Public

☐ RE Restricted to a group specified by the consortium (including the Commission Services)

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Executive Summary

A smooth introduction of automated vehicles in mixed traffic environments requires a mutual understanding between, and cooperation of, the different entities – being automated, connected or simply legacy vehicles. This is especially true when looking at transition areas, where automated vehicles reach their limits and transitions of control happen frequently, leading to new impacts on traffic efficiency and safety.

As shown in D4.2 [1], it is important to address this impact by providing infrastructure advice to automated vehicles. In addition, to achieve a mutual understanding, it is not less important to also inform unequipped vehicles about the issues which are coming up.

This deliverable identifies communication requirements to legacy vehicles, esp. by giving information about reasons of appearing situations, consequences and measures for avoiding negative impacts. Several existing technologies are introduced and their effectiveness in terms of the communication requirements is analysed.

On this basis, the TransAID approach is defined. Here, a mixture of Variable Message Signs (VMS), static signage and an external HMI of CAVs is in focus. To also bridge to a more individual advice, also a web-service approach using mobile devices in the vehicles is included and presented in this deliverable.

All approaches in this deliverable need to be treated as prototypes, as neither the HMI has been tested nor any international study has been performed yet. Nevertheless, it is very important to start this discussion now, as it is of key societal interest to avoid negative impacts when automated vehicles enter the road.

1 Introduction

1.1 About TransAID

The introduction of Automated Vehicles (AVs) is expected to improve traffic safety, reduce fuel consumption and improve traffic efficiency. To do so, automatization of perception and control tasks is employed with the aim of outperforming the capabilities of human drivers. The efforts of the automotive industry are focused on preparing future AVs to support an increasing number of road conditions and traffic situations. However, there will be situations where the automated systems will reach their functional limits and will not be able to handle specific traffic situations on their own [2]. In these situations, a Transition of Control (ToC) to manual driving will be required. The duration of ToC will be influenced by the time required by the driver to recover full situation awareness and safely take over control of the vehicle. This time increases in higher automation levels, where drivers are allowed to perform non-driving related secondary tasks. If the driver is not able to take over control of the car, the automated vehicle will perform a so-called Minimum Risk Manoeuvre (MRM) to bring the vehicle into a safe spot (e.g. decelerating to full stop, or change lane to occupy a safe spot [3]). There will be areas and situations on the roads where high automation can be granted, and others where it will not be allowed or feasible due to system failures, highly complex traffic situations, human factors and possibly other reasons. At these areas, many AVs will have to perform ToCs. We refer to these areas as "Transition Areas" (TAs).

TransAID develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of cooperative and automated vehicles (CAVs), AVs of different SAE (Society of Automotive Engineers) levels, cooperative vehicles (CVs) able to communicate via vehicle-to-anything (V2X), and legacy vehicles (LVs), especially at TAs. A hierarchical and centralized approach is adopted, where control actions are implemented at different layers including Traffic Management Centres (TMC), roadside infrastructure, and vehicles. Following this approach, in the TransAID project, different services have been defined addressing specific complex traffic situations at TAs. The road infrastructure supports the coordination of manoeuvres of vehicles by providing advices, notifications or information to vehicles in order to increase the overall traffic safety and efficiency.

To validate the effectiveness of the traffic management measures developed in the TransAID project simulations taking into account traffic safety and efficiency metrics will be performed. For the simulations to be as reliable as possible, the most relevant microscopic traffic models for mixed traffic behaviour and interactions with Automated Driving (AD) cars are developed [4]. Also, communication protocols for the cooperation between CAVs, CVs, and Road Side Units (RSUs) are implemented, modelled and included. Based on the results of these simulations, the most promising solutions are then implemented as real-world prototypes and demonstrated in closed and controlled environments as proof of concepts for real world's technical feasibility.

1.2 The TransAID iterative approach

The hierarchical and centralized approach of the TransAID project is applied over two iterations, each taking half of the project's total duration. During the first iteration, the focus is on studying aspects of ToCs and TAs through basic scenarios. This implies that realistic models for AD and communication protocols need to be developed and/or adopted to cover the requirements of these simulation scenarios. Using basic scenarios, it is possible to run initial simulations and focus in detail on the relatively new aspects of ToCs, TAs and measures mitigating negative effects of ToCs. The goal of the first iteration is hence to gain experience with all aspects relevant to TAs and mitigating measures. In the second iteration, the achieved experience is used to improve/extend the traffic management measures while at the same time increasing the complexity of the investigated scenarios (e.g. including more challenging scenarios not considered in the first iteration, or combining multiple scenarios in the same evaluation)..

1.3 Purpose of this document

TransAID's major goal is the development and assessment of traffic management measures helping automated vehicles to overcome situations where automation functionality is reaching its limits. Therefore, CAVs are the main target for the TransAID measures. By using the same ITS-G5 protocols, also CVs can be reached with the same measures. For this, it is matter of the Human Machine Interface (HMI) in those vehicles to make the measures work. Because HMI is not a topic in TransAID, it is not investigated in detail, but assumed that the measures will also work for this class of vehicles. On the other hand, simulations have already proven that ToCs have negative effects on whole traffic systems, including all types of vehicles. In order to cope with this, also other vehicles, LVs and AVs, need to be taken into account when developing management measures. In the near future, CAVs will be the minority on the roads. CVs are currently entering the market, but their number will also be low compared to other vehicle classes. Therefore, a broad number of LVs is mixed with some AVs acting on different, possibly lower, levels of automation. In TransAID, the possibility to reach those vehicles with the developed traffic management measures is discussed.

How can infrastructure inform non-cooperative AVs about upcoming threats?

How can infrastructure support LVs to cope with upcoming situations, which are challenging for automated vehicles and therefore possibly also challenging for LVs?

How can drivers of LVs understand that a CAV/AV is currently having issues dealing with the upcoming situation?

This document is trying to answer these questions besides others. The investigations done so far in the project are summarized.

1.4 Structure of this document

After the introductory section, this document discusses about the information that needs to be shared among infrastructure and vehicles of all classes in Chapter 2. Based on the defined TransAID scenarios [5], it is investigated which information given to the CAVs/CVs also needs to be given to LVs/AVs, and which information is needed on top of that so that those vehicles understand CAV movement and behaviour.

Chapter 3 is showing a non-exhaustive list of existing technologies which possibly could be used to share this information with LVs/AVs. It is discussed how useful this technology could be for the intended measures.

Chapter 4 focusses on the TransAID approach: namely, which measure has been taken for which purpose and how this applies to the TransAID scenarios, esp. in WP7 feasibility assessments.

Chapter 5 concludes this document.

1.5 Glossary

Abbreviation/Term	**Definition**
3G	Third generation standard of mobile communication
4G	Fourth generation standard of mobile communication
AD	Automated Driving
ALERT-C	Advice and problem Location for European Road Traffic, Version C
ALINEA	Asservissement Linéaire d'Entree Autoroutière
APTS	Advanced Public Transportation System
ATIS	Advanced Traveller Information System
ATMS	Advanced Traffic Management System
AV	Automated Vehicles
AVCS	Advanced Vehicle Control System
C2C-CC	Car-2-Car Communication Consortium
CAM	Cooperative Awareness Message
CAV	Cooperative and Automated Vehicle
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
CV	Cooperative Vehicle
DAB	Digital Audio Broadcast
DATEX II	DATa EXchange standard, second generation
DENM	Decentralised Environmental Notification Message
dHMI	Dynamic Human Machine Interface
DX.X	Deliverable X.X
EC	European Commission
eHMI	External Human Machine Interface
ETSI	European Telecommunications Standards Institute

FM	Frequency Modulation
GLOSA	Green Light Optimal Speed Advisory
GPS	Global Positioning System
GPSD	GPS Daemon
HERO	HEuristic Ramp metering coOrdinatio
HMI	Human Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport System
ITS-G5	Access technology to be used in frequency bands dedicated for European ITS
LDM	Local Dynamic Map
LED	Light Emitting Diode
LV	Legacy Vehicle
MAP	Map message (ITS-G5 message)
MAVEN	Managing Automated Vehicles Enhances Network (H2020 project)
MCM	Manoeuvre Coordination Message
MRM	Minimum Risk Manoeuvre
MTM	Motorway Traffic Management
OBU	On-Board Unit
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OLR	OpenLR Location Referencing
OpenLR	Open Location Referencing
PND	Personal Navigation Device
RDS	Radio Data Service
RDS-TMC	Radio Data Service Traffic Message Channel

RSI	Road Side Infrastructure
RSU	Road Side Unit
RTM	Radio Traffic Message
RWS	Rijkswaterstaat (here: as Ramp metering strategy)
SAE	Society of Automotive Engineers
SAPS	System Activated Plan Selection
SD	Standard Deviation
SMS	Short Message Service
SVG	Scalable Vector Graphics
TA	Transition Area
TAS	Travel Advisory Systems
TEC	Traffic Event Compact
TMC	Traffic Management Centre
ToC	Transition of Control
ToR	Take-over Request
TPEG2	Transport Protocol Expert Group generation 2
TransAID	Transition Areas for Infrastructure-Assisted Driving
UI	User Interface
UML	Unified Modelling Language
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
VMS	Variable Message Sign
VR	Virtual Reality
VRU	Vulnerable Road User
WGS84	World Geodetic System 1984

WiFi	Wireless Fidelity
WP	Work Package
XML	eXtensible Markup Language

2 Entities, communication and shared information

Following the Sender/Receiver model of Shannon and Weaver [6], communication consists of the following components and entities: sender, message, transmission, noise, channel, reception and receiver. As this deliverable deals with communication to unequipped vehicles, the receiver can be mapped to

- A driver of an unequipped vehicle (LV, AV). It is assumed that all CVs and CAVs could get updated to copy with the TransAID measures. Therefore, these vehicle classes and their drivers are not part this group,
- A communication device (e.g. Radio, or cellular communication device), since the forwarding of the information to the human is a matter of the Human Machine Interface (HMI), which is not part of this work and acts as separate downstream communication
- The vehicle automation function of an AV (of all levels), again without focusing on the forwarding of the message to the human driver or passenger due to the reason mentioned before.

Limited by those receivers, also the possible channels are limited. The following channels could be useful:

- Any sort of electronic communication, with different ranges, e.g. to reach FM radios, cellular communication devices (4G, 5G, …), etc. ITS-G5 communication is not part of this, as this communication technique is in the focus of TransAID and therefore all CVs/CAVs could be informed about TransAID measures through this channel.
- Any visual communication channel. This could be infrastructure-based, e.g. a Variable Message Sign (VMS), traffic light, etc., or vehicle-based, e.g. indicator lights, any external Human Machine Interface (eHMI) or movement-based dynamic Human Machine Interface (dHMI) of future CAVs, or any mixture.
- Possibly, also any acoustic/auditory communication channel could be used, although this has – due to the noise at the receivers – several weaknesses, e.g. requiring high volume. Therefore, this communication channel is not used in TransAID. Nevertheless, it could become of interest when also looking at Vulnerable Road Users (VRUs), which is not in scope of this deliverable.

Furthermore, being the central part of this deliverable, the message itself is of high interest and needs to be further detailed. In TransAID, areas on the road where automated driving is impossible are of major interest, linked to effects of automated vehicles not able to pass these areas. As this deliverable focusses also on countermeasures against negative impacts of those areas, the message should consist of the following information:

- Situational information about the reason **(R)**: This is information about the reason for a situation on the roads. This could be information about upcoming roadworks, closed lanes, broken-down vehicles, etc. This information includes the place and the time of the reason, as exact as possible.
- Situational information about consequences **(C)**: This is information about the consequences of the before mentioned situations, like information about traffic jams, crowded streets, people on the road, etc.
- Measure information **(M)**: To avoid more negative consequences, measures or countermeasures are important. Entities/Receivers need to be informed about the measures, like the creation of corridors for emergency vehicles, the use of detours, lane change information, speed limits, etc. Measures can cover large areas, or focus on

local areas only. Furthermore, measures can have different origins: Some measures are defined by law (e.g. creation of corridors for emergency vehicles), some are provided by road authorities (e.g. speed limits), some are provided by other authorities (e.g. police), etc. Furthermore, measures can be legally binding (e.g. speed limits) or just be meant as advice (e.g. detours).

Each message can be sent by various entities, depending on the chosen communication channel and the availability of information. As knowledge about ToC and about Operational Driving Domains (ODDs) of AVs is required to create messages, the following types of senders are of major interest:

- (C)AVs and CVs could detect issues related to automated driving, and use an external HMI or electronic communication technology to warn other vehicles directly or to forward the warning to vehicles further away.
- Road Side Infrastructure (RSI) is able to locally detect issues related to automated driving, e.g. with cameras. Furthermore, such infrastructure may also provide measures to solve such situations and to avoid negative impacts. Depending on the availability of an uplink of the RSI to e.g. backend services, the range of the measures can be limited to the local vicinity.
- Any backend based service can be used to collect information of various vehicles and their possible issues. The information for this may be collected by e.g. smartphone apps used by passengers or drivers, by in-vehicle services automatically detecting ToCs and their reasons, or by RSI as explained before.

In order to ameliorate the negative effects of TAs as much as possible, it is important that the sent information is reaching the intended receiver(s), and that it is well understood their and leading to the desired change in behaviour. Therefore, it is mandatory that noise is minimized and that the information is presented in a standardized way.

The following subchapters are taking a closer look at the TransAID services and the related scenarios that are and have been under closer investigation in the first and second project iteration, investigating the possibilities and necessities for informing unequipped vehicles as stated before. For each scenario, the information about the reason, the consequences, and the proposed measure (R, C, M) are shown. Please note that the service classification was done to distinguish between the measures for CAVs. Since this deliverable discusses the measures for unequipped vehicles, the scenarios may require other services for solving the situation. In this light, measures of one service can also occur at scenarios originally linked to other services. It is also possible that some measures appear at more than one service.

2.1 Service 1: Prevent ToC/MRM by providing vehicle path information

Service 1 deals in general with the provision of paths information to CAVs, so that there is no need for ToCs and MRMs. The related scenarios show situations where drivers of vehicles know what to do, although the behaviour may interfere with legal issues.

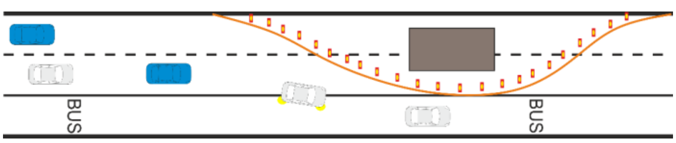

Figure 1: Scenario 1.1 layout

Scenario 1.1 (see Figure 1), investigated during the first project iteration, shows a roadworks scenario, where the only option to continue driving is by using the bus lane, which is not allowed when strictly following the rules. Such scenarios may be enriched by signage telling the drivers that passing the obstacle on the right is allowed, but still, (C)AVs may not understand the sign or may not be able to interpret it correctly when comparing to the local dynamic map available in the vehicle. Therefore, the following reason needs to be communicated:

1.1_R1 Information about the blockage of the free lanes and the availability of a bus lane for passing the incident

This information is accompanied by two different types of consequences, investigated in D3.1 [7] and D4.2 [1]:

1.1_C1 Traffic jams due to the bottleneck on the road

1.1_C2 Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road.

The following measures to unequipped vehicles may be applied to minimize the consequences:

1.1_M1 Clear allowance to use the bus lane in the vicinity of the work zone, possibly even earlier so that drivers have time to get prepared

1.1_M2 (Early) reduction of the speed limit to minimize effects of strong braking

1.1_M3 Keeping larger distances between the cars to allow smoother lane changes and to prevent shockwaves

1.1_M4 Forcing zipper lane changes in front of the work zone

1.1_M5 Advice vehicles to act with special caution and cooperatively

1.1_M6 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

In the second project iteration, Scenario 1.3 has been investigated (see Figure 2). In the shown situation, there is a queue on the off-ramp of a highway, which is blocked by a traffic jam due to an incident further downstream. An AV that wants to use this off-ramp can not do so and needs to calculate and execute a detour. When a detour is not available, it may decide to perform a ToC, as it is not able to solve the situation. In case of MRM, the AV may stop directly on the highway, being the worst solution for all, as this is a safety risk and furthermore leading to a high chance of a traffic jam. The solution may be to act like the LVs and use the emergency lane prior to the exit for queuing up. In most European countries, this behaviour is illegal and will therefore not be chosen by the vehicle automation.

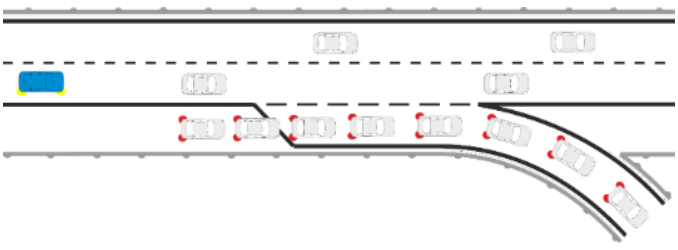

Figure 2: Scenario 1.3 layout

The communication of the following information to unequipped vehicles will be needed, starting with the reason:

1.3_R1 Information about the queue on the off-ramp and the availability of an emergency lane

The following consequences may arise:

1.3_C1 Traffic jams due to strong braking of vehicles

1.3_C2 Sudden lane changes to the emergency lane, when drivers understand that the off-ramp is blocked

1.3_C3 Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road

To solve the situation, the following measures to unequipped vehicles could be applied:

1.3_M1 Clear allowance to use the emergency lane in the vicinity of the off-ramp, possibly even earlier so that drivers have time to get prepared

1.3_M2 (Early) reduction of the speed limit to minimize effects of strong braking. Possibly, there are different speed limits per lane, having the lowest speed at the lane closest to the off-ramp

1.3_M3 Keeping larger distances between the vehicles to prevent shockwaves

1.3_M4 Advice vehicles to act with special caution and cooperatively

1.3_M5 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

In general, it is remarkable that consequences and measures are nearly similar at both Service 1 scenarios investigated. Nevertheless, other scenarios where Service 1 would apply may have different consequences and measures. As TransAID is not investigating all possibilities, only the mentioned consequences and measures are detailed in the following chapters.

2.2 Service 2: Prevent ToC/MRM by providing speed, headway and/or lane advice

In Service 2, again one highway and one urban scenario have been investigated. At first, cooperative highway merging has been investigated in Scenario 2.1 (see Figure 3). Here, a different number of vehicles are driving on the highway and CAVs on the ramp are informed about necessary speed to reach a gap on the highway. If this gap is not available due to dense traffic on the highway, an early ToC advice is given to the CAV, so that drivers have a chance to accomplish merging on their own – assuming that automation functions will take more conservative distances and headways and therefore not be able to perform the merging. Furthermore, accelerations may be limited, so that the vehicles may not be able to reach a gap while driving in automated mode. In this situation, the human driver may be unable to cope with the additional workload when a ToC is performed late.

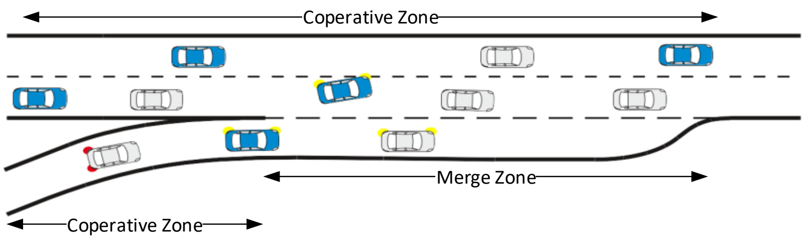

Figure 3: Scenario 2.1 layout

The measure may also be accompanied by speed, headway and lane advice for the vehicles on the highway, in order to open up gaps. For CAVs and CVs, the cooperative speed advice to paired vehicles for gap creation is in focus. Furthermore, cooperative lane changes could be added to this scenario, in case CAVs meet in the merging zone.

For unequipped vehicles, the situation is also difficult. In the investigations, we focus on the following reason, which needs to be communicated:

2.1_R1 Information about difficult merging situation ahead, on the ramp and on the highway

This can lead to several consequences:

2.1_C1 Strong brakings and accelerations of vehicles

2.1_C2 Close mergings with low distances and headways, leading to dangerous situations

2.1_C3 Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road

The following measures to unequipped vehicles could be applied to reduce the consequences:

2.1_M1 (Early) reduction of the speed limit to minimize effects of strong braking. Possibly, there are different speed limits per lane, having the lowest speed at the lane closest to the on-ramp

2.1_M2 Keeping larger distances between the vehicles to prevent shockwaves and to allow (cooperative) lane changes

2.1_M3 Advice vehicles on the highway’s right lane to act cooperatively, e.g. by changing to the left lane, and with special caution

2.1_M4 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

The second scenario in Service 2, scenario 2.3, is depicted in Figure 4. In this urban scenario, the right turn lane (lane 5 in the figure) is blocked by an incident (of any kind). (C)AVs coming from direction C in the figure, which want to turn right at the intersection, are not able to perform a right turn manoeuvre on the right turn lane due to the incident. For a (C)AV, this scenario poses two difficulties. First, the incident has to be recognized as such. If the vehicles involved in the incident have hazard warning lights switched on, recognition is possible, but if not, the incident may be rated as traffic jam. Therefore, the (C)AV would behave totally different, as a traffic jam would normally not result in any ToC action and the (C)AV would simply line up, possibly waiting forever in this case. Second, if the incident has been correctly recognized, the (C)AV has several options. It could perform a ToC, or change lane to the through-lane (lane 6 in the figure). On that lane, it could simply reroute and drive straight, or it could still try to perform the right turn (as a human driver would possibly do), which may result in a sharp turning possibly not allowed or in another sudden ToC when the vehicle discovers while passing the incident that turning is impossible.

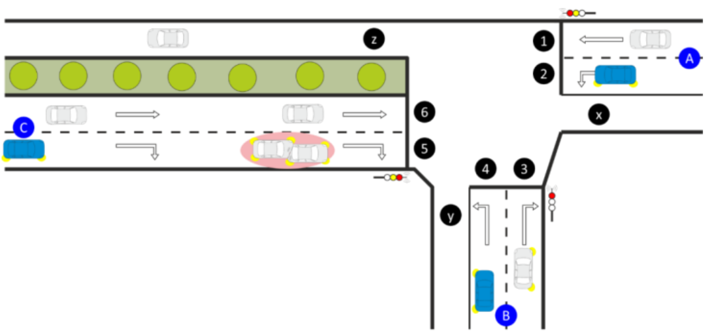

Figure 4: Scenario 2.3 layout

Also unequipped vehicles are affected by this situation, and therefore need to be informed. The following reason should be included:

2.3_R1 Information about incident on the right turn lane

In addition, also the consequences are important:

2.3_C1 Traffic jams due to the bottleneck on the road

2.3_C2 Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road, either in front of the incident or on the through lane when passing

The following measures to unequipped vehicles may be used to reduce the negative impacts:

2.3_M1 Clear allowance to use the through lane also for right turning

2.3_M2 (Early) reduction of the speed limit to minimize effects of strong braking

2.3_M3 Keeping larger distances between the vehicles to prevent shockwaves and to allow (cooperative) lane changes

2.3_M4 Forcing zipper lane changes in front of the incident

2.3_M5 Advice vehicles to act with special caution and cooperatively

2.3_M6 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

2.3 Service 3: Prevent ToC/MRM by traffic separation

This service has been explicitly investigated in the first project iteration. Therefore, there is only one scenario which is discussed here, scenario 3.1, shown in Figure 5. In this scenario, two highway roads are joining. Consequently, traffic on the inner lanes of the joined highway part will show several lane changes. When traffic density is high, lane changes become more complex, esp. when the number of lanes is high. It is assumed that (C)AVs will have problems in performing the lane changes due to the more conservative driving of those vehicles and that some of them need to perform a ToC, or in consequence even a MRM.

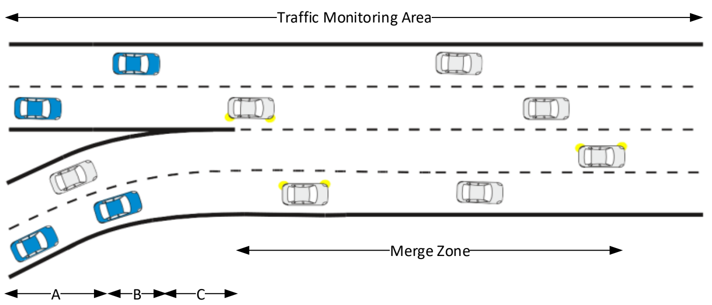

Figure 5: Scenario 3.1 layout (A is the Traffic Separation Area, B the Transition Area and C the MRM Zone).

As countermeasure, the scenario investigated traffic separation. Automated vehicles are advised to take the outer lanes to avoid too many complex lane changes in the inner area of the road.

This of course also affects the unequipped vehicles, as traffic separation is only useful when more vehicles know what to do and have a chance to take part. Therefore, the following topics need to be communicated to the unequipped vehicles:

3.1_R1 Information about joined highways

This results in the following consequences:

3.1_C1 High number of lane changes, possibly performed with low headways

3.1_C2 Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road, either in front of the incident or on the through lane when passing

Regarding the measures to unequipped vehicles, the following are of interest:

3.1_M1 Traffic separation: Automated vehicles use outer lanes

3.1_M2 (Early) reduction of the speed limit to minimize effects of strong braking and close lane changes, esp. on the inner lanes

3.1_M3 Keeping larger distances between the vehicles to prevent shockwaves and to allow (cooperative) lane changes, esp. on the inner lanes

3.1_M4 Advice vehicles to act with special caution and cooperatively

3.1_M5 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

Here, it needs to be mentioned that *3.1_R1*, *3.1_C1*, *3.1_M1* and *3.1_M2* are already standard approaches in some countries and do not need any dynamic signage on the road, since the situation does not change over time and is very static. Therefore, this scenario is treated differently in the following, focusing on the more dynamic aspects of the situation, e.g. measures related to the density of vehicles on the road.

2.4 Service 4: Manage by guidance to safe spot

This service has been investigated in two scenarios. The first is scenario 4.2, shown in Figure 6, which is performed in a highway or highway-like setup as well as an urban setup. The second is an urban scenario only, closer investigated in chapter 2.6, as it is a combination with service 5.

In scenario 4.2, one lane of a two-lane road is blocked by roadworks. Vehicles need to perform a zipper merging before this. Since some (C)AVs have problems in passing roadworks, due to e.g. narrow roads, changed lane markings, dirt on the road etc., it is likely that those vehicles issue a ToC when getting near to the roadworks area. As consequence, some of the ToCs will fail, and MRMs are executed. In worst case, the MRM is performed on the free lane, and the vehicle comes to a stop just in that location where there is only one lane available, leading to the maximum disturbance of traffic. In the scenario, the MRM is managed, so that the CAVs are guided to a more safe place on the left lane, just in front of the roadworks when they need to stop, which is called “safe spot”. This avoids that vehicles executing a MRM are blocking the road.

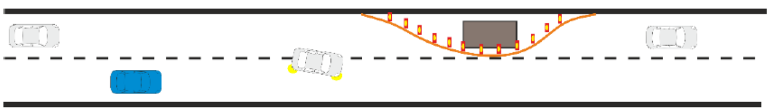

Figure 6: Scenario 4.2 layout

To cope with this and to reduce negative impacts, the following aspects need to be communicated to unequipped vehicles:

4.2_R1 Information about the blockage of the left lane

According to the scenario, the following consequences will be seen:

4.2_C1 Traffic jams due to the bottleneck on the road

4.2_C2 Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road

The following measures to unequipped vehicles can be applied:

4.2_M1 Creation of safe spots for CAVs, clearly marked, so that they are not treated as parking spaces for other vehicles.

4.2_M2 (Early) reduction of the speed limit to minimize effects of strong braking

4.2_M3 Keeping larger distances between the cars to allow smoother lane changes and to prevent shockwaves

4.2_M4 Forcing zipper lane changes in front of the work zone and the safe spots

4.2_M5 Advice vehicles to act with special caution and cooperatively

4.2_M6 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

2.5 Service 5: Distribute ToC/MRM by scheduling ToCs

This service is also investigated in two scenarios dealing with zones where automated driving is impossible (for any reason), and where the performance of ToCs is distributed along the road to minimize the negative effects of several ToCs and related MRMs at the same spot on the road. The first one, scenario 5.1 shown in Figure 7 is discussing this topic independently of other measures, while the second one is a combination with service 4, and therefore closer discussed in chapter 2.6.

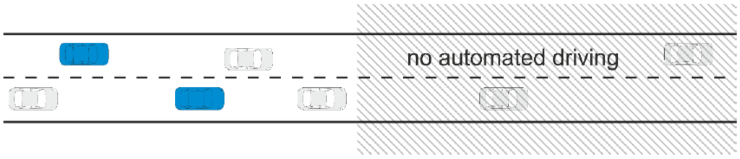

Figure 7: Scenario 5.1 layout

LVs and CVs are not affected by no-AD-zones directly, but only by the consequences of several ToCs and MRMs taking place on the road. Therefore, informing them may be a required step to reduce negative impacts. (C)AVs are affected, so also notifying them (and their drivers) is very useful. While CAVs and CVs can be informed using electronic communication techniques, this is not possible for AVs and LVs.

The following information needs to be communicated to the unequipped vehicles and their drivers:

5.1_R1 Information about the no-AD-zone, and possibly also about the reason (e.g. missing lane markings, fog, work zones, etc.)

The following consequences need to be communicated:

5.1_C1 Traffic jams due to stopping (C)AVs on the road

5.1_C2 ToCs of (C)AVs that are not able to enter the no-AD-zone in automation mode, possibly leading to sudden braking manoeuvres and stopped vehicles on the road

To reduce the negative impacts, the following measures could be applied to unequipped vehicles:

5.1_M1 (Early) reduction of the speed limit to minimize effects of strong braking

5.1_M2 Keeping larger distances between the cars to allow smoother lane changes (e.g. when avoiding braking or stopped (C)AVs) and to prevent shockwaves

5.1_M3 Advice vehicles to act with special caution and cooperatively

5.1_M4 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

2.6 Combined Services 4 and 5: Manage by guidance to safe spot and distribute ToC/MRM by scheduling ToCs

In TransAID's second project iteration, services are combined to investigate the effects of combinations, too. Special interest was put on the combination of the urban variant of scenario 4.2, which is scenario 4.1 and the distribution of ToCs (and in consequence also of MRMs) as discussed in service 5. The resulting scenario 4.1-5 is shown in Figure 8. In this scenario, parking spaces are available parallel to an urban road. At some spot on the road, a no-AD-zone is starting, and therefore (C)AVs need to perform ToCs, and as consequence will sometimes also perform MRMs. In the scenario, ToCs are distributed in space, so that possible MRMs are using available parking spaces as "safe spots". To avoid negative impacts of parking manoeuvres, an available parking space needs to have a larger size, so that forward parking is possible, best even without strong braking manoeuvres on the road. Parking spaces can possibly be reserved for safe spots, or a camera is detecting the availability of spots without prior reservation. Of course, there is a trade-off between available parking spaces and the number of vehicles, which can use the parking spaces as safe spots.

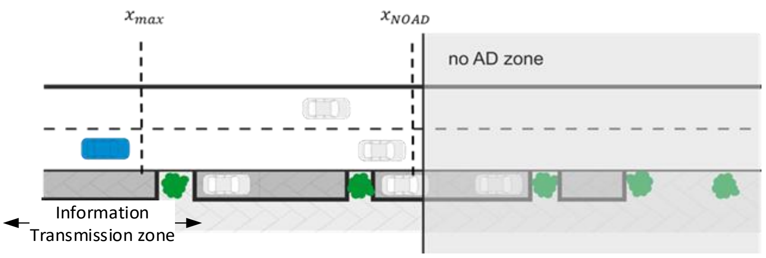

Figure 8: Scenario 4.1-5 layout

For unequipped vehicles, the following information needs to be communicated:

4.1-5_R1 Information about the no-AD-zone, and possibly also about the reason (e.g. missing lane markings, fog, work zones, etc.)

Depending on the number of vehicles adapting to the measure, the number of available parking spaces and the number of CAVs in the area, the following consequences can occur:

4.1-5_C1 Traffic jams due to stopping (C)AVs on the road

4.1-5_C2 ToCs of (C)AVs that are not able to enter the no-AD-zone in automation mode, possibly leading to sudden braking manoeuvres and stopped vehicles on the road

The following measures may be applied to unequipped vehicles:

4.1-5_M1 Creation of reserved safe spots for CAVs.

4.1-5_M2 (Early) reduction of the speed limit to minimize effects of strong braking

4.1-5_M3 Keeping larger distances between the cars to allow smoother lane changes (e.g. when avoiding braking or stopped (C)AVs) and to prevent shockwaves

4.1-5_M4 Advice vehicles to act with special caution and cooperatively

4.1-5_M5 (C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles

2.7 Summary of messages to unequipped vehicles

As said, the same information for unequipped vehicles can occur in several scenarios. This section is therefore summarizing the before mentioned message contents and generalizes them, in preparation of the following chapters.

First, the situational information about the reason **(R)** can be harmonized and generalized. Nevertheless, esp. the reason normally contains very specific information and should not be generalized too much.

Table 1: Summary of the situational information about the reason (R)

ID	Based on	Information	Location precision
R1	*1.1_R1, 1.3_R1, 2.3_R1, 4.2_R1*	Information about blockages, obstacles and incidents on the lanes	Lane specific with a longitudinal precision of a few meters
R2	*1.1_R1, 1.3_R1, 2.3_R1, 4.2_R1*	Information about free areas and available lanes, and bottlenecks	Lane specific with a longitudinal precision of a few meters
R3	*1.1_R1, 1.3_R1, 2.3_R1, 3.1_R1, 4.2_R1, 5.1_R1, 4.1-5_R1*	Information about possible vehicle automation restrictions and limitations	Lane specific with a longitudinal precision of a few meters
R4	*1.1_R1, 1.3_R1, 2.3_R1, 3.1_R1, 4.2_R1, 5.1_R1, 4.1-5_R1*	Information about areas which need to be handled with attention	Lane specific with a longitudinal precision of a few meters

As said, the reason information should also always contain the place and the time.

Also the information about the consequences can be harmonized and generalized, even better than reasons, since consequences are often the same:

Table 2: Summary of the information about the consequences (C)

ID	Based on	Information	Location precision
C1	*1.1_C1, 1.3_C1, 2.3_C1, 4.2_C1, 5.1_C1, 4.1-5_C1*	Information about upcoming traffic jams	Lane specific; longitudinally, the road segment is enough, although a higher precision would be beneficial
C2	*1.1_C2, 1.3_C3, 2.1_C1, 2.1_C2,*	Information about possible sudden	The road segment is enough, although a higher

	2.1_C3, 2.3_C2, 3.1_C2, 4.2_C2, 5.1_C2, 4.1-5_C2	strong braking manoeuvres	precision would be beneficial
C3	*1.3_C2, 2.1_C2, 3.1_C1*	Information about possible sudden sharp lane changes	The road segment is enough, although a higher precision would be beneficial
C4	*1.1_C2, 1.3_C3, 2.1_C3, 2.3_C2, 3.1_C2, 4.2_C2, 5.1_C2, 4.1-5_C2*	Information about ToCs and related MRMs of (C)AVs	The road segment is enough, although a higher precision (up to the exact positions of the vehicles) would be beneficial

Finally, and most importantly for this deliverable, the measures can be harmonized and generalized. The following list summarizes them:

Table 3: Summary of the measures for unequipped vehicles (M)

ID	Based on	Information	Location precision
M1	*1.1_M1, 1.3_M1, 2.3_M1*	Clear allowance to use part of the road for another purpose than intended (e.g. emergency lane for driving, through-lane for turning, etc.), possibly even early so that drivers have time to get prepared	Lane specific with a longitudinal precision of a few meters
M2	*3.1_M1*	Traffic separation	Lane specific; longitudinally, the road segment is enough, although a higher precision would be beneficial
M3	*1.1_M1, 1.3_M1, 2.3_M1, 3.1_M1*	Advice to use a specific lane	Lane specific with a longitudinal precision of a few meters
M4	*4.2_M1, 4.1-5_M1*	Availability of safe spots for CAVs, clearly marked, so that they are not used as e.g. parking spaces for other vehicles	Exact positions with a precision of max. 2 meters
M5	*1.1_M2, 1.3_M2, 2.1_M1, 2.3_M2, 3.1_M2, 4.2_M2, 5.1_M1, 4.1-5_M2*	(Early) reduction of the speed limit to minimize effects of strong braking, possibly different for each lane	Lane specific; longitudinally, the road segment is enough, although a higher precision would be beneficial

M6	*1.1_M3, 1.3_M3, 2.1_M2, 2.3_M3, 3.1_M3, 4.2_M3, 5.1_M2, 4.1-5_M3*	Keeping larger distances between vehicles to allow smoother/cooperative lane changes and to prevent shockwaves	Lane specific; longitudinally, the road segment is enough, although a higher precision would be beneficial
M7	*1.1_M4, 2.3_M4, 4.2_M4*	Forcing zipper lane changes	Lane specific; longitudinally, the road segment is enough, although a higher precision would be beneficial
M8	*1.1_M5, 1.3_M4, 2.1_M3, 2.3_M5, 3.1_M4, 4.2_M5, 5.1_M3, 4.1-5_M4*	Advice vehicles to act with special caution and cooperatively	The road segment is enough, although a higher precision would be beneficial
M9	*1.1_M6, 1.3_M5, 2.1_M4, 2.3_M6, 3.1_M5, 4.2_M6, 5.1_M4, 4.1-5_M5*	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles (possibly including current manoeuvre, time to ToC, time to MRM, etc.)	Vehicle centric

3 Existing services

This chapter summarizes existing technologies for informing unequipped vehicles (without claiming to be exhaustive). As mentioned in the previous chapter, the dynamic information is of key interest here, including broken down vehicles, traffic jams, temporary detours, existing work zones etc. This chapter is divided into three sub sections. The first one deals with information sent to vehicles by centralized services, therefore it contains mostly broadcasted information. The second deals with information provided by local infrastructure. By focusing on dynamic information, no static road signage is part of the description. Third, information provided by vehicles is described.

All required communication aspects (R1-R4, C1-C4, M1-M9) introduced in the above chapter are checked for each available service in tables. The following symbols are used for this purpose:


The service is already capable of providing the required communication aspect with the required precision.


The service is not yet capable of providing the required communication aspect, but is flexible enough to allow its implementation with the required precision.


The service is not capable of providing the required communication aspect or the required precision.

3.1 Information provided by in-car centralized services

In contrast to C(A)Vs, AVs and LVs do not get V2X information. Besides roadside equipment, centralized services are another way to provide information to drivers of those types of vehicles. Centralized services provide traffic information via some communication channel and presentation device to the driver. Below there are five subsections that cover spoken Radio traffic service, Radio Data Service-Traffic Message Channel (RDS-TMC), Transport Protocol Expert Group's generation 2 standard (TPEG2), second generation DATa EXchange standard (DATEX-II) and third-party services.

3.1.1 Radio Traffic Service

At least in Germany, it is common practice that traffic information is provided in a spoken way, every 30 minutes, on nearly all radio stations. Started in the 1970s [8] [9], the service is based on FM stations. The given information is clustered, so that it easier to understand if there is an incident on the used route. The following structure is used:

1. Danger zones on highways/Autobahn
2. Danger zones on national roads
3. Danger zones on regional roads
4. Danger zones in city areas
5. Traffic jams on highways/Autobahn
6. Traffic jams on national roads
7. Traffic jams on regional roads

8. Traffic jams in city areas

In each cluster, the information is sorted by the number of the road in ascending order. As FM radio stations have a limited range, only those incidents in the range of the station are provided. When heavy traffic prevails on the network level, e.g. when vacations are starting or ending or on national bank holidays, traffic jams are only reported when they are above a defined size, to avoid a long lasting service duration. The size can be chosen by the radio stations and will be mentioned in the beginning of the service broadcast.

Normally, though officially not being part of the service, additional information like missing persons' reports or current positions of speed cameras are broadcasted before or after the service.

As the service is spoken, several details can be included, like precise lane information or information that the incident is "behind the curve" or "behind the knoll".

For TransAID, this means that this channel may be used to provide also some of the required information, as shown in Table 4. Some of the information is already present today (R1, R2, R4, C1, M8), some information may be simply added. Only information about safe spots and vehicle-centric information cannot easily be presented in this channel.

Table 4: Coverage of Radio Traffic Services of required information for unequipped vehicles.

R1	✅	R2	✅	R3	⚠️	R4	✅		
C1	✅	C2	⚠️	C3	⚠️	C4	⚠️		
M1	⚠️	M2	⚠️	M3	⚠️	M4	❌	M5	⚠️
		M6	⚠️	M7	⚠️	M8	✅	M9	❌

In general, the most limiting factor of the spoken radio traffic service is the time that it takes to include several additional aspects. As radio stations normally limit the maximum time used for this service, it is very likely that additional parts are not included, or details are limited. In addition, the service requires a lot of driver's attention, as the exact route must be known, as the information is not repeated and, to avoid long service durations, spoken in a fast way.

3.1.2 RDS-TMC

RDS-TMC makes it possible to exchange traffic information via analogue (FM) or digital (DAB, Satellite) radio [10]. Part of the bandwidth of these mediums is used to exchange messages instead of audio information. These messages can be of different types like the radio station ID, audio genre, but also to traffic information. For traffic information there is the Traffic Message Channel (RDS-TMC) field, which is an identifier for the Radio Data System (RDS) to indicate that the data being sent relates to traffic information.

The RDS-TMC information is received by specific devices like built in navigation (i.e. by the OEM) or personal navigation devices (PND) which include an FM or DAB receiver. These devices decode the information to text, map or speech to inform the driver.

The traffic information itself is encoded in ALERT-C which uses a location table for geo-referencing. A large part of the road network is covered by the location table, but not every road. Primarily the inter-urban (i.e. motorway, provincial) roads are included and only limited inner city roads. In Europe, the location table is maintained per country and needs regular updates to reflect changes in road infrastructure. The location table version from the TMC message and the one stored in the receiving device must match to be able to decode the location information.

The precision of each traffic event's location is low compared to that of modern smartphone devices. The user's navigation system only knows, for example, that a crash took place between Exit 3 and Exit 4, northbound on a particular motorway. This limitation requires that traffic events have to be superimposed onto maps by mapping the reported location to the RDS-TMC location table. If the nearest location table point lies at some distance from the exact position of the incident, then the report appears on a section of main road between two junctions instead of at its exact location. It depends therefore on the type of event, whether this location referencing is sufficient or not (e.g. for traffic jams it is, but for incidents it is not ideal).

Together with the location, an event ID is sent. There is a list of up to 2048 event IDs which refer to specific phrases. These refer to the situation communicated such as ‘crash’, or a combination of events like ‘construction causing long delays’. The phrases are used to convey some ‘meaning’ and devices can use translations of the event list to convey the meaning in any language needed. This approach is why RDS-TMC is considered language independent.

Not all of the 2048 entries are used and several hundreds are free to be decided upon. Through the proper channels (i.e. TISA), additions can be suggested so that TransAID concepts are included such as ‘Transition Area’ or ‘no AD zone’. In any case, the information that can be included will mostly be the situational information about the reason, with low location precision performance. Information about the consequences can only be broad, like traffic jams. Same goes for possible counter measures. Detailed information is shown in Table 5. It needs to be explained that even simple information like traffic jams are not marked as solved due to the low location precision, which is below the TransAID requirements.

Table 5: Coverage of RDS-TMC of required information for unequipped vehicles.

R1	⊗	R2	⊗	R3	⊗	R4	⊗		
C1	⚠	C2	⚠	C3	⚠	C4	⚠		
M1	⊗	M2	⚠	M3	⊗	M4	⊗	M5	⚠
		M6	⚠	M7	⚠	M8	⚠	M9	⊗

There are public (free) and private (paid) TMC services depending on the country. Private services are mostly used by specific endpoints such as portable navigation devices (e.g. TomTom, Garmin, etc.) or built in navigation. Private services are either encoded or use specific location tables (see above) which makes it difficult or impossible to use the information for third parties.

Multiple TMC services can exist in parallel, because each one ‘piggybacks’ on the frequency of some radio station. The coverage of the radio station thus determines the maximum area to which traffic information can be disseminated.

Since there are no security aspects included in RDS-TMC, and radio stations can be pirated, it is also possible to broadcast fake TMC messages. Although few examples can be found (see Figure 9), it poses a security risk.

Figure 9: A fake TMC message sent in Belgium about an air raid on part of the A14 [11].

3.1.3 TPEG-2

Traffic Protocols Experts Group (TPEG) can be seen as the successor of RDS-TMC. It was designed to overcome several limitations such as the need of the location tables and limited bandwidth posed by RDS while keeping the strength of a language independent solution [12].

In contrast to RDS-TMC it is not linked to a specific communication technology like FM or DAB, although it was initially designed with DAB in mind. TPEG is a set of data protocols for carrying traffic and travel related information, comprising a range of different applications as well as basic building blocks to manage the transmission of the applications themselves, such as the handling of different messages belonging to a given application, grouping applications into data frames, or the updating and cancellation of messages. Also see Figure 10. TPEG can be carried over different transmission media (bearers), such as DAB or wireless networks (3G, 4G, WiFi).

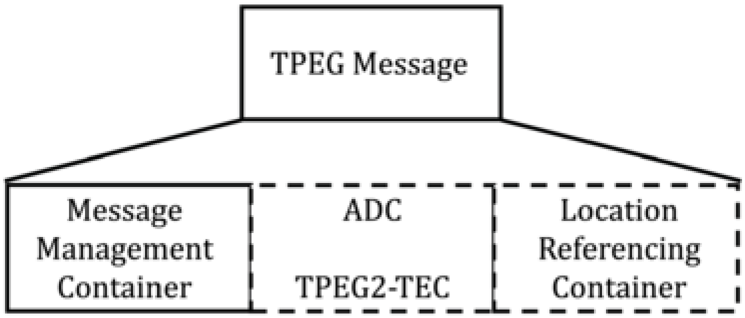

Figure 10: TPEG2 message structure with a TEC container as example

Generation 1 of TPEG provided a binary encoding only and in some cases required a separate specification to map the data to XML encoding. Also, it was found the Road Traffic Message (RTM) application was too broad and/or impractical in the long term. After a revision, TPEG generation 2 (TPEG2) became available. This version uses an UML model to specify the applications and makes it possible to derive both the binary as well as the XML coding.

TPEG applications include, among others, information on road conditions, weather, fuel prices, parking or delays of public transport. For road traffic, the applications Traffic Event Compact (TEC) [13, 14, 15] are the most important.

For TransAID the TEC application is the most relevant. Generally, the Traffic Event Compact application is designed to allow receivers to:

- ensure travel safety for the driver,
- enable the calculation of alternative routes,
- avoid delays (e.g. traffic jams),
- warn the driver of obstructions on route, and
- provide the driver with information on infrastructural problems (e.g. closed petrol stations, non-functioning emergency telephones).

These points already well match the needed situational information about the reason, consequences, and partly even the measures provided in chapter 2. Table 6 gives a more detailed overview. If TransAID specific information is added to the protocol, several parts are possible. Only the information about automation related issues in moving vehicles (M9) cannot easily be addressed by TPEG2.

Table 6: Coverage of TPEG2 of required information for unequipped vehicles.

R1	✓	R2	✓	R3	⚠	R4	✓		
C1	✓	C2	⚠	C3	⚠	C4	⚠		
M1	⚠	M2	⚠	M3	⚠	M4	⚠	M5	✓
		M6	⚠	M7	⚠	M8	⚠	M9	✗

To allow large amounts of information to be delivered and yet not overload the end-users with data of little use to them, the TPEG design philosophy, through explicit coding, is built on the idea of client filtering. This allows end users to choose messages based on any number of criteria, such as type of event, location, mode of transport, direction of travel etc.

TPEG originally uses only WGS84 for location referencing but has recently adapted a slightly modified version of TomTom's OpenLR specification (standard was published in June 2017: TPEG2-OLR [16]. Location references can be annotated with human readable labels (e.g. POI, street name or exit number) to allow text only devices to present an understandable message.

There is no explicit security measure implemented for TPEG2. In theory, it is still vulnerable for fake messages transmitted by untrusted parties. However, no examples of occurrences were found.

For TransAID and automated driving in general, the standards could be extended. It is already used for roadwork, hazard situations (including accidents, dangerous end of queue, narrow lanes, etc.) which likely can be beneficial for LVs and AVs, but also for CV and CAVs. One should keep in mind though that the update frequency is in the order of seconds, although that is better than the order of minutes for RDS-TMC.

3.1.4 DATEX II

Another well-known standard is DATEX II. It was originally developed to exchange traffic management information between traffic centres, but it was quickly adopted by service providers as well. Just as TPEG2, it is not bound to a specific communication technology and is commonly exchanged via the internet over various connections. Another commonality is that DATEX II is also modelled using UML and encoded in a flexible XML structure.

It contains several publication possibilities to exchange information about, for example, real time travel times, traffic flows and speeds, road works, incidents, dangerous situations, etc.

For location referencing it offers several possibilities. One can use ALERT-C encoding [17], similar to RDS-TMC, in which case the receiver would need the right location table version. However, it is also possible to use WGS84 coordinates to specify a point, line or region. In addition, one can choose to use OpenLR geo-referencing.

Given the flexibility it should be very well possible to extend the standard where needed to meet information requirements from TransAID. However, the standard is not directly linked to a broadcast technology and, as stated, is exchanged via the internet. From that perspective, DATEX II would be a trivial choice and any other format, like those defined for V2X message sets, could be used as well.

Table 7: Coverage of DATEX II of required information for unequipped vehicles.

R1	✅	R2	✅	R3	⚠️	R4	✅		
C1	✅	C2	⚠️	C3	⚠️	C4	⚠️		
M1	⚠️	M2	⚠️	M3	⚠️	M4	⚠️	M5	✅
		M6	⚠️	M7	⚠️	M8	⚠️	M9	❌

3.1.5 Third party services

Besides RDS-TMC and TPEG, which are used for both public and private services, several proprietary and/or commercial solutions exist. Well-known examples are, Google Maps, Inrix, Waze and TomTom live. Some of these, like TomTom and Inrix also use RDS-TMC, TPEG and DATEX II to encode and/or exchange information in addition to their own solutions.

Given the fact that these are commercial solutions, available information is limited. In short, they use either an FM, DAB receiver or a 3G/4G cellular connection (internet, SMS, etc.) to send traffic information to the in-car devices (i.e. OEM solution, PND or smartphone). Given the fact that they control the entire communication chain, there are no limitations on extending data formats to exchange any information desired. However, restrictions of the communication medium still apply (i.e. FM is very slow and 3G/4G has a latency of several hundreds of milliseconds).

Waze differs a bit from the other services in the sense that the road users can directly give feedback (i.e. ‘alerts’) via the smartphone app while driving. These ‘alerts’ include road works, road closed, speed trap (police), stopped vehicle on road or hard shoulder and explicit traffic jams (including a severity indication). In addition to feedback from users, through the proper channels, it is also possible to insert information via a web portal / API. In theory, it should be possible to modify the Waze solution to include several other kinds of information. Again, the limitations would be those following from cellular communication technology.

Table 8 shows in a generalized way the possibilities of third-party services to cope with the requirements. Here, it is assumed that standard warnings (e.g. traffic jams) are already part of the systems, while information about automation limits is not included right now. Requirement M9 is rated as not covered, as this requires vehicle-centric positioning. Nevertheless, this shortcoming may be overcome by any third-party service in the future, although it requires a different approach than the services investigated here.

Table 8: Coverage of a generalized third-party service of required information for unequipped vehicles.

R1	✓	R2	✓	R3	⚠	R4	✓		
C1	✓	C2	⚠	C3	⚠	C4	⚠		
M1	⚠	M2	⚠	M3	⚠	M4	⚠	M5	✓
		M6	⚠	M7	⚠	M8	⚠	M9	✗

3.2 Information provided by dynamic local infrastructure

ITS (Intelligent Transport Systems) and C-ITS (cooperative Intelligent Transport Systems) involve multidisciplinary technologies and operations to improve the overall performance of roads. For instance, an ITS system realizes real-time data provision to local infrastructure so that local infrastructure can communicate and visualize the traffic information to road users.

In this section, the information provided by dynamic local infrastructure will be discussed in five subsections. First, the core systems, ITS and C-ITS which enable users to be better informed by the local infrastructure will be introduced. Afterwards, several field components on the local infrastructure side of an ITS system will be discussed: traffic light control, variable message signs, speed advice matrix board and ramp metering.

These subsections include several field components of an ITS system that can provide information to different types of conventional vehicles in TAs, such as LVs and CVs, and even AVs and CAVs with enhancements to the existing infrastructure (which are out of the scope of discussion in this section).

3.2.1 ITS and C-ITS

The ITS concept has been playing a significant role since 1990s. ITS encompasses the use of physical entities (such as infrastructure, vehicle, devices etc.), integrated data and information, communication technologies (such as electronics, information processing, wireless communications, and controls) for management and information provision in all modes of transport. For TransAID, only the field of road transport, including infrastructure, vehicles and users is in the scope of discussion.

On a general level, an ITS system severs the purposes of: 1) improving the mobility of people and goods 2) increasing traffic safety, reducing traffic congestion and mitigating/managing incidents effectively 3) reaching transport policy goals and objectives, such as demand management, public transport priority measures and reduced environmental impact etc.

These purposes are realized through the functions of ITS systems, which are embodied in ITS applications and services. With the evolving development of ITS, the extent to which these technologies are used and the degree of sophistication deployed in these ITS application and services, varies from one region to another.

ITS becomes indispensable due to its role of interfacing and connecting different categories of components of a road transport system. These components can be divided into two broad categories:

- Infrastructure-based control technologies aimed at controlling and managing traffic, such as urban traffic control, including traffic light control systems with embedded control algorithms; and motorway control systems, including ramp metering, variable message signs, speed advice matrix boards. These infrastructure-based elements will be discussed in the next four subsections.
- Vehicle-based control such as ADAS (Advanced Driver Assistance Systems) and ACC (Adaptive Cruise Control). The information provided by the vehicle-based control will be discussed in Section 3.1.3.

With ITS becoming ubiquitous around the world, one common goal of an ITS system is to improve the efficiency and sustainability of transport. The application and service of ITS are widely accepted and used in many countries, thanks to numerous benefits of ITS systems if properly deployed, such as optimizing network capacity/increasing throughput, achieving higher mobility by minimizing traffic congestions, improving traffic safety and efficient infrastructure usage, providing prior information/real-time information for journey planning, route finding and navigation etc.

A core function of ITS is to provide better quality and diversity of services and information for the full spectrum of users- in particular drivers, passengers, vehicles and operators, to improve the operation of the entire road transport system. With the provided information, road users can make better judgements on their travel decisions.

Traditionally, this information reaches road users via local infrastructure. For example, traffic conditions, weather conditions, road maintenance or construction work that may affect travel time and safety, are conveyed via roadside infrastructure such as matrix boards (fixed or dynamic). As the world undergoes digitalization, much attention has been given to vehicle automation recently, but that attention has been almost entirely focused on the vehicles themselves, without regard to the roadside infrastructure on which they operate.

One reason could be that developers attempt to ensure the deployment of a viable system in case the public section fails to deliver the expected infrastructure enhancements. However, if the AVs and the local infrastructure can operate as a well-integrated system in the future, infrastructure enhancements are vital, for example, detailed and carefully validated high definition maps of all the locations where AVs can operate.

As a fundamental physical element of ITS systems, transportation infrastructure has undergone a technology revolution enabling a specialized subset of the Internet of Things (IOT), including intelligent traffic lights, cooperative sensing, wireless/wired communication, Cooperative V2X (long-range cellular and short-range direct communication) data exchange, Variable Message Signs (VMS), individual speed advice to connected vehicles and intelligent ramp metering.

These upgrades, remediation and enhancements not only ensure the reliability and resilience of transport infrastructure, but also proliferate ITS into a multidisciplinary conjunctive field of work due to its endless possibilities to develop solutions for the coexistence and interactions of CAVs and LVs in TAs.

The central feature of ITS is its ability to deliver in real-time, traffic and travel information and flexible means of network control. As a key enabler of a sustainable transport system, the entire application of ITS is based on data collection/transmission, data analysis and data usage in the operations, control and research concepts for traffic management where location plays an important role. Therefore, cooperative sensing, information processing, communication channels, information provided at roadside and intelligent traffic light controls play an imperative role in these applications, such as ATMS (Advanced Traffic Management System), TAS (Travel Advisory Systems), ATIS (Advanced Traveller Information System), AVCS (Advanced Vehicle Control system), APTS (Advanced Public Transportation System) and so on. The lists of applications can go on and deviate from country to country and from region to region.

- *Real-time data collection*

The first and foremost step is real-time data collection, where data is collected via varied hardware devices at the infrastructure side. Infrastructure with detection and monitor functions lays the base of further ITS system. The hardware mainly records the real-time data: traffic count, surveillance, travel speed and travel time, vehicle types, delays and stops, etc. These hardware devices are connected to the servers generally located at data collection centres, which store large amounts of data for further analysis. More details of cooperative sensing and data collection are explained in D5.2 [18].

- *Data transmission and communication*

Secondly, rapid and real-time information communication is the key to proficiency in ITS implementation, hence data transmission in the field consists of data flows from local infrastructure ends to TMC, then returning analysed information from TMC to local infrastructure and then presenting appropriate information to travelers. Traffic-related announcements are communicated to travelers through mobile devices via internet, SMS (as discussed in chapter 3.1.5), through OBU (on-board units) of vehicles, through roadside presentation (traffic light controls, ramp metering, VMS, matrix board etc.), through wireless technologies such as IEEE 802.11p/ITS-G5.

- *Data analysis*

The data that has been collected in the first step, and received at TMC is processed further in various steps, such as data verification and validation (methods like error rectification, data cleaning and data consistency), data synthesis, and adaptive logical analysis. Analyzed data is further used to predict traffic scenario and propagation trends, which are available to deliver appropriate information to users.

With emerging enhancement from every element of ITS, ITS systems and subsystems have gone through a dynamic automation and cooperation process for transmission and communication, which calls for the need of C-ITS.

According to the Car-2-Car Communication Consortium (C2C-CC), C-ITS refers to transport systems, where the cooperation between two or more ITS sub-systems (personal, vehicle, roadside and central) enables and provides an ITS service that offers an enhanced service level, compared to the same ITS service provided by only one of the ITS sub-systems.

C-ITS has been developed for more than one decade. In recent years many C-ITS innovation projects have been implemented and early commercial deployment is starting. Simultaneously, automated driving is gaining momentum. The impact of C-ITS services on a road network can be significant, but it is difficult to estimate due to the novelty of the concept. Most of the current C-ITS systems are evaluated in simulated platforms before deployment and after deployment with hysteresis data.

One of the key influencing factors for the impact is the penetration rate of C-ITS equipped vehicles and their compliance rate where applicable. Another determining factor is the proficiency of simulation system architectures, both high-level and low-level, which can affect the maximum compatibility between real-world and simulated system.

C-ITS applications will make road transport safer, more efficient and more environment-friendly. The European Commission (EC) has reported a common technical framework of C-ITS to facilitate C-ITS services with a comprehensive approach. The framework has listed technical details such as: Day 1 services and Day 1.5 services, security and certification, radio frequency and hybrid communication.

Numerous research has been interested in the potential of C-ITS. According to the survey of Lu et al. [19], the willingness-to-pay of C-ITS services, however, is very low, which indicates the importance of building business cases for sustainable large-scale implementations of these services. Guidelines for C-ITS deployment (per service) in cities with respect to traffic management should initially be proposed at an operational level. Clear strategies are in great need to determine and deploy sustainable services, which can be supported by local authorities, and to ensure interoperability and seamless availability of high-quality services for end users from a perspective of successful business.

3.2.2 Traffic light control

This section gives an overview of traffic light control on urban roads that provide information to users. As a most effective urban infrastructure-based control method, traffic light control systems with embedded control algorithms can be categorized into four types, based on the characteristics of control algorithms. In D4.1 of MAVEN project [20], they are explained in details. The summary given in this section focuses on

- *Static control*

The simplest form of traffic light control is static or fixed-time control. On the infrastructure side, the advantage is that minimum intelligence or investments for sensor technology are required due to its simplicity. Yet the disadvantage is the high maintenance costs. This is due to the manual calibration effort required to keep the plans effective. Although formulae and software tools (such as TRANSYT) are available to calculate these plans, every significant change in traffic demand requires that the calibration procedure has to be repeated.

The traffic control plans are based on average flow. To prevent queue forming, a margin to cope with cycle-by-cycle demand fluctuations is included. When these margins are unnecessary for its respective cycle, the fixed character of the control algorithm increases the delay time for all other traffic. When average demand fluctuates by time of the day, for instance, peak hour and off-peak hour, respective fixed plans are often loaded; which are activated at a predefined time of the day.

Day-to-day differences can also cause queues and congestion forming. System Activated Plan Selection (SAPS) is often used to mitigate this sort of congestion. A few sensors are deployed at several strategic locations in the network to detect congestion and measure traffic volume. The system dynamically decides when to switch between several pre-configured day-to-day plans to cope with the already onset traffic congestions.

From static control, the information provided by traffic light controllers is mostly fixed according to the stages plan of a cycle. On-peak/off-peak hour plans and day-to-day plans introduce the possibility of basic dynamic features for static traffic light controllers.

- *Actuated control*

The heart of actuated control algorithms is based on sensors detecting if traffic is present or not. Typically, two functions for detection are used: stop line detection and gap detection. Stop line detection checks if there is any demand at a signal group. If there is no traffic presented in all signal groups of a stage, this stage will be skipped. Gap detection is used for extension of green light beyond the minimum duration. The minimum duration is calculated based on the safety requirement. As long as there is demand, the green duration is extended until the maximum green time is reached. The maximum green is based on the maximum desired cycle time. Figure 11 illustrates the schematic design of minimum green and maximum green. The solid green rectangles represent the minimum green time and the hatched dark green rectangles represent the optional time available for extension.

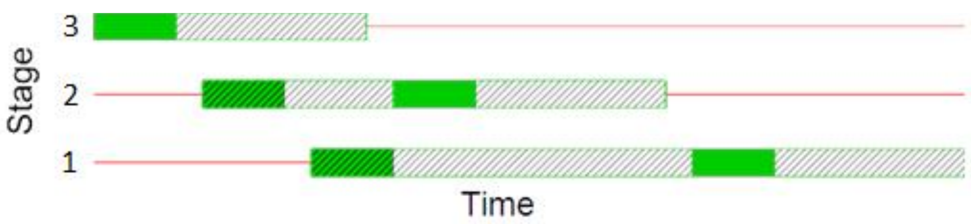

Figure 11: Actuated control schematics

A common actuated traffic light controller application is pedestrian/cyclist traffic light, where presences of pedestrians/cyclists are detected through the push button and traffic lights are actuated to provide information to the users. Another example would be a side link road with significantly lower traffic demand that show red most of the time but once vehicles are detected, shows green.

- *Semi-fixed time control*

Semi-fixed time control is based on a fixed time control plan, but the switching moment can occur between a configured minimum and maximum time. Figure 12 shows the guaranteed green with solid green rectangles; the default configured green duration is indicated as the sum of the solid green and the hatched light green. The maximum allowed green is the total hatched box. For example, a default configured green time of 20 seconds is used, while both at the beginning of a stage and at the end there is a flexibility of (-3, 3) seconds. Meaning the absolute minimum and maximum green times are 14 seconds and 26 seconds respectively.

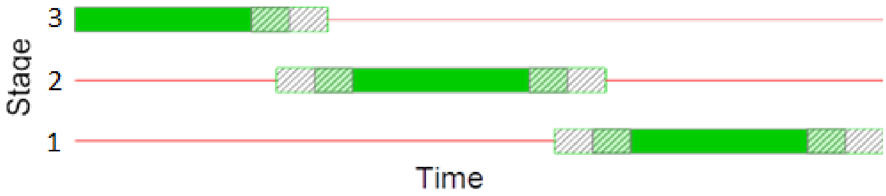

Figure 12: Semi-fixed time control schematics

Since the cycle time is fixed, the flexibility of switching from one stage to another is not cumulative but dependent. If the first stage is slightly congested it will use up all flexibility, even if the second stage is heavily congested. In this case, the information provided by the traffic light controller is dynamic since the switching moment is variable.

- *Adaptive control*

Adaptive control is based on a model of predictive behaviours of the approaches towards the intersection. To illustrate adaptive control algorithm, Figure 13 shows the schematic view of a queue and arrival model. As a vehicle enters an approach of an intersection, the vehicle is created in the model, when the entry detector detects it. The x-axis represents the distance to the stop line (“t = 0” column) in travel time. Every second, vehicles in the arrival pattern are moved one cell closer to the stop line. The queues accumulate at the stop line and discharge with counts from the stop line detector.

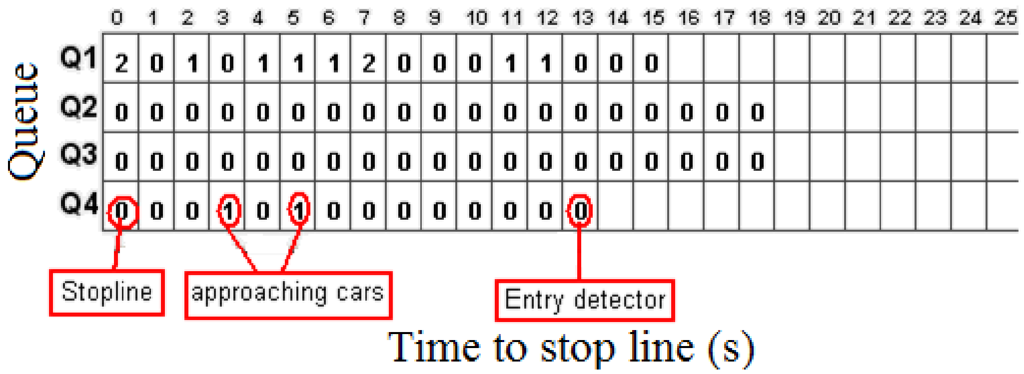

Figure 13: Queue and arrival flow modelling in adaptive control

Adaptive control algorithm uses the model of approaching and waiting vehicles to evaluate different possible control solutions. They are evaluated using a cost function that minimizes delay and stops for all traffic approaching the intersection. The information provided by the traffic light controller is fully dynamic since the plan at an intersection is constantly being updated.

Independent of the used control method, traffic lights could dynamically influence traffic and can therefore be used for at least some of the required information that needs to be presented to unequipped vehicles. Traffic lights as such can only provide limited information. Besides the native ‘red’ for ‘stop’, ‘amber’ for ‘prepare to stop’, and ‘green’ for ‘go’, there are several other indications possible, which can be different from nation to nation. For example, a yellow flashing in Germany indicates that the light is off, but that the vehicles have to give way. In other countries, there is also a flashing red or flashing green possible, or combinations of different colours with different meanings.

As shown in Table 9, for TransAID, traffic lights cannot be used to show any information about TransAID reasons. On the side of consequences, only very limited information can be given, e.g. a red light at a ramp metering device can implicitly indicate that there is currently heavy traffic on the road (C1). For measures, traffic lights also offer only very limited support. The advice to use a specific lane (M3) may be indicated by a traffic light. Speed (M5) and distances (M6) in urban road sections can be very roughly controlled by using traffic light phases. When the traffic light switches, esp. when 'amber' is shown, drivers tend to reduce speed when the distance to the light is higher and tend to speed up at close distances. Here, it has to be mentioned that an approach with traffic lights may be theoretically possible, but the overall performance will be very low. No complex message content can be provided.

Table 9: Coverage of Traffic Lights of required information for unequipped vehicles

R1	✗	R2	✗	R3	✗	R4	✗		
C1	✓ (implicit)	C2	✗	C3	✗	C4	✗		
M1	✗	M2	✗	M3	✓ (implicit)	M4	✗	M5	✓ (roughly)
		M6	✓ (roughly)	M7	✗	M8	✗	M9	✗

3.2.2.1 Ramp metering

Equivalent to traffic light controllers on urban networks, ramp metering regulating on-ramp traffic on freeway networks is discussed in this section. Literature review [21] is conducted for both local ramp metering and coordinated ramp metering.

Ramp meters consist of traffic signals employed at freeway on-ramps to control the rate of vehicles entering the freeway. Metering rates are set to optimize freeway flow and minimize congestion. Rates can be fixed or responsive to local or system-wide conditions.

Ramp metering has always been an important research topic and the aim of ramp metering control is to reduce the inflow from the on-ramp to the motorway in order to postpone congestion on the motorway since this would lead to a capacity drop. Relevant research is mainly based on queuing theory and statistics that do not combine various information sources obtainable from communication-capable vehicles, such as CVs and CAVs. Therefore, the current ramp metering strategies only control the average capacity on a macroscopic level, instead of actively trying to prevent a capacity drop on a microscopic level. The most commonly used strategies are ALINEA [22] and Demand Capacity (DC) [23]. ALINEA control is a feedback control strategy in which the inflow is determined as the difference between the ideal occupancy and the observed occupancy. The on-ramp volume is then adjusted over a certain period. On the other hand, the DC is a feed-forward control strategy, comparing the incoming mainstream flow to an assumed capacity value. These two strategies are on a macroscopic level, so that the set point of capacity has to be significantly below the saturation point. This is because on-ramp traffic is heterogeneous and can cause a disturbance on the mainstream flow, which in turn can lead to congestion when the mainstream is close to the saturation point.

There is another strategy, called the Rijkswaterstaat (RWS) strategy, which is a variation of DC strategy used in field application in the Netherlands [24]. The RWS strategy is activated differently according to prevailing conditions. When the speed on freeway merge sections drops, ramp metering reduces the on-ramp flow at a minimum level, while it increases when the queue on the on-ramp becomes too large. Due to the limited storage space of a single on-ramp, the local control does not guarantee that queues are equally distributed over adjacent on-ramps.

The alternative to reduce flow on the motorway while ensuring equal treatment among on-ramps at the same time is coordinated ramp metering control (by activating an upstream controller). This will spread the extra waiting time over multiple on-ramps, thus causing the queue to spread more equally in the network. A number of different coordinated control strategies are available based on existing literature. These strategies maybe divided into optimal control strategies [25], hierarchical control strategies [26] and rule-based strategies, where rule-based algorithms apply appropriate heuristic rules to the input data in order to estimate the optimal settings for each individual ramp metering control. The HERO algorithm, which incorporates local ALINEA control, is regarded as the most promising approach for large-scale field application of coordinated ramp metering [27]. And the HERO-RWS [28, 29], a variation of HERO cooperating with local RWS control also shows promising results in a case study in Amsterdam A10. Nevertheless, as long as the local control system operates based on macroscopic traffic characteristics, the full utilization of the infrastructure cannot be achieved.

To inform conventional vehicles, ramp metering is an effective measure on the freeway on-ramps. Yet, there is not sufficient research to bring the ramp metering into microscopic level, and to develop ramp metering algorithm encompassing merging assistant, which activates ramp metering on a vehicle basis and cycles with variating red time.

Figure 14: Ramp metering in the US[1].

Ramp metering is a measure, normally applied in conjunction with traffic lights. Therefore, no coverage matrix is given for this.

In the 2nd iteration of TransAID, intelligent ramp metering is realized through sensor fusion, which receives various information sources obtained from communication-capable vehicles, loop detectors and TrafiRADAR; which enables V2X communication such as V2V, V2I and I2V, involving conventional vehicles, connected vehicles and infrastructure devices/units.

3.2.3 Variable Message Signs

VMS have been widely deployed in modern transportation facilities. Located on the side of or cross-over of roadways (e.g. overhead sign bridge/gantry, overhead cantilever or single pillar), VMS are designed to deliver real-time traffic information covering congestion updates, accident/incident report, weather condition, roadwork, lane control and dynamic speed limit/advice speed, etc. The dynamic information dissemination can be controlled either from a TMC (traffic management centre) or from local infrastructure at the site.

VMS (also known as CMS, changeable message signs and DMS, dynamic message signs or matrix sign in the UK) can be categorized as fixed and dynamic. This means that VMSs are set up with permanent, semi-static or dynamic display, based on the information that they are designated to deliver. As there are specific sub-objectives depending on each VMS type, the

[1]Source: https://commons.wikimedia.org/wiki/File:Ramp_meter_from_Miller_Park_Way_to_I-94_east_in_Milwaukee.jpg

main objective of providing information is to provide road users time to avoid an incident, anticipate for unavoidable conditions, or to offer travel directions and improve traffic flow. According to the dissemination content from local infrastructure to road users (mostly conventional vehicles), VMS types, definition/subtypes and descriptions are listed in Table 10.

Table 10: An Overview of VMS types, subtypes and description

VMS types	Definition/subtypes	Description/example
Travel information	Travel times Routing/detouring Directions and guidance Trip/journey information	Travel times between known destinations Routes and alternative routes provision (e.g. DRIP in Dutch)
Congestion warning	Recurring congestion Non-recurring congestion	Congestion along a stretch of road. Non-recurring (often a residual effect of cleared crash)
Variable speed limits	Freeway speed perturbation mitigation GLOSA (green light optimized speed advice)	Delay the onset or reduce phantom jams Recommend a speed to approach the next traffic light in its green phase.
Roadworks warning	Construction Maintenance	Road construction notices Long/short-term Maintenance operations and schedule
Events announcements	Conference Large social gathering Competitions	Special event notice and instructions for road users
Incidents warning	Accidents Crashes/collision (including vehicle spinout or rollover) Vehicle breakdown Vehicle fire Infrastructure failures (e.g.	Incidents of vehicles and infrastructure or both that could affect normal traffic flow on a lane or on shoulder lane

	pavement failures)	
Weather and nature	Road/ Exit ramp closure Slippery road surface Wildfires Debris	Severe weather/prediction announcement Road closure/road condition degradation due to severe weather
Promotion and persuasive messages (off-peak hour)	Carpooling Car park occupancy levels Emergency call lines Speed limit reinforcement Floating car data collection CO_2 emission deduction	Persuasive messages via VMS during the off-peak hour that support traffic management and improve traffic quality

The VMS types are relatable and self-explanatory due to our daily interactions with them. Through many years of development, the VMS matrix can have the following displays:

Figure 15: Variable Message Sign Matrix Displays: Character Matrix, Line Matrix and Full Matrix (from left to right)

Figure 15 above demonstrates the difference between the matrix types. First, the introduction of the term 'phase' in this context is needed: A phase is defined as the limits of the display area available for text, bitmaps, or animation. If messages displayed on a VMS cannot be fulfilled with a single phase, such messages require the use of multiple phases, which allow more than one message to be displayed at a location.

Common VMS technology includes the followings: Flip Disk, LED (Light Emitting Diode), Fibre Optic and Hybrid. While the VMS technology transforms and becomes more and more sophisticated, the hybrid type utilizing both flip disk and fiber optic/LED is prevalent on road networks. Each flip disk has a hole in its centre for light to pass through. The light is generated by a fiber optic bundle or LED cluster. When the pixel is activated the disk is flipped, allowing light to pass through the hole while displaying the reflective side of the disk to vehicles. When the pixel is off its reflective surface is rotated, or flipped, blocking the light source. The advantages of hybrid technology is its function reservation when light source fails and it provides a sharp/readable image of the VMS messages. But as a hybrid type, there are more moving parts which could lead to additional maintenance.

To provide higher quality and cope with maintenance issues, features such as high colour consistency, better contrast ratio, thinner cabinet, improved flatness, high stability and effortless service (walk-in, no glue coating/PCB, easy hardware (light emitting diode/driver) replacement) are developed. The walk-in form factor is a more recent introduction, where maintenance on the sign is performed from the inside of the sign. A key advantage of the walk-in form factor is that lane closures are generally not required to perform maintenance on the sign. Most of the largest VMS units installed today are walk-in units on the freeways. There are also mobile version VMS on the urban road networks, see Figure 16.

Figure 16: Variable Message Signs examples (Above: mobile trailer versions; Below: Overheads versions)

In the light of TransAID messages for unequipped vehicles, VMS have a very good matching according to Table 11. Several aspects are already existing or could easily be implemented, either text or sign based. Nevertheless, some possibly needed traffic signs are not yet existing in some countries, e.g. for traffic separation (M2). The only message, which cannot easily be shown, is the vehicle based ToC/MRM display of M9. As long as the vehicle is driving (and not a standing obstacle), only generalized information ("ToC vehicle in that area") may be shown.

In addition, it has to be mentioned that the longitudinal location precision is depending on the number of VMS along the road. Therefore, a high precision can only be achieved by a high density of such devices. In case of TransAID, where reasons are locally stable (as defined in the "Transition Areas"), mobile VMS may solve the situation.

Table 11: Coverage of a VMS of required information for unequipped vehicles.

R1	✅	R2	✅	R3	⚠	R4	✅

C1	✓	C2	⚠	C3	⚠	C4	⚠		
M1	✓	M2	⚠	M3	✓	M4	⚠	M5	✓
		M6	✓	M7	✓	M8	⚠	M9	⊗

3.2.3.1 Dynamic speed limit and speed advice

Focusing on reducing speed heterogeneity on a microscopic level and the induced congestion/safety problems, this section discusses a typical sort of VMS: dynamic speed limit on the motorway and speed advisory on the urban road, aiming for informing and managing conventional traffic or even connected traffic with individual speed advice.

- *Dynamic speed limit (motorway)*

According to the European Commission of mobility and transport, a fixed speed limit on the infrastructure side informs vehicles to follow the appropriate speed for average conditions. Dynamic speed limits, respectively, are limits that take account of the real-time traffic, road and weather conditions.

In the Netherlands, variable speed limits are denoted by electronic signs that are housed within gantries situated above motorway lanes. Literally, speed limits imposed by dynamic speed limit systems are compulsory, which have the following objectives.

One major objective of dynamic speed limits is to increase safety by better reflecting the safe speed. For example, upstream from an incident (e.g. traffic jams, crashes, road works) speed limits can be temporarily lowered in order to reduce mean traffic flow speed, lead the traffic smoothly to the incident and avoid the occurrence of crashes.

Secondly, dynamic speed limits can inform conventional vehicles about obstructions and can lead them away from a blocked lane.

Thirdly, as mentioned above, dynamic speed limits can improve traffic flow through homogenization of speed, reduce speed variation and changeable manoeuvres of human driving. Headways are also assumed to become smaller in this case, nudging conventional vehicles to behave similar to CVs and CAVs. This last objective is even more vital to TransAID scope.

Extensive literature reviews have been performed to show the effect of dynamic speed limit on travel time, traffic flow and traffic safety through empirical studies and field studies. The empirical studies of Lu & Shladover (2014) [30] gave a comprehensive review of the strategies and algorithms of dynamic speed limits, targeting traffic improvements (safety, throughput, etc.). It concludes that dynamic speed limit can significantly improve freeway traffic safety if the compliance rate is high enough. Traffic throughput reported to be controversial in numerous studies. Some studies reported an improvement in throughput [31, 32]. Some authors reported a reduction of travel times [31, 33].

While previous studies (e.g. Specialist algorithm tested in Dynamax project in The Netherlands) have shown that the use of dynamic speed limits, displayed by road-side equipment, is a successful instrument to stabilize traffic flow and to dissolve formed phantom jams (of all congestion, over 20% is recognized as shockwave jams or so-called phantom jams). In the study of Suijs et al. [34], the effect of in-car speed advice to avoid phantom jam is also discussed. The study introduced prevention based advice systems, making use of the presence of high intensity waves, to be successful in preventing phantom jams. The number of phantom jams and the average jam weight are significantly reduced. Speed differences between vehicles are reduced and traffic is stabilized which provides a contribution to traffic safety.

More interestingly, in the study of Lu & Shladover (2014) [30], the combination of dynamic speed limits with coordinated ramp metering were already reviewed. Most of the designs adopted model predictive control for coordinated dynamic speed limits and ramp metering. The factors that were taken into account by these algorithms are still macroscopic traffic characteristics and conclusions of effects are premature. More details about ramp metering design in TransAID are discussed in section 3.2.2.1.

- *Green Light Optimal Speed advisory (GLOSA) (urban road)*

On the urban road networks, GLOSA is a mobility and safety enhancement application. The speed advisory messages of this application is usually conveyed from infrastructure to LVs (a.k.a. conventional vehicles), which are the main elements of vehicular traffic on signalized streets.

In section 3.2.2 "Traffic light control", it is mentioned that one way to reduce excessive stop-and-go is to optimize signal timing. Historically, signal timing optimization tools were developed to reduce delays and stops experienced by drivers on urban networks. In fact, these KPIs such as delays and stops are adopted in the function of adaptive control algorithm (e.g. ImFlow) to calculate the impact of a signal plan and evaluate whether or not to change the plan every time step.

The detected data, such as presence, count and average speed are essential for accurate speed advice. In D5.2 [18], it is explained in details how detector loops retrieve these data. Recently, V2X communication have incorporated changes in drivers' behaviour (lane change, speed change etc.) to achieve traffic signal optimization at signalized intersections. The real-time/accurate data provided by CVs to infrastructure has been proven instrumental for the GLOSA application in multiple simulation studies.

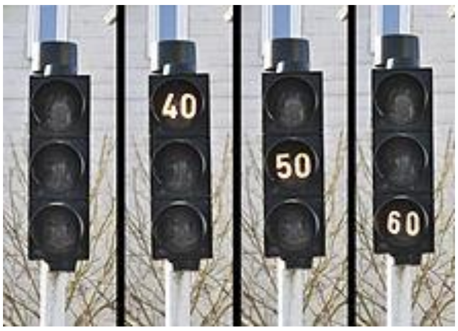

Figure 17: Historical speed advisory sign to achieve GLOSA in Germany

In MAVEN project, extensive research was carried out on combining different types of traffic light control with GLOSA, which shows promising results on actuated control and adaptive control. But the results differ significantly with different penetration rate of CVs and/or (C)AVs.

The GLOSA application in the urban road of the Netherlands are called "Green wave". The underlying control algorithms in operation are mostly fixed control and semi-fixed control (see Figure 18).

Figure 18: Speed advisory sign to achieve green wave on arterial road (Source: Dick Vermaas)

Altogether, the aspect of speed advisory is a specific measure, with several possibilities in showing the advised speed to unequipped road users, or to CVs and CAVs together with Day-1 ITS-G5 applications. As a measure, it plays a different role than the traffic lights and the VMS shown in the previous chapters. Visualization of the measure is mostly done by VMS presently, although there are other historic examples (like shown in Figure 17) without this technology. Therefore, no coverage matrix of the information requirements is given here, as the technology can only be used to generate very precise and useful speed advisory (M5). This is esp. true when the speed advisory is taking into account queues, traffic jams, etc.

3.2.3.2 Corresponding activities in H2020 INFRAMIX

In the TransAID sister project INFRAMIX, possible new visual signs and elements have been elaborated and summarized in [35]. The most interesting part in relation to TransAID is the lane dedication for autonomous vehicles (AVs/CAVs in TransAID terminology), where INFRAMIX performed extensive user studies and finally decided on a specific layout. This layout should according to the authors be used on static traffic signs as well as VMS. The designs are briefly shown in

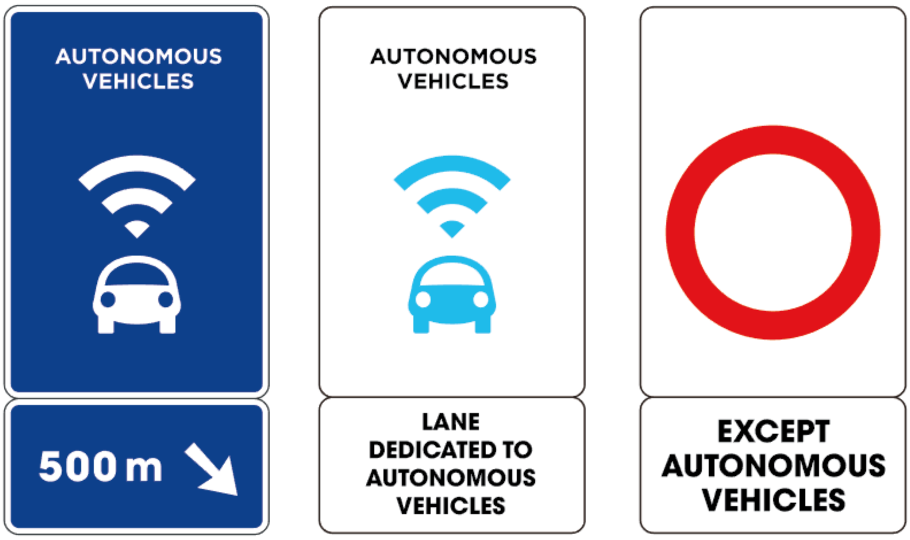

Figure 19: Static traffic signs showing how lanes should be dedicated for automated/autonomous vehicles [35]

Figure 20: VMS showing a lane dedicated for AVs/CAVs [35]

3.3 Information provided by vehicles

Besides the infrastructure-based information provision discussed in the former sections, there are also possibilities for vehicles to give information. AVs and CAVs could provide information about their own status, plans and actions to other vehicles surrounding them. On the other hand, CAVs and CVs could make use of their communication technology to receive advisories from other entities and to forward them to other unequipped vehicles on the road. Although the latter has several yet unspecified implications which are not covered in TransAID (e.g. trust, security issues, legal implications when vehicles or drivers react to forwarded information, etc.), the possibility of using vehicles on the road to forward information, and to control and optimize the behaviour of unequipped vehicles offers several possibilities in terms of traffic efficiency and safety.

Therefore, some possibilities are shown in the following chapters. As CAVs able to cope with TransAID measures are in focus of the project, all aspects are described from the perspective of a CAV possibly influencing unequipped vehicles on the road.

According to [36], the information given to other vehicles is clustered into information given by an external HMI (eHMI), which is a visual information shown on the surface of a vehicle (here: CAV), and information given by the movement of the vehicle/CAV, the so-called Dynamic HMI (dHMI).

3.3.1 External HMI

3.3.1.1 Standard visual signalling devices

The development of AVs focused on acting as much as standard LVs as possible, but safer and with higher comfort, or even greener. Therefore, AVs were planned to only use standard visual signalling devices, like indicators, brake lights etc., to ensure maximum compatibility to other vehicles/LVs.

If an AV plans to change lane, it will simply use the left or right indicator like any LV. If it brakes, it will show this on the brake lights. If a dangerous situation like a MRM or emergency stop is occurring, hazard lights will be switched on.

Additional systems on the market already combine and extend the functionality of standard lights. For example, the Emergency Stop Signal (ESS) or Adaptive Brake Light (ABL), where the brake lights are flashing in case of a strong braking, sometimes combined with enabled hazard warning lights.

Nevertheless, standard lights can also be used for more advanced information as shown in Table 12:

In case of a blockage, obstacle or other incident (R1): If the vehicle itself is the blockage (e.g being broken down), it will indicate this with its hazard lights. In case of any other blockage/obstacle/incident, any SAE Level 5 vehicle, on the road without any driver or passenger, may line up behind and warn other vehicles by the use of hazard lights.

Information about free areas (R2) cannot easily be provided via standard lights. Same goes for information about vehicle automation restrictions and limitations (R3) and areas which need to be handled with attention (R4).

In some countries, the short activation of hazard lights is used to warn oncoming traffic about upcoming situations, like traffic jams (C1) or (in case of low distances) possible sudden braking manoeuvres (C2). The before mentioned ESS would also be used, when the vehicle itself is performing strong braking. Of course, the ESS only applies when strong braking occurs, and not when this is only possible. The same is valid for possible sudden sharp lane changes (C3), but there is currently no existing way of warning others about imminent lane changes of other vehicles. When CAVs perform sudden sharp lane changes, they will indicate this as soon as possible, but this is not the kind of information required by C3.

If ToCs and MRMs are often happening in specific areas, this cannot be indicated (C4) by CAVs, with standard visual signalling, except by using hazard lights consequently when passing such areas. Most likely, drivers of LVs will not understand this, although people may eventually familiarize with the latter operation.

With regard to the measures of TransAID, the clear allowance to use part of the road for another purpose than intended (M1) cannot be given via lights. Of course, the usage of that lane part (possibly in combination with indicator lights showing that the lane is changed) will give the hint that usage may be allowed and required, but this is not necessarily related to the standard lights. The same is true for traffic separation (M2) and the advice to use a specific lane (M3). The availability of safe spots (M4) cannot be indicated at all, except for the case the vehicle occupies the safe spot, which makes it unusable for others.

The reduction of speed (M5) can be simply applied in CAVs. In that case, CAVs will drive with the given speed, leading to the situation that following vehicles behind also need to adapt to approximately the same speed, at least on single lane roads. As shown in some studies (e.g. [37]), the positive effect may be limited, esp. on multi-lane roads where those vehicles get overtaken or at low penetration rates of such systems, where drivers of successor LVs do not understand the benefit of the low speed, leading to tailgating or dangerous overtaking manoeuvres. In all cases, a reduced speed itself is not shown via lights. Braking lights can only indicate the current reduction.

Larger distances between the vehicles (M6) may be attained by using hazard lights, as drivers normally react with caution when the vehicle ahead shows hazard lights. Of course, the range of such measure is very limited, and the understanding of such measure may also not be given, as hazard lights are used for several issues. The same argumentation can be used for M8, where special caution is needed.

Zipper lane changes (M7) cannot be indicated.

The vehicle-centric measure of visualizing own current issues in driving like ToC and MRM (M9) can possibly be shown by hazard lights. This will indicate that there is a problem, but it will not tell anything about the reason or the upcoming action. In addition, the visualization of e.g. lane changes (imposed by a MRM) shall not be feasible when hazard lights are already switched on.

Table 12: Coverage of standard visual signalling devices of required information for unequipped vehicles

R1	⚠	R2	⊗	R3	⊗	R4	⊗		
C1	⚠	C2	⚠	C3	⊗	C4	⚠		
M1	⊗	M2	⊗	M3	⊗	M4	⊗	M5	⊗
		M6	⚠	M7	⊗	M8	⚠	M9	⚠

3.3.1.2 Multicolour auxiliary signals

In the past, research has also been conducted to include additional lights on vehicles for special purposes. Besides the rooftop light bars on emergency and service vehicles, there have also been some attempts to include special lights representing the acceleration of the vehicles to reduce the number of rear-end crashes. These systems (e.g. RCW 46.37.210 [38, 39]) often include a green light in the back when the vehicle is accelerating, and amber lights when the vehicle is not under power of the engine, e.g. standing or idle. In addition, the already existing brake lights are used in an adaptive way, e.g. flashing in case of strong braking, as already described before.

In the EU-H2020 project interACT[2], additional technologies have been investigated, where automated vehicles cooperate with Vulnerable Road Users (VRU) by using a LED strip mounted on the exterior of the vehicle, or a directed signal light. In the project, the lights are used to give information clustered into four categories, which are [40]

- *Category A: information about vehicle driving mode*
- *Category B: information about AVs' next manoeuvres*
- *Category C: information about AVs' perception of the environment*
- *Category D: information about AVs' cooperation capabilities*

Figure 21: An external LED strip used for communication to VRUs in the project interACT [41]

The LED light can be used with different light patterns and colours. It can be illuminated in one colour, or even use animations allowing to show moving lights and therefore even directed information. The directed signal light is used to spot a single VRU and to therefore attract attention of this single VRU.

The categories are very much in line with the required information needed for the communication to unequipped vehicles in TransAID, esp. the vehicle-centric information.

[2] https://www.interact-roadautomation.eu/

Table 13: Coverage of multicolour auxiliary lights of required information for unequipped vehicles.

R1	⚠	R2	⚠	R3	⚠	R4	⚠		
C1	⚠	C2	⚠	C3	⚠	C4	⚠		
M1	⚠	M2	⚠	M3	⚠	M4	⚠	M5	⚠
		M6	⚠	M7	⚠	M8	⚠	M9	✔

As shown in

Table 13, it is basically possible to use such lights for any demanded purpose. Of course, this would require additional studies, as the design of the light patterns needs to be intuitively understandable or general knowledge has to exist about them, so that anybody understands the meaning of the signal. Besides, M9 was basically already investigated in e.g. interACT or presented in [42], except the performance of ToCs.

3.3.1.3 Complex displays

Besides having simple lights or LED strips, it is also possible to use more detailed written information on complex displays. Some of these displays are already used in current vehicles, e.g. the destination shown on busses or information provided on rooftop light bar displays on emergency vehicles, see Figure 22. These light bars can give additional, mostly textual, but also iconified (e.g. arrows), information to surrounding vehicles.

Figure 22: Rooftop light bar with a complex display on a German emergency vehicle (Source: dpa)

Besides, several displays for consumers are on the market (an example is given in Figure 23). These displays can also show texts and sometimes icons, in several colours and even animations.

Although these kinds of displays offer several options, it has to be stated that luminous displays are not allowed in several countries. For example, in Germany it is only allowed to have text displays with red lights to the front and with red or yellow lights to the back, but only for emergency or similar vehicles. Text displays in busses are only allowed if they show the destination.

Figure 23: Commercial display example (Source: Shenzhen Xuancai Optoelectronics Co., Ltd.)

Nevertheless, the option of having more detailed information on complex displays is also researched in the context of automated driving. Examples are giving information to VRUs about intentions and plans of automated vehicles (see Figure 24) and to predecessor vehicles about incidents on the road (see Figure 25).

Figure 24: Drive.AI pioneered the use of an external LED-display screen that can convey a self-driving car's intentions to humans. (Drive.AI [43])

Figure 25: Samsung's Digital Cockpit Tail Display (Source: MapBox[3])

Besides having screens in vehicles showing information to the surrounding, some companies also test other technologies for the provision of information. Here, esp. projection systems are researched, like Daimler's Digital Light concept, shown in Figure 26. This system is able to project icons and lines on the road by using the matrix head lamps of the car. Although the information currently investigated is more for the driver, also additional features like VRU communication is researched. In general, the projection systems offer several possibilities for communication, but mostly the visibility under daylight conditions is low.

Figure 26: Daimler's Digital Light concept and the F 015 laser projection system (Source: "Mercedes News" Forum, [44])

[3] https://blog.mapbox.com/samsungs-digital-cockpit-2020-804f5edc0391

For the TransAID information to unequipped vehicles, the coverage matrix is shown in Table 14. As shown, all types of information are basically possible, although exact information needs to be defined and human factors assessments need to be taken.

Table 14: Coverage of complex displays of required information for unequipped vehicles.

R1	⚠	R2	⚠	R3	⚠	R4	⚠		
C1	⚠	C2	⚠	C3	⚠	C4	⚠		
M1	⚠	M2	⚠	M3	⚠	M4	⚠	M5	⚠
		M6	⚠	M7	⚠	M8	⚠	M9	⚠

3.3.2 Dynamic HMI (dHMI)

Information to other vehicles can be given by using an external HMI as discussed before, but also the movement of vehicles is providing information about e.g. the current state or even the plans. In daily life, e.g. a car reducing speed can give VRUs the signal that they are allowed to cross the street or that other vehicles are given the right of way. In relation to automated vehicles, the usage of this so-called dynamic HMI (dHMI) is a very new approach, e.g. investigated in more detail in interACT [36]. Therefore, several additional studies will be required to get more insights into this topic, which cannot be part of TransAID.

In addition, it has to be mentioned that a changed behaviour of vehicles to provide information to other road users may have effects on road performance criteria, like throughput, traffic efficiency and safety. Furthermore, it will also – like all dHMIs - have an impact on the passengers of the CAV itself, which needs to be investigated as well.

Nevertheless, we want to roughly estimate the options with regard to the TransAID information for unequipped vehicles in the following table.

Table 15: Coverage of a dHMI of required information for unequipped vehicles.

R1	⊗	R2	⊗	R3	⊗	R4	⚠		
C1	⚠	C2	⚠	C3	⚠	C4	⚠		
M1	⊗	M2	⊗	M3	⊗	M4	⊗	M5	⚠
		M6	⚠	M7	⊗	M8	⚠	M9	⚠

In general, we think that there are not many options to use a dynamic HMI to provide information for TransAID. The reason for this is that we are talking about measures in higher speeds, and to other vehicles on the road. Information about specific reasons cannot easily be provided. We think that it could be theoretically possible to create an awareness about areas which need to be treated with care (R4), e.g. by a “careful” movement of the CAV, e.g. by slowing down or keeping larger distances. Same may be applicable to the consequences (C1-C4), but only on a very abstract level.

Most of the measures may not be provided by a specific movement, as it is hard to influence the behaviour of other vehicles, e.g. in terms of lane changes or zipper merging. With regards to a desired more cautious driving (M8) of vehicles behind, it may be an option to reduce e.g. the lane keeping performance of the CAV artificially. The theory behind this is based on the yet unproven estimation that people will keep larger distances to a leading vehicle when this is looking as if it has problems in accomplishing its driving task, e.g. by swerving inside the lane, similarly to follow a drunken driver who is expected to perform reactions abruptly. Here, it has to be noted that esp. swerving will also have huge impacts on the passengers inside the CAV, which may of course possibly understand that there is any issue, but will most likely loose trust in the own vehicle capabilities and in automated driving in general.

Therefore, if any of those possibilities are going to be applied and tested, the perfect parametrization will be key to a successful measure.

4 TransAID approach

In this chapter, the TransAID approach for informing unequipped vehicles is described. In the project, first a special stakeholder consultation with road authorities has taken place, where possible signage was discussed. This is described in section 4.1. Afterwards, a communication matrix has been set up which incorporates the information matrices shown in section 3. This matrix is discussed in section 4.2. Following the matrix definitions, section 4.3 shows how infrastructure support has been designed, while section 4.4 shows how automated vehicles could help in giving information about individual (C)AV issues. Section 4.5 finally focusses on additional service based information, where e.g. a smartphone app is used to enhance the flow of information to individual vehicles.

4.1 Stakeholder consultation

Besides the general stakeholder consultation performed in TransAID's work package 8 (see already available deliverable D8.1 [45] for the first and second project iterations), partner CRT organized consultation meetings with Greek road authorities Egnatia Odos S.A. and Attikes Diadromes S.A. to exchange views with respect to traffic management plans developed for preventing/managing/distributing control transitions. Focus of discussions was mainly placed on informing conventional vehicles in the context of the TransAID proposed traffic management plans. A summary of the road authorities' suggestions and comments can be found below:

- In the era of mixed traffic the need for managing conventional vehicles in the vicinity of Transition Areas will be constant. Thus, VMS availability would be required around these areas. However, that would entail significant investments on infrastructure installation and operation that might not necessarily be feasible. Thus, the design of the traffic management measures should consider the placement of existing VMS or the installation of new ones only at critical locations. For example, in highway portions where several consecutive tunnels are closely spaced (e.g. Egnatia Odos case) that can induce vehicle automation deactivations, Service 5 entitled "Schedule ToCs before no AD zone" should be applied upstream of the first tunnel. Subsequently vehicles can drive in manual mode until they exit the last tunnel when they can enable the automated driving mode again.
- Regarding adverse weather conditions road authorities noted that VMS are regularly placed at locations where fog is frequent. Thus, VMS are normally deployed to inform about fog. In this case, dedicated messages can be added to VMS to advice cautious driving (e.g. existing messages that advise drivers to keep safe car-following distance) to LVs in case AVs are performing ToCs due to adverse weather conditions.
- Traffic management plans developed in the context of TransAID should consider that based on existing guidelines VMS are normally located 1-2 km upstream of the areas where LVs must have completed advised actions.
- It would be meaningful for LV drivers to know which vehicles are driven in automated mode. Thus, an electronic plate showing a respective pictogram (e.g. LV Mode, AV Mode) would simplify traffic management considering that VMS cannot be placed at every possible Transition Area.
- Information provision to LVs in the case of incident scenarios is rather challenging in the absence of connectivity capabilities. Due to random nature of incidents, warning provision through VMS is rarely feasible, thus, other methods for signalling relevant information to LVs should be explored.

- In the case of traffic separation scenario both road authorities suggested guiding CAVs to inner motorway lanes instead of the outer ones, since this strategy facilitates CAV cooperation along the merge area if necessary.
- It would be meaningful that VMS inform LV drivers about the reasons for lane change/keep advice.
- In case of permanent no AD zones, it would be cost effective to add ordinary static traffic signs instead of VMS to inform LVs that CAVs are expected to perform ToCs (either in a coordinated way or not).

Indicative advice that could be provided to conventional vehicles per TransAID scenario through VMS is shown in Table 16. Please note that the stakeholder consultation meeting took place in an early stage of the project. Therefore, only the scenarios of the first project iteration are mentioned.

Table 16: Indicative VMS messages per TransAID Scenario

TransAID Scenario	Indicative VMS Message
Scenario 1.1	Left lanes closed in … km. Please use bus lane.
Scenario 2.1	Keep steady speed and do not change lane. (VMS located 500m upstream of first merge point)
Scenario 3.1	Please use the right/left (depending on the motorway the LV is driving) lane for the next … meters. Caution: Merging Ahead
Scenario 4.2	Caution: Work zone ahead. Respect speed limit. (VMS located 500 m upstream of location where behavioural changes of CAVs start to take place)
Scenario 5.1	Keep safe distance. (500m upstream of traffic management area)

4.2 Communication Decisions

While section 2 discussed the theoretical communication options, section 3 discussed the possible existing options on the market. Based on both, decisions for the project needed to be made, as not all options could be implemented and/or tested within the project. Based on the stakeholder consultation, expert discussion and internal review, a TransAID communication channel matrix has been set up, shown in Table 17. This matrix shows how a source instance of one class communicates to a destination instance of another. TransAID is focusing on the greenish areas. Whenever electronic communication is possible, ITS-G5 communication is used (except the link between several infrastructure entities, incl. backend communication, which is handled mostly using a wired connection). As this is the main focus of TransAID, communication content is described in detail in D5.1 [46], while the implementation is described in more detail in [47]. The communication from infrastructure to unequipped vehicles (LV/AV) is done by using VMS technology. The communication from CAV or CV to unequipped vehicles (LV/AV) is done by an external HMI and a dynamic HMI.

Not covered by TransAID is the direct communication from unequipped vehicles (LV/AV) to anything, although this communication is implicitly part of the project. AV/CAV or infrastructure sensors detect the movements of those vehicles. In case cameras are used, also given signals (indicators/brake lights) can be detected. Both types of information can be used for interpretation, e.g. in case of lane change detection, the detection of broken down vehicles on the road or the detection of non-normative behaviour. In TransAID, parts of this are implemented, described in D5.2 (cooperative perception [18]) and D7.2 [47].

Information from LVs to non-automated vehicles (CV/LV) is not part of the project, as this is matter of human interaction. Information from AVs to non-automated vehicles (CV/LV) could be done by eHMI or dHMI, but this is also out of scope of the project.

Table 17: TransAID communication channel matrix. Green areas are part of TransAID's communication. The dark green box on the right shows the area of interest for this deliverable.

Dst → / ↓ Src	**Infra**	**CAV**	**CV**	**AV**	**LV**
Infra	Cable/ G5	G5	G5	VMS	VMS
CAV	G5	G5	G5	eHMI/dHMI	eHMI/dHMI
CV	G5	G5	G5	eHMI	eHMI
AV	Indirect Sensor	Indirect Sensor	eHMI/dHMI	Indirect Sensor	eHMI/dHMI
LV	Indirect Sensor	Indirect Sensor	Human interaction	Indirect Sensor	Human interaction

Having decided on the channel as shown before, the next important step was to identify how the required information is presented to the unequipped vehicles. Although the existing services in section 3 allow different combinations, we decided to implement the messages shown in Table 18. Here, most of the communication aspects are addressed by a VMS, as this seems to be a simple and effective measure to transmit information. In an iconified way, it is readable by any human driver. Text displays may also help to understand the context. AVs may be able to also "understand" the signals when they are equipped with a camera and received an update about the corresponding content description and the logical implications of the sign.

Possible safe spot positions (M4) may not necessarily require a VMS. Here, a static sign may be equally useful, as the safe spot availability is a static information.

All VMS or static signage is described in detail in section 4.3.

Table 18: Identification of the used TransAID communication channel per required communication aspect.

R1	VMS	R2	VMS	R3	VMS	R4	VMS		
C1	VMS	C2	VMS	C3	VMS	C4	VMS		
M1	VMS	M2	VMS	M3	VMS	M4	Static Sign	M5	VMS
		M6	VMS	M7	VMS	M8	VMS	M9	eHMI/ dHMI

The vehicle-centric driving issue information (M9) should be shown in a vehicle-centric way. As eHMI and dHMI both are new forms to present information to others, the consortium decided to perform a VR experiment instead of implementing this channel on the real test vehicles. The study and the eHMI/dHMI approaches are described in section 4.4.

In addition, another way of providing any information to any unequipped vehicle is by including an additional smartphone app or hardware device in the vehicles, which is able to receive information via ITS-G5, cellular (via backend) or any other communication technology. This way of data provision would be very helpful, as it has the potential to reach several people inside any vehicle. On the other hand, this is only helpful, when the information is also provided by several infrastructures, which still is a long way to go. Nevertheless, the possibility is exemplarily implemented for the highway merging scenarios in TransAID. The procedure is shown in section 4.5.

4.3 VMS and static signage

In order to cover the different communication requirements, a set of VMS traffic signs has been designed based on the formulated requirements. Before presenting all the detailed approaches in section 4.3.2, some general investigations need to be done, which are shown in section 4.3.1. The final design of the VMS per TransAID scenario is summarized in Annex A.

4.3.1 General investigations and limitations

One part of the sign is occurring several times: the visualization of a CAV, either prohibiting or demanding CAVs in an area. One of the most important questions of the VMS design therefore was the design of an easy understandable CAV icon.

In Figure 27, some approaches of TransAID are shown. A textual representation “CAV” was one of the attempts. It is understandable only when the term is known, which will most likely not be the case in the near future. Instead, TransAID also looked for a more iconic design. While in July 2019 H2020 INFRAMIX project was presenting a car from the front (see section 3.2.3.2), combined with a WiFi symbol, TransAID in parallel approached this issue by showing a car from the side, also combined with a more stretched WiFi symbol. Since no usability assessment of the sign designs was performed in the project, it was decided to use that sign in the feasibility assessments in WP7, described in D7.2 [47].

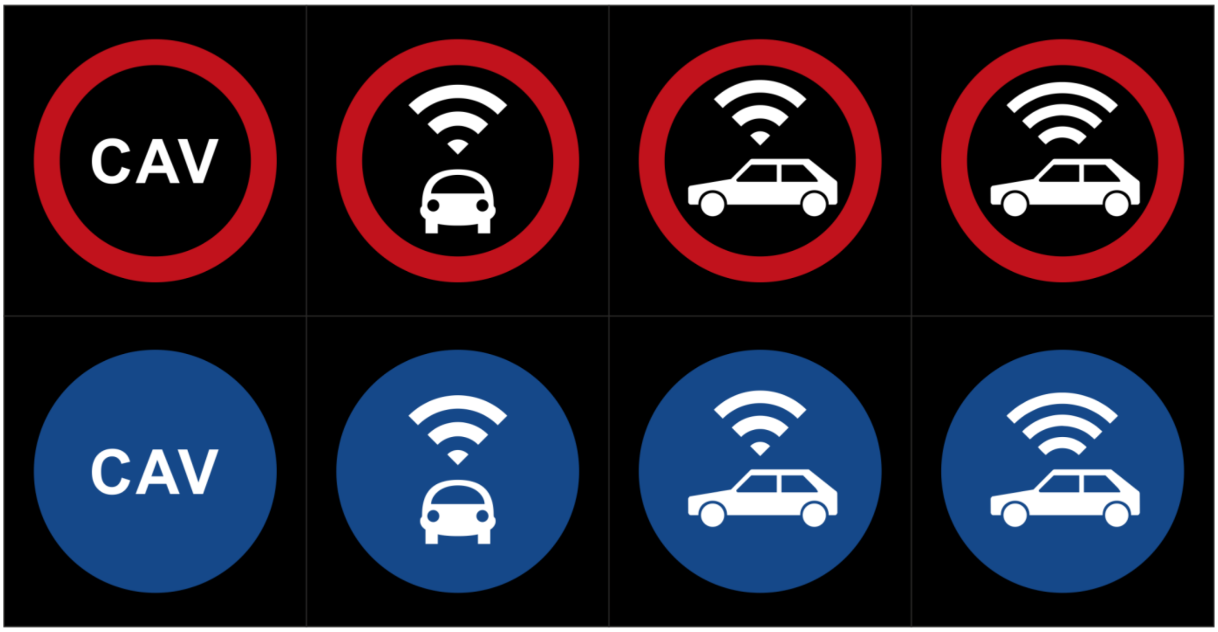

Figure 27: Different designs for showing a CAV. From left to right: plain textual, INFRAMIX design, TransAID intermediate design, TransAID final design

Another important aspect of the VMS design is that current VMS have technical limitations. Some displays can only show a limited number of colours, some only have a very limited resolution. Reason for this is that the displays need to work showing the same image for a long time in all weather conditions, also in strong sun light. Besides, VMS require simple maintenance of individual pixels in case of a malfunction.

The DLR feasibility assessments performed in WP7 are using a nearly rectangular full colour display with a resolution of 39x40 pixels. As result, the shown images of section 4.3.2 need to be resampled for the assessments. As shown in Figure 28, the quality of the sign is drastically reduced, also depending on the method used for resampling. Using anti-aliasing (second from left in the figure), the image is still visible, but very blurry. Down-sampling without anti-aliasing (third from left) leads to sharper edges, but as each pixel then simply gets the colour most available in the original area of that pixel, small areas with several colour changes get hardly recognizable (see vehicle or WiFi symbol in the example figure). Therefore, a manual resampling is done for the feasibility assessment, as shown on the right of Figure 28. Here, the objective is to reduce the details of the image without losing the “message” of the sign.

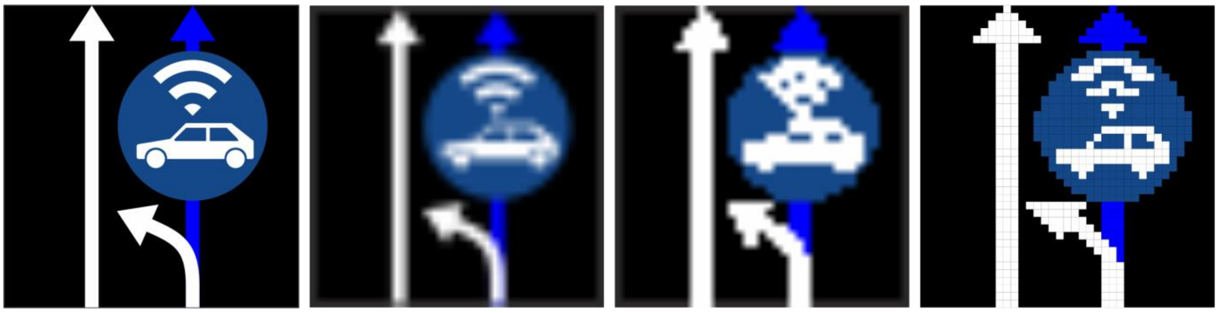

Figure 28: Limitations due to reduced resolutions of VMS on the market. The original image (left) needs to be resampled to 39x40 pixels resolution: with anti-aliasing, without, and manually optimized (from left to right).

In general, we think that the capabilities of VMS, including its resolution will increase in the future. Therefore, the currently required down-sampling is not considered in finding solutions for the TransAID requirements as shown in this chapter.

4.3.2 Requirement specific investigation

In the following, solutions for all required situational information are given. All solutions should be treated as ideas based on expert rating. The shown images are neither validated nor tested, but could be seen as basis for future developments. In addition, traffic signs always need to be put into relation to national signage and design aspects. As this would open up an additional dimension of the design it would overcomplicate the concept of just showing basic ideas about coping with the requirements. Therefore, it has been decided to do the investigation based upon one example design set. In TransAID, the German traffic sign design has been used as basis for TransAID developments.

- *Lane closure/blockages (R1), available lanes/free areas (R2), changed lane purposes (M1)*

In traffic sign design, the indication of closed lanes and available free areas for driving goes hand-in-hand, as drivers need to know what is going on (consequences), and what is expected from them (measure), best with a single glimpse. If possible, also the reason should be shown to enhance the awareness of the upcoming situation. On some available signs, the measure also includes changed purposes of lanes, e.g. the allowance to use the emergency lane or bus lane for driving.

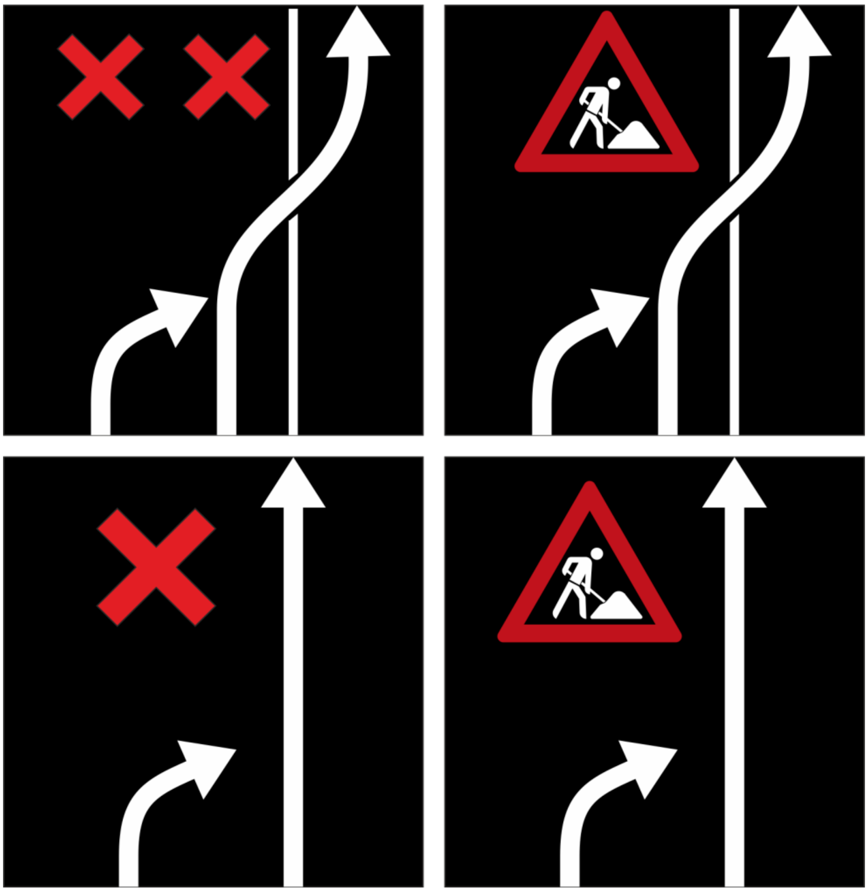

Figure 29: Example VMS designs for blockages and free driving areas (R1, R2, M1)

In TransAID, this approach has been followed. As shown in Figure 29, lane blockages are shown as red crosses (left part of the figure). While this is emphasizing the closure, it sometimes could also be required to emphasize on the reason for the closure. In case of the figure, the reason is upcoming roadworks blocking the lanes (right part of the figure). The allowance to use the emergency lane for driving is indicated by the solid line crossed by the arrow in the upper part of the figure.

Another possibility of combining the information of the reason for the road closure with the consequences and measures is the use of animations, a clear benefit of VMS technology. As shown in Figure 30, this can be achieved by e.g. alternating the regular roadworks sign and the lane closure information.

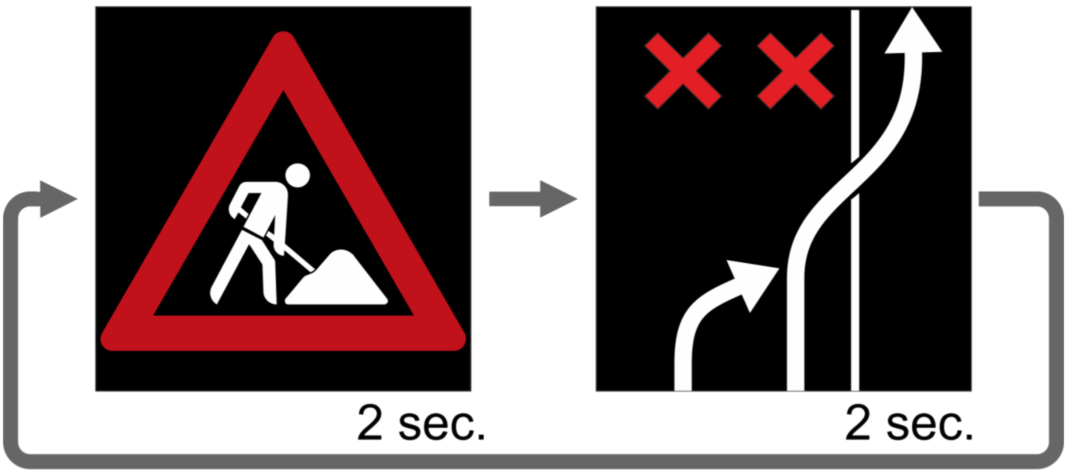

Figure 30: Animated VMS showing reason, consequence and measure

A different approach is needed in case of lanes blocked by traffic jams and vehicles, as it is the case e.g. in TransAID's scenario 1.3, where the off-ramp is blocked. Following the above approach of showing at least the consequences and the measure, the design shown in Figure 31 has been chosen. Here, the warning about an upcoming traffic jam (C1, see further investigations below) is required to raise attention and make drivers aware of possible strong braking (C2) and sudden lane changes (C3) in the vicinity of the off-ramp. In addition, a pictogram of the traffic jam on the off-ramp is combined with the indication of the allowance of the early use of the emergency lane.

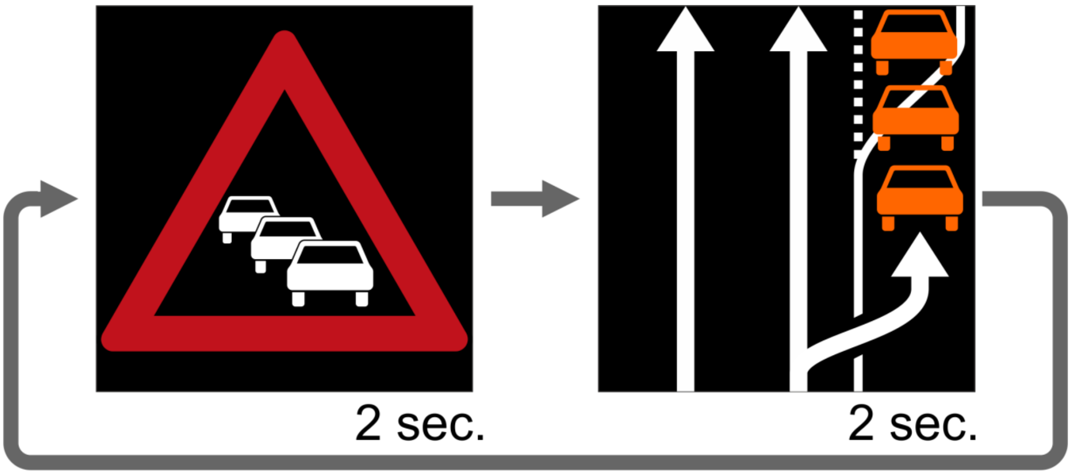

Figure 31: Animated VMS for a blocked off-ramp

- *Automation restrictions (R3)*

Restrictions for automated vehicles can be shown in different ways. Besides the general investigation of the shown symbol for (C)AVs in section 4.3.1, (C)AVs can be either forbidden in specific areas, allowed or prescribed.

Figure 32 shows the different approaches discussed in TransAID. While the upper left image shows the interdiction of (C)AV functionality, the upper right image shows that (C)AV functionality is requested. The latter could also be extended in not allowing the entering without automation functionality.

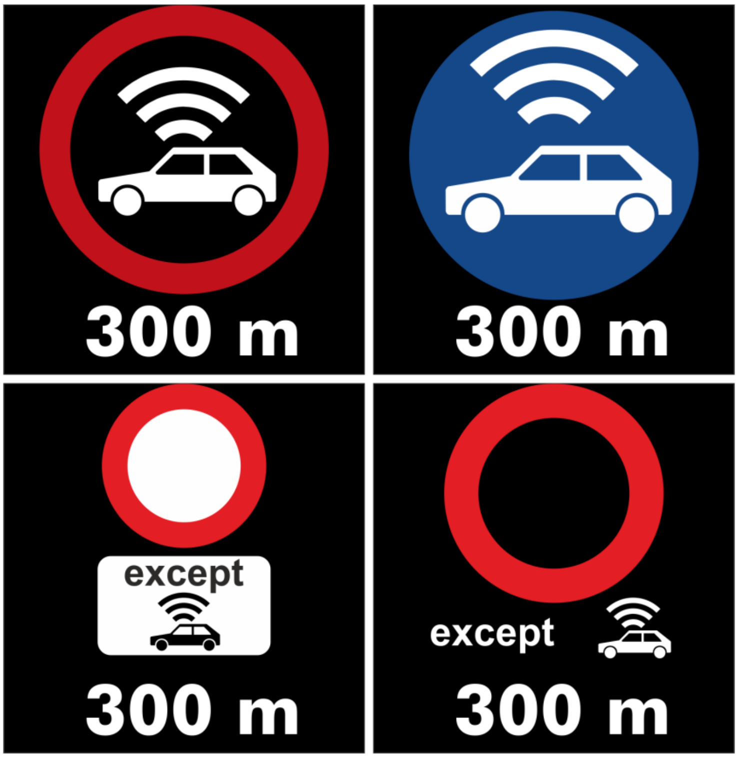

Figure 32: VMS for automated driving restrictions (R3)

- *Areas which need to be handled with attention (R4)*

Existing signage is already including several different possibilities for acquiring the attention of drivers. Internationally, the red triangle is used for this purpose in general, combined with a symbol showing either the reason (e.g. roadworks) or sometimes the consequences (e.g. traffic jams) requiring the attention.

In TransAID, this approach has been followed; examples are shown in Figure 33. In this figure, two versions of the sign are shown. While the black-on-white versions of the sign represent the standard colours also used on static signage, the white-on-black versions are normally chosen for VMS to enhance the readability and reduce blending artefacts.

Figure 33: VMS designs for areas which need to be handled with attention, unspecified (based on German sign 101, above) and special case example roadworks (based on German sign 123, below) (R4)

- *Specific areas, which need to be handled with attention (R4): Traffic jams (C1), sudden braking (C2) and sudden lane changes (C3)*

Similar to the more general advice given before, there are also several signs, which are raising attention about possible abrupt changes in driving behaviour. Warning about traffic jams (Figure 34) is an example for such signs, indicating that drivers need to be prepared for sudden braking of vehicles and a high risk for being stuck in traffic jams.

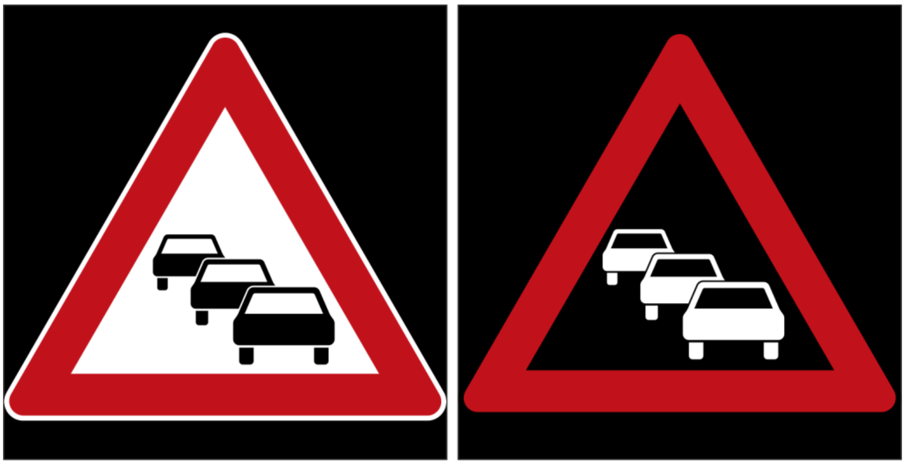

Figure 34: VMS design based on German sign 124 warning about upcoming traffic jam (C1)

In Germany, also other signs escalating the danger are available as static signs, as shown in Figure 35. In those signs, the danger esp. of strong braking (C2), but also implicitly by sudden lane changes being the reason for strong braking manoeuvres (C3), is shown more drastically.

Figure 35: Static signs warning about possible collisions due to any reason (based on German signs 101, 124 and 1006-31, C1, C2, C3)

In TransAID, VMS adaptations are suggested, which can be used when the standard sign showing the danger of upcoming traffic jams is not sufficient (Figure 36).

Figure 36: Possible VMS adaptations for the risk of crashes (C1, C2, C3)

- Further specific areas, which need to be handled with attention (R4): Sudden braking (C2), sudden lane changes (C3) and possible ToCs and MRMs (C4)

In case there is a specific source of danger, which should not be covered by a more general iconic design, text messages can be chosen to express the specific reason for driving with special attention.

Although text messages are always less intuitive, require more attention and time to be read and understood, and require reading abilities of the driver (and possibly also of traffic sign recognition software used in AVs), text messages may focus the attention on specific aspects more clearly, allowing the road operators to give specific hints. Figure 37 shows some possible texts and signs for C2, C3, and C4.

Figure 37: Different examples for extended text messages on VMS (C2, C3, C4)

- *Traffic Separation (M2) and advice to use a specific lane (M3)*

When traffic needs to be separated, the first question is which traffic should be separated. Cities today often already have separated bus or taxi lanes, where a marking on the road is sufficient. In those cases, the correct use of the lanes is directly visible, as only busses or taxis should drive there. Since electric vehicles entered the market, several cities also planned priority lanes for those to foster electric mobility. In TransAID, the idea is to separate CAVs from others. Since CAVs/AVs look mostly like CVs/LVs, it will be difficult for people to identify the correct usage, possibly leading to misuse of such lanes. Furthermore, separation of CAVs is considered to be useful only if the automation functionality is switched on in those cars. Nevertheless, we identified a couple of options for traffic separation of (C)AVs in the project, shown in Figure 38. Here, lanes can be marked with a clear driving interdiction combined with an exception, to raise the awareness that it is not allowed to use such lanes. Since blue is the colour for automated driving in several projects (starting in EU-FP7-HAVEit), it could be possible to also change the colour of that driving lane. In that case, an arrow indicating that lanes should be changed for the other vehicles (M3) can also be helpful. In the same way, lane advice for different types of vehicles may be implemented by using different lane colours.

Instead of the negative driving interdiction, it could also be helpful to suggest traffic separation in a positive way as it is shown on the right of Figure 38.

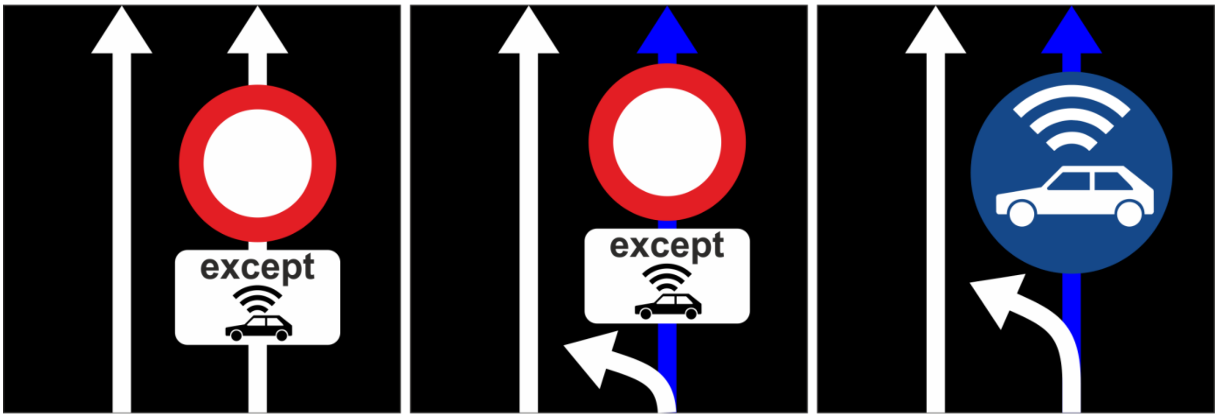

Figure 38: Different approaches for traffic separation (M2), combined with advice to use a specific lane (middle and right, M3)

- *Availability of safe spots (M4)*

Safe spots should be marked with a static sign, as they are not moving in general. In TransAID, several ideas have been discussed (Figure 39). As long as the number of CAVs in cities is low, it could be possible to combine possible safe spot positions with parking spaces for CAVs. Of course, when the number of CAVs on the roads is increasing, this is not helpful anymore since several safe spots will be blocked. In that case, as well as on highways, safe spots should get a more exceptional character. In Germany, the sign 324 is existing, which is marking an emergency stop position on highways without emergency lane. It could be one option to simply use this sign, or to extend it with a CAV sign, as shown on the right of the figure. Flipped, this sign could also be used for safe spots on the left side of a highway.

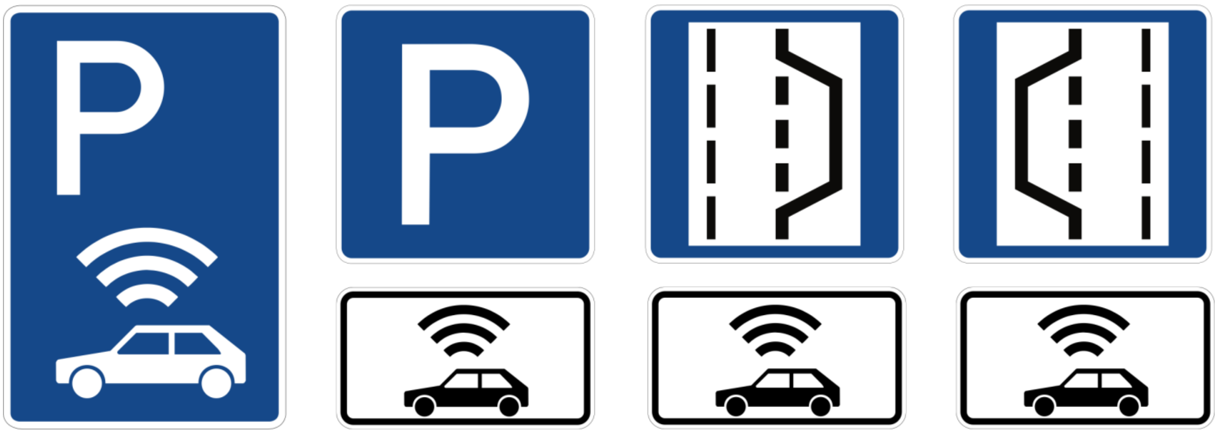

Figure 39: Static signs for parking restrictions (based on German signs 314 and 315, left) and safe spots (right, based on German sign 324, M4)

- *Speed limits (M5)*

Speed limits (M5) should be shown in the way as it is already defined nationally. It may be possible to extend the sign with additional limitations, e.g. when a speed limit is only valid for CAVs/AVs or LVs/CVs.

- *Keeping larger distances (M6)*

In Germany, there is already a sign for minimum distances for trucks (Sign 273-70). This sign could be adapted also for cars as shown in Figure 40, upper row. To emphasize on the distance, it could be helpful to also introduce an arrow on that sign which is typically used for distances in drawings, as shown in the below row of the figure.

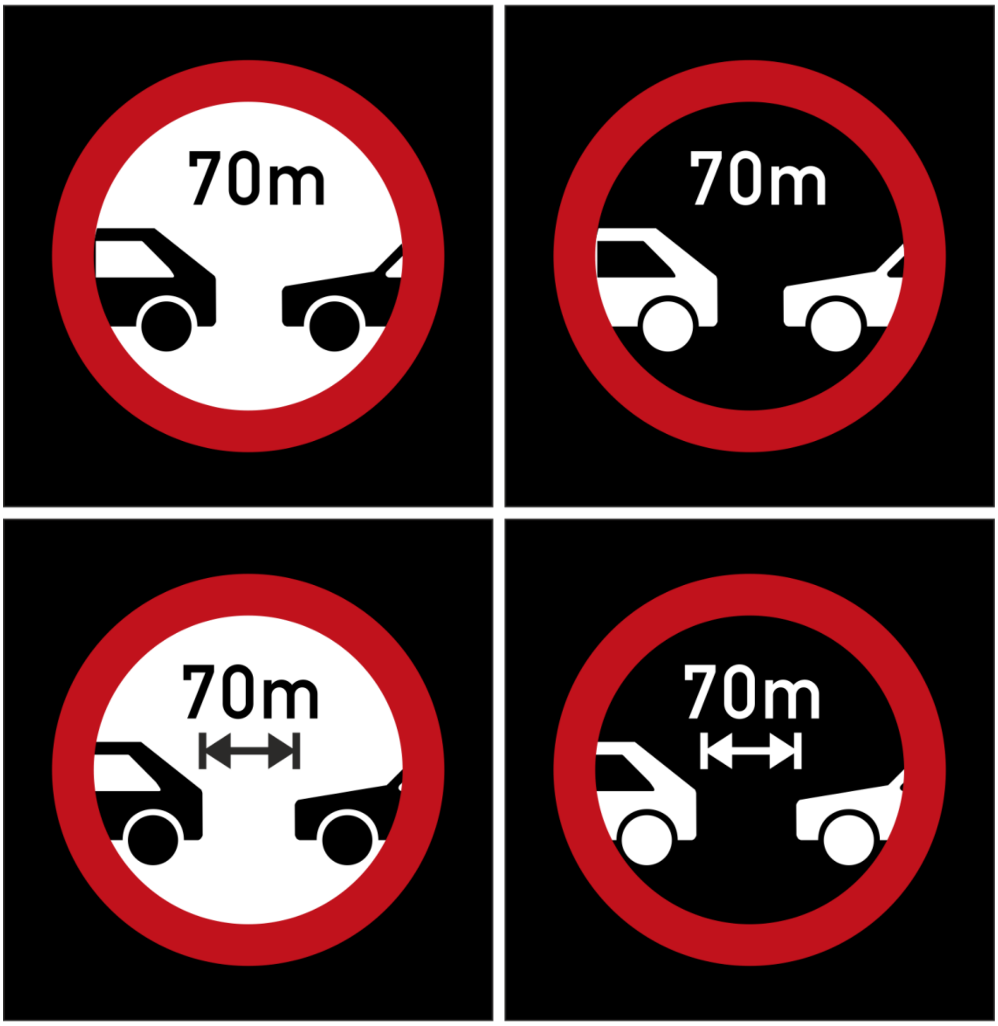

Figure 40: VMS advice for keeping distances (M6)

- *Forcing zipper lane changes (M7)*

There are several options of showing the necessity of zipper merging in different countries. Based on the corresponding US sign for zipper lane changes, which only shows lane markings and a merging arrow, the top left design of Figure 41 has been created. This could also be adapted to necessary lane changes to the left or right lane as shown on the bottom left. In several countries, the simple showing of arrows has been enriched with vehicle icons in different colours, as this emphasizes on the zipper property of the lane change, where cars of both lanes should alternate whenever traffic gets denser. The right part of Figure 41 shows this approach.

Even more emphasis could be placed on the zipper property by using an animated VMS, as shown in Figure 42. Here, it is directly shown how the vehicles on both lanes should act ideally.

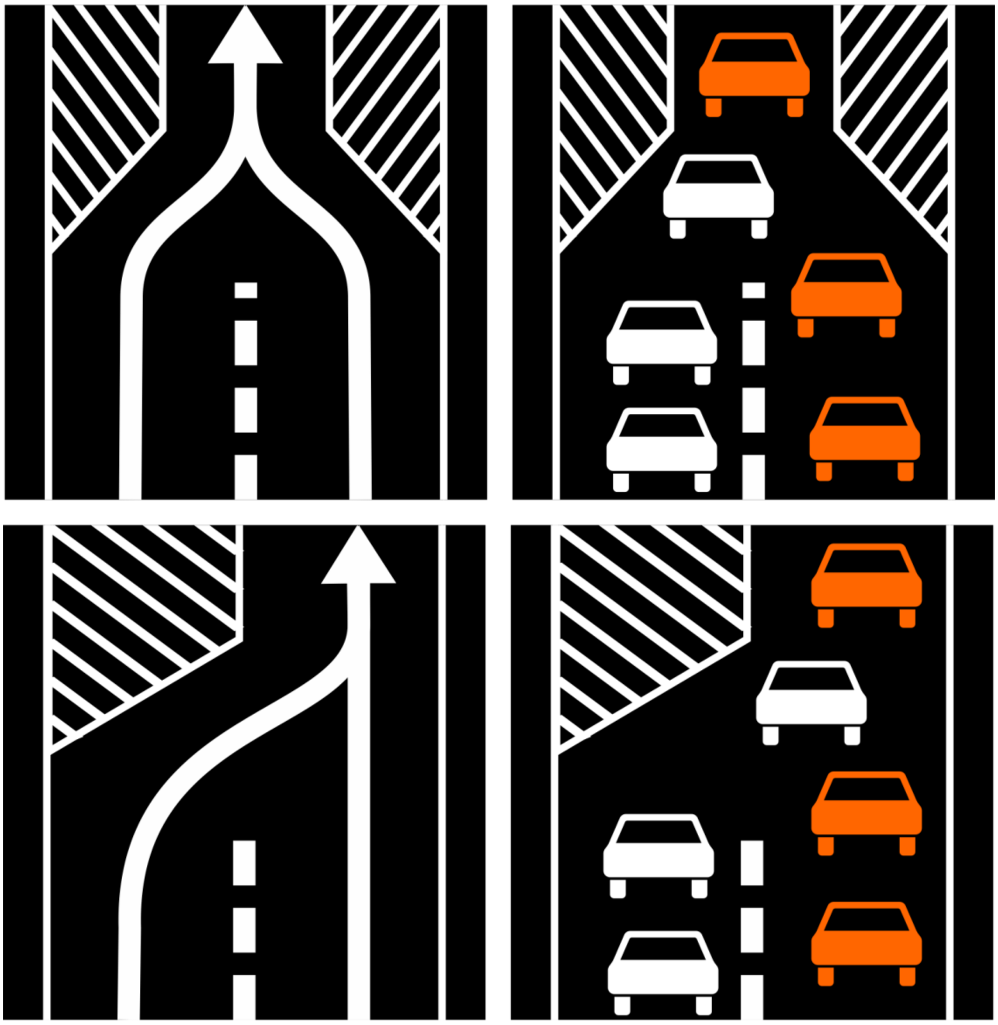

Figure 41: Different zipper merging displays (M7)

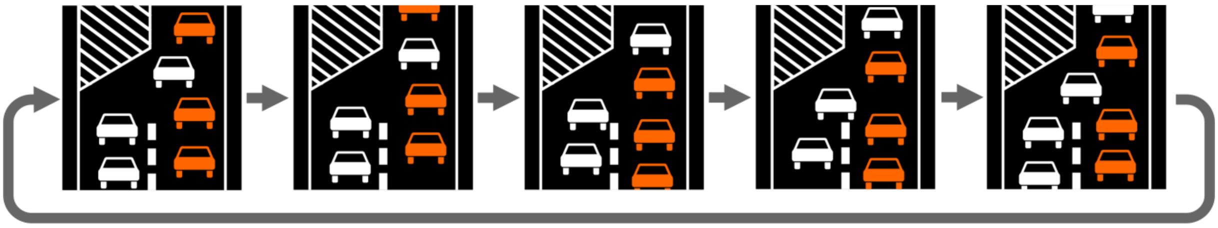

Figure 42: VMS zipper merging example animation (M7)

- *Act with special caution and cooperatively (M8)*

The advice to act with special caution and in a cooperative way (M8) may be given by textual messages on the road, possibly similar to the well-known messages “Drive carefully”, “Someone loves you – drive with care” or “Don’t drink and drive”. Esp. cooperative driving should be addressed in this way, by simply reminding people about their duty to act nicely, anticipatory and defensive when driving.

4.4 Vehicle-centric signage

Besides having infrastructure guiding vehicles through the difficult situations of TransAID scenarios, also the direct information from (C)AVs who have issues in fulfilling the driving task to the surrounding vehicles has been considered as a useful step. If the driver is not able to take over control of the (C)AV, it will perform a MRM to keep the vehicle in a safe state. In TransAID, also MRMs into safe spots are in focus, where the MRM itself is accompanied by a lane change. To guarantee a safe and unproblematic interaction in this special situation, it is necessary to know what kind of and how much information is needed.

To get a better view on this new approach, it has been decided to perform a small Virtual Reality (VR) user study at DLR, which is described in the following.

4.4.1 Setup

As TransAID mainly focusses on urban scenarios, the study concentrated on those. Two different eHMI concepts were tested. In both concepts, a LED light strip was indicating that the vehicle is driving automated. One concept was based on the usage of standard hazard warning lights, the other on showing issues by changing the colour of the light strip. In the latter case, the LED light strip is also animated in order to show the intention of changing lane into the safe spot, adapted from existing sweeping turn signal indicators. In addition, a specific vehicle movement (dHMI) is part of the study. Here, the (C)AV begins to slightly swerve on the driving lane to get attention from drivers behind and to make them understand that the vehicle has issues.

The study covered six different urban scenarios. The main research questions addressed in this study were:

a) Do (C)AVs have to inform traffic participants about problems and resulting manoeuvers?

b) If yes, is there a preference for the information strategy?

Therefore, a VR simulation using Unreal (Figure 43) was used to show six different variants to communicate.

Figure 43: VR setup at DLR, using the Unreal Engine on a HTC Vive Pro headset

The different HMIs and the urban scenario are exemplarily shown in Figure 44.

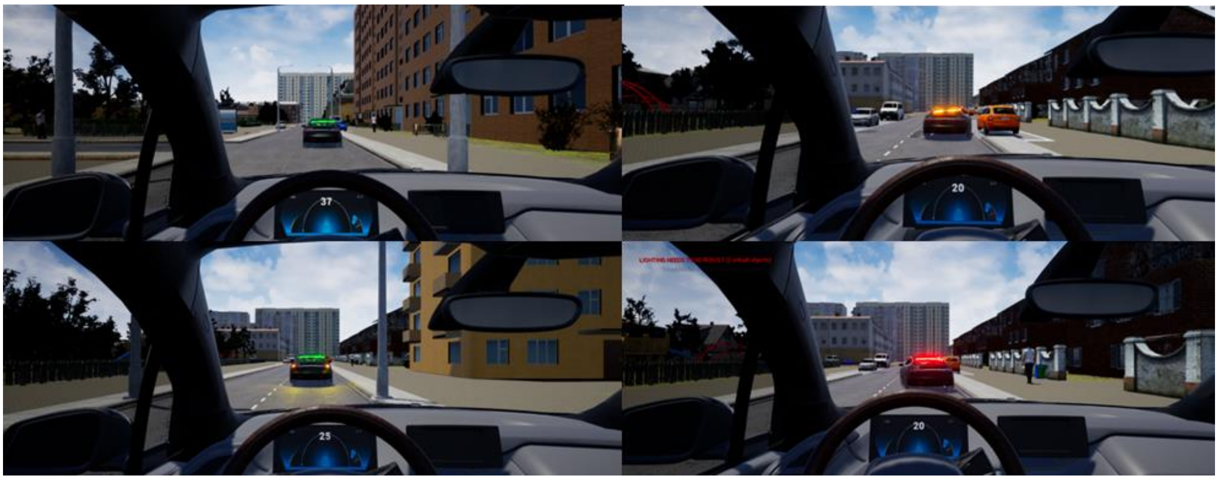

Figure 44: Vehicle-centric displaying of a MRM in a VR study. Top left: Normal driving with greenish automation indication on the light strip. Issues are indicated either by hazard warning lights (bottom left) or by the light strip, first plain (bottom right), then sweeping (top right)

4.4.2 Procedure

To investigate the needed information strategies, 10 participants (male = 4; female = 6; M = 23 years old, SD = 5.5) took a seat on the driver's seat of a vehicle in a VR simulation. This vehicle was following a (C)AV until it performed the MRM by showing the respective information strategy in the different scenarios, as described in the following Table 19.

Table 19: Usability study - six scenarios

Scenario	Information strategy
1	(C)AV do not inform (baseline)
2	(C)AV inform by hazard warning lights
3	(C)AV inform by the LED light strip constantly flashing
4	(C)AV inform by driving waving lines
5	(C)AV inform by driving waving lines + hazard warning lights
6	(C)AV inform by driving waving lines + LED light strip constantly flashing

After each run, the participants were asked about the perceived usefulness and satisfaction using the van der Laan scale. Further questions focused on the information content, a ranking and the subjective perception of the test persons.

4.4.3 Results

The investigation delivered following results:

Table 20: Results of the vehicle-centric eHMI/dHMI VR study

Ranking (Inf. Content)	Scenario	Information strategy	Usefulness	Satisfaction	Inf. content
1	3	LED light strip	0.78	0.35	1.45
2	2	Hazard waring lights	1.04	0.8	1.03
3	5	Driving waving lines + hazard waring lights	- 0.08	-0.64	0.64
4	6	Driving waving lines + LED light strip	0.32	-0.46	0.47
5,5	4	Driving waving lines	-0.86	-1	-1.59
5,5	1	Do not inform	-1.12	-0.85	-1.67

Note: Usefulness & satisfaction [-2;2]; infromation content [-3;3]

It is shown that traffic participants need to be informed about (C)AVs' problems and the subsequent driving behaviour. 70% would like to be better informed that the (C)AV will perform a lane change to the right when entering the safe spot. The concept of a dHMI was assessed as destructive by 90% and leads to misunderstanding ("I thought someone died"), most likely because the swerving was too strong in the experiment.

Furthermore, a significant difference of usefulness and satisfaction was found between all six scenarios. Hazard warning lights scored as well as the LED light strip. The authors of the study believe that the reason for this is two-fold. On the one hand, the LED light strip was designed very bright, making it as important as warning lights on current emergency vehicles. Also the colour of the light is difficult, as it was chosen to take a warning colour (here: orange red), which in some countries is similar to the colour of the rotating or strobe lights of emergency vehicles. On the other hand, people are used to see hazard warning lights when vehicles have issues. The fact that switched on hazard warning lights make it impossible to use indicators to give directional information of a lane change has been also recognized by the subjects, although the sweeping of the LED light strip could not compensate this.

In summary, the LED lights offer additional information, but most likely the design chosen in this experiment is not optimal, reducing the usefulness and satisfaction. More effort should be taken into the design of a specific external HMI for (C)AV states and issues, as already small changes in the design will probably change the impact. As HMI is not part of the TransAID project, this needs to be done out of the project. Only by addressing this topic in detail, future behaviour of (C)AVs can be understandable for surrounding traffic, which is key for a smooth integration.

4.5 Additional service based information

Besides providing information by road side infrastructure or (C)AVs, it is also possible to use back-end systems for informing CVs and LVs via e.g. a smartphone application.

In TransAID use case 2.1, a motorway merging scenario, a merging assistant system is developed to assist CVs and CAVs in on-ramp- highway merging. The simulation study was performed in D4.1 [48], D4.2 [1] and D6.2 [4]. In a nutshell, the algorithm searches for merging gaps and calculates speed advices for a C(A)Vs on the on-ramp and acceleration lane during merging. For the second project iteration, the algorithm is enhanced with pairing an on-ramp C(A)V with a mainline C(A)V if there are no gaps found. The speed advice for the mainline C(A)V to slow down and open a gap are implemented as well, under the assumption that speed advice for the on-ramp C(A)V and mainline C(A)V are supported with a 100% compliance rate. In addition, it is assumed that the communication between vehicles and infrastructure is ideal and punctual.

For TransAID WP 7, a demonstration featuring merging assistant application is under preparation, which is planned on the A13 highway in the Netherlands. In this deliverable, besides informing legacy vehicles with means supported by the local infrastructure (such as traffic control measure described in section 3.1.2.1), the merging assistant application and the system architectures are developed and explained here.

This merging assistant application roots from a single code base (written in Java). This web version application embodies the merging assistant system, which is based on the merging assistant algorithm. To a road user/passenger, the most intuitive representation is to visualize the application on devices close to him/her. Therefore, there are two user interface perspectives: in-vehicle and on the roadside, to express the customized application.

Figure 45 and Figure 46 demonstrate the roadside and in-vehicle application layouts. The main objective is to provide features and services of the application in a dynamic but not distracted manner. The two figures below show the information that is already undergone time synchronization.

Figure 45: Roadside application layout

Figure 45 consists of three blocks. The bottom block is the overview of Scenario 2.1. The merging area is composed of a curved one-lane on-ramp merging into the mainline highway. The TrafiRadar camera (located on the overheads viaduct perpendicular to the highway) will monitor and fuse detected vehicles' speed and positions into the loop detection from the MTM (motorway traffic management) system.

From the roadside perspective, the overview of the entire road network is foremost important but the zoom-in observation on the merging area is crucial as well. Therefore, the right-above block shows the real-time images from the camera source, which provides a direct visual streaming of the merging behaviour.

The information provided on the left-above block is categorized into two parts. The right part indicates the status of the on-ramp ego vehicle (at least CV). Measurements such as distance to merge and ego vehicle speed are updated every 100 ms. The left part gives the advice to the on-ramp ego vehicle for its future merging activity. In the instance of the layout snapshot, the advised speed for the on-ramp ego vehicle to merge into a mainline rightmost lane gap, is 80km/h. Since March 16, 2020, the speed limit on all Netherlands' highway during 06:00 to 19:00 is 100 km/h, the on-ramp speed limit is sometimes lower, based on the curvature/condition of the on-ramp. Moreover, one can also see whether the on-ramp CV has accepted or declined the advice.

Figure 46 shows the in-vehicle application layout and consists of three blocks as well. This layout is intended to present a native compiled UI to the driver inside the on-ramp ego CV. The right-below block gives the downstream traffic situation overview a few time steps ahead. The right-above block shows the speed advice information calculated by the merging assistant. In accordance with the roadside application layout, several cells such as the time to merge, the advisory speed, the distance to merge and the interact button are implemented. The accept- or decline-button is one-push interaction to acknowledge and confirm the speed advice.

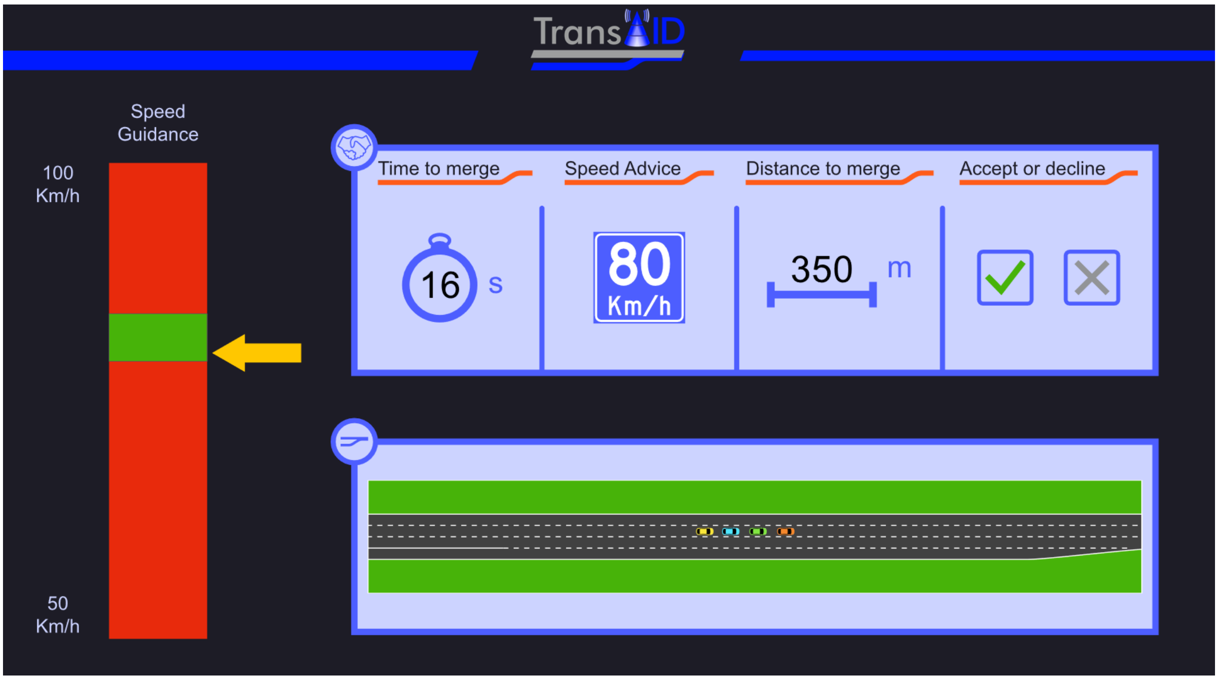

Figure 46: In-vehicle application layout

The speed guidance bar on the left of the figure stands out to the driver. The bar can be considered as a speed axis from 50km/h to 100km/h. The yellow arrow is the current speed of the driver, which is usually constantly adjusting. The green stripe is the speed advice that is offered by the merging assistant system. Following the guidance of the merging assistant application, the driver in the on-ramp ego CV should aim for the middle of the green stripe.

To show an example of how to realize the web version application, the components of the in-vehicle layout interface and their relations are indicated in Figure 47. The static image of the html, svg files are pre-made and sent to WebServer, which is accessible via webpage in any mobile devices that has a web browser. The real-time updated and calculated data are fed from the DataServer to the webpage via web sockets. The real-time updating information has cycled through the mechanism on the left part of the figure below.

The Geonet daemon is running on the OBU (ITS-G5) in the CV, which enables CAM, CPM and MAP (also via the RSU) sending from the CV vehicle to the MergingAssistant. After information syncing, processing and analyzing, the speed advice are included in the MCM messages. MCM and CAM are sent from MergingAssistant to the vehicle. At runtime, DataServer updates relative information every time step accordingly for the WebServer and webpage display.

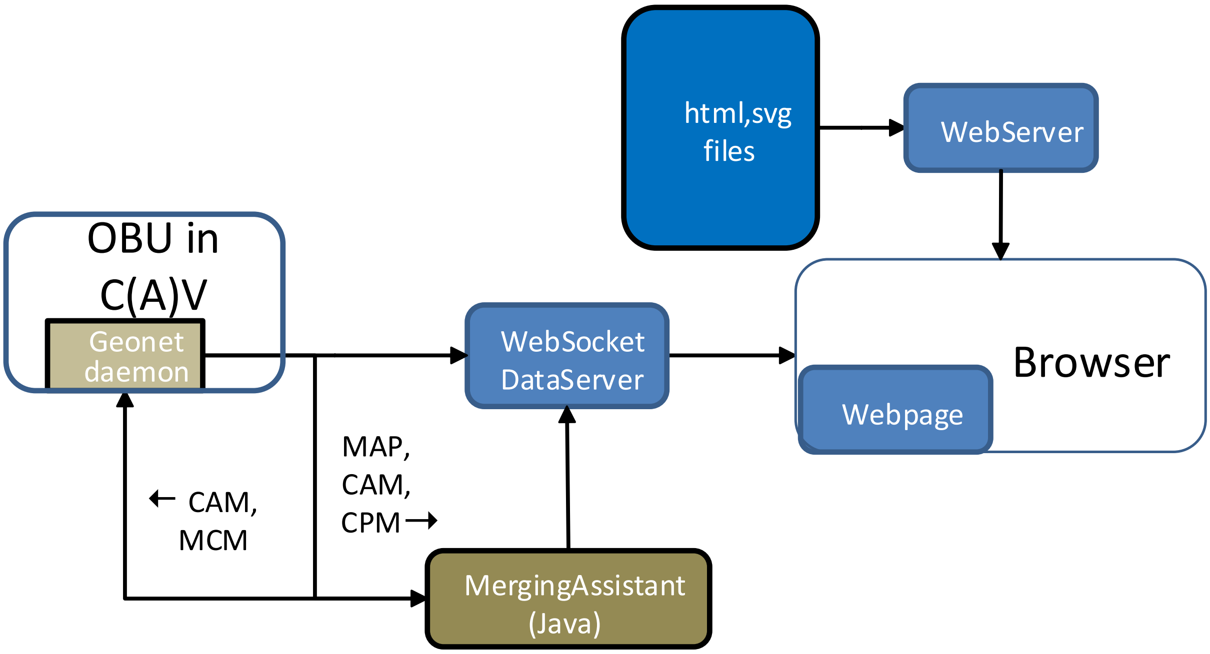

Figure 47: Components of the in-vehicle layout interface

The system architecture of the merging assistant application can be divided into two levels: high-level architectures and low-level architecture. The high-level architecture shows the conceptual design that defines the structure of the application, which has been explained in D4.2 [1] in a simulation environment. In addition, to ensure the field integration of the merging assistant, the field architecture conceptual design will be discussed in D7.2 [47].

The low-level architecture focuses on the components of merging assistant application, from the perspective of the roadside and in-vehicle, which contains the actual designs for hardware, software, data-exchange and communications.

Figure 48 has two halves: the above part encapsulates the roadside architecture and the below part the vehicle side architecture. These two parts can be interpreted from left to right (above half), then from right to left (below half).

Starting with the detection data (such as Loop ID, vehicle speed, length) that are retrieved via inductive loop detectors and sent to the MTM outstation, on the on hand, these data are transmitted via MTM system (cable connected) to the queue maintenance module of the core program of the merging assistant application. On the other hand, the tracking sensor data (such as vehicle speed, position and lane) retrieved via camera or other technology are input to the sensor interface. The two sources of data are fused and then pushed to the queue maintenance module.

The LDM (local dynamic map) module already has loaded pre-made static infrastructure configuration and now gets input from the queue maintenance module. The LDM holds the information for message encoding (such as MAP, CPM and MCM) and the Geonet daemeon running on the RSU holds the mechanism for message encoding/decoding. The LDM also provides inputs for the speed advisory calculation module. To realize the function of the speed advisory calculation module, the task scheduler needs to perform three steps: 1) progressing the queue model every 100 ms; 2) updating the speed advice; 3) preparing MCM, which contains the speed advice for message encoding and then transmitting.

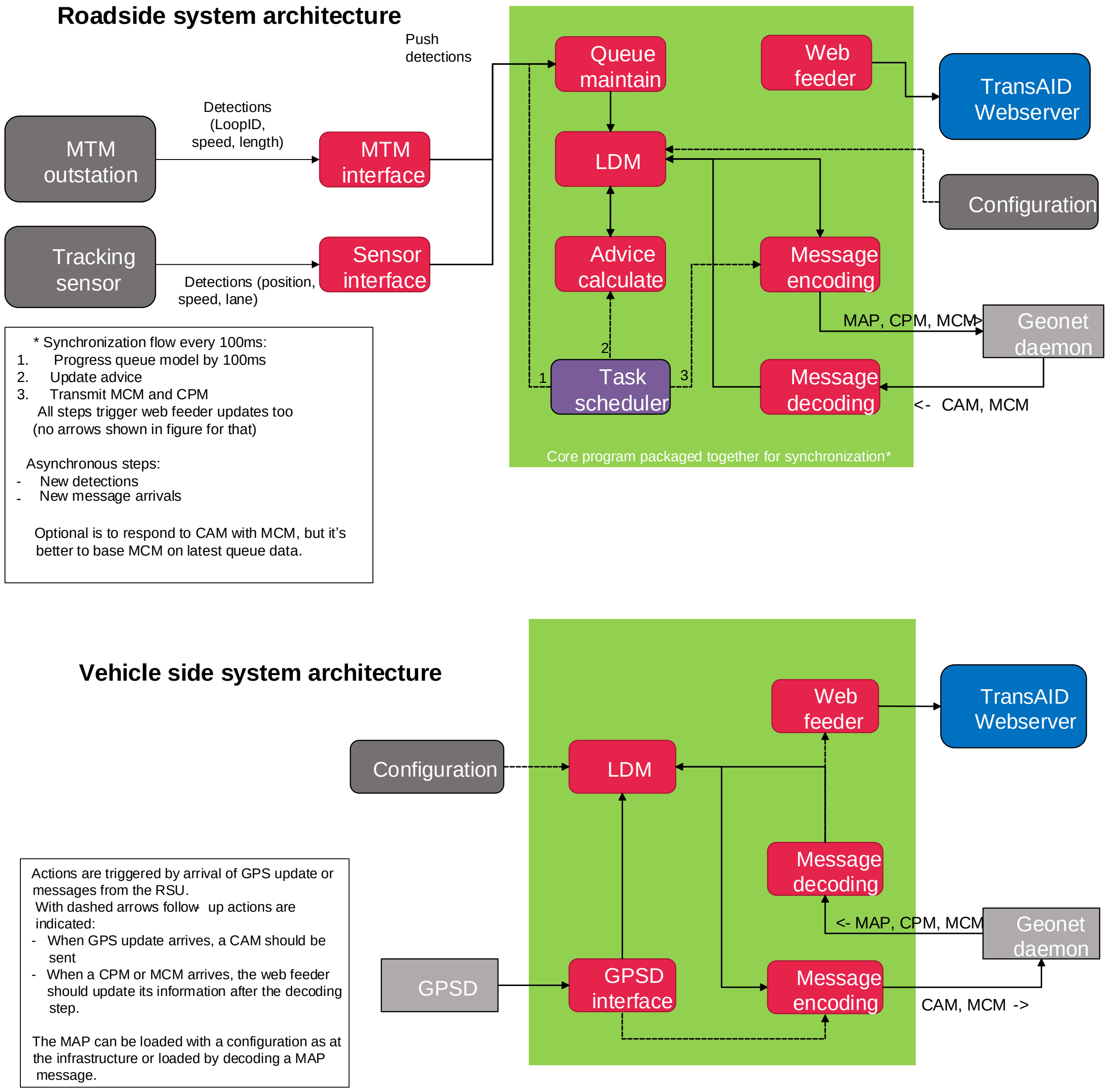

Figure 48: System Architecture of the merging assistant application

The TransAID Webserver on the right of the above half architecture is the one on the right of the below half architecture. The Geonet daemon running on the OBU receives CAM and MCM from the Geonet daemon running on the OBU. The vehicle data configuration provides parameters of the vehicles to the LDM, while the GPS daemon updates are triggered by the arrival of GPS updates or by the arrival of messages from RSU. Data flow of the latter goes through GPSD interface to the LDM module, which provides inputs to encode CAM and MCM messages in order to send to the RSU.

The LDM can load the topology of the merging area with the infrastructure configuration or load the map after decoding the MAP message. The TransAID Webserver should update dynamic information after a CPM or a MCM is decoded. The process above follows the time synchronization of 100 ms.

It should be noted that the merging assistant application is currently under construction. Modulation and feature/function shift could happen in a later phase when it is implemented in a field demonstration.

While the above description is focusing on CVs having an ITS-G5 OBU, it could also be possible to create a system, which is based on a mobile device and a backend. In this case, the mobile device is needed for displaying, but also for assessing the currently driven speed (e.g. via GPS) and the position. To achieve this, the infrastructure must be able to send MAP, CPM and MCM data with low latency to vehicles via a back-end, probably by using future 5G technologies. Besides the technological part, it has to be clarified how the driver of a CV or LV can accept the speed advice without getting distracted too much.

As said, TransAID is neither investigating HMI issues nor 5G communications, but the mentioned approach could bridge between current low ITS-G5 penetration rates and the full potential of the service.

5 Conclusions

This deliverable discussed several options regarding how unequipped vehicles should be addressed when setting up future traffic management measures, esp. dealing with the introduction of automated vehicles in mixed traffic and the related limitations of such vehicles. As shown in D4.2 [1] already, automation limitations will have an impact on traffic efficiency and safety, which needs to be addressed. On the one hand, it is crucial to inform the automated vehicles directly about measures, but on the other the full potential can only be achieved when as many vehicles as possible are adapting their behaviour. Therefore, it is highly relevant to identify good ways of addressing unequipped vehicles.

By analysing communication requirements, this deliverable is setting the basis for informing unequipped vehicles, separated in information about the reason of a situation, the consequences and the measures to be taken. After reviewing existing technologies to provide this information to unequipped vehicles, it has been decided in TransAID that the project will focus on VMS, external HMI of a CAV and additional information provided on mobile devices individually.

All three aspects are discussed in detail. Some of the solutions are prototypically implemented in WP7, esp. different VMS designs and a mobile device solution for highway merging. Results will be presented in the upcoming second iteration version of D7.2 [47]. Others, like the external HMI of CAVs are only implemented virtually, as HMI in general is not part of the TransAID project.

Finally, it should be noted that this deliverable only summarizes ideas how unequipped vehicles should be included in the design of future traffic management measures. The provided signs are neither internationalized in their appearance nor tested. Therefore, further investigations will be required in the future, as such approaches are mandatory to avoid negative impacts when automated driving enters the road broadly.

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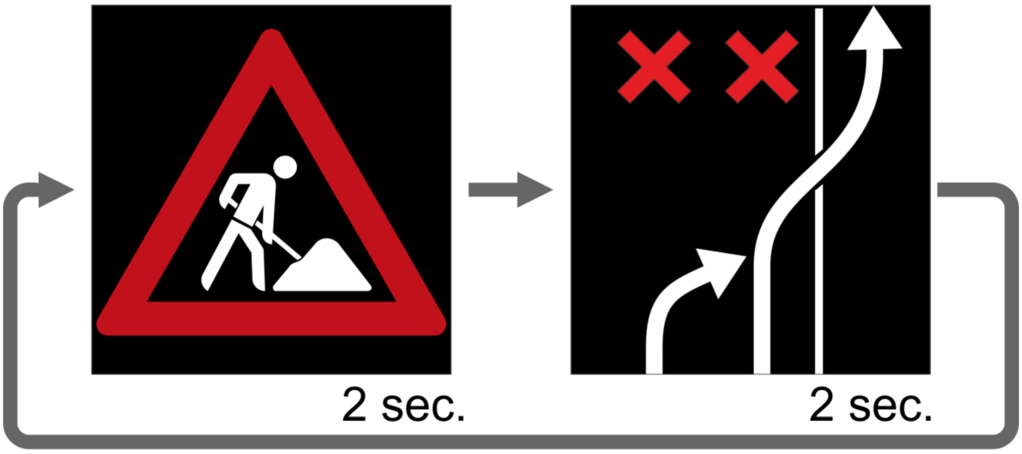
Annex A. Chosen sign layouts per scenario

This annex presents the chosen sign layouts for the prototypical implementation in WP7. Here, only one rectangular VMS is available, reducing the possibilities. Therefore, not all requirements are achieved.

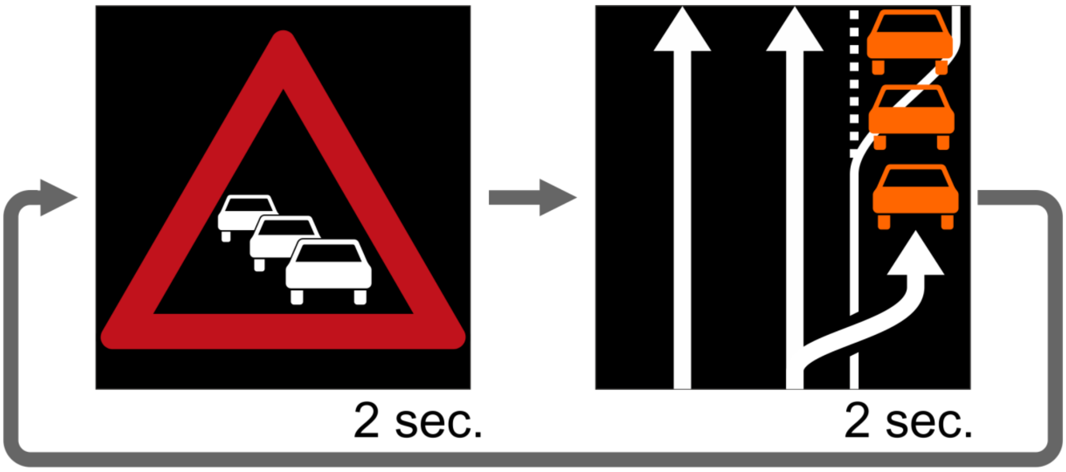
Scenario 1.1:



Requirement	Description	Fulfilled	Comment
1.1_R1	Information about the blockage of the free lanes and the availability of a bus lane for passing the incident	✔	
1.1_C1	Traffic jams due to the bottleneck on the road	✔	implicit
1.1_C2	Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road.	⚠	needs common understanding of AV functionality; enough attention awareness shown
1.1_M1	Clear allowance to use the bus lane in the vicinity of the workzone, possibly even earlier so that drivers have time to get prepared	✔	
1.1_M2	(Early) reduction of the speed limit to minimize effects of strong braking	⚠	Should be shown earlier on additional sign
1.1_M3	Keeping larger distances between the cars to allow smoother lane changes and to prevent shockwaves	⚠	Should be shown earlier on additional sign

1.1_M4	Forcing zipper lane changes in front of the workzone	⚠	Should be shown on additional sign
1.1_M5	Advice vehicles to act with special caution and cooperatively	✔	implicit
1.1_M6	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles	⚠	Should be shown by individual vehicles

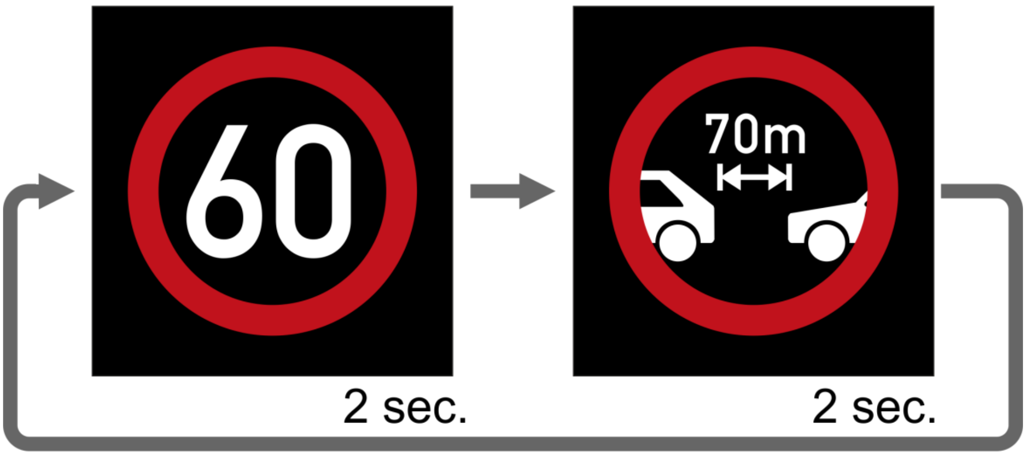
Scenario 1.3:



Requirement	Description	Fulfilled	Comment
1.3_R1	Information about the queue on the off-ramp and the availability of an emergency lane	✔	
1.3_C1	Traffic jams due to strong braking of vehicles	✔	implicit
1.3_C2	Sudden lane changes to the emergency lane, when drivers understand that the off-ramp is blocked	✔	
1.3_C3	Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road	⚠	needs common understanding of AV functionality; enough attention awareness shown

1.3_M1	Clear allowance to use the emergency lane in the vicinity of the off-ramp, possibly even earlier so that drivers have time to get prepared	✅	
1.3_M2	(Early) reduction of the speed limit to minimize effects of strong braking. Possibly, there are different speed limits per lane, having the lowest speed at the lane closest to the off-ramp	⚠️	Should be shown earlier on additional sign
1.3_M3	Keeping larger distances between the vehicles to prevent shockwaves	⚠️	Should be shown earlier on additional sign
1.3_M4	Advice vehicles to act with special caution and cooperatively	✅	implicit
1.3_M5	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles	⚠️	Should be shown by individual vehicles

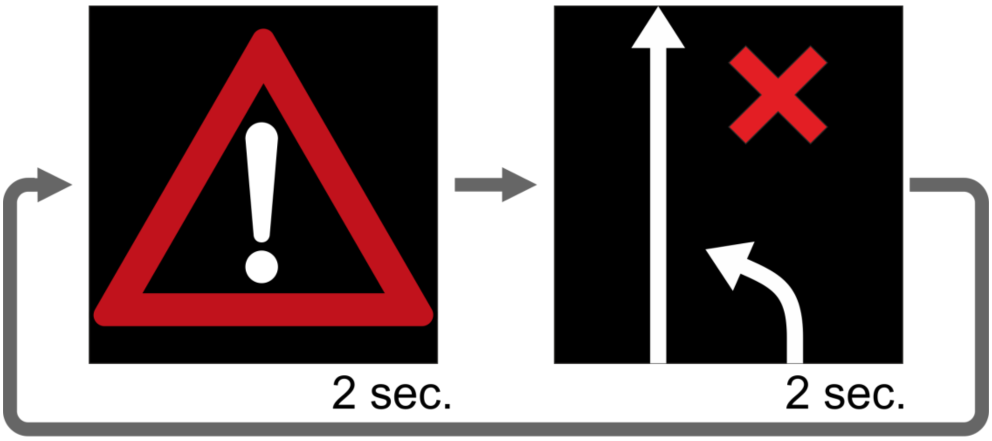
Scenario 2.1:



Requirement	Description	Fulfilled	Comment
2.1_R1	Information about difficult merging situation ahead, on the ramp and on the highway	❌	Skipped, must be taken from surrounding environment
2.1_C1	Strong brakings and accelerations of vehicles	⚠️	implicit

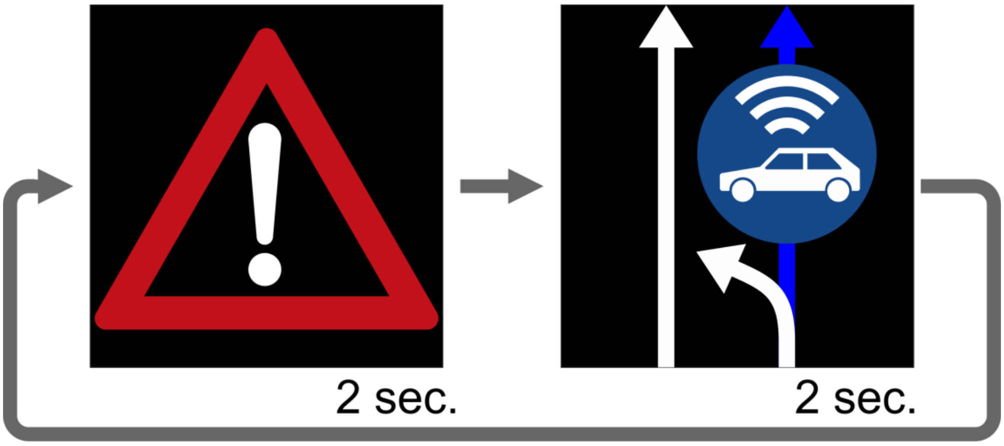
2.1_C2	Close mergings with low distances and headways, leading to dangerous situations		implicit
2.1_C3	Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road		needs common understanding of AV functionality; enough attention awareness shown
2.1_M1	(Early) reduction of the speed limit to minimize effects of strong braking. Possibly, there are different speed limits per lane, having the lowest speed at the lane closest to the on-ramp		
2.1_M2	Keeping larger distances between the vehicles to prevent shockwaves and to allow (cooperative) lane changes		
2.1_M3	Advice vehicles on the highway's right lane to act cooperatively, e.g. by changing to the left lane, and with special caution		Should be indicated by e.g. lane markings
2.1_M4	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles		Should be shown by individual vehicles

Scenario 2.3:



Requirement	Description	Fulfilled	Comment
2.3_R1	Information about incident on the right turn lane	✔	
2.3_C1	Traffic jams due to the bottleneck on the road	⚠	implicit
2.3_C2	Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road, either in front of the incident or on the through lane when passing	⚠	needs common understanding of AV functionality; enough attention awareness shown
2.3_M1	Clear allowance to use the through lane also for right turning	⊗	Skipped, as less relevant (unequipped vehicles will do lane change when possible)
2.3_M2	(Early) reduction of the speed limit to minimize effects of strong braking	⚠	Should be shown earlier on additional sign
2.3_M3	Keeping larger distances between the vehicles to prevent shockwaves and to allow (cooperative) lane changes	⚠	Should be shown earlier on additional sign
2.3_M4	Forcing zipper lane changes in front of the incident	⚠	Should be shown earlier on additional sign
2.3_M5	Advice vehicles to act with special caution and cooperatively	✔	
2.3_M6	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles	⚠	Should be shown by individual vehicles

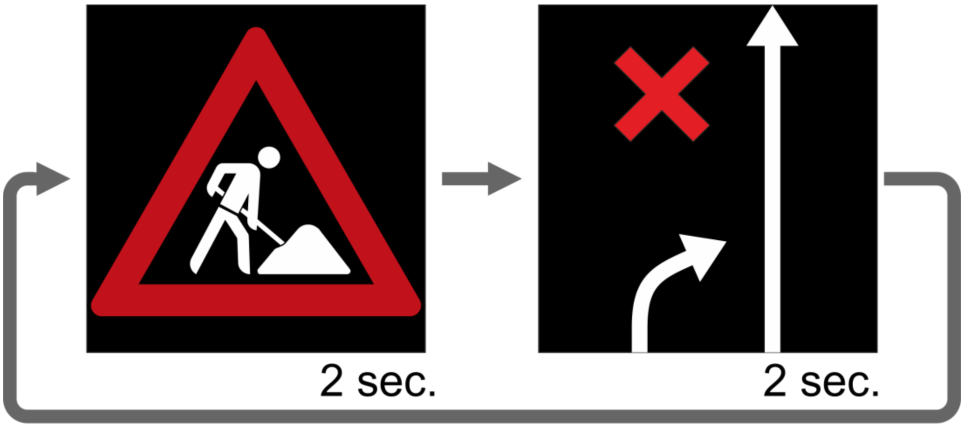
Scenario 3.1:



Requirement	Description	Fulfilled	Comment
3.1_R1	Information about joined highways	⚠	Should be shown earlier on additional sign
3.1_C1	High number of lane changes, possibly performed with low headways	⚠	implicit
3.1_C2	Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road, either in front of the incident or on the through lane when passing	⚠	needs common understanding of AV functionality; enough attention awareness shown
3.1_M1	Traffic separation: Automated vehicles use outer lanes	✓	
3.1_M2	(Early) reduction of the speed limit to minimize effects of strong braking and close lane changes, esp. on the inner lanes	⚠	Should be shown earlier on additional sign
3.1_M3	Keeping larger distances between the vehicles to prevent shockwaves and to allow (cooperative) lane changes, esp. on the inner lanes	⚠	Should be shown earlier on additional sign
3.1_M4	Advice vehicles to act with special caution and cooperatively	✓	
3.1_M5	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can	⚠	Should be shown by individual vehicles

	anticipate the behaviour of those vehicles		

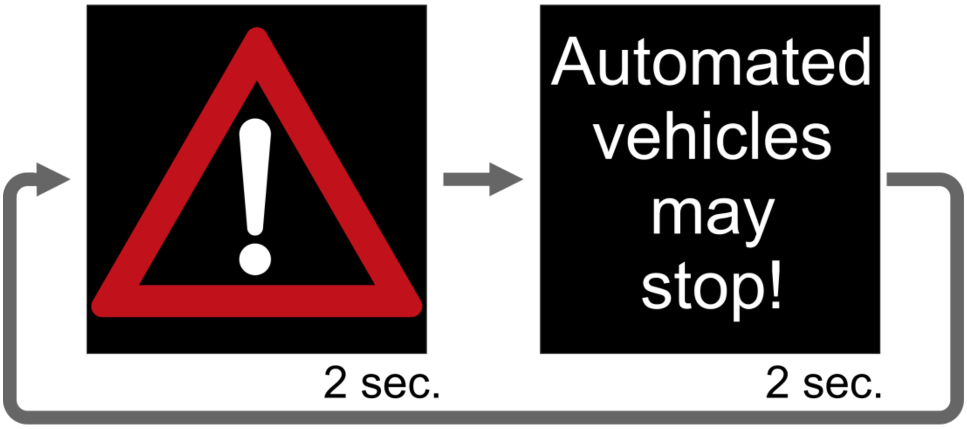
Scenario 4.2:



Requirement	Description	Fulfilled	Comment
4.2_R1	Information about the blockage of the left lane	✔	
4.2_C1	Traffic jams due to the bottleneck on the road	✔	implicit
4.2_C2	Possible ToCs of (C)AVs as they are not able to cope with the situation, possibly leading to sudden braking manoeuvres and stopped vehicles on the road	⚠	needs common understanding of AV functionality; enough attention awareness shown
4.2_M1	Creation of safe spots for CAVs, clearly marked, so that they are not treated as parking spaces for other vehicles.	✔	Static safe spot sign at the safe spot position, possibly extended by lane markings
4.2_M2	(Early) reduction of the speed limit to minimize effects of strong braking	⚠	Should be shown earlier on additional sign
4.2_M3	Keeping larger distances between the cars to allow smoother lane changes and to prevent shockwaves	⚠	Should be shown earlier on additional sign
4.2_M4	Forcing zipper lane changes in front of the workzone and the safe spots	⚠	Should be shown on additional sign

4.2_M5	Advice vehicles to act with special caution and cooperatively	✅	implicit
4.2_M6	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles	⚠️	Should be shown by individual vehicles

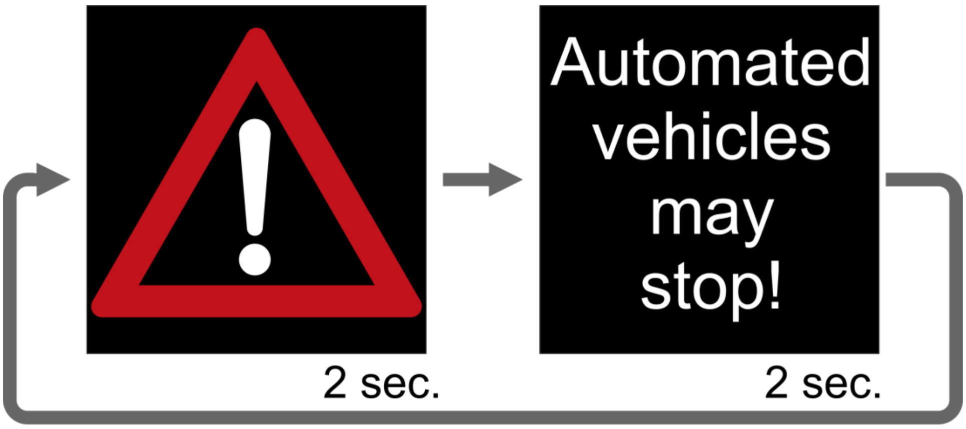
Scenario 5.1:



Requirement	Description	Fulfilled	Comment
5.1_R1	Information about the no-AD-zone, and possibly also about the reason (e.g. missing lane markings, fog, work zones, etc.)	✅	Additional information could be added, if needed by additional sign
5.1_C1	Traffic jams due to stopping (C)AVs on the road	✅	implicit
5.1_C2	ToCs of (C)AVs that are not able to enter the no-AD-zone in automation mode, possibly leading to sudden braking manoeuvres and stopped vehicles on the road	✅	
5.1_M1	(Early) reduction of the speed limit to minimize effects of strong braking	⚠️	Could be easily placed on same sign or on additional signs
5.1_M2	Keeping larger distances between the cars to allow smoother lane changes (e.g. when avoiding braking or stopped	⚠️	Could be easily placed on same sign or on

	(C)AVs) and to prevent shockwaves		additional signs
5.1_M3	Advice vehicles to act with special caution and cooperatively	✅	
5.1_M4	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles	⚠️	Should be shown by individual vehicles

Scenario 4.1-5:



Requirement	Description	Fulfilled	Comment
4.1-5_R1	Information about the no-AD-zone, and possibly also about the reason (e.g. missing lane markings, fog, work zones, etc.)	✅	Additional information could be added, if needed by additional sign
4.1-5_C1	Traffic jams due to stopping (C)AVs on the road	✅	implicit
4.1-5_C2	ToCs of (C)AVs that are not able to enter the no-AD-zone in automation mode, possibly leading to sudden braking manoeuvres and stopped vehicles on the road	✅	
4.1-5_M1	Creation of reserved safe spots for CAVs.	✅	Additional static signs on safe spots

4.1-5_M2	(Early) reduction of the speed limit to minimize effects of strong braking		Could be easily placed on same sign or on additional signs
4.1-5_M3	Keeping larger distances between the cars to allow smoother lane changes (e.g. when avoiding braking or stopped (C)AVs) and to prevent shockwaves		Could be easily placed on same sign or on additional signs
4.1-5_M4	Advice vehicles to act with special caution and cooperatively		
4.1-5_M5	(C)AVs visualize current issues in driving or the current level or status of the used automation systems (incl. ToC and MRM) so that other drivers can anticipate the behaviour of those vehicles		Should be shown by individual vehicles