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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The present document provides an overview of the Manoeuvre Coordination Service (MCS) (clause 4) which enables collective actions to be coordinated between a group of cooperative partners.

A set of main concepts studied for the support of collective actions with associated examples of ITS applications and use cases are provided in clause 5.

Identified impacts on CAM and functional requirements, Functional Safety and Security requirements, as well as minimum performance requirements are provided in clause 6.

Annex A provides examples of Manoeuvre Coordination Messages (MCMs) which were tested in several National and European research projects. An attempt is achieved to derive a common message structure, syntax and semantic.

Annex B provides an example of an applications pipeline using the Manoeuvre Coordination Service based on the results of a collision risk analysis taking profit of Artificial Intelligence.

Introduction

The present document intends to provide some baselines for the standardization of the Manoeuvre Coordination Service (MCS) which will support different applications related to the CCAM (Connected Cooperative Automated Mobility) situation.

The main concepts which are proposed cover the CDA (Cooperative Driving Automation) services "Intent Sharing", "Agreement seeking "and "prescriptive" (see SAE J3216 [i.1]).

An agreement seeking CDA service may take several forms according to the local situation of cooperative partners and their intents.

A prescriptive CDA service requires a special permission which needs to be provided by a relevant authority to the ITS-S using it. In this case, the intent is indeed a mission which is executed by an authorized stakeholder (police intervention, emergency rescue, road maintenance operation (for example during winter), urgent transport of critical goods and materials, etc.).

When manoeuvre coordination has been agreed between subject and target vehicles, these manoeuvres can be seen in CAMs which are disseminated by these vehicles. Consequently, CAMs can be considered as implicit acknowledgement messages of the MCMs.

1 Scope

The present document gives an overview of the Manoeuvre Coordination Service (MCS), describes the class of cooperation, and introduces relevant use cases. Potential requirements (functional, functional safety, security, and performance requirements) are also introduced as well as for the MCM format.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] SAE J3216: "Taxonomy and definition for terms related to Cooperative Driving Automation (CDA) for on-road motor vehicles".

[i.2] https://www.pacv2x.fr/.

[i.3] Imagine: "Virtual Final Presentation".

[i.4] ETSI TR 103 299: "Intelligent Transport System (ITS); Cooperative Adaptive Cruise Control (CACC); Pre-standardization study".

[i.5] SAE J3186: "Application Protocol and Requirements for Maneuver Sharing and Coordinating".

[i.6] ISO 26262: "Road vehicles -- Functional safety -- Part 1: Vocabulary".

[i.7] IEC 61508 (all parts): "Functional safety of electrical/electronic/programmable electronic safety-related systems".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

alternative trajectory: trajectory proposed by a manœuvre coordination partner as an alternative possibility

Connected Cooperative Automated Vehicle (CCAV): vehicle which has connectivity capabilities including V2X communication

NOTE: In the present document "V2X" refers to 3GPP cellular V2X (PC5), DSRC ITS G5 or other standard DSRC technologies meeting ITS application requirements (e.g. performance requirement).

manoeuvre advice: list of manoeuvres which need to be executed by receiving relevant vehicles (subject and target vehicles) to obtain a specific result/outcome

MCS triggering vehicle: release 2 cooperative vehicle (most often probably the subject vehicle) which initiates an MCS either with a request or an offer

NOTE: When an MCS triggering vehicle issues a request, if this one is accepted, this MCS triggering vehicle becomes a subject vehicle. When an MCS triggering vehicle issues an offer, if this one is accepted, this MCS triggering vehicle becomes a target vehicle.

reference trajectory: trajectory being currently driven by the vehicle

release 2 cooperative vehicle: connected cooperative automated vehicle which is equipped with a release 2 conforming set of services which is necessary to contribute to manoeuvre coordination actions

relevant vehicle: cooperative vehicle which can be impacted by the manoeuvre coordination service because of its proximity to other vehicles actively participating in manoeuvre coordination

NOTE 1: A relevant cooperative vehicle may also provide relevant data from its CAMs, CPMs disseminations to active manoeuvre coordination participants. Then, it could affect initiated manoeuvre by aiding or blocking it.

NOTE 2: In SAE J3186 [i.5], "Relevant Vehicle" term is equivalent to "Affected Vehicle".

requested trajectory: trajectory requested to be achieved from a manœuvre coordination partner

subject vehicle: cooperative vehicle, which needs a manoeuvre coordination, to satisfy its intent or to respond to received messages

NOTE 1: Several subject vehicles may be synchronized to execute a manoeuvre.

NOTE 2: In SAE J3186 [i.5], "Host Vehicle" term is equivalent to "Subject Vehicle".

Target Road Resource (TRR): type and description of the road resource which is intended to be occupied by the Executant

target vehicle: cooperative vehicle which actively participates in the accommodation of one accepted subject vehicle manoeuvre

NOTE: In SAE J3186 [i.5], "Remote Vehicle" term is equivalent to "Target Vehicle".

trajectory: planned path with dynamic information (e.g. heading, time, speed, speed variation, etc.) between an origin waypoint and a destination waypoint

NOTE: Clearly indicating a predicted path that can be identified as such by other cooperative ITS-S.

unconnected vehicle: vehicle which has not the required connectivity capabilities necessary to support the Manoeuvre Coordination Service

NOTE: SAE J3186 definition [i.5]: Vehicle which is not capable of V2X communication.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADAS	Advanced Driving Assistance Systems
AEBS	Automated Emergency Brake System
ALK	Active Lane Keeping
AVP	Automated Valet Parking
C-ACC	Cooperative Adaptive Cruise Control
CAS	Cooperative Awareness Service

CCAM	Connected Cooperative Automated Mobility
CCAV	Connected Cooperative Automated Vehicle
CDA	Cooperative Driving Automation
CPS	Collective Perception Service
ESP	Electronic Stability Program
FSR	Functional Safety/Security Requirement
ISA	International Society of Automation
ITS	Intelligent Transport System
ITS-S	ITS Station
MCM	Manoeuvre Coordination Message
MCS	Manoeuvre Coordination Service
ODD	Operational Design Domain
PDU	Protocol Data Unit
RSE	Roadside Equipment
SAE	Society of Automotive Engineers
SSP	Service Special Permission
SV	Subject Vehicle
TG	Target vehicle "G", "G1"...
TR	Technical Report
TRR	Traget Road Resource
TTC	Time To Collision
TV	Target Vehicle
VBS	Vulnerable Basic Service
VRU	Vulnerable Road User

4 General description of the manoeuvre coordination service

4.1 Objectives

The objective of the Manoeuvre Coordination Service (MCS) is to exchange information and develop cooperation between ITS-S in proximity or remotely for the support of the driving automation functions of Connected Cooperative Automated Vehicles (CCAV). Therefore, this service is in support of ITS applications that in turn contribute to automated driving functions.

4.2 Classes of services

4.2.1 Introduction

Several cooperative driving automation services can be identified. SAE J3216 [i.1] distinguishes the four following classes of cooperation to increase cooperation among vehicles:

- Status-Sharing.
- Intent-Sharing.
- Agreement-Seeking.
- Prescriptive.

The clauses below provide more information on the 4 above mentioned classes.

4.2.2 Status-Sharing

Status-sharing corresponds to the communication of data relatively to a present situation under the form of information about an object in its current state or about the result of an event which changed an object state. For example:

- CAMs provide the status of vehicular objects. This is an "Evidence" data set reflecting the current state (present) of the considered vehicular object.

- DENMs provide event notifications indicating a rapid modification of a vehicle object or a road infrastructure state.

EXAMPLE: A closed lane consecutively to a stationary vehicle, road work or accident.

- VAMs are providing the status of Vulnerable Road Users (VRUs).

- CPMs are providing the status of perceived unconnected objects (i.e. vehicles, VRUs, etc.).

It is however considered that status sharing (day 1 functionality) will still be necessary as the layer of information to provide the basic data for ITS application with intent of manoeuvre coordination functionality based on MCS.

4.2.3 Intent-Sharing

Intent-sharing corresponds to the communication of an intent which may impact the manoeuvring of other mobile objects.

A road user of any category, be it automated, human-driven or a vulnerable road user, manoeuvres according to an intent. In most circumstances, this intent is guided by a set of rules, mostly prescribed in the form of traffic rules. When a driver navigates to the right-turning lane, it is only in special circumstances that the driver will not follow the path prescribed by that lane. Additionally, specific tools like turn signals and hand signals are used to indicate an intent in the short term by the indicating road user.

Three types of behaviours could be taking place when considering intent in its current form if present:

- The road user does not indicate any thing, therefore pursuing its current intent. This could be continuing straight on the road.

- The road user indicates a manoeuvre requiring a change, such as switching lanes, turning, crossing the road. This is commonly indicated with intent signals (a pedestrian looking at driver before crossing, turn signals).

- A mistake in setting, (or forgetting) the right intent signal occurred (learner driver, sudden intent changes, or adjustments to road status: avoiding potholes in the lane, lane change without signalling).

Intent sharing is therefore an inherent behaviour road user already utilize. To enable this capability in the long term for CCAVs, the communication of this intent to other road users via an ITS service would enable a wider range of manoeuvre coordination that it is currently possible. By comparison, VBS uses a dedicated container to convey manoeuvre information. This should also be considered here.

The planned manoeuvre can be simply indicated using for example the turning signals of a vehicle or could be more precisely indicated by communicating the planned trajectory of the vehicle and transmitting it in a V2X message.

4.2.4 Agreement-seeking

Agreement-seeking results in manoeuvre which is achieved by a set of cooperative objects (at least two) in a coordinated manner. By seeking and agreeing to coordinate their actions, at least one of them can reach an identified objective.

In the present document, agreement-seeking takes place through the sharing of information, seeking a cooperation agreement. Such agreement needs to be sought and accepted by the cooperative parties. Three different situations can be considered and initiated by cooperative objects. When cooperative objects can receive and communicate intent, agreement-seeking constitutes the next constructive step.

Agreement-seeking results through the sharing of information and the seeking of a cooperation agreement. Such agreement needs to be sought and accepted by cooperative parties. These different situations can be considered and initiated by cooperative objects:

A) V2V cooperation agreement seeking

In this class of service, a MCS triggering can be initiated via the two following triggering conditions:

- A subject vehicle which is seeking a cooperation with one or several target vehicles for the coordination of one or multiple manoeuvres. This is achieved by the subject vehicle via the dissemination of an intent and cooperation request which may involve several sequential exchanges for the accomplishment of the subject vehicle projected manoeuvre.

- One target vehicle which offers its support to one or several subject vehicles for the coordination of their manoeuvres. This is achieved via the dissemination of an intent and a cooperative offer which may involve several sequential exchanges for the accomplishment of subject(s) vehicles(s) projected manoeuvres with the eventual support of other target vehicles.

B) I2V Manoeuvres coordination with roadside infrastructure

In this case, the MCS triggering initiative is taken by a roadside station which has generally a better perception of the local situation due to added precise data sources, such as information from road operators or sensors such as cameras.

The Roadside Station (RSU) identifies maoeuvres target vehicles and suggests them to coordinate their manoeuvres for various mobility purposes which would be identified. This is an offer which is broadcasted via MCMs when the MCS is triggered by the RSU.

The objective of this coordination suggestion needs to be provided to relevant vehicles (subject(s) and target(s)) to be able for them to take a decision to accept it or not.

The intention of relevant vehicles to execute or not the suggested manoeuvre coordination could be given in response by vehicles by for example, supplying their path predictions (or targeted trajectories) which can be reflecting or not their intent (evolution or not of the vehicle reference trajectory provided by CAM) or by an explicit response. However, the suggested manoeuvre coordination needs to be accepted by all relevant subject(s) and target(s) vehicles for starting a collective action. If this is not the case, the initiating vehicle may propose another strategy.

A typical example is the guiding of cooperative vehicles at a tolling station level for them to access the best gate according to specific vehicles' features and rights and considering the current waiting queues at gates' level.

C) C2V Manoeuvres coordination with a central system

A central system may seek agreements with cooperative objects for various purposes such as road safety, traffic management improvement, mobility applications (e.g. Automated Valet Parking (AVP)).

In such case, the central system proposes manoeuvre coordination actions to a selected set of subject vehicles which keep the possibility to accept or refuse the centre proposals.

Additionally, it is critical to consider that there can be different levels of agreement reached which is demonstrated in the following:

- Reception and Acknowledgement/Non-Acknowledgement (ACK/NACK). In this instance the agreement-seeking object (regardless of ITS-S type) communicates intent and manoeuvre and seeks a confirmation or rejection of the proposed manoeuvre.

- Reception and indirect Acknowledgement/Non-Acknowledgement (ACK/NACK). Here the functionality is identical from above, except, the vehicles communicate their decisions by adapting their broadcasted data of other services than MCS, such as path prediction (or reference trajectory) adaptation in the CAM.

- Reception and negotiation phase with consecutive Acknowledgement/Non-Acknowledgement (ACK/NACK) with only one other road user. In this instance the cooperating vehicle is given the option by the agreement-seeking party to choose or counter proposed alternatives.

- Reception and negotiation phase with consecutive Acknowledgement/Non-Acknowledgement (ACK/NACK) with more than one other road user. The added complexity requires multiple rounds of choice and counter proposals between involved objects. This option can potentially lead to the most effective trajectory choice for all involved participants.

Since all of these different options constitute agreement-seeking, it is important to differentiate between them for an implementation and to set a frame for their appropriate level of use. Potentially, the degree of agreement-seeking cannot be decoupled from the use case, the amount of involved road users or the topology, and road use limitation.

4.2.5 Prescriptive

The prescriptive concept is an attempt to extend the manoeuvre coordination service to critical situations which cannot be covered by previously considered concepts.

The main principle remains the same with three important phases:

- Intent sharing phase, but in this concept, the intent is considering mainly fully automated vehicles without a driver in them which can be viewed as being in a critical situation relatively to road users' safety (dangerous driving), to vehicle owner asset protection (e.g. recovery of stolen vehicles), to respect of local or European regulations (e.g. drug or dangerous goods transportation), to terrorist attacks, creating a corridor for emergency intervention or road capacity recovery, etc.

- Prescriptive acceptation phase, which provides more precise information on the origin of this concept use to convince the manoeuvre coordination application of receiving vehicles to accept the provided recommendations.

- Collective action, consisting of executing decided manoeuvre coordination after a complete acceptation of required vehicles partners.

However, The MCS is only providing information to receiving vehicles. This information is deeply checked by the facilities layer of the receiving vehicles before being communicated to the local manoeuvre coordination application of the vehicle if judged correct and relevant.

NOTE: This type of service is already covered by standards for example for vertical signs such as traffic light (status RED) and speed limits which can be considered as "prescriptive messages" leading vehicles to stop at a red-light phase or limit their speed according to the indicated speed limit.

Two main issues need to be considered:

- What will be the roles and responsibilities of OEMs once fully automated vehicles are sold, during all their life cycle (which stakeholders will have to ensure a safe and proper use of these vehicles?). And then, what will be the National and European regulations which will be developed to cover the critical situations identified here above?

- What will be the necessary extensions of security means to make sure that fully automated vehicles be efficiently protected against cyberattacks (collect WG5 viewpoint) and physical vehicles modifications (likely remaining the responsibility of OEMs vehicles functional safety).

4.3 Requirements and Considerations

4.3.1 Introduction

Clause 4.2 focused on the manoeuvre coordination service which can be decomposed into three distinguishable phases:

- The intent sharing phase which initiates the manoeuvres coordination service providing data elements explaining an ITS-S intent (goal) and associated reference trajectory evolution need of one or several subject vehicles.

- The agreement-seeking phase which objective is to obtain the complete agreement of local cooperative vehicles which need to be involved in a collective action to successfully achieve the initial goal being proposed.

- The achievement of the collective action which results of the obtained agreement. However, if this collective action is not completed, local traffic evolutions may impact it leading to some form of collective reconfiguration of the action.

Manoeuvre coordination is based on the prediction capabilities of involved ITS and real-time interactions existing between the functions which are active in the ITS architecture.

4.3.2 Manoeuvre Prediction

A critical precondition for planning safe manoeuvre in road traffic is a precise and correct manoeuvre prediction of road users. These predictions are based on the observation of the road users. Currently, the manoeuvre of road users also depends on unobservable parameters, such as their selected routes, the objects' physical capabilities, or individual comfort, and behaviours parameters. Therefore, predictions of other objects by an ego vehicle are uncertain since this information is missing. To address this uncertainty, road users act more cautiously to increase safety, that also means that they drive slower, wait longer until they found larger gaps to merge in and so on, thereby reducing the overall road traffic efficiency.

Consequently, the prediction improvement is one requirement which needs to be considered for the achievement of manoeuvre coordination. The prediction improvement can be achieved via local context and objects (static and mobiles) perception and the sharing of this perception for example using the CPS.

By adding further data sources such as CAS, VBS and CPS, the pool of available information to the ego vehicle is increased. However, even with these services, the exact planned manoeuvre by all road users can never be determined by the ego vehicle to a high degree of certainty. This is where the explicit communication of a road user intent of any sort to another over a dedicated service like MCS can cover the information gap and provide the receiving vehicle with tools to better estimate other road users' behaviours.

Navigation systems generally plan the itinerary that a mobile object follows to reach an identified destination from a known origin and this, accordingly to criteria provided by the services' user. This itinerary can then be decomposed into a set of relevant trajectories which can be used for the object mobility prediction. The prediction uncertainty level depends on the type of mobile object which is considered:

- A vehicle moving in an automated mode respects the navigation plan, excepted in exceptional situations disturbed by an unexpected event (for example, an accident).

- A vehicle moving in a human driven mode may not respect the proposed navigation plan accordingly to human decisions or driving errors. This is added to unexpected exceptional situations.

- A vulnerable road user may not respect a proposed navigation plan which is more difficult to provide due to less topographic constraints, the low inertia of VRUs and random behaviours related to VRUs risk level profiles.

However, one critical limitation is the capability of a road user to accurately determine its own trajectory. Only when the ego estimation is highly accurate can the road user receiving the information do effective estimation. The position accuracy can already prove to be a limitation if the received manoeuvre information is placing the sender vehicle on a different lane than where it plans the manoeuvre.

More information is provided in annex A.

4.3.3 ITS Architecture Requirements

Four functional categories can be identified in an Intelligent Transport System, as shown in Figure 1.

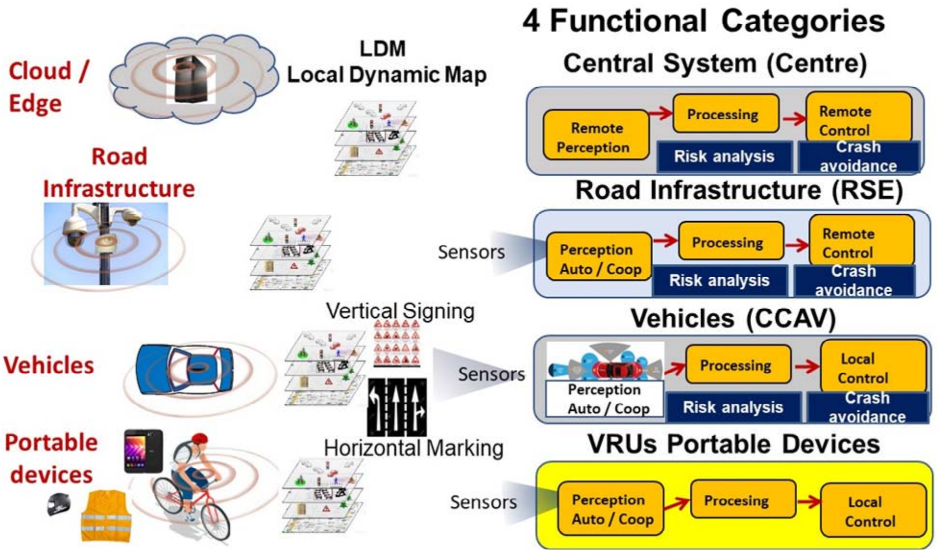

Figure 1: Four functional categories of an ITS

Main applications (e.g. navigation, traffic management, safety, etc.) are supported by functions which are present in the four ITS categories which are represented in Figure 1.

The navigation and collision avoidance functions are key applications of automated vehicles which have to move dynamically on existing road infrastructures according to planned itineraries and this without colliding with other human driven, automated vehicles, and Vulnerable Road Users. The collision risk analysis function is constantly assessing the level of collision risk with the objective to anticipate a collision enabling a crash avoidance function to act on time to avoid it.

The collision risk analysis works on a considerable mass of data which is locally collected by road users and the road infrastructure via their local perception function (autonomous or direct perception) and then processed by specialized ADAS. Perception which is enabled via the use of sensors (video camera, thermal camera, radars, lidars, etc.), needs to be augmented by the collective perception which provides a necessary redundancy when the autonomous perception capabilities are reduced by local contextual factors (e.g. bad weather conditions, traffic density, horizontal marking, vertical signing defects, sensors' limits, etc.).

Central systems located in the cloud or at the edge of the cloud do not benefit from a direct perception of local environments they may have to supervise (e.g. they do not have sensors present in these environments). Consequently, they have to rely on a massive transfer of data provided by local static (roadside equipment) and dynamic (road users (vehicles and VRUs)) objects which are present in environments supervised by central systems. Such situation leads to the specification of potential functional and operational (e.g. minimum performance) requirements which are identified in clause 6 of the present document.

The connectivity enables interactions between these 4 functional categories. Two types of connectivity are then available:

- Short range connectivity supported by standard technologies such as ITS G5 and PC5.
- Long range connectivity supported by standard cellular networks and fibre local area networks (for example private road operators' networks).

The Manoeuvre coordination service is agnostic to the used technology provided that applications' minimum performance and security requirements are fulfilled.