D5.1

Definition of V2X message sets

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Executive Summary

Automated Vehicles (AVs) have potential to improve traffic efficiency and road safety by applying automatization of perception and control tasks. Nevertheless, whenever automated systems reach their functional limits and are not able to handle a traffic situation by their own, they require a Transition of Control (ToC) to manual driving. If the driver does not react in time to a ToC request, an automated vehicle shall try to perform a so called Minimum Risk Manoeuvre (MRM) to bring the vehicle into a safe state (e.g. decelerating to full stop, or change lane to occupy a safe spot). As it can be imagined, besides affecting the safety of an AV driver, a ToC might also negatively impact the safety of surrounding traffic participants and compromise the traffic flow, especially in so called "Transition Areas" where multiple ToCs can occur simultaneously.

In this context, the TransAID project defines, develops and evaluates traffic management measures based on C-ITS to eliminate or mitigate the negative effects of ToCs along Transition Areas in future mixed traffic scenarios where automated, cooperative, and conventional vehicles will coexist. V2X communications from different categories of cooperative vehicles (automated and non-automated) will allow the road infrastructure to perform a more precise and real-time assessment of traffic demands and stream. Once obtained this information, V2X communications will be used by the road infrastructure to inform about warnings and suggest manoeuvres. When implemented by the addressed vehicles, these suggestions will better address traffic situations associated to possible ToCs.

The TransAID traffic management measures are implemented as a sequence of vehicle-to-infrastructure and vehicle-to-vehicle interactions where relevant pieces of information are exchanged. In this context, this document provides a definition of the TransAID message sets in terms of standard V2X messages or suitable extensions to convey information for the TransAID use cases analysed in the project. Based on the requirements of these use cases, ETSI V2X standard messages as well as messages from other R&D projects have been assessed for suitability. The required information already covered by these specifications has been identified and the needed TransAID extensions proposed. In particular, TransAID adopts:

- ETSI ITS Cooperative Awareness Messages for letting vehicles inform the surrounding traffic about their status, position and dynamics properties, and extends them with information needed to indicate current automation levels, distances to preceding and following vehicles and information needed for managing strings of CACC vehicles;
- ETSI ITS Decentralized Environmental Notification Messages to inform vehicles about road hazards, and profiles and extends them with information needed to notify the presence of a zone where automated driving is not possible, to notify about lane closure and new speed limits to secure an area after an accident or to notify the occurrence of Transitions of Control or Minimum Risk Maneuvers;
- ETSI ITS Collective Perception Messages to transmit information about locally detected objects (i.e. non-cooperative traffic participants, obstacles and alike) in form of standardized abstract representations to improve situational awareness, without extensions;
- ETSI ITS MAPEM Messages to convey intersections and/or road segment topologies and identifies possible solutions to prevent or mitigate possible negative effects of ToC. This includes special permissions to temporarily drive automated on bus or emergency lane, or the presence of safe spots where Minimum Risk Maneuvers can be performed, among others;

- ETSI ITS SPATEM Messages to convey dynamic information about the state of a signalized intersection as well as phase and timing information along its input-output connections, without extensions;
- ETSI ITS In-Vehicle Information Messages to transmit static as well as dynamic road sign and message sign information on highways, without extensions;
- ETSI ITS Maneuver Coordination Message to support coordination of manoeuvres among cooperative automated vehicles, and proposes an extension of this message allowing transmission of suggestions from the infrastructure to the cooperative automated vehicles in order to increase the overall traffic safety and efficiency.

Detailed ASN.1 specifications of these messages for application in real-world cooperative automated vehicles and infrastructure prototypes are included in the dedicated deliverable D7.2, where the theoretical concepts of deliverable have been put into practice.

It is important to point out the generic philosophy adopted for the definition of the TransAID message set. Rather than designing messages from the scratch, TransAID reuses as much as possible the definitions of already available standard messages. Any extension proposed on the top of these standards is such to ensure backwards compatibility with original solutions as well as interoperability with already existing systems. These are fundamental aspects to be considered to foster future transfer of the TransAID concepts into C-ITS standards, hence their adoption in future real-world deployments.

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1 Introduction

This section presents a concise overview of the TransAID project followed by the purpose and structure of the document.

1.1 TransAID focus and objective

Automated Vehicles (AVs) have potential to improve traffic efficiency and road safety by applying automatization of perception and control tasks aimed at going beyond the capabilities of human drivers. A growing number of useful automation features in series cars is a visible trend already today. Moreover, first examples of highly and full automated driving have been showcased to work on real roads under specific conditions (e.g. highway scenarios) and are about to go on the market [1][2][3][4][5][6]. In this context, the automotive industry is spending efforts for preparing future highly and fully AVs to support an increasing number of road conditions and traffic situations. Despite these efforts, different studies have shown that automated driving will not be always possible: whenever for the different reasons listed in [7] automated systems reach their functional limits and are not able to handle a traffic situation by their own, they will require a Transition of Control (ToC) to manual driving (downward ToC in this case). As the system detects that automation can be resumed, an upward ToC to automated driving is triggered. In case of downward ToC, the driver needs some time to be in the conditions to take over safely. This time (hence the duration of a safe ToC) generally increases with higher levels of automation, especially if the driver is distracted [8] and as the traffic density increases [9]. If the driver is not responding to a ToC request, an automated vehicle shall try to perform a so called Minimum Risk Manoeuvre (MRM) to bring the vehicle into a safe state (e.g. decelerating to full stop, or change lane to occupy a safe spot [10]). As it can be imagined, besides affecting the safety of an AV driver, a ToC might also negatively impact the safety of surrounding traffic participants and compromise the traffic flow, especially in so called “Transition Areas” where multiple ToCs can occur simultaneously.

In this context, the TransAID project aims at developing and test traffic management measures to eliminate or mitigate the negative effects of ToCs in Transition Areas. The TransAID traffic management measures shall be designed to operate in future mixed traffic scenarios where automated, cooperative, and conventional vehicles will coexist. To this aim, TransAID extends conventional signalling means by cooperative ITS (C-ITS) and V2X communications, whose deployment at both vehicles and road infrastructure in Europe is about to start as a “Day1” phase in 2019 as stated by the industrial organization Car2Car Communication Consortium (C2C-CC) and the road infrastructure platform C-Roads [11]. In TransAID, infrastructure and vehicles will use C-ITS to improve their perception and knowledge of the environment. In fact, V2X communications from different categories of cooperative vehicles (automated and non-automated) will allow the road infrastructure to perform a more precise and real-time assessment of traffic demands and stream composition (i.e. share of different vehicle categories according to the TransAID vehicle classification of [12]). Once obtained this information, V2X communications will be used by the road infrastructure to inform about warnings and suggest manoeuvres that, when implemented by the addressed vehicles, will help managing more effectively traffic situations associated to possible ToCs. These suggestions will be either implemented directly by vehicles (e.g. performing a ToC at a given position and time), or will be the triggering condition for the execution of cooperative manoeuvring by Cooperative Automated vehicles (CAVs). In fact, in of conflicting situations (e.g. a CAV is suggested to move onto a lane where another CAV is following with higher speed), CAVs will start using V2X communications to negotiate the right of way, hence ensuring safety without hampering the traffic flow.

1.2 The TransAID iterative approach

As already mentioned above and better detailed in the deliverable D2.1 [7], TransAID measures are designed to follow a hierarchical approach where control actions are implemented at different layers including centralised traffic management, infrastructure, and vehicles. TransAID therefore takes into account a foreseen mix of conventional/legacy vehicles (LV), cooperative non-automated vehicles (CV), non-cooperative automated vehicles (AV) and cooperative automated vehicles (CAV). The infrastructure will integrate the acquired information at the Traffic Management System (TMS). The TMS will generate progression plans which are taken over by the infrastructure and communicated to vehicles, either by V2X communication from the Roadside Infrastructure (RSI) or by e.g. variable message signs (VMS) for reaching non-equipped vehicles (LV/AV).

To validate the effectiveness of its management measures, TransAID adopts simulations taking into account traffic safety and efficiency metrics. For the simulations to be as reliable as possible, the most relevant microscopic traffic models for mixed traffic behaviour and interactions with AD cars are developed. Also, communication protocols for the cooperation between CAVs, CVs, and the cooperative RSI 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.

The above mentioned approach 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 transition of control and transition areas 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 scenarios' simulations. Using the basic scenarios, it is possible to run many simulations and focus in detail on the relatively new aspects of ToC, Transition Areas (TAs) and measures mitigating negative effects of ToC. 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 services in the same evaluation scenario). The second iteration consequently needs additional functionalities from the traffic and communication protocols point of view, whose modelling has been implemented at later stages.

1.3 Purpose of this document

The TransAID consortium has defined its traffic management measures in the form of five "services", each of them applicable to a number selected relevant scenarios [7]. Out of all the possible combinations of services/applicable scenarios, a list of combinations has been identified for examination in the first [12] and second [13] project iterations. The selection has been made considering the modelling solutions achievable in the first and second parts of the project from AD modelling, traffic management (TM) and communications perspective. The selected study cases for the first TransAID iteration are the following (please refer to [12]):

- Service 1 on scenario 1.1,
- Service 2 on scenario 2.1,
- Service 3 on scenario 3.1,
- Service 4 on scenario 4.2 and
- Service 5 on scenario 5.1

Furthermore, the selected cases for the second iteration are (please refer to [13]):

- Service 1 on scenario 1.3,
- Service 2 on scenario 2.1,
- Service 2 on scenario 2.3,
- Service 2 and 4 on scenario 4.2 and
- Service 4 and 5 on scenario 4.1-5

Each of the above mentioned scenarios has been described as a detailed sequence of steps ("storyline") including initial and desired traffic situations as well as the vehicle-to-infrastructure and vehicle-to-vehicle interactions needed for the execution of a given service [12][13][15]. These scenarios representations are necessary to establish the functional requirements to be modelled in simulations and then implemented in real prototypes.

In this context, this document is aimed at providing a definition of the V2X Facility-layer [16] message sets that are needed to support the TransAID traffic management measures in the scenarios selected for the project evaluations. As it will be detailed in the following sections, these messages have been designed to have a twofold purpose. From one side they cover requirements that are common to each of the above mentioned scenarios, such as helping the RSI to improve the detection and classification of vehicles with different types of automation and communication capabilities. From the other side, they serve purposes that are specific to a given service, such as distributing in time and space ToCs before a TA. To design this set of messages, a careful review of the already available V2X message standards has been performed. This review has been followed by an analysis of the scenarios' storylines in order to identify the information needed to be exchanged at each step of the envisioned I2V and V2V interactions. This approach has allowed identifying the information covered by the already available standard message sets, and of course the needed TransAID extensions to these messages.

For the message definitions provided in this document, the following aspects have to be taken into account. As TransAID focuses on modelling/simulation and prototypical evaluation, the definitions presented in this document are a conceptual version (suitable for modelling and simulation purposes) of the ASN.1 specifications needed for implementation on real vehicles and infrastructure prototypes. These prototypical ASN.1 specifications can be found in the dedicated TransAID deliverable D7.2 [14] . Furthermore, it is important to point out the generic philosophy adopted for the definition of the TransAID message sets. Rather than designing messages from the scratch, TransAID tries to reuse as much as possible the definitions of already available standard message sets. Any extension proposed on the top of these standards is such to ensure backward compatibility with original solutions as well as interoperability with already existing systems. These are fundamental aspects to be considered to foster the future transfer of the TransAID results into current and upcoming C-ITS standardization activities and hence real-world deployments.

1.4 Structure of this document

The rest of this document is organized as follows:

Section 2 describes the state of the art in terms of available standard V2X message sets and message sets solutions adopted in other related R&D projects.

Section 3 briefly recalls the TransAID services and scenarios adopted as the basis for the V2X message definition.

Section 4 outlines the requirements needed by the selected services and scenarios in terms of information needed to be exchanged by the TransAID message set.

Section 5 introduces the concept of Maneuver Coordination Service (MCS) as it is currently proposed in the related standardization activity which is still in a very early stage. The concept descriptions include insights on how it can be applied to the TransAID purposes and how it can be extended to cover the projects requirements.

Section 6 provides the definition of the TransAID messages. As mentioned before, these messages can exhaustively cover the requirements of the considered services and scenarios.

Section 7 briefly concludes the deliverable, summarizing the results and providing some considerations on the future use of the defined messages in the rest of the project.

ANNEX A contains a comprehensive and detailed definition of the various data fields and elements used by the TransAID messages. This is provided in the form of a table mapping the TransAID service requirements to C-ITS standard messages and their extensions.

ANNEX B lists the TransAID project's contributions provided to relevant V2X standardization and specification activities till the time of writing this document.

ANNEX C describes the TransAID proposal for extending the Maneuver Coordination Message format with respect to the current version discussed at ETSI TC ITS.

1.5 Glossary

Abbreviation/Term	Definition
ACC	Adaptive Cruise Control
AD	Automated Driving
ADAS	Advanced Driver Assistance Systems
ASN1	Abstract Syntax Notation One
AV	Automated Vehicle
C-ITS	Cooperative Intelligent Transport Systems
C2C-CC	Car2Car Communication Consortium
CA	Cooperative Awareness
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CAV	Cooperative Automated Vehicle
CCH	Control Channel
CDD	Common Data Dictionary
CLCM	Cooperative Lane Change Message

CMM	Convoy Management Message
CP	Collective Perception
CPM	Collective Perception Message
CSAM	Cooperative Speed Advising Message
CSM	Cooperative Sensing Message
DCC	Decentralized Congestion Control
DENM	Decentralised Environmental Notification Message
DX.X	Deliverable X.X
ERTRAC	European Road Transport Research Advisory Council
ETSI	European Telecommunication Standards Institute
FoV	Field of View
GLOSA	Green Light Optimal Speed Advice
HF	High Frequency
HMI	Human Machine Interface
I2V	Infrastructure to Vehicle
iCLCM	i-GAME Cooperative Lane Change Message
ISO	International Organization for Standardization
ITS	Intelligent Transport System
ITS-G5	Access technology to be used in frequency bands dedicated for European ITS
IVIM	In-Vehicle Information Message
IVS	In-Vehicle Information Service
LAM	Lane Advice Message
LF	Low Frequency
LOS	Level Of Service (from Highway Capacity Manual)
LV	Legacy Vehicle
MAPEM	Map Message

MCDM	Multimedia Content Dissemination Message
MCM	Manoeuvre Coordination Message
MCS	Manoeuvre Coordination Service
MIO	Most Important Object
MRM	Minimum Risk Manoeuvre
PDU	Protocol Data Unit
RLT	Road and Lane Topology
RSI	Road Side Infrastructure
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SCH	Service Channel
SPAT	Signal Phase and Time
SPATEM	Signal Phase and Time Message
SRM	Signal Request Message
SSM	Signal State Message
SUMO	Simulation of Urban MObility
TA	Transition Area
TC	Technical Committee
TCI	Task Capability Interface
TM	Traffic Management
TMS	Traffic Management System
ToC	Transition of Control
ToR	Take-over Request
TransAID	Transition Areas for Infrastructure-Assisted Driving
TTI	Traffic and Traveller Information
V2I	Vehicle-to-Infrastructure

V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-anything
VMS	Variable Message Sign
VRU	Vulnerable Road Users
WP	Work Package

2 State of the art

This chapter provides an overview of the V2X messages specified by standardization and R&D activities which have been the basis for the TransAID definitions.

2.1 Messages standardized or under standardization

The standard V2X messages being most relevant for the TransAID scope are described in the following subsections.

2.1.1 CAM

The Cooperative Awareness Message (CAM) is a message created by the Cooperative Awareness (CA) service [17] residing at the Facilities layer of the ETSI ITS communication architecture stack [16]. CAMs are exchanged between C-ITS stations equipped with V2X technology (i.e. vehicles, infrastructure stations, etc.) to create and maintain awareness of each other and to support cooperative performance of vehicles using the road network. CAMs provide information about presence, position, dynamics and basic attributes of the originating station. The received information can be used to support several C-ITS applications. For example, by comparing the position and dynamics of the originating station with its own status, a receiving station is able to estimate a collision risk.

The general structure of a CAM is shown in Figure 1. A CAM is composed of a common ITS PDU header [18] and multiple containers.

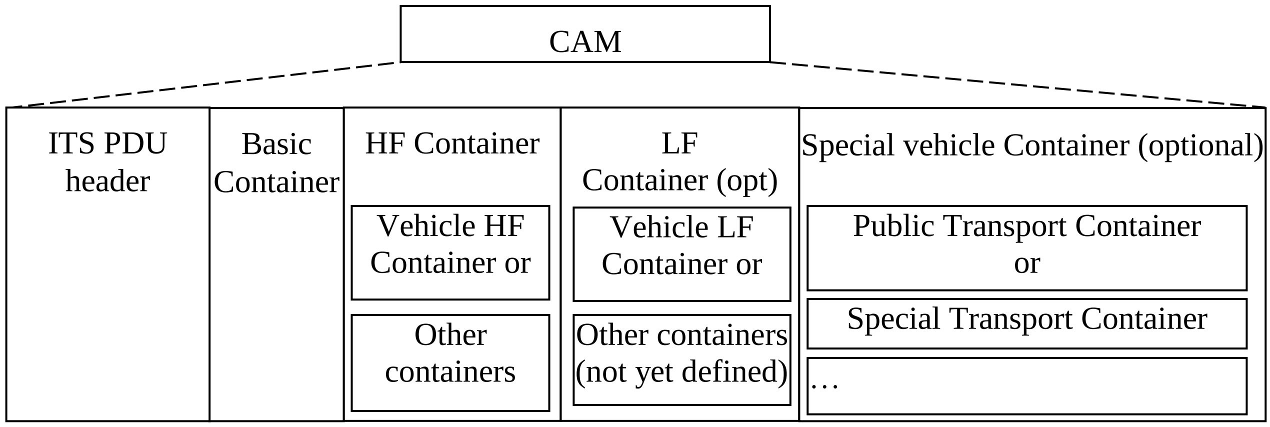

Figure 1 General structure of a CAM for vehicles [17]

A CAM originated by a vehicle shall comprise one basic container, one high frequency container and may also include a low frequency container and one or more special containers:

- The basic container includes basic information related to the originating stations as the position and type of station.
- The high frequency container includes information that shall be transmitted with high frequency. In this regard, the standard allows the possibility to select the right option for its transmission. For vehicles, the only option specified by the standard at this stage is the

BasicVehicleContainerHighFrequency including dynamic information like vehicle speed, acceleration, etc. This option is the one used by the car industry for Day1 deployment [19].

- The low frequency container includes information whose transmission frequency can be lower. In this regard, the standard allows the possibility to select the right option for its transmission. For vehicles, the only option specified by the standard at this stage is the *BasicVehicleContainerLowFrequency* including static or slow-changing vehicle data like the status of the exterior lights or the vehicle role (i.e. public transport, emergency vehicle, etc.). This option is the one used by the car industry for Day1 deployment [19].
- The special vehicle container includes information specific to the vehicle role.

Similarly, a CAM originated by an RSU shall comprise a basic container and one high frequency container that include information like the RSU position and the protected communication zones.

Every ITS station periodically transmits CAMs employing broadcast communications [20] in the control channel (G5-CCH) [21], also referred as SCH0, channel used for Day1 deployment [19]. The CAM is transmitted to other ITS stations which are located in one hop distance in the communication range of originating station.

According to [17], the CAM generation frequency of a vehicle is dynamically adjusted in the interval 1-10Hz. There are two main factors that modify the CAM generation frequency: the channel congestion and the vehicle dynamics. The Decentralized Congestion Control (DCC) [22] assesses the current usage of the radio channel and defines the maximum CAM generation frequency. On the other hand, if the vehicle dynamics undergo a significant change, a CAM shall be triggered if the DCC requirements are fulfilled. Particularly, a CAM will be triggered whenever one of the following conditions is given:

- The absolute difference between the current vehicle heading and the heading included in the last CAM exceeds 4°.
- The distance between the current vehicle position and the position included in the last CAM exceeds 4 m.
- The absolute difference between the current vehicle speed and the speed included in the last CAM exceeds 0.5 m/s.

When a CAM is generated, the CA basic service shall construct the CAM PDU with the mandatory containers, that is, the basic container and the vehicle high frequency container. Optionally, a CAM may include optional containers such as the vehicle low frequency container or the special vehicle container. However, those optional containers have additional generation requirements and shall not be included unless the time elapsed since the last transmission of the container is equal or greater than 500 ms.

The CAM generation frequency for RSU stations shall be set in such a way that at least one CAM is transmitted while a vehicle is in the communication range of the RSU restricted to a maximum generation frequency of 1 Hz.

2.1.2 DENM

The Decentralized Environmental Notification Message (DENM) [23] is another Facilities layer message. It contains information related to a road hazard or abnormal traffic conditions such as the type of event and its position. It is employed to alert other road users about the occurrence of an unexpected event that has potential impact on road safety or traffic condition. The DENM is also considered for Day1 deployment [19].

The management of a DENM transmission depends on whether the vehicle is the generator of the message or a forwarder. For example, a vehicle may inform other vehicles about an emergency brake, in this case, the source vehicle generates the transmission and termination of the DENM. However, in other situations like for example in presence of black ice on the road, the event will be persistent once the vehicle that detected the black ice has left the area. In this case, the DENMs will be relayed by other ITS stations (as long as considered valid) and the DENM will be terminated once an ITS station detects that the black ice disappeared. In order to manage these situations four different types of DENMs are defined:

- New DENM: a DENM generated by a station whenever an event is detected for the first time.
- Update DENM: a DENM generated by the originating station of a previous DENM in order to update the information of the event.
- Cancellation DENM: a DENM sent by the originating station to inform about the termination of the event included in the original DENM.
- Negation DENM: a DENM that informs about the termination of an event sent by a different station from the originating station.

The general structure of a DENM [23] is shown in Figure 2. A DENM is composed of a common ITS PDU header [18] and multiple containers. The DENM payload may consist of four parts: the management container, the situation container, the location container and the à la carte container:

- The management container contains information related to the DENM management and the DENM protocol.
- The situation container contains information related to the type of the detected event.
- The location container contains information of the event location, and location referencing.
- The à la carte container contains information specific to the use case which requires the transmission of additional information that is not included in the previous three containers.

The ITS PDU header and the management container are mandatory for all types of DENM. The situation container, the location container and the à la carte container are optional and shall not be present in cancellation or negation DENMs. If the situation container is present, the location container shall be present as well. The presence of the à la carte container is restricted to the applications specified in [24][25][26].

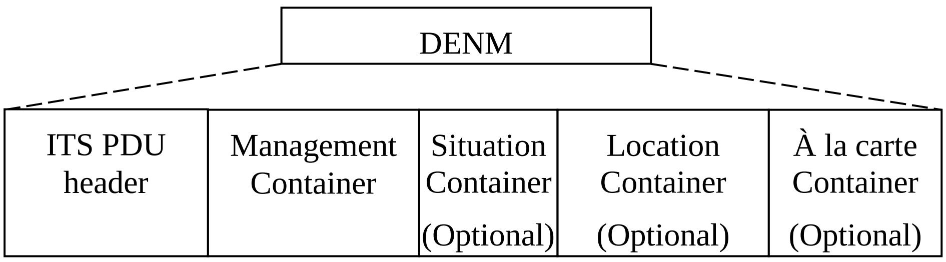

Figure 2 General DENM structure [23]

The transmission of a new DENM starts whenever a new event is detected for the first time. A DENM shall include the validity duration time of the event, that is the time from which the DENM is no longer valid and shall not be taken into account by receivers. Furthermore, a DENM must define a destination area where the message should be disseminated. ITS stations that receive the DENM may forward the message to assure that the message reaches all the ITS stations inside the destination area. Similarly, a DENM may be repeated to allow new ITS stations entering in the destination area to receive the message. The transmission of a DENM will stop when the validity duration time is expired or a Cancellation or a Negation DENM is transmitted.

2.1.3 CPM

The Collective Perception (CP) service uses CP Messages (CPMs) to transmit data about locally detected objects (i.e. non-cooperative traffic participants, obstacles and alike) to improve situational awareness. By exploiting the increasing sensing and communication capabilities of future vehicles, CP is considered by the car industry as a natural key enabler for cooperative automated driving applications [27]. For this reason, CP standardization has been recently started at ETSI ITS [28][29] at later stages of deployment (Day2 and beyond). ETSI CPMs foster sustainability and interoperability by transmitting abstract representations of detected objects instead of type- and vendor-dependent raw sensor data. In addition, CPMs abstract descriptions can derive from detections made by single sensors or by result of local sensor fusion algorithms, which provides implementation flexibility. The CP is designed to allow sharing detections made by both vehicles and RSI. For this purpose, detected object descriptions are shared referred to a coordinates system that is different according to the nature of the CPM originating station. In the case of a vehicle, xy axes take origin from its center-front and change direction as the vehicle moves. This is not suitable for static RSUs. Here, the adopted coordinate system is centered on a reference point placed close to the RSU with xy aligned to east and north, respectively, as for SPAT/MAP representations [30]. Receiving stations map received object descriptions onto their local coordinate system. To allow this mapping, originating stations shall always transmit data about their coordinate system (e.g. reference point, and for vehicles also speed, orientation, etc.). Besides this, they shall communicate their detection capabilities in terms of installed sensors' Fields of View (FoV). When receiving a CPM with no object detected in a given direction, a CAV can make a cross-check by analyzing the FoV information: if it says that the originating station has no sensors covering that direction, objects can be actually present in reality. The above mentioned CP operation is supported by the CPM message structure as depicted in Figure 3. This includes four containers:

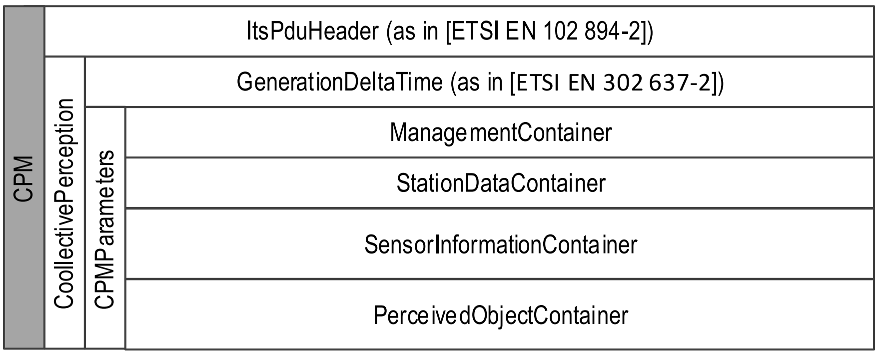

Figure 3 General CPM structure [28]

1) The Management Container: carries originating station information required by receivers for local mapping of object detections. It includes the reference point position and originating station type (vehicle or RSU), as well as identification of a given message segment if message segmentation is applied.
2) The StationData container provides more specific information about the originating station. This frame distinguishes between two different options depending on the originating station type: The OriginatingVehicleContainer option indicates vehicle dynamic properties such as heading, speed, acceleration, orientation, etc.). The OriginatingRSUContainer option contains an identifier of

the intersection or road segment where objects shall be detected. As this identifier is the same as in MAP messages, detected objects' positions can be matched to MAP-like intersection topology representations.

3) Sensor Information Container (optional): describes the originating station's detecting capabilities at separate installed sensors or as overall sensor fusion. For this purpose, it includes a list of *SensorEntries*, each specifying a sensor identifier and type. A *SensorEntry* can be further specified, selecting among alternative representation options. The *VehicleSensor* and *StationarySensorRadial* options allow specifying mounting position, opening angles and ranges for vehicle and RSU sensors, respectively. On the contrary, other RSUs-tailored options allow explicitly specifying position and shape of road regions where detections are possible.

4) Perceived Object Container (optional): consists of a list of *ObjectData* each providing description of a detected object. Each object is assigned an identifier allowing its tracking at receivers. The identifier of the sensor through which the object is detected is also included. This permits retrieving the corresponding sensor information from the Sensor Information Container. *ObjectData* specifies time of measurement, as well as object distance from the reference point of the originating station's coordinates system. To enable correct interpretation of this information at the receiving side, *ObjectData* also contains the object's reference point position considered for distance calculation. Several other description elements are optionally allowed as long as provided by the used sensors. These are relative speed/acceleration, yaw angle, dimensions, dynamic status, object classification etc. For implementation of use cases requiring matching of objects onto MAP-like road topology representations, a *MatchedPosition* data field is introduced. This includes the identifier of the lane where the object is detected, as well as its distance from the start of the lane. The lane belongs to the topology described by MAPs for the intersection or road segment identified in the *OriginatingRSUContainer*.

The CPM generation rules define how often a CPM is generated by the originating station and which information (detected objects and sensors information) is included in the CPM. Periodic and dynamic policies are being investigated and discussed as part of the ETSI standardization process.

The periodic policy generates CPMs periodically every *T_GenCpm*. In every CPM, the originating station includes information about all the objects it has detected. The CPM should be transmitted even if no objects are detected. The periodic policy is being used as a baseline in the standardization process to compare its performance and efficiency with more advanced policies such as the dynamic one. With the dynamic policy, the originating station checks every *T_GenCpm* if the environment has changed and hence is necessary to generate and transmit a new CPM. If this is the case, the originating station also decides the objects that should be included in the CPM. An originating station generates a new CPM if it has detected a new object, or any of the following conditions are satisfied for any of the previously detected objects:

a) Its absolute position has changed by more than 4m since the last time it was included in a CPM.

b) Its absolute speed has changed by more than 0.5m/s since the last time it was included in a CPM.

c) The last time the object was included in a CPM was 1 second ago.

All new detected objects and those that satisfy at least one of the previous conditions are included in the CPM. If no object satisfies the previous conditions, a CPM is still generated every second, but only including the Management Container, the Station Data Container and the Sensor Information Containers (i.e. without any Perceived Object Container). It should be noticed that these CPM generation rules are an adaptation of the CAM generation rules [17] for detected objects. In addition, these generation rules are a draft proposal (hence subject to possible changes in the final specifications).

During the first iteration of the TransAID project, the effects of the CPM generation rules on the awareness of traffic participants as well as on the communication load have been studied via computer simulations [43]. During the second iteration of the project, this analysis will be the basis for the definition of enhanced CPM generation rules. The enhanced CPM generation rules will be described on the second version of Deliverable 5.2, which will be published in M30.

2.1.4 MCM

The ETSI TC ITS is currently defining the Maneuver Coordination Message (MCM) which can be used to coordinate maneuvers between ITS stations. The MCM is at early stage of standardization [31]. The TransAID project is actively contributing to the standardization process by participating in all the meetings and presenting the TransAID proposals for the MCM (please refer to Section 6.7).

2.1.5 MAPEM

The Map Message (MAPEM) is an I2V message used by the RSI to convey many types of geographic road information. At the moment the MAPEM is used to convey one or more intersection lane geometry information within a single message. The message content includes items such as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications). The contents of this message define the details of indexing systems that are in turn used by other messages to relate additional information about events at specific geographic locations on the roadway. Most commonly used examples of this kind are the signal phase and timing via the Signal Phase and Timing (SPATEM) message. The SPATEM message is used to convey the current status of one or more signalized intersections. Along with the MAPEM message (which describes a full geometric layout of an intersection) the receiver of this message can determine the state of the signal phasing and when the next expected phase will occur.

The MAPEM message is the effective result of the Road and Lane Topology (RLT) infrastructure service which manages the generation, transmission and reception of a digital topological map. This service along with its operational parameters is defined in ETSI TS 103 301 [32], which in turn refers to the SAE J2735 data dictionary [30]. Being part of the Day1 deployment in Europe, data elements, data frames and service parameters of the MAPEM shall be used according to the definitions provided by the C-ITS Infrastructure Functions and Specifications of the C-Roads Platform [33].

The MAPEM message structure consists of an ITS PDU header and MapData container at the top level. The MapData may include intersections, road segments topological descriptions and user restrictions. Next to multiple identifiers, a revision number, a reference point, and lane width and speed limit information, both the intersections and road segments include a list of lanes. Each lane is described by a list of node points and has general properties such as the direction of use and lane users (Figure 4). In addition, more detailed properties can be set at the node level, which either persist at a single node or remain valid until disabled at another node. Finally, each lane may contain a list of connections to other lanes, which is particularly relevant for intersection to connect ingress lanes to egress lanes. For signalised intersections, connections contain information about signal groups which also provides the link to the SPATEM message.

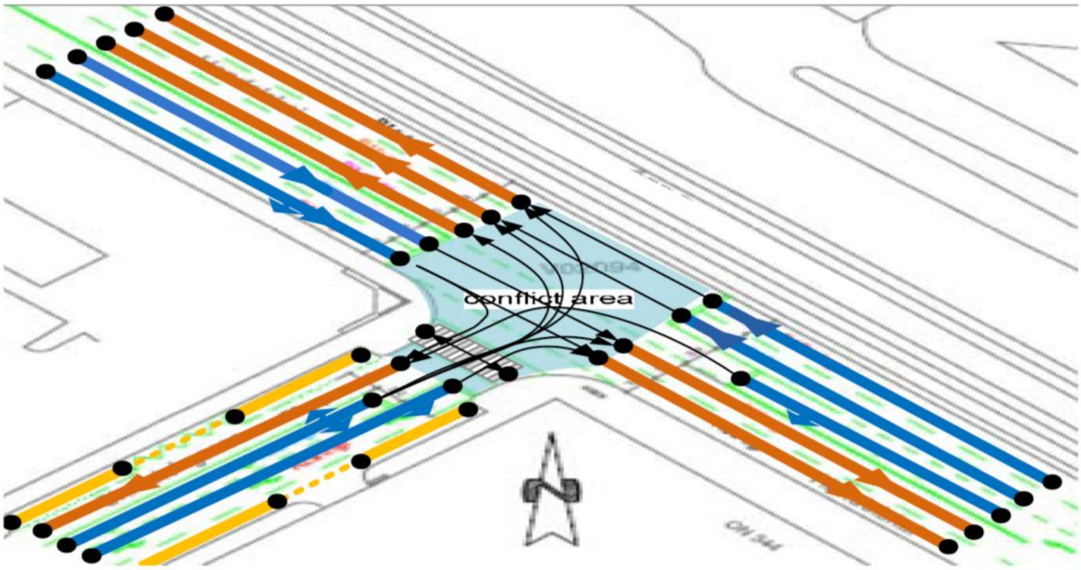

Figure 4 Example of lane topology [32]

Typically, MAPEM does not change very often in time. The same MAPEM content is retransmitted continuously in a broadcast fashion, unless the application indicates to transmit a new MAPEM, e.g. if anything about the road and lane topology has changed.

2.1.6 SPATEM

The Signal Phase and Timing Message (SPATEM) is an I2V message primarily used to communicate the intersection status to vehicles approaching an intersection. The SPATEM message usually contains dynamic information about the state of a signalized intersection. It can contain the traffic light state, future state predictions, speed advice, queue state information and whether a priority request is active.

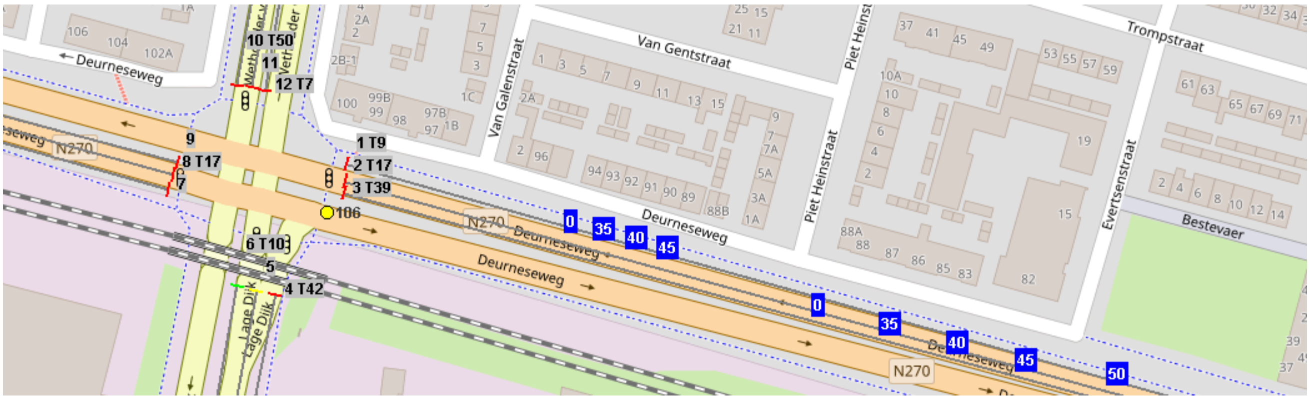

Figure 5: Example of SPaT data plotted on top of a MAP

Figure 5 shows approaches towards an intersection. The lanes with their nodes are shown as grey lines ending with a perpendicular bar (Red, Green or Yellow) that represents a stop line. The colour of this bar directly reflects the signal state of the traffic light. A number next to the signal group number represents the time to the next signal change (e.g. 1 T9, means signal group 1 is turning green in 9 seconds). The lanes are derived from a series of nodes contained in the MAPEM message and describe the curvature of the road. This helps determining relative distances, which is useful for the speed advice. The speed advice is shown as a blue square with a speed number inside. Most important for intersection use cases is the mapping of lanes to the number of signal group. Using that mapping, the SPATEM only has to refer to a signal group number and does not need to redefine the lane information. Without a MAPEM this is not possible and a SPATEM without a matching MAPEM cannot be used.

With the aforementioned data, the SPATEM can be used for different services: red light violation warning, Green Light Optimal Speed Advice (GLOSA), queue length warning and feedback on priority requests. The priority request should, however, be covered by a Signal State Message (SSM) as a reply to a Signal Request Message (SRM). The SPATEM is broadcasted every second or when there is updated information.

The SPATEM is defined in Europe by the ETSI TS 103 301 [32], which in turn refers to the SAE J2735 data dictionary [30]. Being part of the Day1 deployment in Europe, data elements, data frames and service parameters of the SPATEM shall be used according to the definitions provided by the C-ITS Infrastructure Functions and Specifications of the C-Roads Platform [33]. The structure of the message is shown in Figure 6. Officially, the highest level contains the default ITS PDU header (also used by CAM, DENM, MAPEM, etc.) and the actual SPAT content as defined in [30].

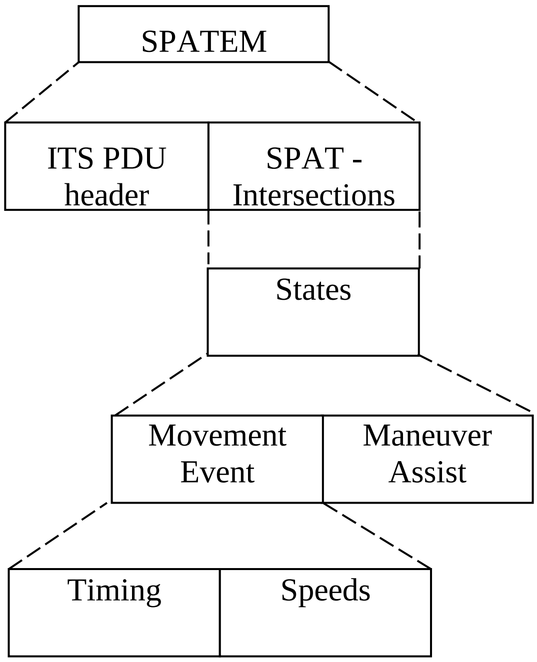

Figure 6: Basic structure of SPATEM message [32]

The structure of the message is quite hierarchical with the five most important vertical layers shown in the figure. The SPAT layer can contain timestamps of message creation and up to 32 different intersection objects. For each intersection, several data parameters can be included like the name, id, operational state, the enabled lanes and a series of up to 255 more complex objects containing the current state of each movement. These state objects are identified with a signal group number and can contain both manoeuvre assist and movement event data. The manoeuvre assist data can contain queue length information, conflicting vulnerable road user presence on the road and whether a vehicle should stop at the stop line or not.

The movement event is the most used data in the SPAT. It contains the status of the traffic light (different kinds of dark, red, amber or green) and compound data fields with timing and speed. For timing there are several fields: minimum, maximum and likely moment that the light will change to the next state and the confidence of those values. It is possible to include multiple consecutive timing events in the message. Speed advice consists of a list of speed distance pairs; they should be interpreted as speed advice for traffic participants starting from that particular distance up to the stop line.

2.1.7 IVIM

The In-Vehicle Information message (IVIM) is an I2V message format conveying information about infrastructure-based traffic services needed for the implementation of use cases focusing on road safety and traffic efficiency. For the first phase of C-ITS deployment in Europe, C-Roads and the C2C-CC have agreed on adopting IVI profiling examples based on the IVI message format standardized in ISO TS 19321[32][34]. In turn, this standard refers to the sign catalogue established by ISO TS 14823 [35], which presents standardized codes for existing signs and pictograms used to deliver Traffic and Traveller Information (TTI). The IVIM message transmission is operated in accordance to the standard ETSI TS 103 301 [32], which describes facilities layer protocols and communication requirements for infrastructure-based services. Similar to other ETSI C-ITS messages, an IVI PDU is encapsulated in the *ItsPDUHeader* and transmitted as IVIM through the lower layer of the communication stack.

C-Roads uses the IVIM to transmit static as well as dynamic road sign and message sign information on highways. Static road signs are actual sign plates placed on the side of the road. On the contrary, dynamic road signs are signs that indicate variable information. An example of dynamic road sign is the Variable Message Sign (VMS) mounted on a highway gantry (see Figure 7). Here, the left sign (A) refers to the left lane. The right sign refers to the right lane. The sign in the middle (B) shows information common to both lanes (example taken from the Austrian Eco-AT project [36]).

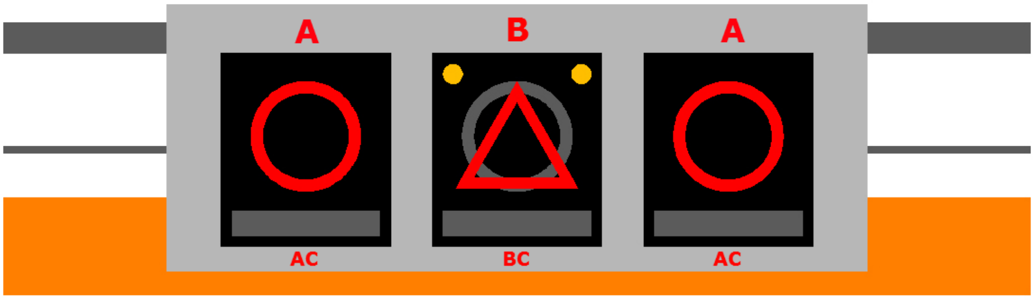

Figure 7 Example of VMS adopted in Austria for a two-lane highway [36]

The purpose of the IVIM is to enable the receiving vehicle to know at any time and condition all the relevant signage information. Information is relevant based on time and location, but also based on characteristics and type of the receiving vehicle. The signage information shall be filtered according to geographical relevance and other relevance criteria (e.g. only information relevant ahead should be presented to the driver) [36]. In this context, the following definitions apply:

The relevance area (or relevance zone) is the area for which the signage information is applicable (e.g. red area in Figure 8). Each separate sign is associated a specific relevance area that can vary depending on time and location.

The awareness area (or detection zone as defined) is the area where drivers have to be informed (e.g. yellow area in Figure 8) because they are approaching the relevance area.

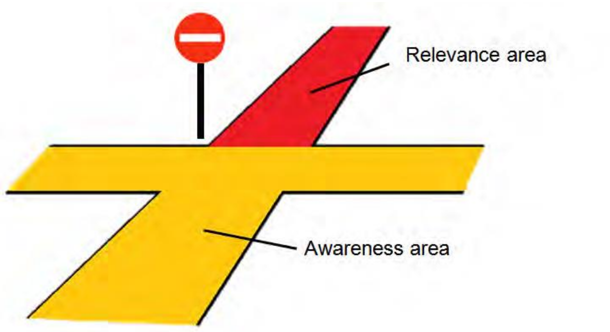

Figure 8 Relevance and awareness areas for the IVS service [36]

The IVIM structure is according to the message format of the ISO TS 19321 [34], described in Table 1:

Table 1: IVI message format description (ISO TS 19321[34])

IVI Management Container It is mandatory and provides the receiving vehicle with enough information to handle the entire IVI message and decide on its further processing
Location Container The Location Container describes the essential information for receiving vehicles to understand where and how the information provided in the IVI Application Container applies. It is formed by a part which is common to all the parts of the Application Container plus a sequence of *GlcParts* that can be specific to the distinct parts of the application container. The first *GlcPart* is used by C-Roads to define the detection zone of the Information (the concept of an IVI detection zone is the equivalent of a DENM trace and corresponds to the awareness area in Figure 8). The other *GlcParts* are used to define the relevance zones that apply to the distinct parts of the application container (the concept of an IVI relevance zone is the equivalent of an *eventHistory* used for roadworks DENMs).
Application Container (General IVI Container) The Application Container provides the IVI information to be processed by vehicles. This information refers to location information for its spatial validity. It is a sequence of *GlcParts*, each defining a given piece of information.

The rules for the generation and handling of IVIM messages at facilities layer are defined by the Standard ETSI TS 103 301 [32]. Similar to the other I2V messages, the IVIM is also broadcasted.

Moreover, as the DENM, the IVIM message format contains data elements that allow receiving stations to unambiguously identify it (*iviIdentificationNumber*), and determine the status and time validity of its content (e.g. *iviStatus*, *timestamp*, *validFrom*, *validTo*). According to [32], every time a new IVIM message is generated at an RSU, the data element *iviStatus* is set to “new” and the timestamp is set to the current time. The standard [32] specifies that the IVIM message has to be periodically repeated with a given repetition interval. For repetitions of an IVIM, its *iviIdentificationNumber*, *iviStatus* and *timestamp* do not change. However, an IVIM can be updated by the originating RSU (e.g. to indicate a new *validTo* value). When an IVIM is updated, its *iviIdentificationNumber* does not change, its *iviStatus* is set to “update”, and its *timestamp* is set to the current time. In general, an IVIM transmission is stopped upon expiration of the validity of its content.

It is worth mentioning that at the moment of writing this deliverable, the ISO TS 19321 [34] is being revised to allow the road infrastructure to provide information about applicable regulations which are specific to one or more automation levels. Such information may include clearance information for a certain sections to automated driving, as well as minimum, maximum or recommended speed, and minimum and recommended inter-vehicle distance, per automation level.

2.1.8 MCDM

The ETSI TC ITS is currently defining the Multimedia Content Dissemination Message (MCDM) in order to share multimedia content between ITS stations describing events for different applications [37]. For example, a road safety application can employ pictures or videos about obstacles on the road. Similarly, a traffic management application can employ pictures or videos about the traffic conditions in a specific area. Multimedia information provides enriched data that can improve the environmental perception or the perception of products and services locally available (i.e. electric vehicle charging spots, national patrimony information, etc.)

A MCDM is segmented into a certain number of units depending on the size restriction of the access layer employed to transmit the message. The first unit to be transmitted includes a management container enabling the linkage of transmitted successive units of the same MCDM.

The general structure of a MCDM is shown in Figure 9. The first MCDM shall include a common ITS PDU header [18] and the following containers:

- The management container contains information related to the MCDM management.
- The situation container contains information related to the triggering source of the MCDM.
- The location container contains information of the event location.
- The application payload container (optional) contains the specific application data elements.
- The multimedia container contains the multimedia data to be transmitted.

The other MCDM ITS PDU (when needed) includes a minimum subset of the management container and a multimedia container.

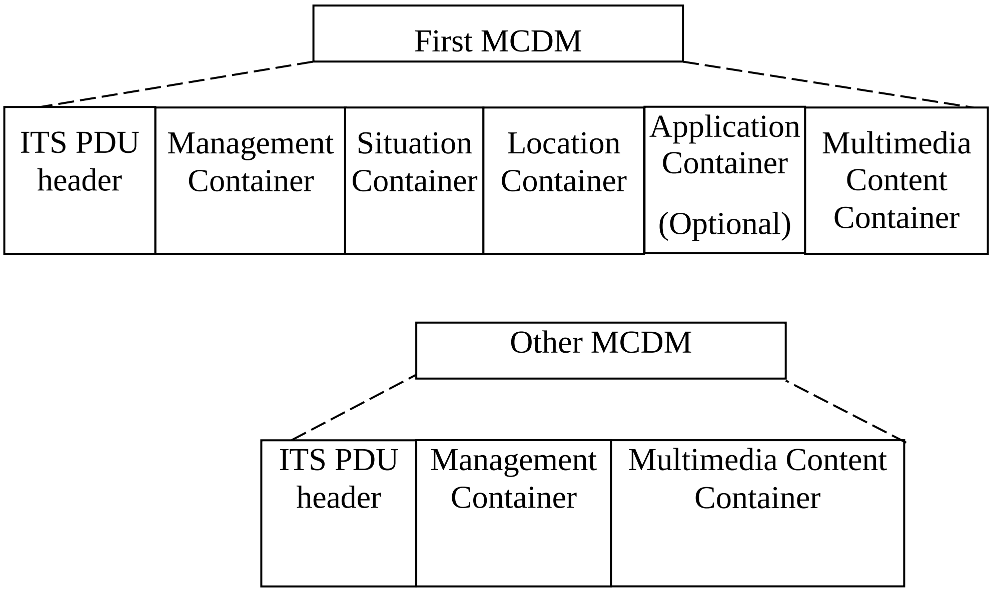

Figure 9 General MCDM structure [37]

The MCDM can be disseminated employing different addressing modes. It can be disseminated to all the users within the communication range of the transmitter (broadcast), to all the users in a geographical area (geobroadcasting), to a determined set of users (multicast) or to a single user (peer to peer). Furthermore, MCDMs can be repeated or forwarded in order to allow the reception of the message by a minimum number of ITS stations when required by an application.

It is important to stress out that, differently from the other I2V messages described so far, the MCDM is not yet considered by the C-Roads or the C2C-CC for deployment at any of the envisioned deployment phases.

2.2 Non standardized messages

Besides the standard V2X messages, TransAID has considered also relevant message definitions deriving from related R&D initiatives.

2.2.1 CAM extensions

Past and ongoing R&D projects have proposed extensions of the standard CAM to serve automated driving-related purposes. The following sections briefly describe the main contributions in this context.

2.2.1.1 AutoNet2030

The AutoNet2030 project proposed an extension of the standardized CAM service [17] defining new high and low frequency containers to support cooperative driving applications such as convoy and platoon driving, or cooperative lane change [38]. The CAM was extended with additional options for the standard high frequency and low frequency containers. These options are called respectively *AutomatedVehicleContainerHighFrequency* and *AutomatedVehicleContainerLowFrequency*. The *AutomatedVehicleContainerHighFrequency* is an alternative compact version of the *BasicVehicleContainerHighFrequency* used by the car industry for Day1 deployment [19] and includes the minimum set of information needed for car following applications (speed, acceleration, etc.). This allows transmitting this message more frequently (e.g. at 10Hz or more) as it consumes less network resources when transmitted. The *AutomatedVehicleContainerLowFrequency* is an alternative version of the *BasicVehicleContainerLowFrequency* and introduces information like driving mode (e.g. semi or fully automated), enabled automated systems (e.g. CACC, platooning), target speeds and accelerations, predicted trajectory, etc. sent at lower frequency (e.g. 2Hz). Besides this, Autonet2030 introduces a non-backward compatible extension of the Day1 CAM by including a data element *distanceToPrecedingVehicle* to the *BasicVehicleContainerHighFrequency* to support CACC and cooperative Lane Change on semi-automated vehicles. According to the Autonet2030 protocol, CAMs including the new Automated Vehicle High and Low Frequency Container are transmitted on an alternative SCH compared to the standard SCH0 used for Day1 deployment [19]. This is motivated by the valid reason not to congest the SCH0 channel used from the very initial phase of C-ITS introduction. On the contrary, CAMs with the modified *BasicVehicleContainerHighFrequency* will still be transmitted on the SCH0 adopted for Day1 deployment. The introduction of changes in the *BasicVehicleContainerHighFrequency* will provoke that the semi- or fully automated vehicles transmitting these modified CAMs on the SCH0 will not be "understood" by the cooperative vehicles already deployed in the Day1 phase and hence will compromise backward compatibility.

2.2.1.2 MAVEN

The MAVEN project also proposed extensions of the CAM messages [39]. In this case, extensions were needed to let CAMs support platooning (strings of cooperative ACC vehicles) applications and interactions with the road infrastructure [41]. These extensions were made in such a way to ensure by design support of advanced functionalities for automated vehicles and platoons while ensuring backward compatibility. It is indeed necessary that CAVs keep providing cooperative (not-automated) vehicles and existing C-ITS infrastructure (RSUs) with the information available from Day1 C-ITS deployment. In fact, from the moment of Day1 C-ITS deployment, the information received in standard CAMs will be used to implement Day1 applications such as detection of traffic jams ahead (at cooperative not-automated vehicles) or estimation of incoming traffic demands (at C-ITS infrastructure/RSUs). To ensure this service continuity it is needed that extended CAMs transmitted by CAVs are in a backward compatible format (i.e. "understandable" by already deployed C-ITS systems). If backward compatible formats are adopted, CAVs and newly deployed RSI will be able to process the whole messages including the extensions; cooperative non automated vehicle and already deployed infrastructure will just discard the extensions yet processing the rest of the message.

Two separate extended CAMs are used in MAVEN:

1) Extended CAM on SCH0: carries information for CAVs to detect opportunities to initialize a platoon as well CAV and/or platoon features reusable by the infrastructure (planned route, desired speed, platoon ID, participants, etc.). As indicated in Figure 10, this information is contained in an optional special vehicle container called *MAVENAutomatedVehicleContainer*, and hence ensures backward compatibility with pre-existing Day1 systems in this channel.
2) Extended CAM on SCHx: carries the needed information to manage and control platoons of MAVEN CAVs in a distributed manner. It is transmitted at a fixed higher frequency [10-30Hz] and using a separate ITS channel not to overload Day1 systems on the SCH0 (the same approach is suggested in [38][40]). Its transmission is triggered during the platoon initialization phase. Then, the message is populated following the distributed platoon logic running at individual vehicles. An *AutomatedVehicleContainerHighFrequency* is always transmitted to carry important information that CAVs consider for close following. The

AutomatedVehicleContainerLowFrequency is included every x messages, mostly with information reflecting the platooning state machine running at each vehicle and used for distributed platoon management [41].

A more detailed description of the CAM extensions structure is reported in Figure 10.

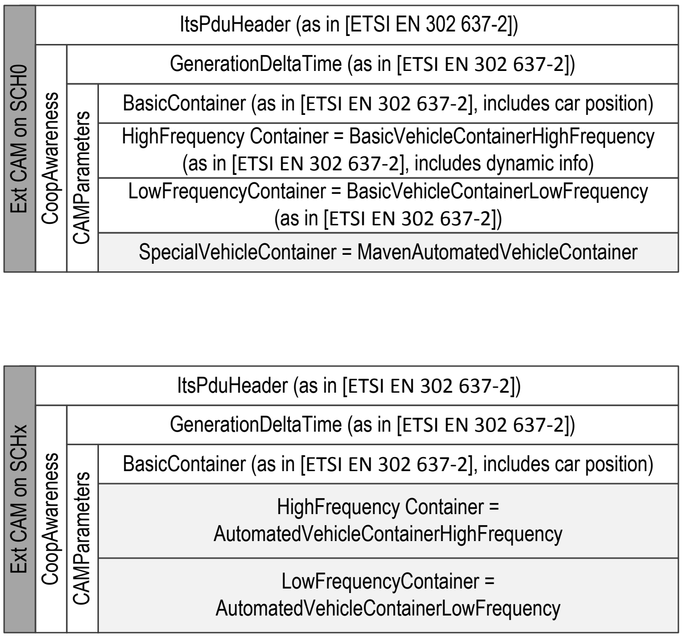

Figure 10 MAVEN extended CAMs structure [39]

2.2.1.3 CAM extensions for CACC

The CACC pre-standardization study performed at ETSI [40] collects the requirements of past and ongoing research activities and proposes an extension of the CAM to support vehicle employing the CACC system. The CACC system allows vehicle to automatically adjust their speed in order to keep a target time gap with the preceding vehicles while maintaining a minimum safety distance. In order to do so, communication between vehicles is necessary to exchange information about the vehicle dynamics and compute the parameters to control the longitudinal control systems of the vehicle. For the transmission of this information, and following the approaches of Autonet2030 and MAVEN, two additional containers are proposed as an extension to the CAM standard: the automated vehicle container low frequency (Table 2) and the automated vehicle container high frequency (Table 3). Those containers are alternative to the basic high and low frequency container defined in the current version of the CAM standard [17]. Furthermore, an additional container is proposed in order to allow the road side infrastructure to support the execution of the CACC by employing the Road Side CACC container (Table 4).

Table 2 Automated Vehicle Container Low Frequency

Name	Optional	Description
Target speed		Target speed set by the CACC application

Target longitudinal acceleration		Target longitudinal acceleration set by the CACC application
Braking capacity		Maximum braking capacity of the vehicle that transmits CAM.
Target distance to preceding vehicle	X	Target time gap set by the CACC application to the preceding vehicle
Target distance to following vehicle	X	Target time gap set by the CACC application to the following vehicle
Path prediction	X	Predicted path of the vehicle that transmits CAM
Group ID	X	ID of the CACC string
Group speed	X	Measured speed of the CACC string
Limited legnth	X	Limited total length of the CACC string
String lead vehicle position		Last known position of the string lead vehicle
Limited length in number	X	Limited length of CACC string in number of vehicle
Order in string		Position of transmitting vehicle ITS-S in CACC string
Lead vehicle		Station ID of the CACC string lead vehicle

Table 3 Automated Vehicle Container High Frequency

Name	Optional	Description
All elements of the Basic Vehicle Container High Frequency		
Distance to preceding vehicle	X	Currently not defined
Azimut angle to target vehicle	X	The measured azimuth Angle between subject vehicle and target vehicle.

Table 4 Road side CACC container

Name	Optional	Description
Recommended target time gap	X	Recommended target time gap for vehicles accepting road side CACC service

Starting position	X	Position starting from which the road side CACC service is available.
CACC lane position	X	Lane at which the road side CACC service is available
Recommended speed	X	Recommended speed limit for vehicles using the road side CACC service.
Limited length	X	Types of vehicles which may use the road side CACC service
String lead vehicle position		Last known position of the string lead vehicle
Limited length in number	X	Limited length of CACC string in number of vehicle
Recommended vehicle type	X	Types of vehicles which may use the road side CACC service

The pre-standardization study of the CACC at ETSI proposes also some modifications in the triggering conditions of the CAM sent by vehicles. It offers two options for modifying the transmission frequency of the CAM. The proposal is to either fix the frequency of the CAM to 10Hz whenever the CACC is engaged or to dynamically vary the frequency between 10 Hz and 30 Hz as a function of the target time gap. Similarly, for the road side infrastructure two options are given: to set a fixed frequency of 1 Hz or to set a periodic transmission triggered by a mobile ITS station (e. g. by receiving a CAM from a vehicle).

2.2.2 LAM

The Lane Advice Message (LAM), designed by the MAVEN project [39], assists cooperative automated vehicles in chosing the optimal lane when approaching an intersection. It was concluded that a new message is required to cover the needs of this use case. A possibility considered was using the SPAT and letting vehicles automatically change to the lane with the highest speed advice. However, this would lead to oscillation effects when too many vehicles follow the advice. Therefore, a new message was introduced. The message was designed in a way to use as many pre-existing elements of the SAE J2735 dictionary [30] as possible. It starts with the common ITS PDU header for uniformity with other messages in the dictionary. Relevant locations are referenced from the MAPEM, to prevent having to send the topology information twice.

An example scenario for the lane advice is shown in Figure 11. In this situation the vehicle with *stationID* 2 gets an advice to merge to lane 1. Since both vehicles in front and behind the gap are cooperative, the LAM can provide information about the neighbouring vehicles as well. However, as indicated by the presence of a red non-equipped vehicle, this is not always the case and therefore the neighbour indications are optional. The location where- and the time when the lane change should take place are also optional, but provided by the RSU when it has sufficiently precise knowledge to help the vehicle to optimally merge. For emergency situations where lane 1 is already full, the RSU can simply advise to merge and then it’s up to the vehicle to find a gap. The target vehicle, lane, and intersection are mandatory because leaving these out would make interpretation of the advice impossible. The reason for the advice is also mandatory, so vehicles can assess the criticality of the situation.

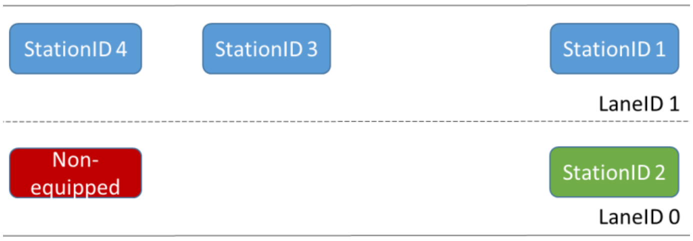

Figure 11: Scenario for Lane Advice

The message structure is shown in Figure 12. Optional fields are indicated as grey, while mandatory elements are white. The advice reason is a choice and marked as light grey, precisely one of the options has to be selected. The lane advice list can contain up to 256 elements, which is a consequence of the message being a broadcast. This way other vehicles around can also read the lane advice given and anticipate on certain vehicles changing lanes.

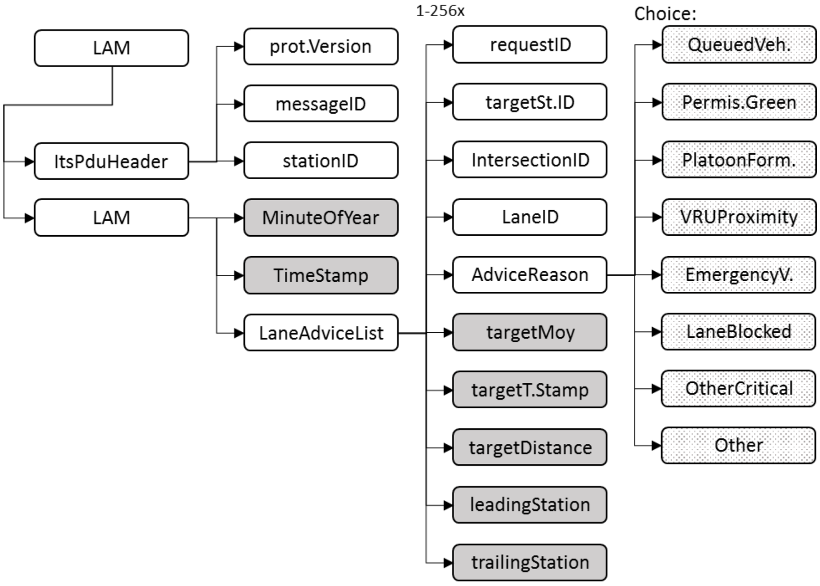

Figure 12: LAM message structure

The message follows the same principles as already explained with the scenario in Figure 11. The message is only transmitted when there is an active advice. This means that there is a vehicle that should change lanes. Once the vehicle has changed the lane or actively declined the advice, the retransmissions will stop. With at least one active advice, the message is broadcasted every second or earlier in case of an update. When an update occurs, the advice should get a new *requestID*.

The *requestID* can be used by vehicles in their MCMs or CAM extensions as a reply to the RSI to indicate whether the vehicle is going to adhere to the lane advice or not.

At the moment, the LAM message is foreseen as a valuable tool for the TransAID services. For reuse of the LAM functionality, TransAID considers the most optimal solution to integrate the LAM contents into the MCM message by adding a specific RSU container to be transmitted by RSUs only. However, if consensus cannot be reached in the MCM standardization process for adding this extra information to the MCM, the separate LAM message can still be used in TransAID to support its use cases.

2.2.3 Other automated-driving related messages

2.2.4 iCLCM

The i-GAME Cooperative Lane Change Message (iCLCM) is a message defined in the i-GAME project to support cooperation between vehicles [42]. The iCLCM message includes information to support platoon management, cooperative lane changes and intersection management. Thus, the iCLCM includes information about the ego-vehicles dynamics, about the future planned manoeuvres and also about detected vehicles. Figure 13 shows the general structure of the iCLCM, which is composed by the common ITS PDU header and several containers:

- The iCLCM header: an additional header that includes the generation time.
- The Vehicle HF container: includes additional information about the vehicle on a high frequency rate.
- The LF container: includes information that does not need to be updated at high frequency
- The MIO: includes information about the neighbours, the Most Important Objects.
- The Lane: the lane ID on which the vehicle is currently driving.
- The Pair ID: containing the station ID of the pairing partner.
- The Merge container: includes all information needed to perform the actual merging.
- The S container: a container for additional information that is needed for the scenario execution.

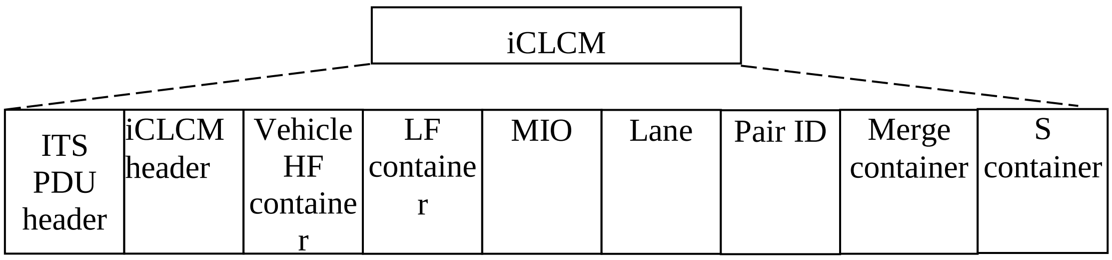

Figure 13 General iCLCM structure [42]

The dissemination of the iCLCM is periodic with a fixed frequency of 25Hz. This high frequency is defined in order to provide reception reliability by redundancy and hence ensure reduced inter-vehicle safety distances.

2.2.5 Autonet2030 messages

The Autonet2030 project also defined a set of messages with different functionalities based on the multiple scenarios defined in the project. The relevant messages for TransAID are the following ones [38]:

- CLCM (Cooperative Lane Change Message): this message supports the execution of cooperative lane changes.
- CMM (Convoy Management Message): This allows cooperative vehicles to plan automated adjustments of their speed and heading according to a decentralized mechanism, or to plan needed lane change manoeuvres ahead.

- CSM (Cooperative Sensing Message): This message supports the collective perception in order to enhance the environmental perception of vehicles.
- CSAM (Cooperative Speed Advising Message): This message is to reliably deliver the advised driving speed for a given road segment through a scalable broadcast-based approach.

2.2.5.1 CLCM

The CLCM is defined to support the planning, preparation and execution of a cooperative lane change for one or various vehicles (i.e. a platoon or convoy) [38]. The general structure of a CLCM is composed by a common ITS PDU header, an additional header specific for the CLCM and a message body container that shall include one of the following data frames:

- Lane change request: A cooperative lane change payload used to request and announce the cooperative lane change by the subject vehicles.
- Lane change response: A cooperative lane change payload used by a (potential) target vehicle to respond to a lane change request.
- Lance change abort: A cooperative lane change payload to abort an ongoing cooperative lane change
- Lane change prepared: A cooperative lane change payload used by a target vehicle to inform the originating station that the target vehicle has opened the gap for the subject vehicles to perform the lane change.

The dissemination of the CLCM is not periodic but rather on demand. The dissemination of messages can be started by an originating station, which can be an RSU or a vehicle that wants to initiate a cooperative lane change.

2.2.5.2 CMM

The CMM is defined to support the management of a convoy of vehicles, that is, a group of vehicles driving together maintaining a given formation [38]. This message supports the vehicle joining in- or leaving from the convoy, the management of the formation and the cooperative lane changes of the convoy.

The general structure of a CMM is composed by a common ITS PDU header, an additional header specific for the CMM and a message body container that shall include one of the following data frames:

- Join Request Message employed when a new vehicle wants to join the convoy
- Join Accept Message employed to acknowledge to a vehicle the acceptance in the convoy
- Lane Change Message employed to manage a cooperative lane change in the convoy
- Leave Message used by a vehicle that wants to leave the convoy
- Response Message used to acknowledge the reception of other messages
- Modify Graph Message employed to update the local graph of convoy members
- Modify Group Speed Message used to modify the group speed of the convoy.

The dissemination of CMMs is not periodic but rather on demand. The occurrence of an event (i.e a new vehicle wants to join the convoy or a vehicle wants to perform a lane change, etc.) will trigger the transmission of the message.

2.2.5.3 CSM

The CSM is designed to share information about detected obstacles among C-ITS stations [38]. In particular, the CSM is restricted to dynamics obstacles such as vehicles, cyclists, pedestrians, etc.

The general structure of the CSM is composed by a common ITS PDU header and a cooperative sensing container, which includes the description (i.e. position, speed, heading, etc.) of the detected obstacles.

The CSM is transmitted every second including all the detected dynamic obstacles since the last transmission of the CSM.

2.2.5.4 CSAM

The CSAM is designed to support the delivery of speed advices to the vehicles inside a given road segment [38]. The speed advises are computed by a server based on semi-permanent data such as speed limits, roadwork restrictions, weather restrictions, etc.

The general structure of a CSAM is composed by a common ITS PDU header and a message body container that shall include one of the following data frames:

- Speed Request Message employed to poll from the server the speed advices
- Speed Send Message employed to broadcast the speed advices
- Speed Report Message employed by a vehicle to report that the speed advice cannot be followed.

The dissemination of the message is initiated by a C-ITS station that polls the server every 10 seconds employing the Speed Request Message data frame and then broadcast the speed advice to its neighbour C-ITS station employing the Speed Send Message data frame. The Speed Report Message is event-driven and only transmitted when a vehicle cannot follow the speed advice.

3 TransAID Services

This chapter briefly describes the services and scenarios employed in the two iterations of the TransAID project.

3.1 First iteration services

3.1.1 Service 1 on Scenario 1.1: Provide path around the road works via bus lane

In case road works block the main road and the alternative route is provided via the bus lane, a path must be provided to CAVs. CAVs need to know that the normal lanes are blocked and that the bus lane is allowed for driving. If this information was not provided, the CAVs would detect the lane blockages at last moment and would need to perform a MRM (come to a stop), because no alternative route can be calculated. By receiving a drivable path around the road works, CAVs have information about the blockage in time and can circumvent the road works using the path. In this way, CAVs can maintain their AD mode and ToCs and/or MRMs are prevented (Figure 14[1]).

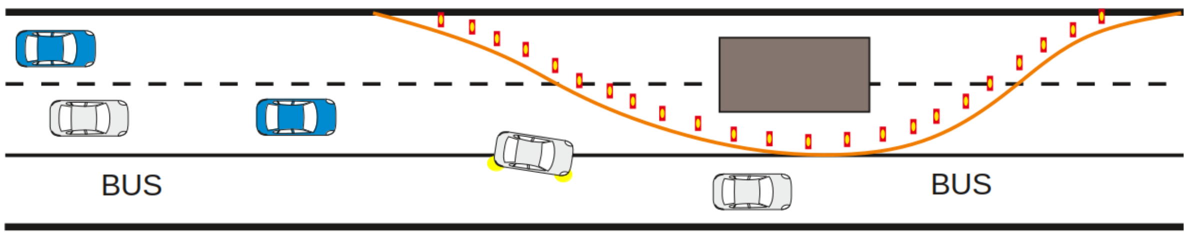

Figure 14 Road work scenario for Service 1

3.1.2 Service 2 on Scenario 2.1: Prevent ToC/MRM by providing speed, headway and/or lane advice

The ‘Prevent ToC/MRM by providing speed, headway and/or lane advice’ scenario focusses on motorway onramp merging sections as is illustrated in Figure 15. The lateral perception of automated vehicles is usually limited to the immediate area around the vehicle required for changing lanes at that moment. However, at the on-ramp it is more important to oversee a larger section of the motorway. On the main road automated vehicles may not break up platoons or create extra space for vehicles on the onramp when they have no space to merge. The infrastructure can assist in both cases using its sensors that measure the traffic situation at both the onramp and the motorway itself and broadcast advice messages to assist the merging process. Without infrastructure assistance, situations would occur where the automated vehicles cannot solve the situation and have to initiate a ToC or MRM to mitigate potentially dangerous situations.

[1] Please notice that the blue cars in this as weel as in the other figures of the section indicate CAVs.

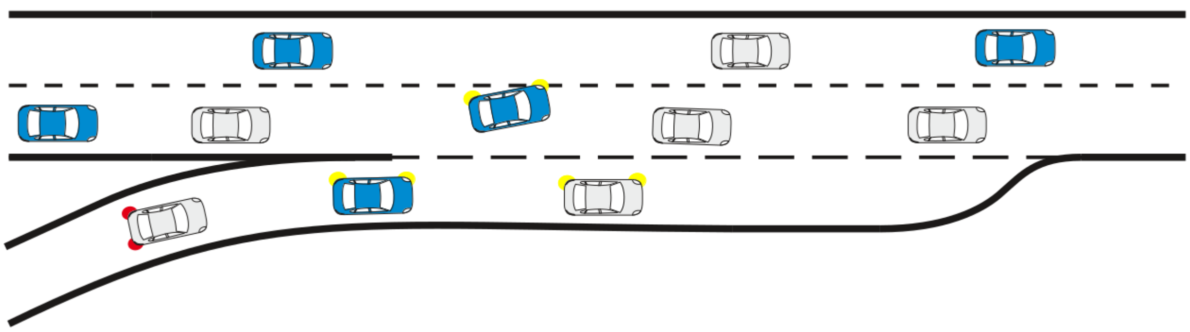

Figure 15: Motorway onramp scenario for Service 2

The infrastructure has several options to advise vehicles on the road: lane advice including position and time of the lane change, speed advice, headway advice, lane change at the motorway itself, platoon breakup and ramp metering.

3.1.3 Service 3 on Scenario 3.1: Apply traffic separation before motorway merging/diverging

As described in deliverables D2.1 and D2.2, Service 3 aims at reducing the interactions between automated and non-automated vehicles and consequently the number of potential ToCs on automated vehicles by separating these vehicle classes over different sectors of the road. On Scenario 3.1, Service 3 is applied to a two two-lane motorways merging in a four-lane motorway (see Figure 16). In this scenario, the RSI disseminates a traffic separation measure where the automated vehicles are advised to move to the outermost-lanes and the non-automated vehicles are advised to move to the inner lanes. As a result, the above mentioned interactions are minimized in the middle lanes, where dangerous human-initiated manoeuvres can occur (e.g. sudden/delayed merging, cut-offs, quick take overs, etc.).

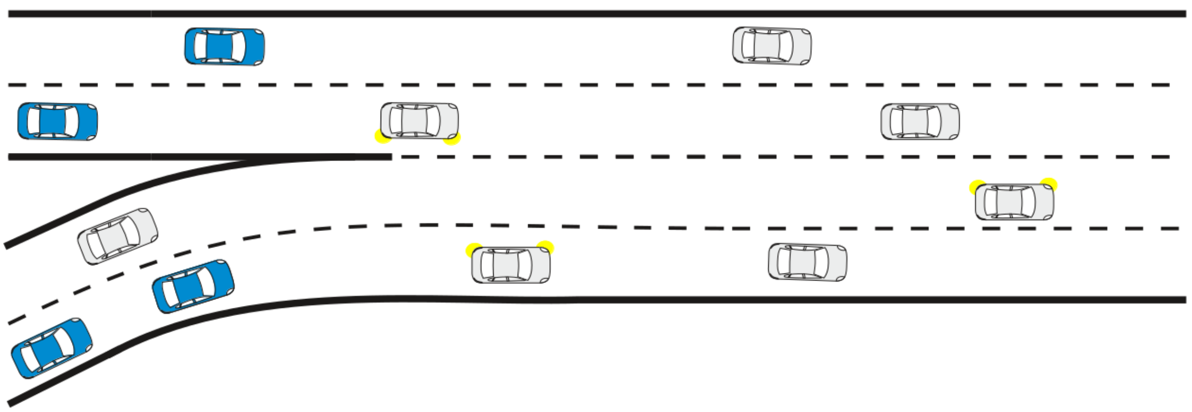

Figure 16 Motorway merging scenario for Service 3

3.1.4 Service 4 on Scenario 4.2: Safe spot in lane of blockage

Service 4 is basically an additional measure to the other services and is employed when the ToC is about to fail. This situation is depicted in Figure 14 and Figure 17, where road works are blocking one proceeding lane of the motorway road. The deployed RSI holds information about the construction area and its vicinity and shares this information to the approaching CAVs.

Some CAVs are not able to pass the construction site without any additional guidance and in such case they need to perform a ToC. In case the ToC is not successful, the respective CAV must perform a MRM. Without additional measures, the CAV would simply brake and stop on the lane it is driving. This might disrupt the traffic flow when happening on the right lane as shown in Figure 17. To avoid this situation, the RSI continuously monitors the area just in front of the construction site and offers a place on the road as a safe spot to the vehicle, if available. This safe spot may e.g. be placed in front of the construction site on the closed lane. The CAVs will use this shared safe spot information to plan and execute the MRM in a less critical way.

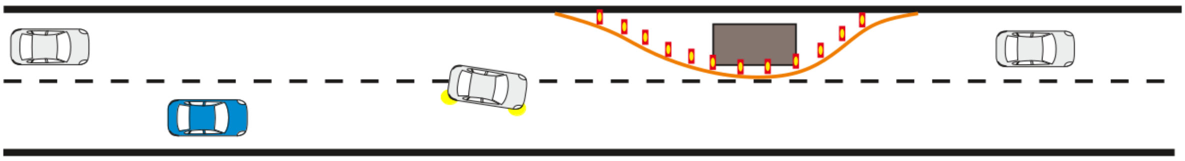

Figure 17 Road works scenario for Service 4

3.1.5 Service 5 on Scenario 5.1: Schedule ToCs before no AD zone

After a transition of control (ToC) from automated to manual mode, the driving characteristics are different (e.g. different headway, different lateral movement variation, different overtaking behavior, etc.). Consequently, the traffic flow and safety are disturbed at Transition Areas, where multiple transitions of control occur. To prevent these negative effects ToCs are distributed in time and space upstream of the Transition Area. As a result, the ToCs are extended to a large area and thus the negative effects of ToC in the traffic flow and safety are reduced.
Figure 18 shows the Scenario 5.1 where multiple CAVs are approaching an area where the automated driving is not possible. This can occur because the automated driving mode reaches its system limits, due to the complexity of the situation, or due to a particular traffic regulation that forbids the automated mode in this area. The RSI collects information about the traffic stream and determines the optimal location and time for the CAVs to perform a downward ToC. CAVs approaching the no AD zone receive the ToC advises and execute the ToC before entering the area. As a result, the ToCs are extended to a large area and thus the negative effects of ToC in the traffic flow and safety are reduced.

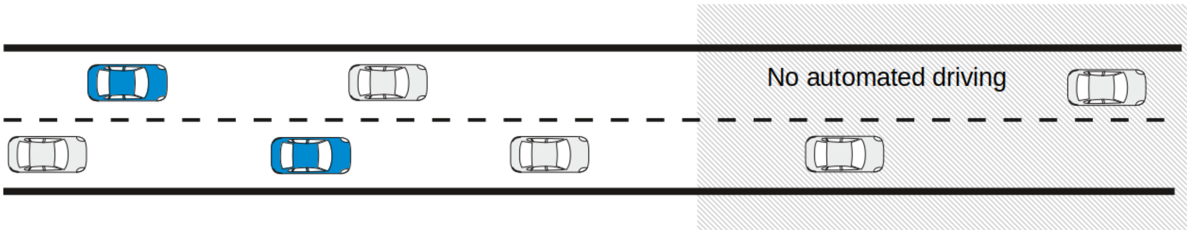

Figure 18 Schedule ToC before no AD-zone for Scenario 5

3.2 Second iteration services

3.2.1 Service 1 on Scenario 1.3: Queue spillback at exit ramp

CAVs, AVs, CVs, and LVs approach an exit on a motorway. There is a queue on the exit lane that spills back onto the emergency lane. We consider a queue to spill back as soon as there is not enough space on the exit lane to decelerate comfortably (drivers will start decelerating upstream of the exit lane). Vehicles are not allowed to queue on the emergency lane, but queuing on the right-most lane of the motorway will cause (a) a safety risk due to the large speed differences between the queuing vehicles and the regular motorway traffic, and (b) a capacity drop for all traffic (including vehicles that do not wish to use the exit). In the baseline of this scenario vehicles queue on the main highway lanes and the speed limit remains unchanged (drivers/(C)AVs have to decide on their own to slow down when they notice the queue). When traffic management is introduced, the RSI will allow (and facilitate) vehicles to queue on a section of the emergency lane and gradually reduce the speed limit for approaching the queue. This is expected to reduce the capacity drop and safety risks.

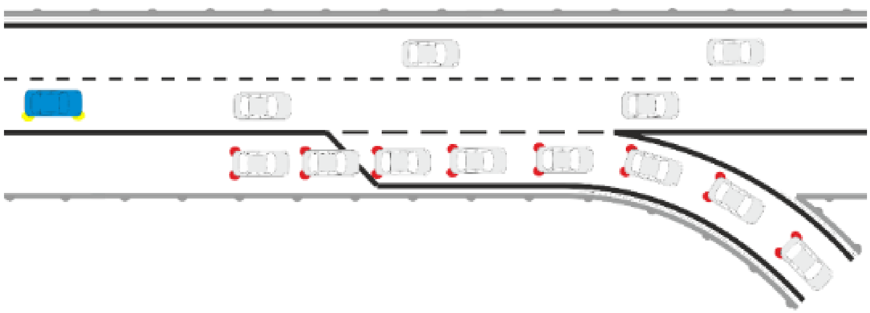

Figure 19: Schematic presentation of the scenario. A queue at an exit ramp spills back and vehicles queue on the emergency lane.

Without application of the TransAID service in this scenario, the vehicles behaviour will be the following. If an AV or CAV approaches the exit, it will try to merge into the exit lane. It can be assumed that the vehicle is capable of merging successfully and no driver interaction is required. In case of spill back, merging might be difficult. If the vehicle does not manage to merge into the exit lane, it can generate a ToR. Since the (C)AV will usually be able to merge into the exit lane autonomously, a ToR will not be generated until the (C)AV has tried to merge autonomously. If this attempt is unsuccessful, the vehicle might slow down to a very low speed, or come to a complete stop on the main road (next to the exit ramp) while it waits for the driver to perform the ToC. This is a potentially dangerous situation. If the ToC fails, the (C)AV would perform an MRM. The vehicle most likely cannot stay on the main road, but in order to drive to the emergency lane (where it can perform a safe stop), it is reasonable to assume that it would have to drive beyond the exit ramp. From there, the driver would take control again, merge into the right most lane and drive to the destination using another exit. Nevertheless, merging from the emergency lane into high-speed traffic on the highway is a dangerous manoeuvre. It would be safer (and faster) if the (C)AV did not perform any MRM and autonomously decide to reroute after the ToR failed. This is the approach we use in this scenario: the (C)AV tries to merge into the exit lane, but when it fails to do so it does not generate a ToR and decides to reroute instead without interaction with the driver. Traffic operations continue normally once vehicles have passed the off-ramp.

3.2.2 Service 2 on Scenario 2.1: Prevent ToC/MRM by providing speed, headway and/or lane advice

In theory all functionality of the speed, headway and lane advice service was already described for the first iteration. Therefore, the service is still the same as shown in Figure 15 and described in Section 3.1.2. However, it is worth highlighting that in the first iteration not all the possible functionalities were implemented. Only speed guidance for vehicles at the on-ramp was provided. In the second iteration, the full set of functionalities will be implemented, including headway and lane change advices to vehicles coming upstream from the motorway itself.

3.2.3 Service 2 on Scenario 2.3: Intersection handling due to incident

An incident occurs just before the stop line of the right-turning traffic lane on the west approach (approach C, lane 5). The incident is blocking lane 5 and therefore vehicles driving on this lane will need to use the through traffic lane (approach C, lane 6) to drive around the incident. Vehicles driving from approach C to lane y can drive around the incident and go back to lane 5 just before the intersection to make a right turn. Without additional TransAID measures (baseline scenario), depending on whether the (C)AV can recognise the situation, either a ToR is issued which ends up in a ToC or an MRM, or the (C)AV recognises the situation. In both cases, automated and manually driven vehicles will try to merge into lane 6 to overcome the incident. Part of the vehicles in automated mode which do not know how to turn right safely are assumed continue their journey to lane x and find a new route. Manually driven vehicles and another portion of the vehicles driving in automated mode are assumed to turn right at the junction.

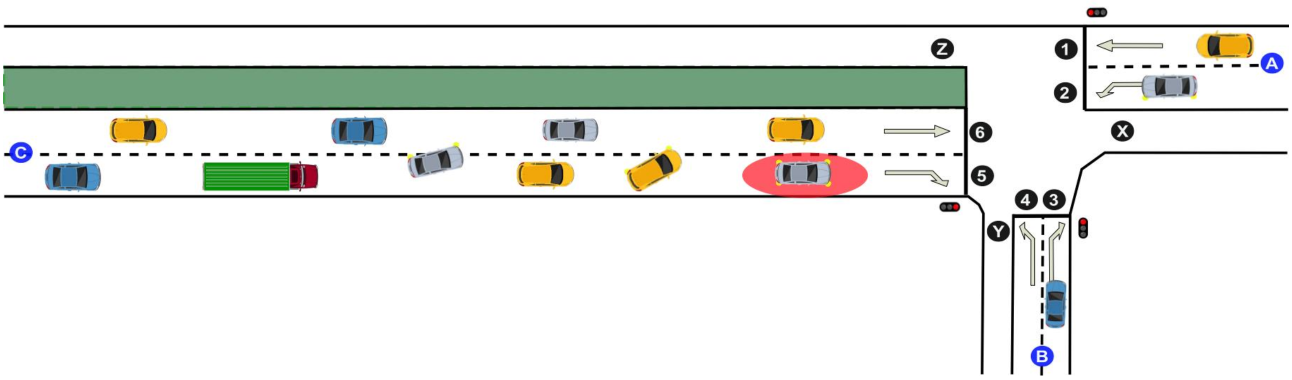

Figure 20: schematic overview of Service 2 on Scenario 2.3

To improve the traffic situation (safety- and LOS-wise), the RSI continuously monitors the area around the junction. When the RSI receives information about an incident it will deploy all the following countermeasures. CAVs and CVs:

1. will receive information about the incident itself (position, type, etc.);
2. will receive a message of a lane closure;
3. will receive a reduced speed limit;
4. will be informed that they can turn right on lane 6.

According to the received information, CAVs can make the right turn while maintaining their automated driving mode (thus preventing a ToC).

The traffic light control (TLC) will also be updated to support the measures, by:

1. Communicating that lane 6 is available to make a right turn;

2. Change the TLC-programme to support the temporary situation.

Please notice that AVs and LVs will not receive any information. Therefore, ToCs will occur for AVs in the same way as in the baseline situation.

In addition to the intersection handling service it can be assumed that other TransAID measures can also apply for additional safety and traffic efficiency. During the simulation activities in WP4 this will be kept in mind. Nevertheless, to keep the level of complexity under control, scenario 2.3 focusses on the intersection handling only. Possible optional services are:

- Individual lane change advice
- Individual gap advice
- Safe spot information
- Individual MRM guidance
- Individual triggering of ToC points

3.2.4 Service 2 and 4 on Scenario 4.2: Safe spot in lane of blockage & Lane change assistant

As described in the title, this section describes the concurrent application of two services in the same scenario. A two-lanes road (urban or motorway) is blocked with a construction site that covers the left lane of the road. Some CAVs will not be able to overpass the construction site without human intervention due to system limitations. Thus, CAVs will trigger a ToC somewhere upstream of the construction site and the human driver will take control of the car. Eventually, ToCs will be unsuccessful, which will result in MRMs. Without additional traffic management measures, the CAVs will simply brake and stop on the current lane where they are driving. If a CAV stops on the right lane, it will disrupt the traffic flow and can even completely block the road if it stops at the construction site. If the CAV stops further upstream on the left lane, it will essentially create a second lane drop bottle neck.

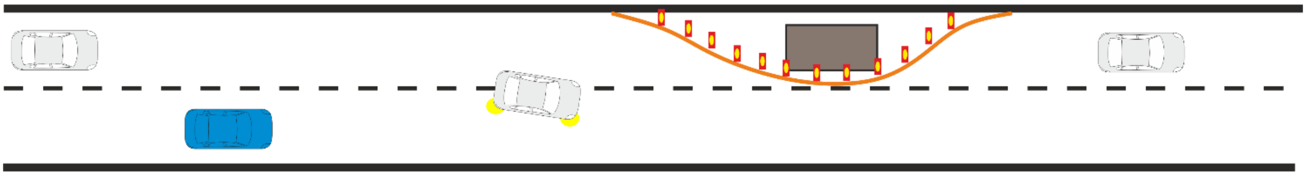

Figure 21: schematic overview of Scenario 4.2

To avoid the latter situations, the RSI will continuously collect information about the construction area in its vicinity and disseminate this information to approaching CAVs. In particular, the RSI will offer pre-determined spaces as safe spots for CAVs approaching the construction site. The CAVs will use the safe spot location information to come to a stop in case of MRM. Additionally, the RSI will use V2X information received from CAVs and CVs along with data fusion from road sensors to acquire accurate knowledge of the traffic conditions and facilitate the early merging of CAVs providing lane change advices (Lane Change Assistant Service). To ensure smoother merging of the CAVs on the right free lane, the RSI distributes lane change advices in space and time to prevent local traffic turbulences. Furthermore, the Lane Change Assistant Service can be combined with cooperative manoeuvring to enhance its performance. Hence the possibility diminishes that CAVs stop in front of the work zone on the left lane (waiting for merging to the right lane) and occupy safe spots that should be available for CAVs performing MRMs.

3.2.5 Service 4 and 5 on Scenario 4.1-5: Distributed safe spots along an urban corridor

Another example of simultaneous application of two services is presented. Services 4 and 5 extend the Safe Spot information (see Section 3.1.4) to an urban scenario where AD restrictions apply. The situation is depicted in Figure 22, where a CAV is approaching a no AD zone. The deployed RSI has knowledge about the zone boundaries and the area upstream. As a consequence, it shares this information to the approaching CAVs.

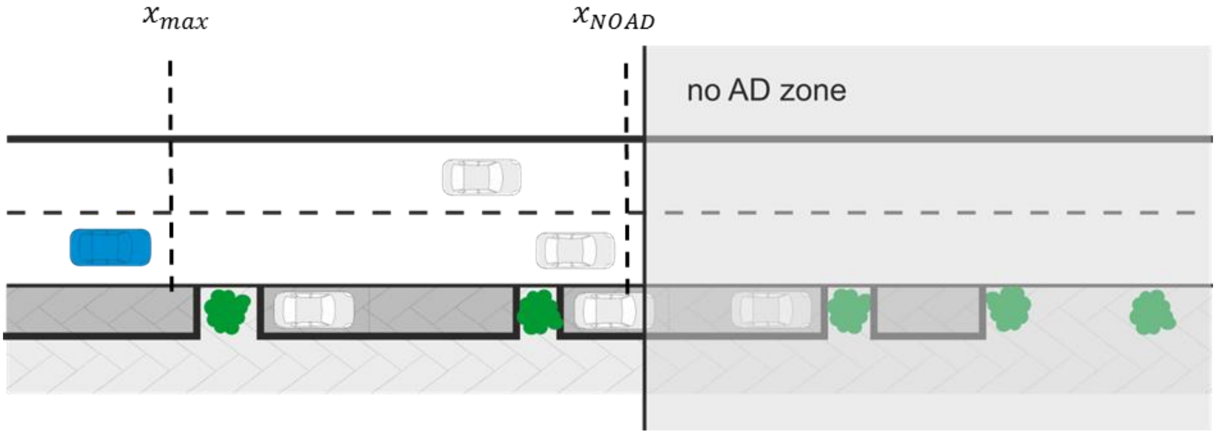

Figure 22 Safe spot in front of no AD zone for scenario 4.1-5

For CAVs, the AD restrictions deployed by the RSI will induce a ToR. When applying traffic management procedures, the RSI will send ToC advices instead. In case the ToC is not successful, the respective CAV must perform a MRM. Similar to Section 3.1.4, this may imply MRM vehicles to block the traffic if no additional measures are applied. To avoid this situation, the RSI monitors the area upstream where multiple parking spots or stopping zones are available as safe spots for the MRM. In TransAID, area occupancy sensing is implemented with a stationary camera and image-based detection of vehicles at the considered spots. Depending on occupancy and ToC timing, different safe spots will be provided. The CAVs will use this safe spot information to plan and execute the MRM in a less critical way, if needed.

4 Requirements of the services

As previously mentioned, TransAID aims at developing traffic management measures for Transition Areas. To do so, V2X connectivity is employed to exchange valuable information between vehicles and with the infrastructure. The definition of necessary information to exchange is based on requirements set by the TransAID services detailed in [12] and briefly recalled in Section 3. This section defines the "information requirements" as the information that needs to be shared between the TransAID actors with connectivity capability. We first describe the requirements that are common to all TransAID services and then we detail the specific requirements of services from the first and second iteration of the project. Please notice that definition of other requirements like triggering conditions and transmission frequency of messages will be based on outputs of preliminary simulations of traffic management measures performed by the TransAID Task 4.2, which is ongoing at the time of writing this document. The complete version of the TransAID V2X message set including message generation rules will be presented in the second version of Deliverable 7.2 to be submitted in the project month M36. This deliverable will combine the theoretical definitions of the present document along with inputs from computer simulations of WP4 and implementation results from WP7 real world tests

4.1 General requirements

There exist some similarities between the TransAID services that lead to a set of common information requirements for all services. These general requirements can be classified in five categories:

- Information about the ego vehicle
- Information about detected vehicles/obstacles
- Information about ToC/MRM
- Information about the road network
- Information about traffic rules

In the following, these five categories are detailed and the associated information requirements are defined.

4.1.1 Information about the ego vehicle

In C-ITS, it is essential for vehicles and road infrastructure to be aware of any other nearby traffic participants. To this aim, cooperative (automated) vehicles can share information about themselves to alert others vehicles and the road infrastructure about their presence, position and dynamics on the road. In the context of TransAID, this will additionally help cooperative automated vehicles to plan their manoeuvres, the road infrastructure to suggest traffic management measures and hence it is the base for defining cooperative manoeuvres between vehicles and assisted by the infrastructure. In addition, ego-vehicle information is also a pre-requisite for formation and management of strings of vehicles driving in CACC mode. Table 5 details the information that needs to be shared by cooperative vehicles in this regard.

Table 5 List of information about the ego vehicle

Requirement	Description
Type of vehicle	The information about the type of vehicle (e.g. car, truck,

	bus, etc)
Length	Length of vehicle
Width	Width of vehicle
Position	Position of the vehicle
Lane position	Lane in which the vehicle is currently driving
Speed	Speed of the vehicle
Acceleration	Acceleration of the vehicle
Heading	Heading of the vehicle
Driving mode	Current driving mode of the vehicle (e.g. cruise control, adaptive cruise control, etc.) employed to estimate the behaviour of the vehicles.
Current automation level	Current engaged level of automation of the vehicle. Can be employed by the infrastructure to determine the traffic stream composition
Information for CACC string initialization	Includes planned route, desired speed ranges, acceleration and deceleration capability, etc.
Information for CACC string management	Includes control flags needed for the distributed management of CACC strings operations (joining, leaving, breaking-up, etc.)
Planned future trajectory	Planned future trajectory of the vehicle. It is used for cooperative maneuvering including CACC
Desired future trajectory	This trajectory is employed when a CAV wants to start a cooperative maneuver. The CAV indicates the trajectory that it wants to execute in order to start the cooperation

4.1.2 Information about detected vehicles/obstacles

Nowadays, vehicles have the capability to perceive their surrounding environment and detect obstacles, VRUs or other vehicles employing on-board sensors such as cameras, LIDARs, radars, etc. Similarly, the road infrastructure can make use of various types of road sensors to monitor the presence of different kinds of traffic participants. By sharing this information via V2X, other cooperative traffic participants and the RSI can be aware of obstacles or vehicles that they cannot currently detect themselves and act accordingly. This is of special relevance in a mixed traffic scenario where conventional and cooperative vehicles coexist. This information can be employed by cooperative (automated) vehicles and the RSI to detect conventional vehicles that cannot share their presence due to their lack of connectivity. As a result, the road infrastructure can employ this information, together with the information about the ego vehicle, to estimate the status and composition of the traffic stream. The list of information that would be needed to share is detailed in Table 6.

Table 6 List of information about the detected vehicles/obstacles

Requirement	Description
Size of obstacle	Observable dimensions of the detected obstacle
Position	Position of the detected obstacle
Speed/heading	Speed and heading of the detected obstacle
Acceleration	Acceleration of the detected obstacle
Lane position	Current lane where the detected obstacle is located

4.1.3 Information about transitions of control

Automated vehicles can currently drive in different traffic conditions, but there still exist situations that automated vehicles cannot handle efficiently and safely. In these situations, a transition of control is needed to handover vehicle control to the driver. Furthermore, if the ToC fails a MRM will be initiated and the vehicle will come to a safe stop. In order to reduce the impact of a ToC/MRM in the traffic flow, a cooperative automated vehicle can share information about the ToC/MRM to their neighbours and RSI so they can act accordingly. Table 7 details the information that needs to be shared by cooperative automated vehicles related to transitions of control and minimum risk manoeuvres.

Table 7 List of information about ToC/MRM

Requirement	Description
Transition alert	Alert about an upcoming ToC
Target automation level	Desired automation level when the ToC is executed
Trigger time of ToC	Time when the ToC will start
MRM alert	Alert about an upcoming MRM
Trigger time of MRM	Time when the MRM will start

4.1.4 Road network information

In this category we group information that the road infrastructure is requested to transmit to inform traffic participants about the topology and features of the road network. This information is useful for cooperative (automated) vehicles in order to extend their knowledge of the road beyond their sensor range. Furthermore, it can also be employed to establish a common and unambiguous reference to certain parts of the road to which status information is related (e.g. informing about which lanes are blocked by road works) or where traffic management measure apply (e.g. lane change advices, etc.). The specific list of information that needs to be shared in this regard is detailed in Table 8.

Table 8 List of information about the road network

Requirement	Description
Number of lanes	Number of lanes of the road
Width of lanes	Width of the lanes of the road
Curvature of the lanes	Curvature of the lanes of the road
Incoming lanes	ID's and coordinates of the lanes that infer to a apecific road section or intersection
Outgoing lanes	ID's and coordinates of the lanes that defer from a specific road section or intersection
Type of lane	Type of lane, i.e. emergency lane , bus lane, etc.

4.1.5 Traffic rules information

Information about the traffic rules of the interested area can be disseminated by the road infrastructure to cooperative (automated) vehicles for planning of future manoeuvres. This is of special relevance for dynamic traffic rules such as dynamic speed limitation or other information displayed in variable message signs. Table 9 details the list of information of this category.

Table 9 List of information about the traffic rules

Requirement	Description
Type	Type of traffic rule (speed limit, give way, etc)
Area of application	Area of the road where the traffic rule applies

4.2 Service requirements

Differently from the previous one, this section provides service-specific information requirements as they apply to the scenarios analysed in the first as well as in the second project's iteration.

4.2.1 First iteration

4.2.1.1 Requirements of Scenario 1.1: Provide path around road works via bus lane

In Service 1, the RSI provides information about a path through a bus lane to CAVs approaching a road works area in order to allow CAVs to overpass the road works while keeping the automated driving mode. All cooperative (automated) vehicles need to be alerted about the presence of the road works and the state of the road lanes. CAVs need to receive the path to overpass the road works and also information that the bus lane is allowed for driving in the road works area. Table 10 details the list of specific requirements for Service 1.

Table 10 List of requirements for Service 1

Name	Description
Road works alert	This alert provides a warning to all cooperative vehicles (including CAVs) to indicate a potentially dangerous road works situation. CAVs automation logic can take this into account and possibly take different actions. CVs are also alerted and risk of incidents is reduced.
Path to overpass road works	The normal infrastructure is blocked by road works. The only way through is via the bus lane which is normally not available to non-bus vehicles. Upcoming CAVs need information about the alternative path, because without that information an alternative path cannot be calculated. The point from which vehicles can start merging to the bus lane is thus implied in this requirement/information as well.
Lanes closed	CAVs need to know that the normal lanes are not available for driving, so that they can anticipate their decisions. Otherwise they would detect the obstacles blocking the lanes at the last moment.
Bus lane allowed for driving	Altought the bus lane might be marked as the alternative route, the CAV logic might still prevent the vehicle from adopting it, since it concludes thatit is not allowed to pass the solid line and/or drive on the bus lane (according to normal traffic rules). This premission needs to be provided explicitly or implicitly (done so by providing an temporary MAPEM in which it isn’t a specific bus lane anymore).

4.2.1.2 Requirements of Scenario 2.1: Prevent ToC/MRM by providing speed, headway and/or lane advice

Service 2 aims at preventing ToC or MRM by letting the RSI provide speed, headway and/or lane advices in a motorway on ramp merging scenario. The infrastructure computes and disseminates the advices to the cooperative (automated) vehicles in order to increase the overall traffic flow and safety. Table 11 details the list of specific requirements for Service 2.

Table 11 List of requirements for Service 2

Requirement	Description
Gap with preceding vehicle (transmitted by vehicles)	This is valuable information especially with mixes of LV/C(A)V to determine gap progression and adjust lane/speed advice.
Gap with following vehicle (transmitted by vehicles)	This is valuable information especially with mixes of LV/C(A)V for the infrastructure to determine gap progression and adjust lane/speed advice.
Lane advice with target lane, time or position to change, reason for the advice and optionally which are the leading/trailing vehicles (transmitted by the infrastructure)	This is the core of the solution for this scenario. By providing this advice, traffic should become smoother and merging with or around automated vehicles should occur without ToC/MRM.
Individual gap advice (transmitted by the infrastructure)	Another core measure for this scenario. Creating gaps on the main road is the complementary part to the lane advice for vehicles on the onramp.
Confirmation gap advice (transmitted by vehicles)	In case a vehicle cannot comply for whatever reason, the infrastructure can use this knowledge to adjust its solution.
Confirmation of lane advice (transmitted by vehicles)	In case a vehicle cannot comply for whatever reason, the infrastructure can use this knowledge to adjust its solution.

4.2.1.3 Requirements of Scenario 3.1: Apply traffic separation before motorway merging/diverging

In this scenario, service 3 is applied with the RSI disseminating a traffic separation measure suggesting the automated vehicles to move to the outermost-lanes (in Figure 16 being the left lane on the highway merging from the left, and the right lane on that merging from the right in the direction of travel) and the non-automated vehicles are advised to move to the inner lanes (in Figure 16 being the right lane on the highway merging from the left, and the left lane on that merging from the right in the direction of travel). The RSI collects information about vehicles driving on the highways upstream in order to characterize the traffic flow and the traffic stream composition in terms of automated and non-automated vehicles percentage. This information is used to determine the needed lane changes on individual vehicles and the Service Area where to apply them. In order for the RSI to disseminate the needed separation measure, the following information must be communicated to cooperative and cooperative automated vehicles (Table 12):

Table 12 List of requirements for Service 3

Requirement	Description
Target lane	The lane to move to for an individual vehicle to apply the suggested traffic separation policy
Advice reason	Reason for applying the advised lane change
Lane change position	Optimal position to start executing the advised lane change (if known)
Lane change moment	Optimal moment to start executing the advised lane change (if known)
Leading and following vehicles	ID's of the vehicles leading and following the advised one (if known)
Advised speed	Speed to maintain when applying the traffic separation
Triggering point of ToC	Distance from the starting point where a ToC should be triggered if the lane change is not performed

4.2.1.4 Requirements of Scenario 4.2: Safe spot in lane of blockage

In this scenario, CAVs are approaching a complex traffic situation, due a road topology modified by the presence of the lane blockage, where ToCs might be triggered. Some of these ToCs might fail and consequently MRM will be executed. In order to mitigate the negative effects of performing MRMs, in Service 4 the RSI defines and communicates safe spots where the MRM can be performed. Table 13 details the list of information that needs to be shared by the RSI.

Table 13 List of requirements for Service 4

Requirement	Description
Updated road topology, especially of the blocked area and upstream of it.	The update road topology is the basis for referencing locations at which certain actions have to take place compared to the normal situation.
Safe spot(s)	In addition to the updated road topology, the road infrastructure provides information about defined safe spots.

4.2.1.5 Requirements of Scenario 5.1: Schedule ToCs before no AD zone

This service applies a traffic management measure where the transitions of control are scheduled in time and space before an area where it is not possible to drive in the automated mode. The infrastructure collects information about the traffic stream and for each upcoming CAV computes the best place and time for performing the ToC. CAVs must receive the time window and the area where they can perform the ToC. Similarly, other cooperative vehicles must be alerted about the presence of the no AD zone. Table 14 details the list of specific requirements for Service 5.

Table 14 List of information specific for Service 5

Requirements	Description
Area of transition	Area of the road where a CAV can perform the ToC
Time of transition	Time when the ToC should be initiated
Reason for transition	Reason why the vehicle should perform a ToC
Alert about the no AD-zone	Alert about the presence of an area where the automated driving is not possible

4.2.2 Second iteration

4.2.2.1 Requirements of Scenario 1.3: Queue spillback at exit ramp

In this scenario, the infrastructure and/or the CAVs will monitor the traffic situation at the exit ramp. When a queue is detected, the RSI will open the emergency lane for queuing and will adapt the speed limit to reduce speed differences between queuing vehicles and vehicles that continue driving on the main road. Table 15 details the list of information that needs to be shared by the RSI.

Table 15 List of requirements for scenario 1.3

Requirement	Description
Alert about end of queue	The RSI alert vehicles that there is a queue in the emergency lane.
End of queue position	Position of the end of the queue
Emergency lane allowed for driving	The RSI communicates whether or not the emergency lane can be used for queuing, and specifies how far upstream of the exit ramp the emergency lane can be used.
Speed limit	The speed limit is gradually reduced from free flow (e.g., 120 km/h) to 50 km/h at the queue. The speed limit can be different per lane. The RSI communicates the appropriate speed limit per road section and lane to the C(A)Vs.

4.2.2.2 Requirements of Scenario 2.1: Prevent ToC/MRM by providing speed, headway and/or lane advice

Similarly to Section 3.2.2 most information of this service was already given in the first iteration, despite not all functionality being implemented in WP4 during the first iteration. Therefore, the requirements of Table 11 still apply and are nearly complete. The differences are indicated in the table below in italics:

Table 16: List of additional requirements in the second iteration for service 2

Requirement	Description
Lane advice with target lane, time or position to change, reason for the advice and optionally which are the leading/trailing vehicles (transmitted by the infrastructure). *An indication at which speed the lane change should be carried out has to be added.*	This is the core of the solution for this scenario. By providing this advice, traffic is expected to become smoother and merging with or around automated vehicles should occur without ToC/MRM. *The speed indication helps trajectory planning of automated vehicles in order not to execute the lane change with a speed that would immediately cause an unsafe situation once the lane change is complete due to a large speed difference with leading/trailing vehicles.*
SPaT message with ramp meter state information	*This can be seen as a day 1 message and therefore considered trivial and out of scope for TransAID. However, it should be noted that a future deployment site that has the ramp meter option enabled should still support this day 1 service.*

4.2.2.3 Requirements of Scenario 2.3: Intersection handling due to incident

In this scenario, CVs and CAVs are approaching a traffic light-controlled junction where an incident occurred. The RSI will inform about the situation and will provide information how to approach and cross the junction and which restrictions are in place. Table 17 details the list of information that needs to be shared by the RSI.

Table 17 List of requirements for Service 2.3

Name	Description
Alert about the incident	Information about the incident that is blocking the lane.
Incident position	Position and lane of the incident that is blocking the road lane.
Closed lane	Conveys the stretch of road (1 lane) where no driving is allowed to secure the incident area.

Speed limit	Send temporary speed limit to all vehicles upstream of the incident.
Speed limit starting position	Starting position where the speed limit applies
Merge advice	Side of the road to which the traffic should flow to overpass the incident.
End of speed limit and closed lanes	End point where the speed limit and the lane closure apply.
Updated junction topology	Intersection topology representation's update now indicating the new right turn connection from lane 6.
Updated signal groups	TLC update on signal group 5 and 6, now indicating that signal group 5 is disabled and signal group 6 on lane 6 is altered to include the right turn in addition to straight ahead.
Signal timing	Send signal status and timing to the vehicles.

The above requirements address the measures of lowering the speed limit and updating the intersection topology and TLC program to facilitate a right turn from lane 6. The scenario might benefit from additional measures such as coordinated lane changes (like in scenario 4.2), distribution of ToCs (see scenario 5.1) and/or safe spots (scenario 4.2 & 4.1-5). The requirements for such additional measures are listed in the sections of those other scenarios. Those additional measures will be explored in T4.2 if time and resources allow.

Another possible measure is to adjust the TLC program more significantly (e.g. a turn-by-turn strategy). However, there are no additional requirements for such a measure (i.e. Signal timing is already included).

4.2.2.4 Requirements of Scenario 4.2: Safe spot in lane of blockage & Lane change assistant

Service 4.2 is applied to a two lane road scenario where a construction site blocks one of the lanes. Some CAVs will not be able to overpass the construction site and a ToC will be triggered. In case of ToC failure, a MRM will take place with the consequent disturbance in the traffic flow and safety. To overcome this situation, the infrastructure provides safe spot information and lane change advices to CAVs approaching the construction site. Table 18 shows the list of information that needs to be transmitted by the RSI for this purpose.

Table 18 List of requirements for Service 4.2

Requirement	Description
Road works alert	This alert provides a warning to all cooperative vehicles (including CAVs) to indicate a potentially dangerous road works situation. CAVs automation logic can take this into

	account and possibly take different actions. CVs are also alerted and risk of incidents is reduced
Lanes closed	CAVs need to know that one of the lanes is not available for driving, so that they can anticipate their decisions. Otherwise they would detect the obstacles blocking the lanes at the last moment
Safe spot(s)	The road infrastructure provides information about defined safe spots
Area of transition	Area of the road where a CAV can perform the ToC
Time of transition	Time when the ToC should be initiated
Reason for transition	Reason why the vehicle should perform a ToC
Target lane	Advised target lagne to move to for an individual vehicle
Lane change position	Optimal position to start executing the advised lane change (if known)
Lane change moment	Optimal moment to start executing the advised lane change-(if known)
Gap advice	Advised gap to maintain with the preceding vehicle

4.2.2.5 Requirements of Scenario 4.1-5: Distributed safe spots along an urban corridor

In this scenario, CAVs are approaching a zone where AD is not supported and where ToCs will be triggered. Some of these ToCs might fail and consequently MRMs will be executed. In order to mitigate the negative effects of performing MRMs, in Service 4 the RSI defines and communicates safe spots where MRM can be performed. Service 5 also defines and communicates AD restrictions. Table 19 details the list of information that needs to be shared by the RSI.

Table 19 List of requirements for Service 4/5

Requirement	Description
Alert about the no AD-zone	Alert about the presence of an area where the automated driving is not possible
No AD zone boundaries	This marks the area on which the AD restrictions are applied. This information can include single lanes, or whole road segments and intersections and must include the entry points of the no AD zone for each lane or road segment where transitions are to be applied. Time validity for these restrictions is also

	communicated.
Safe spot(s)	the road infrastructure provides information about defined safe spots mapped on the road topology representation
Starting point of safe spot assigned	Starting point of the lane where the vehicle should do the stop once the MRM is executed
End point of safe spot assigned	End point of the lane where the vehicle should do the stop once the MRM is executed

5 Applying TransAID concepts to MCS

As mentioned in Section 2.1.4, the ETSI TC on ITS is currently specifying the Maneuver Coordination Service (MCS) in order to support a framework where unambiguous rules for the coordination of CAVs manoeuvres can apply [31]. The TransAID project is actively participating in the standardization process (see Annex B), which is nowadays on its early stage of standardization and an agreement on how vehicles should coordinate their maneuvers has not yet been achieved. This section describes the current proposal for the coordination of CAVs manoeuvres as discussed at ETSI. On this basis, the current TransAID approach to accommodate the I2V TransAID TM measures in the MCS is explained.

5.1 Current ETSI MCS concept

The current MCS concept seeks to reduce prediction errors on the estimation of other vehicle's behaviour and to coordinate the manoeuvres of different vehicles by exchanging detailed information about the vehicle's intended manoeuvres. Note that a manoeuvre based on a wrong prediction may lead to inefficient driving, reduced driving comfort or may provoke safety critical situations. This concept is exclusively based on V2V interactions and consists of a three stages process. First, the need for a given manoeuvre coordination is detected. Second, the type of coordination is agreed between the involved partners. Finally, the coordinated manoeuvre is executed. Coordination between CAVs is needed whenever a CAV wants to perform a manoeuvre but it cannot perform it due to the future planned trajectory of another CAV which possesses the right of way. In this situation, both CAVs can communicate and negotiate for allowing the original CAV to perform its desired manoeuvre. The negotiation of a coordinated manoeuvre is governed by the right of way rules. The CAV that possesses the right of way must agree to modify its future trajectory. Otherwise, the coordinated manoeuvre will not be executed.

In order to detect the need for coordination a CAV must be able to predict the behaviour of other participants of the traffic flow and plan its future trajectory accordingly. The estimation of the future trajectory of other vehicles is subject to errors. In order to reduce the prediction error, the proposal is to make all CAVs continuously broadcast an MCM message including their immediate future trajectory referred to as "planned trajectory". In this way, a CAV can compare its planned trajectory with the received trajectories and compute if these intersect. In that case, vehicles without the right of way will need to modify their planned trajectories. In order to negotiate a coordination of manoeuvres, a new trajectory is introduced in the MCM and referred to as "desired trajectory". A CAV that detects a need for coordination can send a desired trajectory together with the planned trajectory. At the receiving side, the presence of a desired trajectory is interpreted as a request for coordination. Any CAV that receives a desired trajectory will determine if it is capable to modify its planned trajectory to allow the transmitting CAV to follow its desired trajectory. In case of holding the right of way, the receiving CAV has to also determine if it is willing to leave way. If the receiving vehicle agrees with the coordination, it will modify its planned trajectory accordingly. Once the transmitting vehicle receives the new planned trajectories from the surrounding CAVs, its desired trajectory will become its new planned trajectory in the MCM. Note that this can imply a cascade process where, in order to allow a desired trajectory of another CAV, a CAV must send a desired trajectory itself. Figure 23 shows an example of coordinated manoeuvre executed employing MCMs. In the top subfigure, we can observe how the grey CAV wants to overpass a slow truck. However, the grey CAV cannot directly update its planned trajectory because the new trajectory will intersect with the planned trajectory of the green CAV, which possesses the right of way. For this reason, the grey CAV sends a desired trajectory in order to request for coordination. The green CAV receives the desired trajectory and adjusts its planned trajectory (reducing its current speed) allowing to the grey vehicle to employ its desired trajectory as a planned trajectory as shown in the second subfigure.

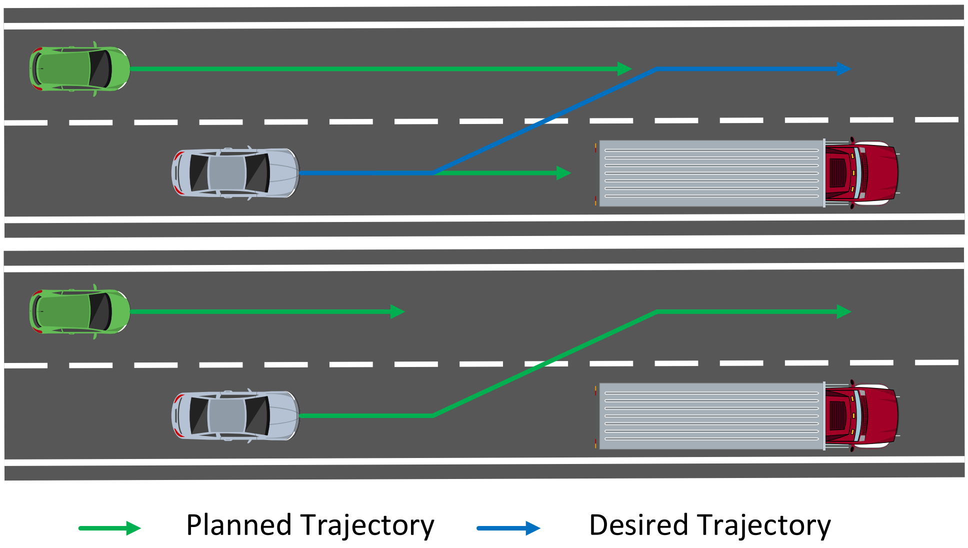

Figure 23 Example of cooperative manoeuvre execution employing the MCM

5.2 TransAID proposal

The TransAID project is focused at Transition Areas with mixed traffic compositions where multiple transitions of control can potentially take place. Figure 24 shows the process of a downwards ToC where a human driver takes control of the vehicle. Once the ToC is triggered, the automated mode will keep driving following the planned trajectory until the driver is ready to take control of the vehicle. From this point, the human driver takes control of the car and the driving dynamics will be modified accordingly to the orders of the human driver. Consequently, the future trajectory cannot be longer predicted by the vehicle. Furthermore, the exact time when the human driver will take control of the vehicle is also unknown. For these reasons, the ToC cannot be described as a common trajectory. Other vehicles need to be aware of the ToC and plan their trajectories accordingly. This case is similar to the MRM case. An MRM is triggered whenever a ToC fails and the driver is not able to take control of the vehicle. However, it is not possible to anticipate the time when the driver will take control of the car or whether or not the ToC will fail.

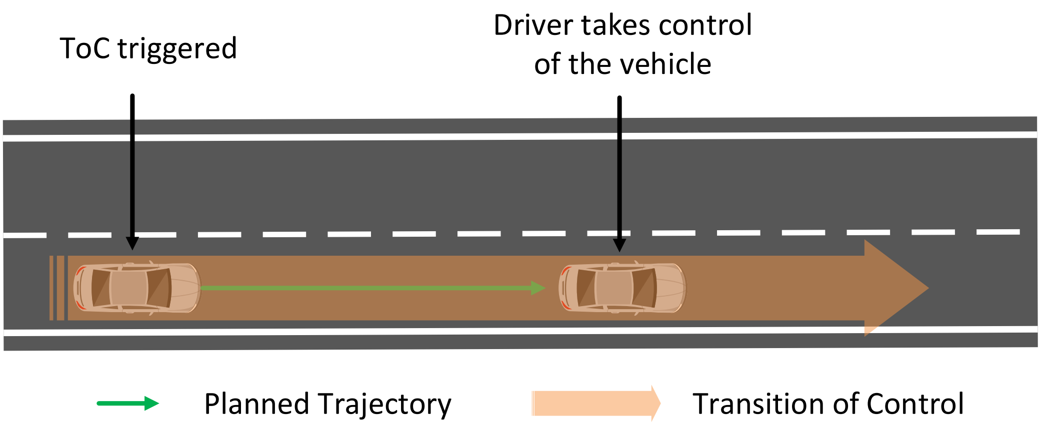

Figure 24 Transition of Control process

Figure 25 shows an example of a problematic situation that can occur when a vehicles tries to cooperate with another vehicle that is executing a ToC. In the figure, the grey vehicle wants to perform a lane change to the right lane. If the grey vehicle plans its manoeuvre taking only into account the planned trajectory of the green vehicle, the grey vehicle can decide that it is safe to perform the lane change. However, the green vehicle is performing a ToC at any point the human driver can take control of the vehicle and modify the future trajectory generating a safety conflict. This problematic situation can be solved if grey vehicle is informed in advance about the ToC of green vehicle. Then, the grey vehicle will act accordingly and perform the lane change to the right lane downstream of the road avoiding the safety conflict with green vehicle.

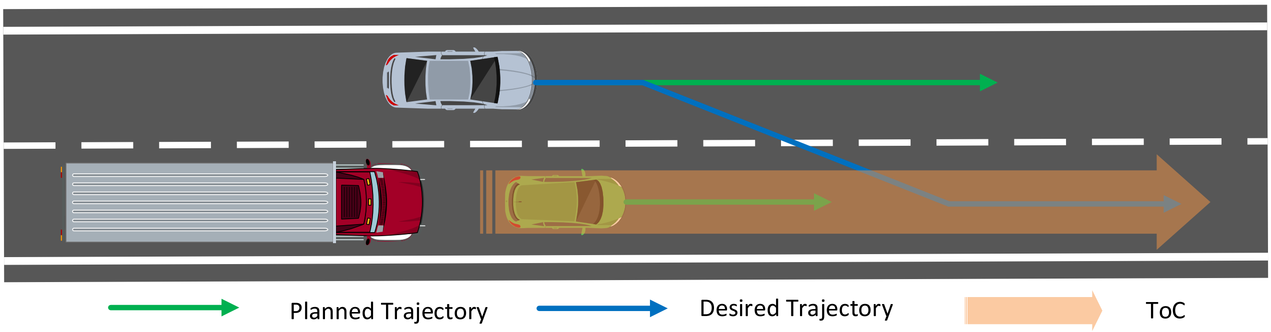

Figure 25 Example of problematic situation during a maneuver coordination involving a vehicle executing a ToC.

Moreover, the current concept proposal for the MCM is focused on V2V interactions only, where CAVs locally negotiate based on their desired and planned trajectories. This can lead to inefficient decisions that negatively affect to the traffic flow and safety. Figure 26 shows an example of inefficiency that the current MCS proposal could generate. In front of a road works area, vehicles on the left lane need to merge to the right lane in order to overpass the road works. However, the vehicles on the right lane have right of way. Therefore, if the CAVs on the right lane are just “automatically” respecting the traffic rules, they will not leave way and modify their planned trajectories. As a consequence, all the vehicles on the left lane will get stuck in front of the road works area.

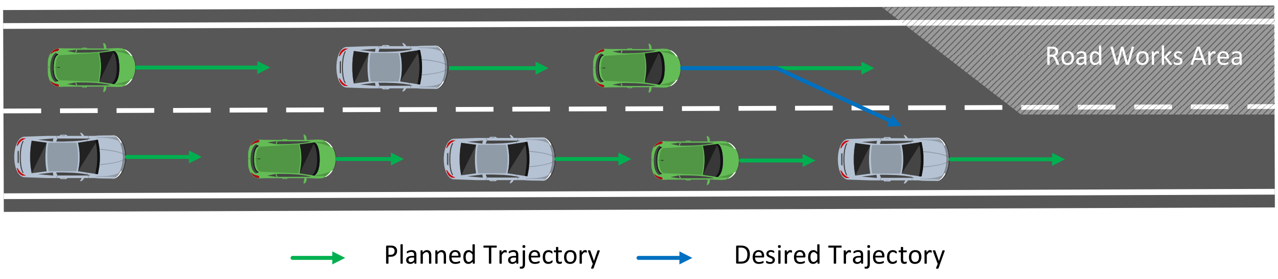

Figure 26 Example of inefficiencies of current MCM proposal

In this context, the infrastructure can play an important role by providing suggestions to the CAVs so that they can take better decisions (i.e. more efficient decisions in terms of the overall traffic flow). For example, in the situation described in Figure 26 the infrastructure can coordinate the merging of the vehicles in a single lane by temporary giving the right of way to vehicles on the left lane. Similarly, in other situations as the ones described by the TransAID services, the infrastructure can send suggestions to CAVs (e.g. lane change advices or speed advices) in order to increase the overall traffic flow and safety.

In the TransAID project, we propose to extend the current ETSI MCS approach by allowing the RSI to participate in the MCS service. The TransAID MCS proposes an MCM format differentiating between MCMs sent by a vehicle and MCMs sent by the infrastructure (see Annex C). The vehicle will send MCMs using the VehicleManeuverContainer where including their future planned trajectories, desired trajectories and ToC/MRM information together with information about the dynamics of the vehicle. On the other hand, the infrastructure will send MCM using the RSUSuggestedManeuverContainer. This container will include information to coordinate the traffic from a global perspective in order to increase the traffic flow and safety. As a result, the TransAID MCM transmitted by the RSI will be able to disseminate the TransAID TM measures. The infrastructure will transmit in the RSUSuggestedManeuverContainer a generic vehicle advice data field to individual CAVs. This generic advice will in turn include different specific advice types. There are three different specific advice types, the lane advice (based on the MAVEN LAM [39]), the car following advice and the ToC advice. The complete TransAID format proposal for the MCM can be found in Annex C.

The MCM proposal of the TransAID project exploits V2I communications, and is fully complementary to the current V2V-based approach discussed at ETSI. Some of the benefits of using the infrastructure to support manoeuvre coordination include [44]:

1) Neutral coordination: Road infrastructure (or authorities) is currently utilized to support traffic management under particular conditions such as traffic jams, peak hours or under the presence of roadworks. Simultaneously managing multiple manoeuvres in a small area can be a challenge for a fully distributed solution. CAVs could hence benefit from the support of the road infrastructure to coordinate manoeuvres. Road Side Units (RSUs) deployed along the road could support vehicles in the manoeuvre coordination process by providing advices or suggestions so that vehicles can take better decisions. For example, when two lanes are merged into a single lane due to roadworks, the infrastructure could help coordinate in time and space the merging manoeuvres in order to reduce traffic disruptions. Similarly, the infrastructure could also send suggestions to CAVs regarding lane change or speed advices. The support from the infrastructure could hence be considered as a natural evolution of current road traffic signalling systems.

2) Enhanced perception: The V2V distributed approach proposed to date for manoeuvre coordination needs to detect that the coordination of a manoeuvre is necessary in order to initiate the process. The detection capabilities are hence in principle limited to the V2V range. Using RSUs can mitigate this limitation. RSUs could be strategically located in specific areas with extended V2I range thanks to a higher elevation of the antennas and better propagation conditions. These nodes can gather information about the driving conditions through the Cooperative Awareness Message (CAM) [17] and Collective Perception Message (CPM) [29] messages received from vehicles. They can also fuse this data with other ITS sensors (e.g. cameras and inductive loops) to further improve the perception capabilities and increase the detection range. This increases the time and space in which vehicles can coordinate their manoeuvres, and can benefit traffic management. In addition, it is particularly useful under mixed traffic scenarios where conventional, connected and automated vehicles coexist.

3) Coordination of multiple vehicles: Complex traffic situations could require the coordination of multiple vehicles. Coordinating multiple vehicles through a V2V distributed approach can require a pairwise and sequential coordination of the manoeuvres. This can increase the time needed to coordinate all vehicles and hence impact the road traffic. Road infrastructure nodes could facilitate this coordination by acting as a common coordination entity that provides coordinated advices to multiple vehicles.

6 TransAID V2X message set

This chapter defines the current version of the TransAID V2X message set. The definition of the message set is based on an analysis of the current versions of the standardized messages. The objective of the analysis is to identify the fields of the standardized messages that can be employed in order to fulfil the information requirements detailed in Section 4. Furthermore, necessary message extensions for TransAID purposes are also identified.

6.1 CAM profiling and extensions

A CAM contains status and dynamics information about the vehicle that is originating it (ego-vehicle) such as the vehicle type, current position, speed, acceleration, etc. Part of this information is necessary for the TransAID project as it is stated in Section 4.

6.1.1 Information already in the standard/ Fields of the message used

Table 20 shows a list of the standard fields of the CAM that contain the information required by the TransAID services (often reusing elements of the ETSI ITS CDD [18]).

Table 20 List of information available in the CAM

Category	Name	Container	Field	Optional	Reference
Information about the ego vehicle	Type	Basic Container	Station type		CDD A.78
	Length	Basic Vehicle Container High Frequency	Vehicle length		CDD A.131
	Width	Basic Vehicle Container High Frequency	Vehicle width		CDD A.95
	Position	Basic Container	Reference position		CDD A.124
	Lane position	Basic Vehicle Container High Frequency	Lane position	x	CDD A.40
	Speed	Basic Vehicle Container High Frequency	Speed		CDD A.126
	Acceleration	Basic Vehicle Container High Frequency	Longitudinal acceleration		CDD A.116
			Lateral acceleration	x	CDD A.115
			Vertical acceleration	x	CDD A.129
	Heading	Basic Vehicle Container High Frequency	Heading		CDD A.112

	Driving mode	Basic Vehicle Container High Frequency	Acceleration control	x	CDD A.2

6.1.2 Extensions needed

From the analysis of the information requirements of all the TransAID services, we identify that the CAM needs to include the current automation level and also the distance gap with the following and preceding vehicles. Furthermore, advanced vehicle automated functions such as CACC analysed in the second iteration of TransAID require exchange of information to identify opportunities to build CACC strings, for controlling lateral and longitudinal driving at short inter-vehicle distance and finally for managing CACC operations like joining, leaving or breaking-up CACC strings. The ETSI CACC pre-standardization study TR 103 299 [40] (see Section 2.2.1.3) are incomplete. Moreover, although the EU H2020 project ENSEMBLE is defining V2X specifications for close-following driving [45], these specifications apply specifically to truck platooning, and hence are not generically applicable to CACC with other vehicle categories. In order to cope with the TransAID objectives and to assure backwards compatibility with the current version of the CAM, we follow the approach of the MAVEN project [39] (see Section 2.2.1.2) where new containers are created to include specific information of CAVs and CACC of CAVs (MAVEN platoons [41]). Table 21 shows how the identified requirements for the TransAID project can be fulfilled employing CAM extensions similar to those defined in MAVEN.

Table 21 Extensions of the CAM proposed in the MAVEN project and the ETSI TR 103 299

Category	Name	Container	Field	Optional	Reference
Ego-vehicle information	Current automation level	Extension needed			
	Gap with preceding vehicle	MAVENAutomatedVehicleContainer	distanceToPreceedingVehicle	x	MAVEN
	Gap with following vehicle	MAVENAutomatedVehicleContainer	distanceToFollowingVehicle	x	MAVEN
	Planned route at next intersection (in/out lane)	MAVENAutomatedVehicleContainer	RouteAtIntersection		MAVEN
	Planned route in terms of next intersection	MAVENAutomatedVehicleContainer	IntersectionsRoute		MAVEN

	s to cross				
	Desired min and max speed for driving in a platoon	MAVENAutomatedVehicleContainer	DesiredSpeedRange		MAVEN
	Supported max positive and negative accelerations	MAVENAutomatedVehicleContainer	AccelerationCapability		MAVEN
	Lane the vehicle is currently driving	AutomatedVehicleContainerHighFrequency	LanePosition	x	MAVEN
	Planned vehicle trajectory in terms of future positions and headings	AutomatedVehicleContainerHighFrequency	PlannedPath	x	MAVEN
	Lane the vehicle plans to drive to	AutomatedVehicleContainerHighFrequency	PlannedLane	x	MAVEN
	Id of the Platoon that the vehicle is currently in	AutomatedVehicleContainerLowFrequency	PlatoonId		MAVEN
	List of following vehicle IDs	AutomatedVehicleContainerLowFrequency	PlatoonFollowers	x	MAVEN
	State of the platoon that the vehicle is currently in	AutomatedVehicleContainerLowFrequency	PlatoonVehicleState		MAVEN
	Forming state of the platoon that	AutomatedVehicleContainerLowFrequency	PlatoonFormingState		MAVEN

	the vehicle is currently in				

The ASN1 definitions of the finally adopted TransAID CAM extensions are included in deliverable D7.2 as a result of application of the theoretical specification of this deliverable into real-world prototypical implementations.

6.2 DENM profiling and extensions

A DENM contains information related to a road hazard or an unconventional traffic condition, such as its type, position and any other supporting information. By receiving a DENM, the driver of the vehicle can be aware of a potential dangerous situation on the road, like for example the presence of a slow vehicle, a road works area that partially blocks some of the road lanes, or an emergency brake of a vehicle.

6.2.1 Information already in the standard/ Fields of the message used

Table 22 shows a list of the standard fields of the DENM that contain the information required by the TransAID services (often reusing elements of the ETSI ITS CDD [18]).

Table 22 List of information available in the DENM

Category	Name	Container	Field	Optional	Reference
Scenario 1.2 and 4.2.	Road works alert	Situation Container	Event type		CDD A.10
	Closed lanes	Road works container	closedLanes	x	CDD A.106
Scenario 1.3	Alert about end of queue	Situation Container	Event type		CDD A.10
	End of queue position	Management Container	Event position		CDD A.124
Scenario 2.3	Alert about the incident	Situation Container	Event type		CDD A.10
	Incident position	Management Container	Event position		CDD A.124
		AlacarteContainer	lanePosition	x	CDD A.40

Note: for Scenario 2.3 two DENM messages are broadcasted. One is indicating the position of the incident itself and the lane where it is occurring. The other is part of the traffic measures indicating a speed limit (upstream) and a closure of the lane upstream of the incident (see DENM extension in

Section 6.2.2). To link the 'traffic measure DENM' to the one informing about the incident, the referenceDenms DF is used.

6.2.2 Extensions needed

Based on the analysis of the current version of the DENM and the information requirements of the TransAID services, we identify the need of extending the DENM as described in Table 23 (often reusing elements of the ETSI ITS CDD [18]). On the one hand, it is necessary for Service 5 to alert vehicles about the presence of an area where the automated driving in not possible or allowed. This includes the description of the spatial area where the automated driving restrictions applies. Similarly, in scenario 2.3 additional traffic measures need to be disseminated to upcoming vehicles to secure the incident area (e.g., lane closure, speed limits, etc.) For this reason, we have defined a new ADrestrictionContainer to be included in the DENM alacarte container. Furthermore, whenever a vehicle is about to trigger a ToC or a MRM it is important to alert surroundings vehicles in order to allow them to plan their manoeuvres accordingly. Both alerts can be included in the DENM by extending the Event type data field including these new types of alert. Note that in the current version of the DENM the road works, accidents and dangerous ends of queues are already included as a road hazard.

Table 23 List of extensions for the DENM

Category	Name	Container	Field	Optional	Reference
Scenario 5.1 and 4.1-5	Alert about no AD-zone	Situation Container	Event type		CDD A.10
	No AD zone boundaries	ADrestrictionContainer	laneID	x	
		ADrestrictionContainer	areaStartPoint	x	CDD A.109
		ADrestrictionContainer	areaEndPoint	x	CDD A.109
Scenario 4.1-5 and 2.3	Allowed AD level	ADrestrictionContainer	allowedADlevel	x	
Scenario 2.3	Closed lanes	ADrestrictionContainer	closedLanes	x	CDD A.106
	Speed limit	ADrestrictionContainer	speedLimit	x	CDD A.73
	Speed limit starting position	ADrestrictionContainer	startingPointSpeedLimit	x	CDD A.109
	Speed limit end position	ADrestrictionContainer	endPointSpeedLimit	x	CDD A.109
	Closed lanes starting position	ADrestrictionContainer	startingPointClosedLanes	x	CDD A.109
	Closed lanes	ADrestrictionContainer	endPointClosedLanes	x	CDD A.109

	end position				
	Merge advice	ADrestrictionContainer	trafficFlowRule	x	CDD A.85
	Link to incident DENM	ADrestrictionContainer	referenceDenms		CDD A.102
ToC information	Transition alert	Situation Container	Event type		CDD A.10
ToC information	MRM alert	Situation Container	Event type		CDD A.10

Note that the *ADrestrictionContainer* will include a list of lanes affected in order to be able to describe areas including more than one lane. The ASN1 definitions of the TransAID adopted DENM extensions are included in deliverable D7.2 as a result of application of the theoretical specification of this deliverable into real-world prototypical implementations.

6.3 CPM profiling and extensions

As described in Section 2.1.3, the CPM message is used to transmit information about locally detected objects (i.e. non-cooperative traffic participants, obstacles and alike) in form of standardized abstract representations to improve situational awareness. In the context of TransAID sharing this information is necessary to let the RSI be aware about non-cooperative vehicles, hence allowing to better estimate the traffic flow as well as the traffic composition as stated in Section 4. The next subsections show a list of the CPM fields required by the TransAID services.

6.3.1 Information already in the standard/ Fields of the message used

From the analysis performed about the TransAID services, the information needed to describe detected vehicles and obstacles is contained in the following CPM data fields [29] (often reusing elements of the ETSI ITS CDD [18]).

Table 24 List of information available in the CPM

Category	Name	Container	Field	Opt.	Reference
Information about detected vehicles and obstacles	Size of obstacle	PerceivedObjects Container	PlanarObjectDimension1	x	CPM C.23
			PlanarObjectDimension2	x	
	Position	PerceivedObjects Container	xDistance		CPM C.15
			yDistance		

			zDistance	x	
	Speed/heading	PerceivedObjects Container	xSpeed	x	CPM C.18
			ySpeed	x	
			zSpeed	x	
	Acceleration	PerceivedObjects Container	xAcceleration	x	CDD A.116
			yAcceleration	x	CDD A.115
			zAcceleration	x	CDD A.129
	Lane position	PerceivedObjects Container	matchedPosition	x	CPM C.26

6.3.2 Extensions needed

As it can be seen from Section 6.3.1, the information required by the TransAID services for the scenarios considered in the project is covered by data fields and elements already included in the current standards. No extensions are needed.

6.4 IVIM profiling and extensions

As described in Section 2.1.7, the IVIM can be used by the RSI to transmit static as well as dynamic road sign and message sign information on highways. The added value of using a C-ITS message like the IVIM is to enable receiving vehicles to know at any time and condition all the relevant signage information. Information is relevant based on time and location, but also based on characteristics and type of the receiving vehicle. Applying this approach to TransAID allows RSI to fulfil the generic requirement of sharing information about traffic rules to be respected (see Section 4.1.5). Furthermore, the IVIM can also be employed to transmit generic advices (i.e. speed advices) to cooperative vehicles that are not able to decode Day 2 and beyond messages such as the MCM. The next subsections show a list of the IVIM data fields required by the TransAID services.

6.4.1 Information already in the standard/ Fields of the message used

The information needed to be disseminated by the RSI to convey generic traffic rules is contained in the following IVIM data fields [32] (often reusing elements of the ETSI ITS CDD [18]).

Table 25 List of information available in the IVIM

Category	Name	Container	Field	Opt.	Reference
Information about traffic rules	Type of traffic rule	ApplicationContainer	relevanceZoneIds	x	IVI 7.3.30
			applicableLanes	x	CDD A.40
			iviType		IVI 7.3.13

			vehicleCharacteristics	x	IVI 7.2.2
			roadSignCodes		IVI 7.2.14
	Area of application	LocationContainer	zoneId		IVI 7.3.30
			LaneNumber	x	CDD A.40
			Zone		IVI 7.2.23

6.4.2 Extensions needed

As it can be seen from Table 25, the information required by the TransAID services for the scenarios considered in the first and second iterations is covered by data fields and elements already included in the current standards. No extensions are needed.

6.5 MAPEM profiling and extensions

As described in Section 2.1.5, the MAPEM [32] can be used by the RSI to convey one or more intersection geometry and/or road segment maps within a single message. The MAPEM content includes such items as complex intersection or road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications). The contents of this message involve defining the details of indexing systems that are in turn used by other messages to relate additional information (usually SPAT for signalling information).

Using the MAPEM, TransAID can provide information about the road to cooperative (automated) vehicles. This can be the regular situation, but the MAPEM can be used to provide information about a changed road topology situation as well, e.g. a road works situation.The MAPEM thus satisfies the information requirements regarding the regular and temporary road network (layout).

6.5.1 Information already in the standard/ Fields of the message used

In Table 26, the required information for the five scenarios is listed and mapped to the data containers and fields available in the dictionary standard [30] used by the MAPEM.

Table 26 List of information available in the MAPEM

Category	Name	Container	Field	Opt.	Reference
Information about the road network	Number of lanes	Road Segment	roadLaneSet (list)		SAE 6.106
	Width of lanes	Road Segment	laneWidth	x	SAE 7.80
	Curvature of lanes	Road Segment	lane Crown Point Center		SAE 7.124
		Road Segment	lane Crown Point Left		SAE 7.124

		Road Segment	lane Crown Point Right		SAE 7.124
	Incoming lanes	Road Segment	connectsTo (list)	x	SAE 6.15
			mergePoint (nodeattribute)		SAE 7.99
	Outgoing lanes	Road Segment	connectsTo (list)	x	SAE 6.15
			divergePoint (nodeattribute)		SAE 7.99
	Type of lane	RoadSegment	LaneAttribute		SAE 6.36
Scenario 1.1	path to overpass road works	Road Segment	GenericLane		SAE 6.25
	Bus lane allowed for driving	Road Segment	DF_LaneTypeAttributes= DE_LaneAttributes-Vehicle	x	SAE 6.40
			LaneSharing		SAE 7.79
Scenario 4.2 and 4.1-5	Safe spots	Road Segment	LaneAttributes-Parking,-- parking and stopping lanes		SAE 7.70
Scenario 1.3	Emergency lane allowed for driving	Road Segment	DF_LaneTypeAttributes= DE_LaneAttributes-Vehicle	x	SAE 6.40
Scenario 1.3 and 4.2	Speed limit	Road Segment	RegulatorySpeedLimit	x	SAE 6.101
Scenario 2.3	Updated junction topology and signal groups (i.e. change in connections between lanes).	Road Segment	connectsTo [ConnectsToList]		SAE 6.15
			Connection – connectingLane [ConnectingLane]		SAE 6.12
			lane [LaneID]		SAE 7.77
			maneuver [AllowedManeuvers]		SAE 7.4
			remoteIntersection [Intersection-ReferenceID]		SAE 6.28
			region [RoadRegulatorID]		SAE 7.122
			id [IntersectionID]		SAE 7.48
			signalGroup [SignalGroupID]		SAE 7.131
			userClass [RestrictionClassID]		SAE 7.121
			connectionID [LaneConnectionID]		SAE 7.75

For Scenario 2.3 the requirements are similar to the overall (generic) 'Information about the road network' part at the top of the table. However, in Scenario 2.3 this 'default' information is updated to match the new situation in the scenario. Some information needs to be inferred from the whole message. For example, the number of lanes of a road segment is not explicitly available, but one can count the number of specified lanes (of a specific type). Detailed curvature of the road can be specified via the stated fields in the table. In addition to that, the shape of the lane/road is provided by nodes of which the entire road segment is composed. Lane usage is defined by the LaneTypeAttributes and LaneSharing as present in the field. For example, a lane restricted to bus use in the baseline is replaced by ordinary vehicle lane shared with other road users. In addition to temporarily redefining the road network through a MAPEM, information like 'closed lanes' is also provided through a DENM message.

6.5.2 Extensions needed

No extensions are foreseen for the MAPEM standard.

6.6 SPATEM profiling and extensions

The Signal Phase and Timing Message (SPATEM) is an I2V message primarily used to communicate the intersection status to vehicles approaching an intersection. The SPATEM message usually contains dynamic information about the state of a signalized intersection. It can contain the traffic light state, future state predictions, speed advice, queue state information and whether a priority request is active. The SPATEM can only be used in conjunction with the MAPEM since the MAPEM describes to which manoeuvres (from which lane to which lane) the signal status applies.

6.6.1 Information already in the standard/ Fields of the message used

In Table 27, the required information for the five scenarios is listed and mapped to the data containers and fields available in the dictionary standard [30] used by the SPATEM.

Table 27 List of information available in the SPATEM

Category	Name	Container	Field	Opt.	Reference
Service 2.1 and 2.3.	Ramp metering / Signal timing (light color)	MovementState	eventState [MovementPhaseState]		SAE 7.103
Service 2.3	Updated signal groups	MovementState	signalGroup [SignalGroupID]		SAE 7.171

The eventState essentially provides information about the signal state (i.e. green, yellow, red traffic light). The signalGroup element is used to link the state to the MAPEM in which is described to which connection/manoeuvre the state applies.

6.6.2 Extensions needed

As it can be seen from Section 6.6.1, the information required by the TransAID services for the scenarios considered in the project is covered by data fields and elements already included in the current standards. No extensions are needed.

6.7 MCM profiling and extensions

As described in Section 2.1.4, the TransAID proposal for MCM supports the coordination of manoeuvres between cooperative automated vehicles and as well as the transmission of suggestions from the infrastructure to strategically coordinate CAVs in such a way to increase the overall traffic safety and efficiency. Table 28 details the fields of the MCM that can be employed to transmit the information requirements of the TransAID project.

Table 28 List of information available in the TransAID MCM proposal

Category	Name	Container	Field	Opt.
Ego-vehicle information	Planned trajectory	VehicleManeuverContainer	plannedTrajectory	
	Desired trajectory	VehicleManeuverContainer	desiredTrajectory	x
information about ToC/MRM	Target automation level	VehicleManeuverContainer	targetAutomationLevel	x
	Trigger time of ToC	VehicleManeuverContainer	triggerTimeOfToC	x
	Trigger time of MRM	VehicleManeuverContainer	triggerTimeOfMRM	x
Scenario 2.1	Confirmation of speed advice	VehicleManeuverContainer	adviceResponseList	
	Confirmation of lane advice	VehicleManeuverContainer	adviceResponseList	
	Lane advice with target lane, time or position of the change, the reason for the advice and optionally which are the leading/trailing vehicles.	RSUSuggestedManeuverContainer	adviceID	
			laneAdviceReason	
			laneChangeStartPosition	x
			laneChangeEndPosition	x
			laneChangeMoment	x
			laneChangeSpeed	x
			leadingVehicle	x
			followingVehicle	x
			targetLane	
			triggeringPointOfToC	x
	Individual	RSUSuggestedManeuverContainer	adviceID	

	speed/gap advice		adviceLaneID	x
			adviceStartPosition	x
			adviceEndPosition	x
			desiredBehaviour	
Scenario 3.1	Advice ID	RSUSuggestedManeuverContainer	adviceID	
	Advice reason		laneAdviceReason	
	Lane change position		laneChangeStartPosition	x
			laneChangeEndPosition	x
	Lane change moment		laneChangeMoment	x
	Advice speed		laneChangeSpeed	x
	Leading and following vehicles		leadingVehicle	x
			followingVehicle	x
	Target lane		targetLane	
	Triggering point of ToC		triggeringPointOfToC	x
Scenario 5.1	Area of transition	RSUSuggestedManeuverContainer	placeOfStartOfTransition	x
			placeOfEndOfTransition	
	Time of transition		timeOfTriggerTransition	x
	Reason for transition		tocAdviceReason	x
Scenario 1.3	Gap advice	RSUSuggestedManeuverContainer	adviceID	
			adviceLaneID	x
			adviceStartPosition	x
			adviceEndPosition	x
			desiredBehaviour	
Scenario 4.2	Area of transition	RSUSuggestedManeuverContainer	placeOfStartOfTransition	x
			placeOfEndOfTransition	x
	Time of transition		timeOfTriggerTransition	x

	Reason for transition		tocAdviceReason	
	Target lane		targetLane	
	Lane change position		laneChangeStartPosition	x
			laneChangeEndPosition	x
	Lane change moment		laneChangeMoment	x
	Gap advice		adviceID	
			adviceLaneID	x
			adviceStartPosition	x
			adviceEndPosition	x
			desiredBehaviour	
Scenario 4.1-5	Starting point of safe spot assigned	RSUSuggestedManeuverContainer	placeOfStartSafeSpot	
	End point of safe spot assigned		placeOfEndSafeSpot	

In addition to the MCM profiling proposed in this section for covering the requirements of the TransAID investigated services and scenarios (also schematically summarized in Annex A), Annex C describes an even more generic version of the TransAID MCM, with additional data elements that can be suitable for other similar services. The ASN1 definitions of the TransAID proposed MCM are included in deliverable D7.2 as a result of application of the theoretical specification of this deliverable into real-world prototypical implementations.

7 Conclusion

The TransAID projects aims at designing traffic management measures for transition areas with mixed traffic compositions. Within this context, the use of V2X communications is of key importance to facilitate the cooperation between vehicles and with the infrastructure. This document introduces a definition of the V2X Facility-layer message sets employed in the TransAID project to facilitate the deployment of the TransAID Services in the scenarios selected by the project. The definition of the message set is based on an exhaustive review of the state of the art of V2X messages defined by standardization bodies or related research projects. The storylines of the TransAID services have been analysed in order to define the information that is required to be transmitted by cooperative vehicles and/or the infrastructure. Based on the list of requirements, the ETSI V2X standard messages as well as messages from other R&D projects have been assessed for suitability. Based on this, the required information already covered by these specifications has been identified and the needed TransAID extensions proposed. In this context, proposals for profiling of CAMS, DENMS, IVIMs, SPATEMs and MAPEMs and for extensions of CAMs and DENMs have been provided. In Addition, an interesting concept for extension of the ETSI ITS Maneuver Coordination Service allowing the inclusion of RSI suggestions has been presented. The concepts presented in this deliverable are going to be adopted for the simulations of WP6 and prototypical implementations of WP7. In this last WP, ASN1 definitions of the TransAID message sets will be generated and published.

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Annex A: Mapping of TransAID service requirements onto C-ITS standard messages elements and extensions

			Requirement	Message	Container	Field	Optional	Reference
Information shared by CVs and CAVs	Ego-vehicle information	Vehicle type	Type of vehicle	CAM	Basic Container	Station type		CDD A.78
			Length	CAM	Basic Vehicle Container High Frequency	Vehicle Length		CDD A.131
			Width	CAM	Basic Vehicle Container High Frequency	Vehicle Width		CDD A.95
		Vehicle dynamics	Position	CAM	Basic Container	Reference Position		CDD A.124
			Speed	CAM	Basic Vehicle Container High Frequency	Speed		CDD A.126
			Acceleration	CAM	Basic Vehicle Container High Frequency	Longitudinal Acceleration		CDD A.116
				CAM		Lateral Acceleration	x	CDD A.115
				CAM		Vertical Acceleration	x	CDD A.129
			Heading	CAM	Basic Vehicle Container High Frequency	Heading		CDD A.112
			Lane position	CAM	Basic Vehicle Container High Frequency	Lane Position	x	CDD A.40
			Driving mode	CAM	Basic Vehicle Container High Frequency	Acceleration Control	x	CDD A.2
			Current automation level	CAM	New Autonomous Vehicle Container	CurrentAutomationLevel		
	Other vehicle information	Vehicle type	Size of obstacle	CPM	PerceivedObjectsContainer	PlanarObjectDimension1	x	CPM C.23
				CPM	PerceivedObjectsContainer	PlanarObjectDimension2	x	CPM C.23
		Vehicle dynamics	Position	CPM	PerceivedObjectsContainer	xDistance		CPM C.15
				CPM		yDistance		CPM C.15
				CPM		zDistance	x	CPM C.15
			Speed/Heading	CPM	PerceivedObjectsContainer	xSpeed	x	CPM C.18
				CPM		ySpeed	x	CPM C.18
				CPM		zSpeed	x	CPM C.18
			Acceleration	CPM	PerceivedObjectsContainer	xAcceleration	x	CDD A.116
				CPM		yAcceleration	x	CDD A.115
				CPM		zAcceleration	x	CDD A.129
			Lane position	CPM	PerceivedObjectsContainer	matchedPosition	x	CPM C.26
Information shared by CAVs	Ego-vehicle information	Manoeuvres	Planned future trajectory	MCM	VehicleManeuverContainer	plannedTrajectory		
			Desired future trajectory	MCM	VehicleManeuverContainer	desiredTrajectory	x	
		Spacing information relative to other vehicles	Gap with preceding vehicle	CAM	MAVENAutomatedVehicleContainer	distanceToPreceedingVehicle	x	
			Gap with following vehicle	CAM	MAVENAutomatedVehicleContainer	distanceToFollowingVehicle	x	
		ToC information	Transition alert	DENM	Situation Container	Event type		CDD A.10
			Target automation level	MCM	VehicleManeuverContainer	targetAutomationLevel	x	
			Trigger time of ToC	MCM	VehicleManeuverContainer	triggerTimeOfToC	x	
			MRM alert	DENM	Situation Container	Event type		CDD A.10
			Trigger time of MRM	MCM	VehicleManeuverContainer	triggerTimeOfMRM	x	

		CACC		Planned route at next intersection (in/out lane)	CAM	MAVENAutomatedVehicleContainer	RouteAtIntersection		
				Planned route in terms of next intersections to cross	CAM	MAVENAutomatedVehicleContainer	IntersectionRoute		
				Desired min and max speed for driving in a platoon	CAM	MAVENAutomatedVehicleContainer	DesiredSpeedRange		
				Supported max positive and negative accelerations	CAM	AutomatedVehicleContainerHighFrequency	AccelerationCapability		
				Lane the vehicle is currently driving	CAM	AutomatedVehicleContainerHighFrequency	LanePosition	x	
				Planned vehicle trajectory in terms of future positions and headings	CAM	AutomatedVehicleContainerHighFrequency	PlannedPath	x	
				Lane the vehicle plans to drive to	CAM	AutomatedVehicleContainerHighFrequency	PlannedLane	x	
				Id of the Platoon that the vehicle is currently in	CAM	AutomatedVehicleContainerLowFrequency	PlatoonId		
				List of following vehicle IDs	CAM	AutomatedVehicleContainerLowFrequency	PlatoonFollowers		
				State of the platoon that the vehicle is currently in	CAM	AutomatedVehicleContainerLowFrequency	PlatoonVehicleState		
				Forming state of the platoon that the vehicle is currently in	CAM	AutomatedVehicleContainerLowFrequency	PlatoonFormingState		
Information shared by RSI	Information about the road network	Description of the network		Number of lanes	MAPEM	Road Segment	RoadLaneSet(list)		SAE 6.106
				Width of lanes	MAPEM	Road Segment	LaneWidth / dWidth	x	SAE 7.80
				Curvature of lanes	MAPEM	Road Segment	lane Crown Point Center		SAE 7.124
					MAPEM	Road Segment	lane Crown Point Left		SAE 7.124
					MAPEM	Road Segment	lane Crown Point Right		SAE 7.124
				Incoming lanes	MAPEM	Road Segment	ConnectsTo (list)	x	SAE 6.15
					MAPEM	Road Segment	MergePoint (nodeattributes)		SAE 7.99
				Outgoing lanes	MAPEM	Road Segment	ConnectsTo (list)	x	SAE 6.15
					MAPEM	Road Segment	divergePoint (nodeattribute)		SAE 7.99
				Type of the lane	MAPEM	RoadSegment	LaneAttributes		SAE 6.36
		Traffic rules of the area		Type of traffic rule	IVIM	ApplicationContainer	relevanceZoneIds	x	IVI 7.3.30
							applicableLanes	x	CDD A.40
							iviType		IVI 7.3.13
							vehicleCharacteristics	x	IVI 7.2.2
							roadSignCodes		IVI 7.2.14
				Area of application	IVIM	LocationContainer	zoneId		IVI 7.3.30
							LaneNumber	x	CDD A.40
							Zone		IVI 7.2.23
	Information to overpass the transition area	First iteration services	Scenario 1.1	Road works alert	DENM	Situation Container	Event type		CDD A.10
				path to overpass road works	MAPEM	Road Segment	GenericLane		SAE 6.25
				closed lanes	DENM	Road Works Container	Closed lanes		CDD A.106
				Bus lane allowed for driving	MAPEM	Road Segment	DF_LaneTypeAttributes=DE_LaneAttibutes-Vehicle	x	SAE 6.40
					MAPEM	Road Segment	LaneSharing		SAE 7.79
			Scenario 2.1	Confirmation of speed advise	MCM	VehicleManeuverContainer	adviceResponseList		

				execution					
				Confirmation of lane change execution	MCM	VehicleManeuverContainer	adviceResponseList		
				Gap with preceding vehicle	CAM	New Autonomous Vehicle Container	DistanceToPrecedingVehicle		
				Gap with following vehicle	CAM	New Autonomous Vehicle Container	DistanceToFollowingVehicle		
				Speed advice	MCM	RSUSuggestedManeuverContainer	adviceID		
							adviceLaneID		
							advicePosition		
							desiredBehaviour		
				Lane advice reason	MCM	RSUSuggestedManeuverContainer	laneAdviceReason		
				Lane change position	MCM	RSUSuggestedManeuverContainer	laneChangePosition		
				Lane change moment	MCM	RSUSuggestedManeuverContainer	laneChangeMoment		
				Lane change speed	MCM	RSUSuggestedManeuverContainer	laneChangeSpeed	x	
				Leading and following vehicles	MCM	RSUSuggestedManeuverContainer	leadingVehicle	x	
							followingVehicle	x	
				Target lane	MCM	RSUSuggestedManeuverContainer	targetLane		
			Scenario 3.1	triggering point of ToC	MCM	RSUSuggestedManeuverContainer	triggeringPointOfToC		
				Target lane	MCM	RSUSuggestedManeuverContainer	targetLane		
				Advice reason	MCM	RSUSuggestedManeuverContainer	laneAdviceReason		
				Lane change position	MCM	RSUSuggestedManeuverContainer	laneChangePosition		
				Lane change moment	MCM	RSUSuggestedManeuverContainer	laneChangeMoment		
				Advised speed	MCM	RSUSuggestedManeuverContainer	laneChangeSpeed	x	
				Leading and following vehicles	MCM	RSUSuggestedManeuverContainer	leadingVehicle	x	
							followingVehicle	x	
			Scenario 4.2	Road works alert	DENM	Road Works Container	Event type		CDD A.10
				closed lanes	DENM	Road Works Container	Closed lanes		
				Safe spots	MAPEM	Road Segment	LaneAttributes-Parking, --parking and stopping lanes		SAE 7.70
			Scenario 5.1	Area of transition	MCM	RSUSuggestedManeuverContainer	placeOfStartOfTransition	x	
					MCM	RSUSuggestedManeuverContainer	placeOfEndOfTransition	x	
				Time of transition	MCM	RSUSuggestedManeuverContainer	TimeOfTriggerTransition	x	
				Reason for transition	MCM	RSUSuggestedManeuverContainer	tocAdviceReason	x	
				Alert about the no AD-zone	DENM	Situation Container	Event type		CDD A.10
		Second iteration services	Scenario 1.3	Alert about end of queue	DENM	Situation Container	Event type		CDD A.10
				End of queue position	DENM	Management Container	Event position		CDD A.124
				Emergency lane allowed for driving	MAPEM	Road Segment	DF_LaneTypeAttributes=DE_LaneAttibutes-Vehicle	x	SAE 6.40
				Speed limit	MAPEM	Road Segment	RegulatorySpeedLimit	x	SAE 6.101
			Scenario 2.1	Confirmation of speed advise execution	MCM	VehicleManeuverContainer	adviceResponseList		
				Confirmation of lane change execution	MCM	VehicleManeuverContainer	adviceResponseList		
				Gap with preceding vehicle	CAM	New Autonomous Vehicle Container	DistanceToPrecedingVehicle		
				Gap with following vehicle	CAM	New Autonomous Vehicle Container	DistanceToFollowingVehicle		
				Speed advice	MCM	RSUSuggestedManeuverContainer	adviceID		

							adviceLaneID		
							advicePosition		
							desiredBehaviour		
				Lane advice reason	MCM	RSUSuggestedManeuverContainer	laneAdviceReason		
				Lane change position	MCM	RSUSuggestedManeuverContainer	laneChangePosition		
				Lane change moment	MCM	RSUSuggestedManeuverContainer	laneChangeMoment		
				Lane change speed	MCM	RSUSuggestedManeuverContainer	laneChangeSpeed	x	
				Leading and following vehicles	MCM	RSUSuggestedManeuverContainer	leadingVehicle	x	
							followingVehicle	x	
				Target lane	MCM	RSUSuggestedManeuverContainer	targetLane		
				Ramp metering	SPATEM	MovementState	eventState [MovementPhaseState]		SAE 7.103
			Scenario 2.3	Alert about the incident	DENM	Situation Container	Event type		CDD A.10
				Incident position	DENM	Management Container	Event position		CDD A.124
					DENM	AlacarteContainer	LanePosition		CDD A.40
				Allowed AD level	DENM	ADrestrictionContainer	allowedADlevel	x	
				Closed lanes	DENM	ADrestrictionContainer	closedLanes	x	CDD A.106
				Speed limit	DENM	ADrestrictionContainer	speedLimit	x	CDD A.73
				Speed limit starting position	DENM	ADrestrictionContainer	startingPointSpeedLimit	x	CDD A.109
				Speed limit end position	DENM	ADrestrictionContainer	endPointSpeedLimit	x	CDD A.109
				Closed lanes starting position	DENM	ADrestrictionContainer	startingPointClosedLanes	x	CDD A.109
				Closed lanes end position	DENM	ADrestrictionContainer	endPointClosedLanes	x	CDD A.109
				Merge advice	DENM	ADrestrictionContainer	trafficFlowRule	x	CDD A.85
				Link to incident DENM	DENM	ADrestrictionContainer	referenceDenms		CDD A.102
				Updated junction topology and signal groups	MAP	Road Segment	connectsTo [ConnectsToList]		SAE 6.15
					MAP	Road Segment	Connection – connectingLane [ConnectingLane]		SAE 6.12
					MAP	Road Segment	lane [LaneID]		SAE 7.77
					MAP	Road Segment	maneuver [AllowedManeuvers]		SAE 7.4
					MAP	Road Segment	remoteIntersection [Intersection-ReferenceID]		SAE 6.28
					MAP	Road Segment	region [RoadRegulatorID]		SAE 7.122
					MAP	Road Segment	id [IntersectionID]		SAE 7.48
					MAP	Road Segment	signalGroup [SignalGroupID]		SAE 7.131
					MAP	Road Segment	userClass [RestrictionClassID]		SAE 7.121
					MAP	Road Segment	connectionID [LaneConnectionID]		SAE 7.75
				Updated signal groups	SPATEM	MovementState	signalGroup [SignalGroupID]		SAE 7.171
				Signal timing	SPATEM	MovementState	eventState [MovementPhaseState]		SAE 7.103
			Scenario 4.2	Road works alert	DENM	Situation Container	Event type		CDD A.10
				Lanes closed	DENM	Road Works Container	Closed lanes		CDD A.106
				Safe spots	MAPEM	Road Segment	LaneAttributes-Parking, -- parking and stopping lanes		SAE 7.70

					Area of transition	MCM	RSUSuggestedManeuverContainer	placeOfStartOfTransition	x	
						MCM	RSUSuggestedManeuverContainer	placeOfEndOfTransition	x	
					Time of transition	MCM	RSUSuggestedManeuverContainer	TimeOfTriggerTransition	x	
					Reason for transition	MCM	RSUSuggestedManeuverContainer	tocAdviceReason	x	-
					Target lane	MCM	RSUSuggestedManeuverContainer	targetLane		
					Lane change position	MCM	RSUSuggestedManeuverContainer	laneChangePosition		
					Lane change moment	MCM	RSUSuggestedManeuverContainer	laneChangeMoment		
					Gap advice	MCM	RSUSuggestedManeuverContainer	adviceID		
								adviceLaneID		
								advicePosition		
								desiredBehaviour		
				Scenario 4.1-5	Alert about the no AD-zone	DENM	Situation Container	Event type		CDD A.10
					Allowed AD level	DENM	ADrestrictionContainer	allowedADlevel	x	
					No AD zone boundaries	DENM	ADrestrictionContainer	laneID		
						DENM	ADrestrictionContainer	areaStartPoint		CDD A.109
						DENM	ADrestrictionContainer	areaEndPoint		CDD A.109
					Safe spots	MAPEM	Road Segment	LaneAttributes-Parking, -- parking and stopping lanes		SAE 7.70
					Starting point of safe spot assigned	MCM	RSUSuggestedManeuverContainer	placeOfStartSafeSpot		
					End point of safe spot assigned	MCM	RSUSuggestedManeuverContainer	placeOfEndSafeSpot		

Annex B: List of contributions to V2X standardization and specification

1) A. Correa et al. (University Miguel Hernandez of Elche), participation at the ETSI ITSWG1-Maneuvering Coordination Service drafting session, 26 February 2018: Introducing TransAID objective and focus for possible MCS service application.
2) A. Correa et al. (University Miguel Hernandez of Elche), participation at the ETSI ITSWG1-Maneuvering Coordination Service drafting session, 18 October 2018: Challenges and solutions for maneuver coordination.
3) M. Sepulcre et al. (University Miguel Hernandez of Elche), participation at the ETSI ITSWG1-Collective Perception Service drafting session, 23 January 2019: Simulation Study on Collective Perception.
4) M. Rondinone et al. (Hyundai Motor Europe Technical Center), "Transition Areas for Infrastructure Assisted Driving", presentation at the C2C-CC Working Group Roadmap meeting, 19 June 2018: Introducing the TransAID services and scenarios for consideration in the C2C-CC roadmapping
5) M. Rondinone et al. (Hyundai Motor Europe Technical Center), "Concepts for infrastructure support to transitions in vehicle automation", presentation at the C2C-CC Working Group Roadmap meeting, 24 September 2018: updates on TransAID results for consideration in the C2C-CC roadmapping
6) A. Correa et al. (University Miguel Hernandez of Elche), "V2X for transition of control in cooperative automated driving", presentation at the C2C-CC Forum, 21 November 2018:

Annex C: Proposal for the MCM format

Container	Data Frame		Opt.	Type	Description
MCM > ITS PDU Header	protocol version			Integer 0-255	version of the ITS message and/or communication protocol
	message id			Integer 0-255	Type of the ITS message
	station id			integer 0-4294967295	Identifier for an ITS-S
MCM > ManeuverCoordination > GeneationDeltaTime					Generation time of the message
MCM > ManeuverCoordination > MCMParameters > BasicContainer					Includes ref position and station type
MCM > ManeuverCoordination > MCMParameters > ManeuverContainer = choice between vehicle or RSU containers > VehicleManeuverContainer	plannedTrajectory				Future trajectory of the vehicle
	desiredTrajectory		x		Desired trajectory if other vehicles agree
	MinDistanceAhead		x	integer 0 - 10000	Minimum distance to the front bumper of the vehicle that other vehicles need to respect when they want to accept the desired trajectory
	MinDistanceBehind		x	integer 0 - 10000	Minimum distance to the rear bumper of the vehicle that other vehicles need to respect when they want to accept the desired trajectory
	MinTimeHeadwayAhead		x	integer 0 - 65535	Minimum time headway in milliseconds that need to be respected by a preceding vehicle when they want to accept the desired trajectory
	MinTimeHeadwayBehind		x	integer 0 - 65535	Minimum time headway in milliseconds that need to be respected by a following vehicle when they want to accept the desired trajectory
	triggerTimeOfToC		x	Sequence	Time when the ToC process starts
		Minute		integer 0 - 527040	Time when the ToC will be triggered in minutes since the start of the year
		Millisecond		integer 0 - 65535	Time when the ToC will be triggered in milliseconds since the start of the minute
	targetAutomationLevel		x	Enumeration	Level of automation of the vehicle after the ToC
	triggerTimeOfMRM		x	integer 0 - 65535	Time in milliseconds since the trigger of the ToC when the MRM will be triggered if the driver does not take control of the car
	length				
		Value		integer 1 - 1023	Length of the vehicle.
		Confidence		Enumeration	To indicate whether the presence of a trailer is detectable or whether the length is included in the length value
	heading				
		Value		integer 0 - 3601	Orientation of a heading with regards to the WGS84 north.
		Confidence		integer 0 - 127	The absolute accuracy of a reported heading value for a predefined confidence level
	speed				
		Value		integer 0 - 16383	Speed value
		Confidence		integer 0 - 127	The absolute accuracy of a reported speed value for a predefined confidence level
	longitudinalAcceleration				
		Value		integer -160 - 161	Vehicle acceleration at longitudinal direction in the centre of the mass of the empty vehicle
		Confidence		integer 0 - 102	The absolute accuracy of a reported acceleration value for a predefined confidence level
	lateralAcceleration				
		Value		integer -160 - 161	Vehicle acceleration at lateral direction in the centre of the mass of the empty vehicle
		Confidence		integer 0 - 102	The absolute accuracy of a reported acceleration value for a predefined confidence level
	verticalAcceleration		x		
		Value		integer -160 - 161	Vehicle acceleration at vertical direction in the centre of the mass of the empty vehicle.
		Confidence		integer 0 - 102	The absolute accuracy of a reported acceleration value for a predefined confidence level
	yawRate				

		Value					integer -32766 - 32767	Vehicle rotation around z-axis of coordinate system centred on the centre of mass of the empty-loaded vehicle
		Confidence					enumeration	The absolute accuracy range for reported yaw rate value for a predefined confidence level
	curvature							
		Value					integer -30000 - 30001	The inverse of a detected vehicle turning curve radius scaled with 30 000A curvature detected by a vehicle represents the curvature of the actual vehicle trajectory.
		Confidence					enumeration	The absolute accuracy range of a reported curvature value for a predefined confidence level.
	curvatureCalculationMode						enumeration	It describes whether the yaw rate is used to calculate the curvature for a reported curvature value.
	driveDirection						enumeration	It denotes whether a vehicle is driving forward or backward
	lanePosition						integer -1 - 14	The transversal position information on the road in resolution of lanes, counted from the outside border of the road for a given traffic direction.
	steeringWheelAngle							
		Value					integer -511 - 512	Steering wheel angle of the vehicle at certain point in time.
		Confidence					integer 1 - 127	The absolute accuracy for a reported steering wheel angle value for a predefined confidence level
	adviceResponseList						Sequence size 1--3	List of advice response objects
		adviceResponse					Sequence	Single advice response object
			adviceID				integer 0-255	Identifier for the acknowledgement
			adviceFollowed				Bit string	Advice response: followed or not followed
RSUSuggestedManeuverContainer	intersectionReferenceID					x		Specific lane ids are referring to this intersection id
	roadSegmentreferenceID					x		Specific lane ids are referring to this roadsegment id
	vehicleAdviceList					x	Sequence size 1-8	List of lane advice objects, one per vehicle
		VehicleAdvice					Sequence	Single vehicle advice object
			targetStationID				integer 0-4294967295	StationID of the vehicle the advice is targeted at
			adviceStatus				Enumeration	Status of the advice, new, updated, cancelled
			LaneAdvice			x		Single lane advice object
				adviceID			integer 0-255	Identifier for acknowledgement
				laneAdviceReason			Enumeration	Indicates the reason why the CAV should perform the lane change
				laneChangeStartPosition		x	integer 0 - 10000	Start position where the lane change advice applies
				laneChangeEndPosition		x	integer 0 - 10000	End position where the lane change advice applies
				laneChangeMoment		x	Sequence	Time when the lane change should be performed
					Minute		integer 0 - 527040	Time when the lane change should start in minutes since the start of the year
					Millisecond		integer 0 - 65535	Time when the lane change should start in milliseconds since the start of the minute
				laneChangeSpeed		x	Integer 0-500	Speed advice at the moment of the lane change
				leadingVehicle		x	integer 0-4294967295	StationID of the vehicle intended to be ahead of the target vehicle after merging
				followingVehicle		x	integer 0-4294967295	StationID of the vehicle intended to be behind of the target vehicle after merging
				targetLane			integer 0 - 255	The lane number towards the target vehicle should move
				triggeringPointOfToC		x	integer 0 - 10000	Distance from the starting point where a ToC should be triggered if the lane change is not performed
			CarFollowingAdvice			x	Sequence	Single speed advice object
				adviceID			integer 0-255	Identifier for acknowledgement
				adviceLaneID		x	integer 0 -255	LaneID to which the advice and position applies
				adviceStartPosition		x	integer 0 - 10000	Start position where the target speed/gap applies
				adviceEndPosition		x	integer 0 - 10000	End position where the target speed/gap applies
				desiredBehaviour			Choice	
					targetGap	CHOICE	integer 0-255	Target distance in m towards vehicle ahead

									targetSpeed	CHOICE	integer 0 - 255	Value of the speed advised to the target vehicle
							TocAdvice			x	Sequence	Single ToC advice object
								adviceID			integer 0-255	Identifier for acknowledgement
								adviceLaneID		x	integer 0 -255	LaneID to which the advice and position applies
								tocAdviceReason			Enumeration	Indicates the reason why the CAV should perform the ToC
								placeOfStartOfTransition		x	integer 0 - 10000	Position where the ToC should start
								placeOfEndOfTransition		x	integer 0 - 10000	Distance from the starting point where the ToC can be done
								timeOfTriggerTransition		x	Sequence	Time when the ToC should start
									Minute		integer 0 - 527040	Time when the ToC should start in minutes since the start of the year
									Millisecond		integer 0 - 65535	Time when the ToC should start in milliseconds since the start of the minute
							SafeSpotAdvice			x	Sequence	Single ToC advice object
								adviceID			integer 0-255	Identifier for acknowledgement
								adviceLaneID			integer 0 -255	LaneID to which the advice and position applies
								placeOfStartSafeSpot			integer 0 - 10000	Initial point of the area where the safe spot can be done
								placeOfEndSafeSpot			integer 0 - 10000	End point of the area where the safe spot can be done