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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).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

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.

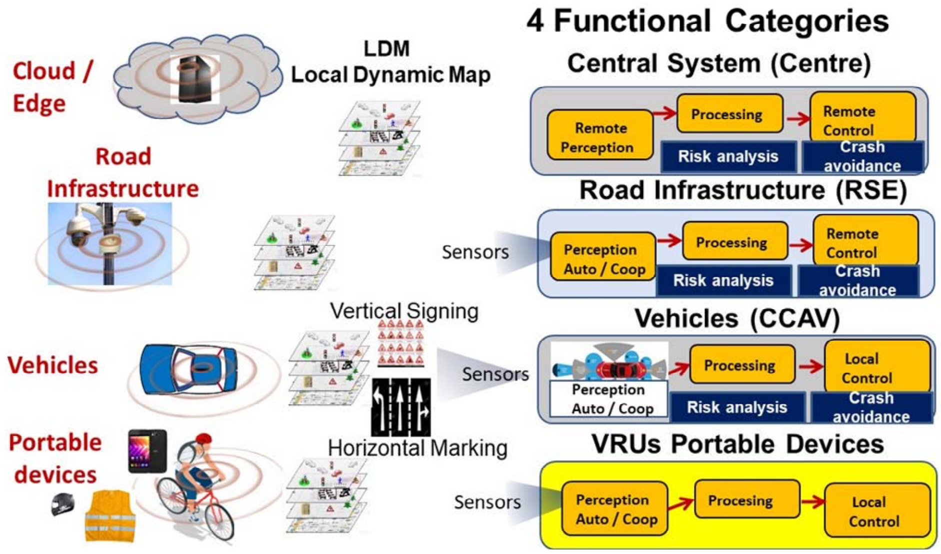

Figure 1: Four functional categories of an ITS

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.

4.3.4 Traffic flow heterogeneity

For a long time, in-service vehicles will exhibit various capabilities in terms of connectivity and automated levels, from low automation which are currently only using ABS or ESP to most elaborated ones of SAE automated level 4 or 5 including automated terrestrial or flying taxis for example which are commercially announced for 2024. This will be a problem for CCAVs which may not cooperate with basic unconnected vehicles not equipped with high level of automated capabilities. Consequently, the vehicles' computation of all use cases needs to consider such traffic flow heterogeneity and then combine their local (autonomous) perception capabilities with received remote perceptions and willingness to cooperate (perception/action fusion). This adds a level of complexity in the implementation of cooperative manoeuvre use cases in general, as each manoeuvre needs to be capable of handling these different levels of technology fitting.

The Manoeuvre Coordination Service needs that all vehicles cooperating in manoeuvre coordination get an overall perception of the traffic situation around them. The Collective Perception Service (CPS) can be used to increase the perception of non-cooperative vehicles by cooperative vehicles sharing their own perception.

Furthermore, more minute differences can also impact the interconnectivity of such vehicles. Depending on protocol versions, antenna placement, and use case implementation, vehicles will differ in their capabilities.

This opens the question to how it can be assured that vehicles communicating data such as intent, agreement and proposals are equipped with the same use case and can execute the use case in the same manner.

This means that the MCS use cases need to be developed considering such traffic flow heterogeneity.

5 Main concepts

5.1 Introduction

The proposed main concepts are classified considering the main classes of cooperative services identified in clause 4.2 and the cooperative interactions which may be existing between functions distributed in the four functional categories identified in Figure 1.

5.2 Concept A1, V2V cooperation class "agreement seeking"

5.2.1 Overview

This concept focuses on Vehicle to Vehicle' cooperation. The information dissemination is then achieved using the broadcasting communication protocol, as in this phase, the originating vehicle may not already know which Target Vehicle(s) will be involved in the resulting collective action.

Before starting this agreement seeking phase, it is assumed that the originating vehicle got the local awareness status of other nearby cooperative vehicles and has already identified a clear intent needing the start of a collective action using the MCS.

The V2V agreement seeking (manoeuvre negotiation phase in SAE J3186 [i.5]) cooperation class is illustrated by three use cases reflecting generic situations presenting this concept.

5.2.2 Description

The concept is based on broadcasting once own trajectories to other vehicles. In the base definition it uses two different kinds of trajectories:

a) Reference trajectory: The trajectory the vehicle plans to drive currently.

b) Requested trajectory: The trajectory the vehicle would like to drive but this is not possible since its necessary manoeuvring space is blocked by another vehicle with higher driving precedence.

The reference trajectories are used to inform other vehicles about the own plan and the requested trajectories to request assistance in situations that could not be solved in a suitable way by the vehicle alone.

The concept follows four rules:

1) The MCS is initiated by one cooperative vehicle which communicates its intent and associated reference trajectory.

2) Reference trajectory needs to be free of conflicts.

3) Detected conflicts need to be solved by following the relevant traffic regulations:

   a) A conflict can be resolved by adapting the vehicles own reference trajectory in a suitable way (e.g. slowing down). Doing this is mandatory for the vehicle with the lower precedence. The vehicle with the lower precedence might in addition send a requested trajectory to inform other vehicles about its need for cooperation. A conflict may also be resolved via negotiation and counter-proposal measures in further exchanges.

   b) The vehicle with the higher precedence might also adapt its own reference trajectory if it finds it acceptable.

4) Persisting conflicts indicate differences in understanding of the situation and need to be resolved with a fallback.

   This rule needs to be followed by all vehicles, regardless of their precedence. The fallback is typically slowing down.

A conflict means that the vehicles following their trajectories get too near to each other or even collide. Too near could mean a TTC of e.g. 0,5 seconds. It depends on personal safety definitions.

Persisting conflicts could occur if vehicles have a different understanding of safety distances. E.g. in highway-entering situations the entering vehicle finds TTC below 1 second suitable, but the vehicle already on the highway prefers values above 1 second. In this case, rule 3 might not get active from the lower precedence vehicle's perspective. Nevertheless, also such situations should be improved by this manoeuvre coordination concept.

Permanently, periodically sending the reference trajectory helps to increase the awareness of own plans to other vehicles and to find out if a cooperation with other vehicles is necessary and with whom.

The local traffic regulations, which are valid at the location of the conflict, are used to decide which role a vehicle takes within a cooperation. The vehicle with the lower precedence will be called Subject Vehicle (SV). The vehicle with the higher precedence Target Vehicle (TG).

A cooperation typically starts with one SV sending a requested trajectory (starting the cooperation) additionally to its reference trajectory. If affected and suitable a receiving vehicle TG considers the requested trajectory in its planning and adapts its own reference trajectory to make it possible. The reception of the adapted reference trajectory is the indication for the requesting vehicle SV that its request has been granted by that vehicle TG. In the base concept there is no explicit granting or declining of requests (see also extensions to base concept). Now, all involved vehicles should follow their coordinated reference trajectories to realize the manoeuvre as agreed. The vehicles inform each other about aberrations by periodically sending MCMs with their reference trajectories (rule 1). Small adaptations are typically made by following rule 3b. Bigger changes of conditions might make sending a new request trajectory necessary.

Extension to base concept:

The extensions are mainly intended to support finding a partner for cooperation or to find a better solution for the involved vehicles:

- All exchanged trajectories are tagged with cooperation costs (see more explanation below) between -1 and 1:
  - -1 represents the best possible trajectory a vehicle could achieve with the help from other vehicles.
  - 1 corresponds to the highest effort a vehicle could do to fulfil another vehicle's request.
- Alternative trajectory: the alternative trajectory is only provided by a cooperative vehicle to indicate a cooperation offer to improve another vehicle's manoeuvrer.

- Explicit granting/decline of requested trajectory or offered alternative trajectory:
  - Inform the requesting/offering vehicle explicitly if the cooperation need represented by its request/offered trajectory is accepted or rejected (ACK/NACK).

  In the base concept, the cooperation acceptance is implicitly expressed by modifying the own reference trajectory.

- Vehicle automation status informs of the current vehicle automation level (which impacts its reaction time and the accuracy of its planned trajectories, among other things).

Cooperation costs:

"Cooperation costs" is a reward or penalty system trying to put the subjective benefit (negative cost) or inconvenience (positive cost) a vehicle experience for being involved in a cooperation into numbers. Since they describe subjective semantics, no mathematical exact or unique or standardized formula is used. Instead, the vehicle-local costs of two semantic-threshold trajectories are taken and then the vehicle-local costs of the trajectory whose cost is being evaluated are put into relation of these two vehicle-local costs. This relation is used to find out the cooperation costs, since the semantic-threshold trajectories have defined cooperation cost values. Since two different vehicles/OEMs have different formulas for their local costs, the cooperative costs for the same trajectory will not be the same. Nevertheless, the costs help to find a trend what a cooperation might mean for a certain vehicle. The threshold trajectories are defined as:

- Best possible trajectory (cooperative cost value defined as -1). The trajectory a vehicle should drive, if all the other equipped vehicles fulfil every wish, regardless of physical possibility. A way to calculate such a trajectory is to assume that the other vehicles would virtually not exist and then plan a trajectory for this assumed situation.

- Highest effort trajectory (cooperation cost value defined as +1). The trajectory a vehicle would drive to fulfil the wish of another vehicle, and which is the maximum it would defer from its own egoist plan. It might be difficult to find such trajectory. Therefore, an easier way that could be used would be to consider the fact that not the trajectory itself is needed but only its vehicle-local costs for building the relation. One way to get the vehicle-local costs is to take the vehicle-local costs of the currently driven trajectory and add a constant value to it or multiply it with a constant factor. This factor/offset could be depending on the situation, i.e. if the vehicle needs support or is in a stable situation like cruising on a highway.

Actors' roles in a cooperation:

- MCS Initiating vehicle: A subject vehicle may initiate a collective action by providing its intent and a new proposed trajectory becoming its new reference one. Another cooperative vehicle may initiate a collective action by offering its contribution to one or several potential subject vehicles (proposing an alternative trajectory which would become its reference one if accepted).

- MCS negotiation is achieved by cooperative vehicles (subject vehicle and potential target vehicle(s)) seeking an agreement to achieve a proposed intent or offer.

- MCS action which is required to achieve the goal such as described in the initial intent, or which would be responding to an offer.

- Relevant vehicles stay passive regarding MCS but can collect the exchanges to update the evolution of their neighbourhood.

- Non communicating traffic participants may disturb a collective action leading the partners to change their collective action strategy.

During a collective action, all MCS capable vehicles send out their reference and alternative trajectory periodically.

The requesting vehicle (SV) plans, with the knowledge of prior MCM, a collision free trajectory and a better suited requested trajectory.

The cooperating vehicle (TV) detect the collision risk of its own reference trajectory with the requested trajectory and decides to be cooperative or not.

NOTE: The reference trajectories can also be disseminated by CAMs version 2, if the reference trajectory such as predicted by vehicles are added to the CAM version 2. The use of path prediction is misleading as its definition can be like the one of "trajectory".

Goal:

The requesting vehicle improves its own manoeuvre situation by means of cooperation/coordination with the cooperating vehicles.

A further goal is to achieve a common awareness of the plans of all vehicles and so to provide means to improve situations, that are a step ahead of a dedicated manoeuvre coordination procedure.

Needs:

At least two MCS capable vehicles need to establish a cooperation. These vehicles need to be properly positioned in the traffic flow to contribute efficiently to the manoeuvre coordination of the subject vehicles.

Geographic scope:

This is a local geographic scope delimited by the observation capabilities (autonomous + collective perceptions) of involved relevant cooperative vehicles.

Pre-conditions:

The subject and target vehicles which are cooperating need to be standard release 2 cooperative vehicles having the capability to exchange and manage standard messages belonging to release 2.

The subject and target vehicles capabilities (perception, ad-hoc communication, and all other processing functions) need to be fully operational (satisfying minimum performances requirements).

The subject and target cooperative vehicles need to have the capability to perceive not-cooperative vehicles moving in their vicinity.

Flow diagram:

An overview of the flow diagram to be associated to V2V cooperation is provided in Figure 2. This flow diagram is relevant for "agreement seeking" and "prescriptive" concepts.

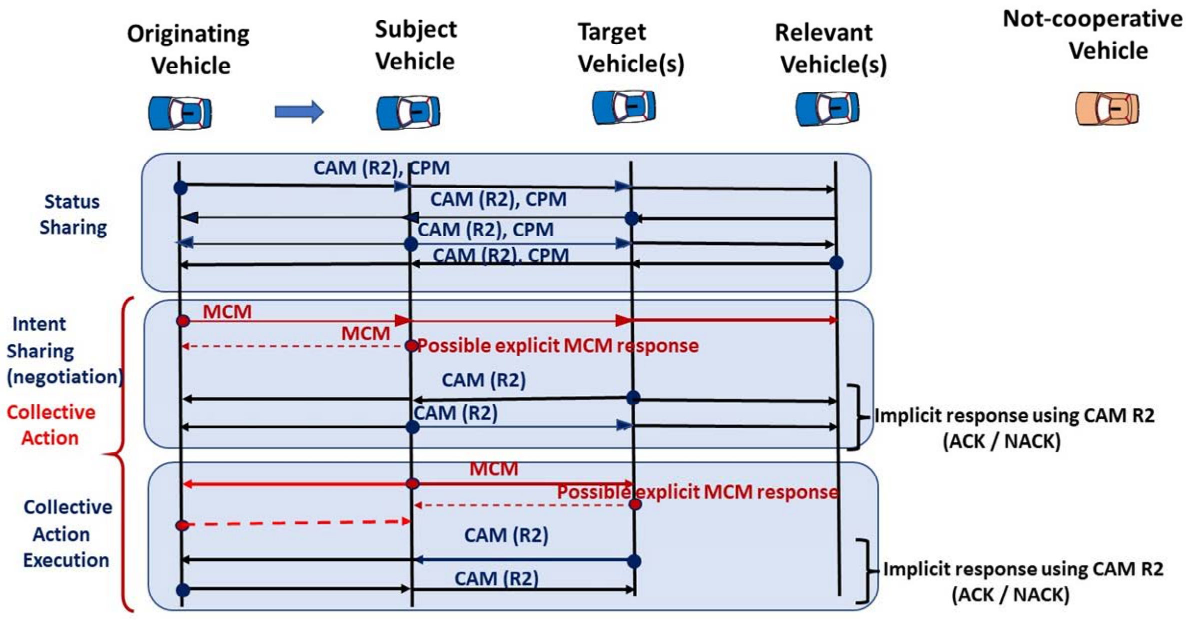

Figure 2: Flow diagram overview for V2V Manoeuvres' coordination cooperation

5.2.3 Lane change assistance use case

Figure 3 provides an illustration of several lane change assistances when a subject vehicle needs to overtake one or several other vehicles and then cutting in front of another vehicle when returning in its originating lane.

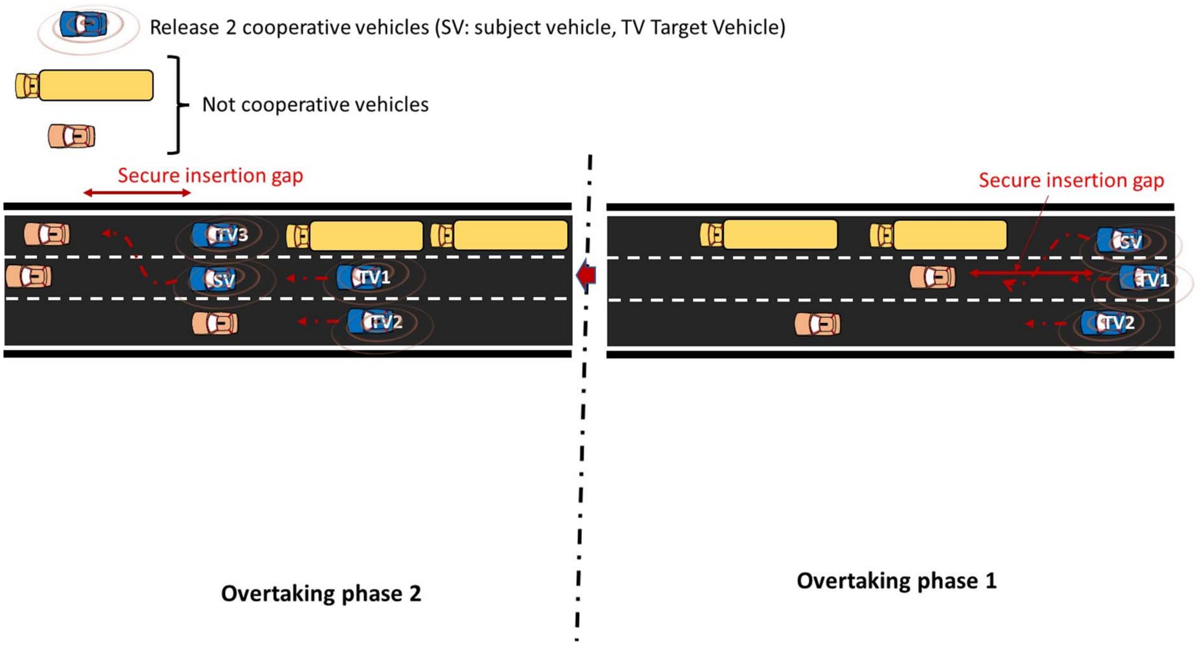

Figure 3: Two consecutive lane change assistance when overtaking a file of vehicles

Overtaking phase 1:

This first phase of overtaking consists for the Subject Vehicle (SV) to negotiate with target vehicle TV1 and target vehicle TV2 their cooperation for changing of lane safely with the goal of overtaking the file of vehicles progressing on the right lane:

- The SV can initiate a cooperation request by including its intent and proposed new reference trajectory in the initial MCM. TV1 and TV2 will receive the initial MCM from SV and may decide either to accept it (ACK) or refuse it (NACK).
- The TV1, after checking the request for a possible collision with its own reference trajectory could do the following:
  - Refuse the cooperation (NACK) as judged being too costly for it.
  - If accepting (ACK), plan a trajectory with less velocity and send this the other vehicles as its new reference trajectory.
  - If accepting (ACK), plan a lane change to the third lane by initiating itself a cooperation with TV2 providing its intent and new proposed reference trajectory.
  - Once a solution is agreed between the three vehicles (end of the negotiation phase), the manoeuvre can be executed with the confirmation of the on-board sensors of SV that the appropriate gap has been created.
- For the case, that TV2 wants to initiate a lane change into the middle lane, it needs to initiate a cooperation providing its intent and its new reference trajectory. Since both vehicles (TV2 and SV) have the same right to change into the middle lane, the first one, who sends out his intent and reference trajectory will be the one to merge into the newly created gap.

Overtaking phase 2:

The second phase of overtaking consists for the Subject Vehicle (SV) to negotiate its safe return in its originating lane (the right lane). This is achieved with the cooperation of Target Vehicle (TV3) which accepts or not (result of the negotiation) to create a safe insertion gap between itself and the vehicle moving ahead of it.

As for the phase 1, the process would be the same.

NOTE: The negotiation is always present as potential target vehicles may accept (ACK) or refuse NACK) to cooperate.

5.2.4 Lane merging assistance use case

Figure 4 provides two illustrations of one lane merging assistance: Three lanes merging into two lanes due to road topology (Use Case C) and three lanes merging into two lanes due to an obstacle (e.g. an accident) in the rightmost lane (Use Case D).

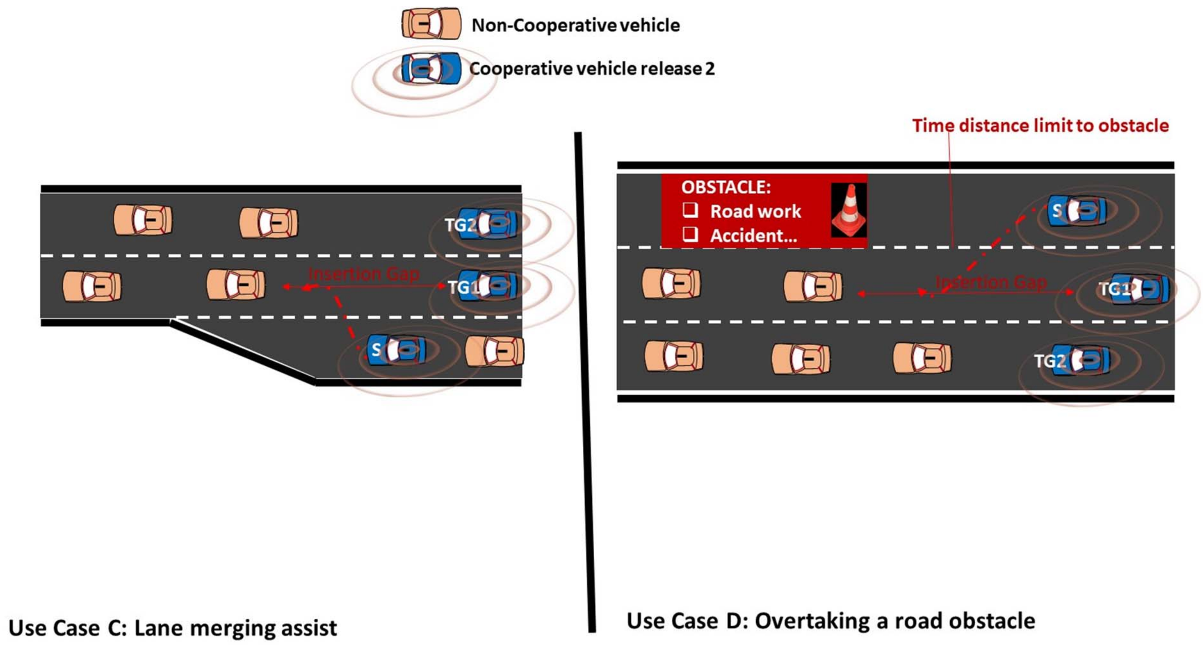

Figure 4: Lane merging assistance use cases

Use Case C:

In Use Case C, the left lane is merging with the lane in the middle. This leads the subject vehicle trying to safely insert between the Target Vehicle TG1 and the vehicle ahead of it. The process is the same as the regular lane change as depicted in the overtaking scenario.

Use Case D:

In Use Case D, the right lane is temporarily closed due to a road hazard which can be signalled by a DENM. In such case, a subject vehicle (S) progressing on the right lane needs to change lanes before reaching the time distance limit forcing it to stop to avoid a collision with the obstacle which is at the origin of the right lane closing.

The presence of a release 2 cooperative vehicle (TG1) is a chance for the subject vehicle to negotiate the creation of a safe insertion gap before reaching the time distance limit to obstacle. The MCS triggering can be achieved via a request issued by the subject vehicle (S) or by an offer issued by the target vehicle (TG1).

The cooperation of the TG2 target vehicle is also necessary to avoid that this one disturbs the subject vehicle insertion by changing of lane at the same time. Due to the difference in normalized trajectory cost for the subject vehicle, the difference of cost between a collision free trajectory and the request trajectory would be very high. So TG1 will explicitly accepts the request trajectory of the subject vehicle but deny a request of TG2. Therefore, a reference trajectory from the subject vehicle will be placed before TG1 to merge into the gap to be opened.

5.2.5 Intersection/Roundabout crossing assist use case

Figure 5 shows 2 use cases (Use Case A and Use Case B) describing situations which could globally improve the traffic management efficiency at intersection/roundabout levels.

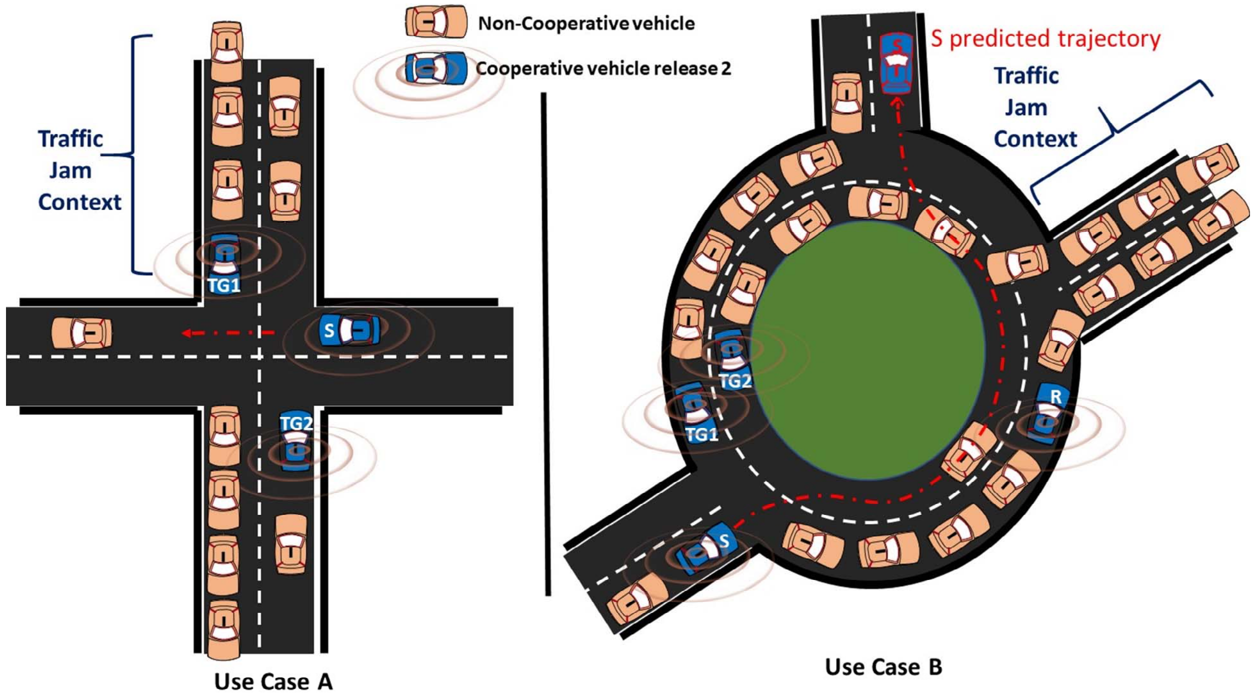

Figure 5: Illustration of use cases focusing on considered V2V cooperation

- Vehicles TG1 and TG2 offer cooperation to vehicle S by providing the surrounding with their reference trajectories. They also provide alternative trajectories to aid vehicles S to calculate a proper request trajectory. The request should fit to the alternative trajectories of both TG1 and TG2, so that the request trajectory of S is acceptable.
- Vehicles TG1 and TG2 receive the requested trajectory from S and verify with their own manoeuvre planning algorithms that they can accept the request trajectory from S.
- The request trajectory is either accepted or declined implicitly or explicitly (ACK or NACK), so that the vehicle S either has a collision free request trajectory, which becomes the new reference trajectory or has to generate a new request trajectory, which either addresses different vehicles or is more suitable for TG1 and/or TG2.
- The agreed collective action can be achieved by the subject vehicle (S) and target vehicles (TG1 and TG2) which follow their new agreed reference trajectories and check their correct execution with sensors and communication like CAMs.

5.2.6 Information flow diagrams

The information flow diagram presented in clause 5.2.2 in Figure 2 is applicable.

Since the offer of TG1 & TG2 until the completion of their collective action, this concept involves a continuous exchange of reference trajectory information in MCMs by the cooperative vehicles.

During the collective action including the intent (here the offer), participating vehicles regularly transmit their reference trajectory and optionally alternative trajectories as offers for others to aid with their manoeuvre planning. The content of the reference trajectory can replace the internal prediction of other vehicles movement.

If another vehicle detects a need for cooperation based on the MCM exchange with nearby vehicles, it may send a request trajectory alongside its reference trajectory. These trigger certain mechanisms in the receivers' manoeuvre planning (application part) to evaluate the request trajectory of the other vehicles:

1) Check if this request collides with the receiver's own reference trajectory.
2) If yes, then plan possible trajectories for oneself to fulfil the request.

3) If the cost is low enough, create a new reference trajectory based on the calculation. Then sends an agreement (ACK).

4) If the cost is too high, do not change the reference trajectory and send out a cooperation denial (NACK) with the trajectory ID of the evaluated request trajectory.

Vehicles can explicitly acknowledge or deny a certain request trajectory, as the transmitted trajectory includes an identification number. Additionally, an implicit answer is given with their next reference trajectory (if contained in CAMs).

These measures help to find a quick solution for the problem at hand, so every target vehicle is aware of the situation.

5.2.7 Situation analysis

Hypothesis:

MCM should indicate the current driving mode of the cooperative vehicle (human driven or self-driving) for the subject vehicle to be able to assess the probability and accuracy achievement of the shared agreement.

Use Case A:

This use case is elementary since target vehicles TG1 and TG2 have just to stop to leave the subject vehicle crossing the road. That are two elementary manoeuvres similar to the ones considered by SAE J3186 [i.5].

Use Case B:

This use case is also elementary if the subject vehicle goal is just to enter the roundabout (the two target vehicles have also just to stop to give way to the subject vehicle). But if the goal of the subject vehicle is to reach as quickly as possible the roundabout exit, much more manoeuvre coordination will be necessary. But of course, the achievement of this second goal is depending on the density of cooperative vehicles being engaged in the roundabout.

So, it will be necessary to clearly scope the limits of a single collective action comprising several manoeuvre coordination phases which could be sequentially executed.

Post-conditions:

In the best case, the subject vehicle obtains the possibility to achieve its planed manoeuvre.

In a worst case, the cooperative process was stopped due to the reject of the subject vehicle request by one target vehicle or the disturbance of the insertion process by a non-cooperative vehicle. In this case the traffic regulations apply.

Information requirements:

The subject vehicle needs to provide its motion prediction for relevant cooperative vehicles (release 2) to identify themselves as targets. The subject vehicle should also provide some rational for getting the assistance of targeted vehicles (intent description).

All relevant vehicles (those concerned by the proposed manoeuvres) need to have their perception capabilities fully operational to analyse the local context and the evolutions of dynamic objects.

Communication mode:

During a collaborative action, the MCM is disseminated to every relevant vehicle. The broadcasting mode enables the identification of target vehicles when the subject vehicle does not have a sufficient perception of its environment.

Since cooperation partners are initially not known, this information helps other vehicles planning their next step of driving.

5.3 Concept A2, V2V cooperation class "Prescriptive"

5.3.1 Overview

This concept focuses on Vehicle to Vehicle' cooperation (including vehicles used by Vulnerable Road Users).

As presented in clause 4.2.5, the prescriptive cooperation class includes, as well the 3 following phases:

- The intent phase which provides information about the intent of the MC initiating vehicle and its requested reference trajectory. In this concept, the intent is related to a clear authorized mission granted to a particular stakeholder.
- The Agreement Seeking (negotiation) phase with potential other subject and target vehicles.
- The collective action resulting of an agreed cooperation.

The main difference with the agreement seeking cooperation class resides in:

- The intent which is considered as of more importance of those provided in "agreement seeking", because they are provided by authorities which have special privileges (police vehicle, emergency vehicle in a rescue mission, road operator in a winter maintenance mission, public transport, etc.) and act to preserve safety, health, asset of road users as well as community economy.
- The agreement seeking can be regulated in such a way that it could be mandatory to concerned vehicles (subject and target) to respond positively to an originating request, excepted in some particular situations to be identified.

NOTE: A VRU (for instance, a police officer using a motorcycle) may be considered as a vehicle having a service specific permission to coordinate cooperative vehicles manoeuvre.

5.3.2 Description

This concept is used to instruct subject vehicle(s) and target vehicles to coordinate a requested manoeuvre for satisfying legal and safety objectives. The prescriptive aspect is granted by the delivery of service specific permissions (SSPs) by relevant authorities to a vehicle operated by a representative of this authority (e.g. a police officer). In such a case, the manoeuvre coordination proposed by the authorized actor needs to be executed, excepted for particular situations which need to be clearly identified.

Actors' roles and responsibilities:

Only relevant cooperative vehicles (having MCS capability) are involved in this collective manoeuvre coordination service (see the use case illustration below). More than two vehicles can be involved depending on the local situation and, in such case, vehicles' manoeuvres can be synchronized. The Target Vehicle (TV1) is a vehicle owning a Service Specific Permission (SSP) which has been granted from a relevant local or global authority.

A VRU (for instance, police officer) equipped with a relevant device or riding a motorcycle can be the actor originating the manoeuvre coordination.

Subject vehicle is the vehicle which is identified by the Target Vehicles (TV1) for the execution of a prescribed manoeuvre.

Other Target Vehicles (TV2, TV3) are relevant cooperative vehicles having the capability to receive and process MCS and which need to act to facilitate the indicated manoeuvre (requested manoeuvre coordination) of the subject vehicle.

Other Relevant Vehicles (RV) are cooperative vehicles which may provide interesting information about the traffic situation via their CAMs and CPMs.

Non-cooperative vehicles may not cooperate to assist the subject vehicle targeted evolution and may also disturb the targeted evolution process.

The TV1 vehicle is fully responsible of the Manoeuvres Coordination which need to be securely achieved. The subject vehicle and other targeted vehicles are also responsible of their own manoeuvres responding to the TV1 vehicle prescription.

Goal:

The goal is to request one or several cooperative release 2 vehicles to execute a set of manoeuvres to reach a specific objective such as:

- Intercepting a stolen or dangerous vehicle (for example, follow me and stop).
- Requesting a vehicle to stop for a police inspection/control (e.g. safe deceleration).
- Managing locally the traffic (e.g. contextual corridor management) for facilitating emergency rescue and road maintenance intervention (open a contextual corridor in front of me).

Needs:

It is needed that one or several relevant cooperative vehicles be properly positioned in the traffic flow to cooperate in order to enable the subject vehicle(s) to safely achieve its targeted manoeuvre.

It is also needed that non-connected/cooperative vehicles do not take profit of the new created situation to exploit it to the detriment of the identified subject vehicle(s).

Pre-conditions:

The subject and target vehicles which are cooperating need to be release 2 standard cooperative vehicles, having the capability to disseminate and process standard CAMs release 2 and MCMs.

The Target (T) vehicle needs to get the service specific permission level required to directly propose actions on the subject vehicle(s) to be intercepted and other local release 2 cooperative vehicles which could be contributing to or at risk during the interception manoeuvre.

5.3.3 Example: Interception situation

Figure 6 shows a use case describing an interception situation achieved by motorcyclist policeman.

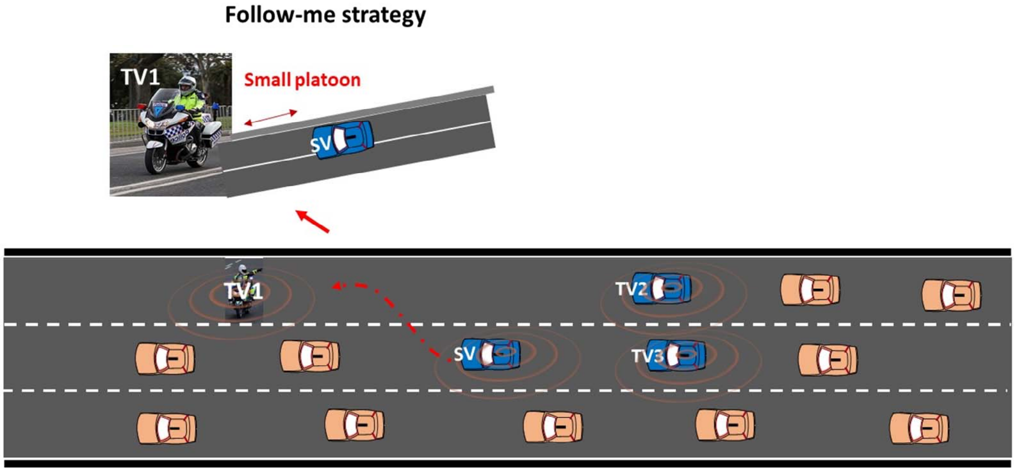

Figure 6: Interception of a target vehicle by a motorcyclist policeman

In this example:

- The Target Vehicle 1 (TV1) broadcasts a MCMs requesting the subject vehicle to achieve a specific manoeuvre with the objective of intercepting it. The interception may consist of immobilizing locally the subject vehicle or to lead it to a safer place for inspection via a "follow-me" instruction. In the second case, the TV1 and SV are constituting a small string of vehicles moving in synchronization.
- At the same time, the Target Vehicle 1 (TV1) instructs other target vehicles (TV2 and TV3) to achieve a manoeuvre coordination to facilitate the interception of the subject vehicle: TV2 is requested to decelerate for creating (for SV) a safe insertion gap between TV2 and TV1 while TV3 is requested to remain in its own lane.

5.3.4 Information flow diagram

The information flow diagram presented in Figure 2 of clause 5.2.2, stays relevant. In this A2 concept, the originating vehicle is the police motorcyclist which initiates a collective action by sending its intent to intercept the subject vehicle.

This prescriptive intent (mission) is associated with the reference trajectory of the police motorcyclist which may request the subject vehicle to follow it so forming a small platoon of two vehicles. Then, the subject vehicle reproduces the reference trajectory of the police vehicle until reaching a final destination. The police motorcyclist provides a minimum inter-distance between the two vehicles to safely progress according to the local traffic density, but, if possible, to avoid the insertion of another vehicle between the police vehicle and the subject vehicle.

5.3.5 Situation analysis

Hypothesis:

If a target vehicle is perceived by the police vehicle as presenting a risk during the initial negotiation phase, the police vehicle may also coordinate the manoeuvre of this target vehicle to facilitate the interception of the subject vehicle.

If the subject vehicle presents some danger for nearby other vehicles (e.g. dangerous gas/liquid leakage), the police vehicle needs to continue to keep them away of the subject vehicle by involving them in the collective action. Consequently, the collective action may stay active a long time until the subject vehicle is secured somewhere.

Post-Condition:

The vehicle interception needs to be achieved. If a refusal is received (NACK), a clear justification needs to be given (for example: misbehaviour detection).

Information requirement:

A clear intent corresponding to a stakeholder mission needs to be provided. The originator needs to be authorized.

Communication mode:

Broadcasting at the level of the access layer is preferable especially if the originating vehicle has not a sufficient perception of its environment, not being able to identify the potential target vehicles. Moreover, the multicast can be used at the level of the facility layer to address only potential target vehicles, according to perception capabilities of the originating vehicle.

5.4 Concept B1, I2V cooperation class "Agreement Seeking"

5.4.1 Overview

This concept B1 focuses on the use of a roadside equipment for assisting one or several subject vehicle(s) to complete a specified manoeuvre for satisfying a traffic management objective. The traffic management objective can be local under the responsibility of the local RSU or global under the responsibility of a traffic management centre connected to the RSU.

This concept leads to trajectory and speed recommendations being addressed to cooperative standard release 2 vehicles part of the local traffic. Though subject vehicles may experience an individual benefit from the coordinated manoeuvres, at some cost for the target vehicles, the main reason for engaging in the coordinated manoeuvre recommended by the RSU is to improve the traffic flow and road safety.

5.4.2 Description

One or several roadside piece(s) of equipment collect via their autonomous perception sensors the traffic situation existing in local area where release 2 cooperative vehicles are moving. The present Roadside Units (RSUs) may also receive standard messages (CAMs, CPMs) from cooperative vehicles and use them for augmenting their local perception.

Based on collected perception data, the RSU(s) suggest manoeuvre coordination to relevant release 2 cooperative vehicles for them to achieve identified goals.

According to cooperative vehicles responses, the RSU(s) may initiate a collective action by disseminating more MCMs to partners vehicles.

Actors, roles and responsibilities:

Roadside units are pieces of road infrastructure equipment which have release 2 cooperative capabilities (in particular the MCS capability) as well as the full perception capability covering the local area in which considered cooperative vehicles are moving:

- cooperative release 1 vehicles which provide traffic information and cooperative release 2 vehicles which may contribute to the overall manoeuvre coordination suggested by the RSU.

A roadside unit disseminates behaviour recommendations, especially speed regulation requests, recommended distance to preceding vehicles, or trajectories to target vehicles in order to manage the traffic flow.

A roadside sensors' network as well as release 1 cooperative vehicles may be used to provide the roadside unit with information regarding the current traffic situation.

Subject vehicles are aided in handling specific manoeuvre such as turning left into oncoming traffic at complex intersections or merge onto roads in dense traffic situations. Subject vehicles maintain responsibility for the safety of their trajectory at all times, on the basis of their own perception of the traffic situation. The subject vehicle may optionally use perception data from incoming CPMs as well as account for trajectory intents from incoming CAMs or MCMs.

Target vehicles are release 2 cooperative vehicles which execute manoeuvre suggested by the RSU once they are accepted.

Once the subject and target vehicles have accepted to coordinate their actions for the achievement of subject vehicle(s) goals, they remain responsible for their own manoeuvre at all times. In the simplest case, an explicit agreement or commitment is required with respect to RSU suggestions. This limits the kind of achievable coordinated manoeuvre, as those need to remain within the domain of individually manageable manoeuvre for all participants.

EXAMPLE 1: Slowing down is not likely to put vehicles in an unsafe situation, whereas reducing safety distances does.

Goal:

The goal of the roadside unit initiating the cooperative manoeuvre is to improve the traffic flow and road safety.

EXAMPLE 2: Avoiding of deadlock situations on lanes which, according to traffic code, do not have the right of way (priority). This can be achieved by assisting vehicles turning left at a four intersection or merging on a major road.

Needs:

It is needed that one or several relevant release 2 cooperative vehicles be properly positioned in the traffic flow to cooperate in order to enable the subject vehicle(s) to safely achieve their targeted manoeuvres in respect of RSU suggestions.

It is also beneficial that non-cooperative vehicles do not take profit of the new created situation (see example 3) to exploit it to the detriment of the identified subject vehicles.

EXAMPLE 3: Inserts in a gap created for a subject vehicle.

Geographic scope:

This is a local geographic scope delimited by perception capabilities (autonomous + cooperative perception) of involved relevant RSU and involved cooperative vehicles. The geographic scope is also limited to areas relevant to traffic management applications, such as intersections, highway access, as well as congested stretches of road.

Pre-conditions:

The subject and target vehicles which are cooperating need to be standard release 2 cooperative vehicles.

Target vehicle may or may not cooperate, in case of non-cooperation the coordinated manoeuvre does not take place. The manoeuvre stays however safe, insofar subject vehicles will remain able to navigate by themselves at all times.

The effectiveness of this approach depends on the density of release 2 cooperative vehicles on the road that may be able to participate in coordinated manoeuvre. Cooperativeness is expected to be the preferred behaviour, due to overall benefits to road safety, comfort, and traffic management for the inconvenience of a minor occasional slow down.

5.4.3 Toll Barrier use case

Figure 7 shows the access to a toll barrier where MCS would ease the traffic flow.

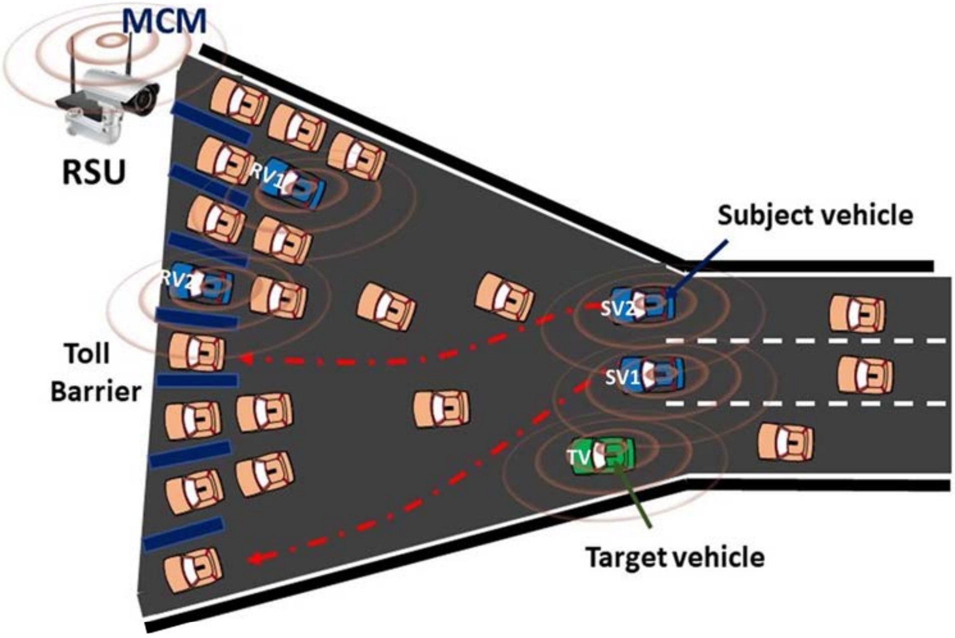

Figure 7: Access to toll-barrier use case

Subject vehicles (SV1 and SV2) are supported by the RSU to reach the most relevant gate to pass through the toll barrier. Selection criteria could be the following:

- type of vehicle, privileges associated to vehicles;
- type of payment;
- the respective vehicles' queues lengths at each gate level;
- trajectory to follow after the toll gate.

The target vehicle (TV in green) receives suggestion (e.g. slowdown) from the RSU to easy the safe progression of a subject vehicle (SV1).

Relevant vehicles (RV1 and RV2) are cooperative vehicles providing information (via their CAMs, CPM) about the traffic situation at gates' level.

5.4.4 Four-way crossing use case

Another use case worth to be considered is the four-way crossing use case shown in Figure 8.

In this use case an urban four-way intersection is under the monitoring of a roadside unit, providing manoeuvre proposals aiming at reducing congestion behind the subject vehicle.

In this case the subject vehicle has the navigation goal of turning to the left but has to give right of way to oncoming traffic therefore blocking the following vehicles. In dense traffic, this may cause traffic jams or even deadlock situations.

In this case, a roadside unit may instruct the target vehicle to create an opening for the subject vehicle to turn left.

In case the target vehicle cooperates and surrenders its right of way, the subject vehicle waits until the created opening is significant enough for it to be identified by its onboard perception and to go through safely. Alternatively, the subject vehicle may get a hint of the planned coordinated manoeuvre from the roadside unit, and may engage early in the manoeuvre, though this implies significant higher requirements to all the participants of the coordinated manoeuvre.

In case the target vehicle does not surrender its right of way, the subject vehicle stops at the intersection and waits for the next opening in order to make the turn.

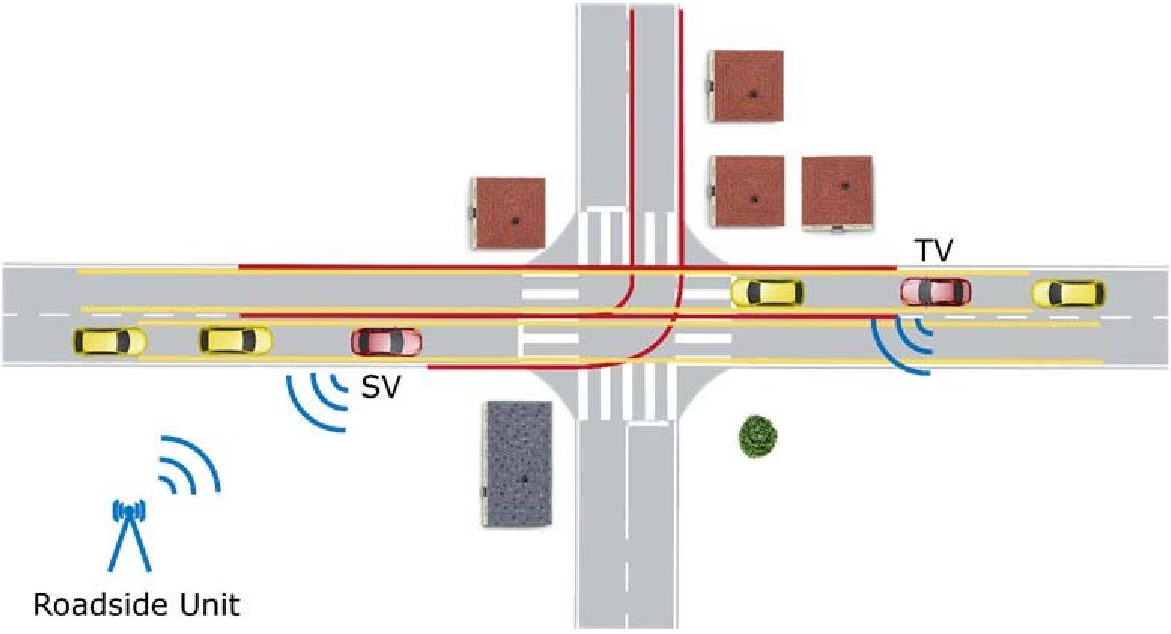

Figure 8: Four-way crossing use case

5.4.5 Highway merge use case

In the use case shown in Figure 9, the SV may get assistance from a cooperative release 2 Target Vehicle (TV) for inserting onto a main road with a merging manoeuvre.

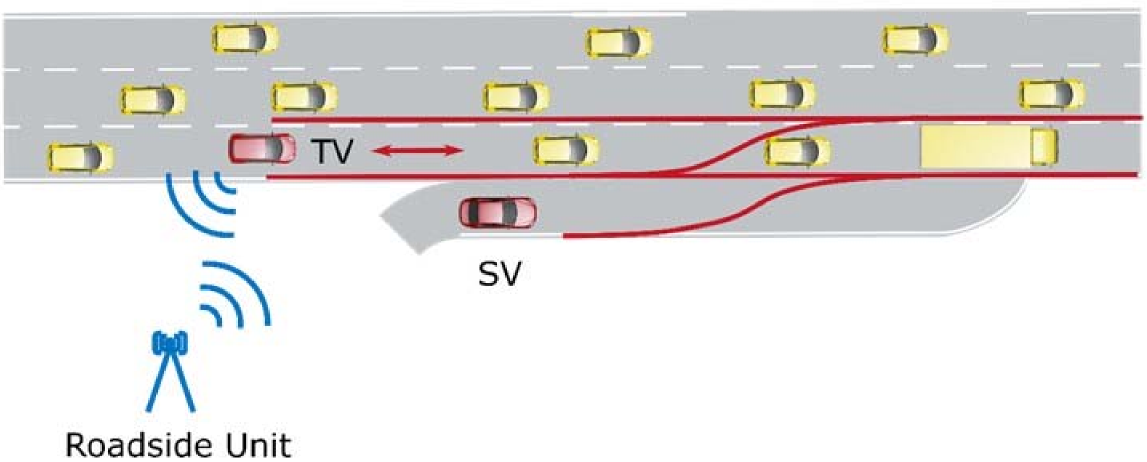

Figure 9: Highway merging use case

The RSU recognizes the opportunity for assisting the Subject Vehicle by requesting a target vehicle to let the SV merge in front of it. Ideally, the TV's manoeuvre is well anticipated and only a minor slowdown is required from his part to create a gap that can be independently detected by the SV on the insertion lane.

In case the target vehicle does not abandon its right of way, the subject vehicle has to slow down and wait for another opportunity to merge.

5.4.6 Information flow diagram

Figure 10 shows a generic information flow diagram for the concept A2 above described.

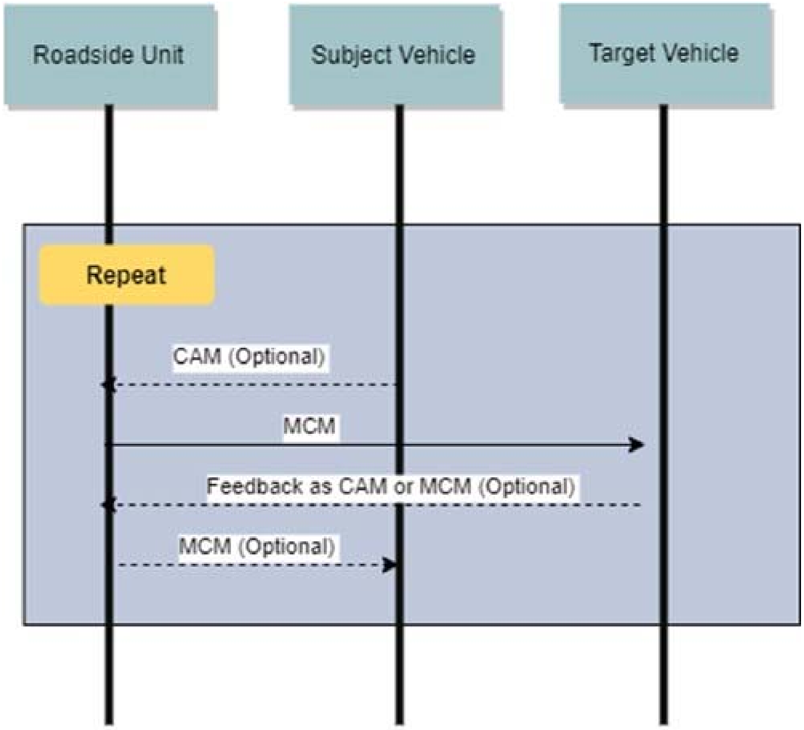

Figure 10: Information flow diagram for the crossing assist use case

The perception of the roadside unit and the subject vehicle may be handled by their local perception or with some level of cooperative perception (CAM, CPM). In case the local perception is sufficiently capable, unidirectional communication from the roadside unit to the target vehicle is a possible scenario.

The communication between subject vehicle and roadside unit is optional, although communicating the intention of the SV of turning left, for example with a CAM message would be beneficial. This intention may however alternatively be detected by roadside unit thanks to a traffic surveillance camera identifying a turn light signal. In this case, the subject vehicle can also be a manually driven, non-communicating vehicle.

The roadside unit instructs the target vehicle to slow down to create an opening for the subject vehicle to drive through. The target vehicle, remaining responsible for its own trajectory may or may not comply. Feedback may optionally be communicated back to the roadside unit.

In the case where there is no feedback, the subject vehicle needs to wait for a sufficiently large opening in the traffic flow to appear to engage in a left turn.

During execution of the manoeuvre, the roadside unit disseminates the updated trajectory recommendation as long as beneficial given the traffic conditions and behaviour of the target vehicle.

5.4.7 Situation analysis

Hypothesis:

One directional communication with responsibility on the vehicle side presents the lowest safety risk and safety requirements for the roadside unit communication protocols and traffic participants. This implies however some limitations to the efficiency of the manoeuvre proposals.

Traffic management goals may be tolerant to low penetration rates and do not require the highest possible manoeuvre coordination efficiency.

Operation in high density traffic situation is also a factor that may favour low communication load, which is reached by reducing the number of individual feedbacks from cooperative vehicles.

CAM release 2 should indicate the current driving mode of the cooperative vehicle (human driven or self-driving) for the subject vehicle to be able to assess the probability and accuracy achievement of the reached agreement.

CAM may also be used as an immediate feedback of the release 2 cooperative vehicles which are targeted by subject vehicles. The dynamic data elements contained in CAM indicate the manoeuvre evolutions of targeted vehicles.

But another approach can be developed via the use of responding MCMs which confirm or not the acceptation of proposed manoeuvre coordination and provide evidence of target vehicles support to subject vehicle(s).

CAM may also contain all data elements related to selection criteria (vehicle privileges, vehicle payment types available, etc.) used by the RSU to provide the trajectory to follow to reach the most appropriate gate.

Post-conditions:

In the best case, the subject vehicle obtained the possibility to achieve its planed manoeuvre.

If the window of opportunity closes or if the target vehicle does not comply or delivers negative feedback, the roadside unit will stop communication until the next opportunity arises.

Information requirements:

The roadside unit requires awareness of the traffic situation in the area of interest. This can be achieved by means of using CAM and CPM messages of passing vehicles, or thanks to local traffic sensors.

The roadside unit needs to acquire knowledge of the subject vehicle's intention to assist it adequately. This can be unambiguous depending on road configuration or this can be achieved with a CAM from the subject vehicle.

The roadside unit also requires knowledge of the capabilities of the target vehicle to provide appropriate recommendations.

The RSU needs to provide the recommended manoeuvre for target release 2 cooperative vehicles to adjust their trajectories and motion dynamics accordingly.

The recommended manœuvre may be a trajectory including a motion dynamic prediction, a speed recommendation, or a request to extend the distance to the front vehicle. The RSU may also provide some rational for getting adhesion of target vehicles. The timeliness of the recommendation needs to be ensured.

Communication mode:

The broadcast mode is used at the level of the access layer. However, some multicast mode could be used at facilities layer level to identify the targeted vehicles using their station ID (see clause A.1 presenting the French PAC V2X project approach).

5.5 Concept B2, I2V cooperation class "prescriptive"

5.5.1 Overview

This concept B2 focuses on the use of a roadside equipment for acting to facilitate the manoeuvre coordination of one or several subject vehicle(s) for satisfying a global objective (e.g. safety, traffic management, vehicle interception by relevant authority, etc.).

Traffic management objective can be local under the responsibility of the local RSU or global under the responsibility of a traffic management centre connected to the RSU.

B2 concept leads to prescriptive manoeuvre coordination addressed to one or several subject vehicles and target vehicles. Several levels of prescription could be defined in terms of execution constraints. For example, the prescription levels could be:

- Level 0 Mandatory for vehicle interception or inspection.
- Level 1 Mandatory for safety purpose.
- Level 2 Mandatory for emergency intervention.
- Level 3 Mandatory for road operator intervention (e.g. during bad winter weather conditions).
- Level 4 Mandatory for global traffic management purpose.
- Level 5 Mandatory or advisory (on the responsibility of the local traffic authority) for local traffic management purpose.
- Level 6 Mandatory for platooning collective action.
- Level 7 Mandatory for giving priority to public transport.
- Etc.

5.5.2 Description

Actors' roles and responsibilities:

Roadside units are pieces of road infrastructure equipment which have release 2 cooperative capabilities (the MCS capability) as well as the full perception capability covering the local area in which considered cooperative vehicles are moving:

- cooperative release 1 vehicles which provide traffic information and cooperative release 2 vehicles which may contribute to the overall manoeuvre coordination suggested by the RSU.

Subject vehicles are release 2 cooperative vehicles which execute manoeuvre prescribed by the RSU.

Target vehicles are release 2 cooperative vehicles which contribute to ease the manoeuvre of subject vehicles.

In all cases, the manoeuvre coordination execution remains in the responsibility of release 2 cooperative vehicles which receive prescribed instructions from the RSU. A subject or target vehicle may not execute the prescribed manoeuvre, but this will need to be justified. Likely a level 0 (mandatory) prescription should be executed even if this consists only to stop the subject vehicle. Others non-execution could be judged not appropriate by receiving release 2 cooperative vehicles, but in such case, it could be mandatory to record the reason of this non execution for a further inspection of the vehicle if required by a safety or traffic management authority.

Goal:

The goal is to request one or several release 2 cooperative vehicles to contribute to a manoeuvre to reach a specific objective such as:

- Avoiding a collision between several vehicles.
- Managing globally or locally the traffic (for example, contextual corridor management) for facilitating emergency rescue and road maintenance intervention (open a contextual corridor in front of the vehicle).

Needs:

The initially targeted cooperative vehicle (stolen or dangerous) needs to be a release 2 cooperative vehicle supporting this class of cooperative service.

It is expected that the density of release 2 cooperative vehicles be sufficient to achieve the targeted goal (e.g. contextual corridor management).

It is also needed that non-connected or/and non-cooperative vehicles don't take profit of the new created situation to exploit it to the detriment of the subject vehicle.

Geographic scope:

This is a local geographic scope delimited by the perception capabilities (autonomous + cooperative perceptions) of involved relevant cooperative vehicles. Moreover, geocasting communication mode can be beneficial for the creation of a contextual corridor.

Pre-conditions:

The subject and target vehicles which are cooperating need to be release 2 standard cooperative vehicles.

The RSU needs to get the service special permission level required to directly propose actions on the subject vehicle(s) to be intercepted and other local release 2 cooperative vehicles which could be contributing to or at risk during the interception manoeuvre.

5.5.3 Wrong Way Driving use case

Figure 11 presents a safety situation (vehicle engaging in countersense) illustrating this concept B2.

The Subject Vehicle (SV) is detected by the RSU as engaging in countersense at the exit level of a highway. In most of the case, the subject vehicle is human driven but, an automated vehicle could also engage in countersense in case of the defect of one critical function (ex: its positioning system).

The first safety manoeuvre to achieve is then slowing down and stopping the subject vehicle. But this is not enough, and the subject vehicle needs to be guided to return to a normal situation without putting at risk other vehicles being in its vicinity. If the subject vehicle is a release 2 cooperative vehicle, which is in a human driven mode, it could be activated in an automated driven mode (the human being not in a vigilance state to correct its mistake) and then be guided by the RSU to find back its correct evolution.

An automated evolution of the situation is conditioned by the local presence of release 2 cooperative vehicles (Target Vehicles) which are facilitating the manoeuvre of the subject vehicle via a coordination of their own manoeuvre.

If it is not possible to benefit from such favourable situation another solution would be to alert a local relevant authority (road operator or police) to send physically a patrol to regulate the local situation.

Figure 11 presents the best case relying on the presence of release 2 cooperative vehicles which are coordinating their manoeuvres to resolve this situation without the need for a physical intervention.

The RSU detects the arrival of the subject vehicle engaging in a wrong way by means of its autonomous perception sensor (e.g. camera). Automatically, the RSU instructs the SV to stop on the right of the road. This can be an emergency brake to avoid a collision with vehicles exiting the highway.

The subject vehicle executes this first manoeuvre.

The RSU identifies release 2 cooperative target vehicles which may contribute to a return of the subject vehicle on an acceptable trajectory. If the analysis is favourable (all target vehicles are positioned properly), the RSU instructs them to stop to enable further manoeuvre from the subject vehicle.

After a verification of its instructions' execution from relevant target vehicles, the RSU may instructs the subject vehicle to go backward (or make a U turn if the highway exit enables it) to find back an acceptable trajectory.

Once the subject vehicle is again on its right track, the RSU may release all stationary target vehicles and the manoeuvre coordination process can be ended.

If the RSU detects that release 2 cooperative vehicles are not properly positioned to correct the trajectory of the subject vehicle, the RSU may send an alarm to the road operator requesting a physical intervention to eliminate the problem.

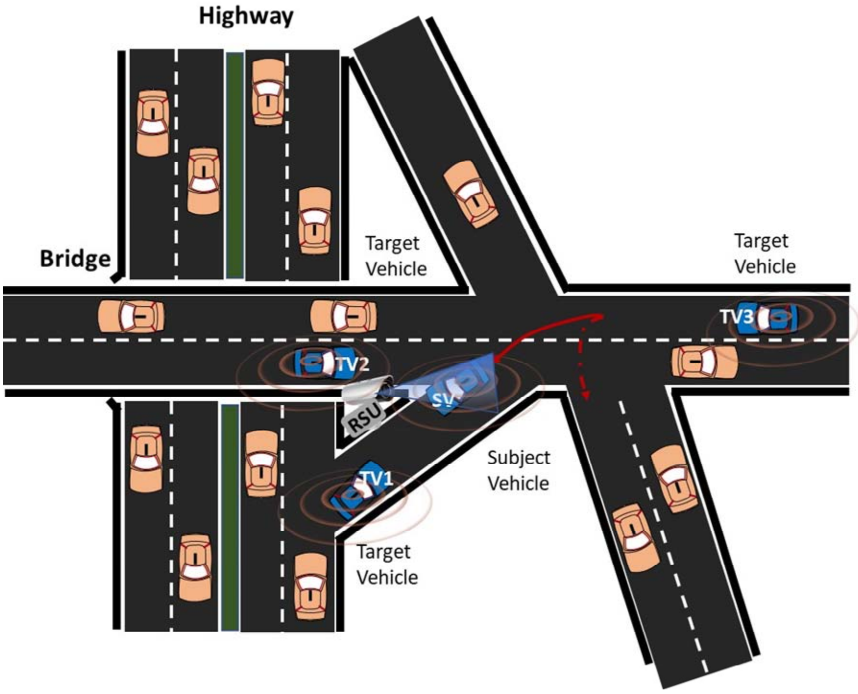

Figure 11: Concept B2, wrong way driving use case

5.5.4 Information flow diagram

Figure 12 shows a generic information flow diagram for the concept A2 above described.

All release 2 cooperative vehicles are broadcasting release 2 CAMs enabling the release 2 roadside unit (RSU) to monitor their respective evolutions.

The RSU detects that the Subject Vehicle (SV) is engaging in a wrong way (the exit of the highway in countersense) and broadcast MCMs with the purpose to resolve the detected problem.

These MCMs contain instructions to safely stop the subject vehicle on the side of the road and request also other release 2 cooperative vehicle to temporarily stop to have the possibility for the subject vehicle to go back in a position enabling it to correct its mistake.

When the target vehicles (TV1, TV2, TV3) are temporarily immobilized, the RSU may send instructions to the subject vehicle (e.g. "moving back" or "making a U turn" depending on the available road space).

Once the subject vehicle has regained its expected position, the RSU may release target vehicles which can pursue their respective trajectories.

The MCMs may contain all data elements which are required to guide them during the subject vehicle manoeuvre. CAMs broadcasted (or unicasted) by relevant cooperative vehicles can be used as feedback giving evidence of the execution of proposed manoeuvre. Explicit feedback MCMs could also be one solution.

If the subject vehicle is a not cooperative vehicle, the RSU can detect it but cannot act on it. In this case, an alert can be sent to the road operator for a physical intervention.

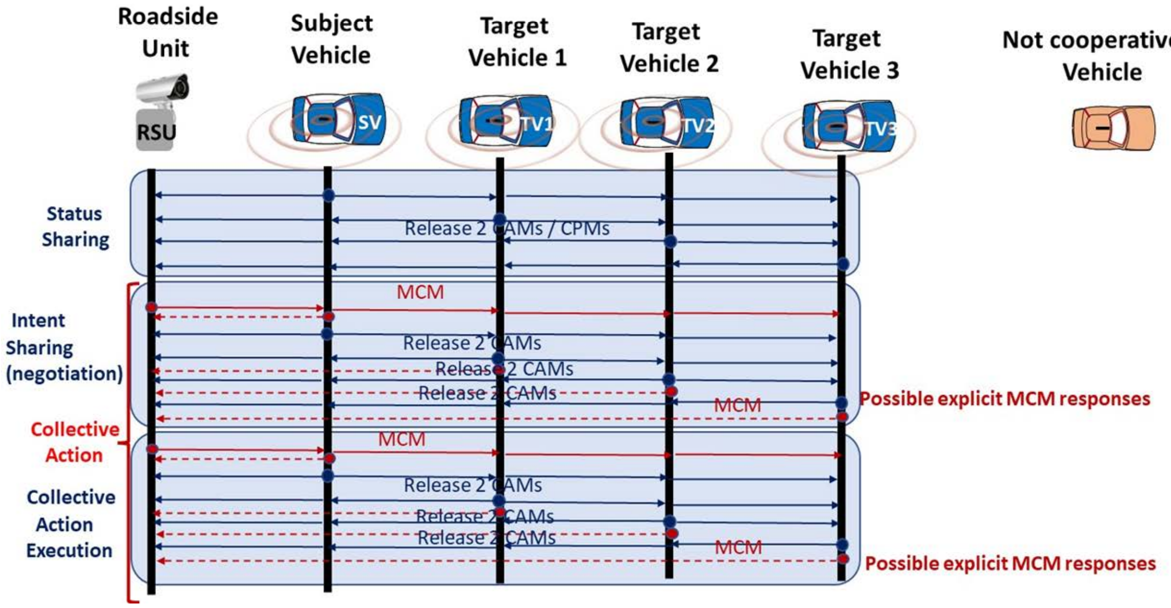

Figure 12: Information flow diagram for concept B2

5.5.5 Situation analysis

Hypothesis:

Release 2 CAM should indicate the current driving mode of the cooperative vehicle (human driven or self-driving) for the target (T) and subject (S) vehicles to be able to assess the probability and accuracy achievement of the prescribed instructions.

CAM may also be used as an immediate feedback of the release 2 cooperative vehicles which are cooperating (the target (T) and subject (S) vehicles). The dynamic data elements contained in CAM indicate the manoeuvre evolution of targeted vehicles and possibly their intents via their path predictions.

But another approach can be developed via the use of responding MCMs which confirm or not the acceptation of proposed manoeuvre coordination and provide their path predictions.

Prescriptive cooperation class needs to strongly consider the following two factors:

- The RSU needs to get an SSP which grants it the full capabilities authorization to act on release 2 cooperative vehicles clearly identified. This permission needs to be provided by the relevant authority.
- The security of the SSP needs to be reinforced.

If the subject vehicle is not a release 2 cooperative vehicle, the RSU cannot control its manoeuvre. In such case, an alert can be sent to the road operator to trigger a physical intervention.

Post-conditions:

In the best case, the subject vehicle and the targeted vehicle(s) achieve their manoeuvres in safe conditions.

In a worst case, the cooperative process is stopped due to a cause which needs to be identified and likely be registered (recorder function) at the RSU and participant vehicles level for further actions.

Information requirement:

The RSU needs to provide its intent and proposal for relevant cooperative vehicles (subject and targets) to identify themselves and achieve the recommended manoeuvre. The RSU needs to indicate the cooperation class "prescriptive" to subject and target vehicles which are mainly concerned by the cooperative manoeuvre.

NOTE: In case of prescriptive class, the intent can be considered as a mission (emergency mission, road capacity restoring (for example: Snow removal) mission, police interception or inspection mission, etc.).

Communication mode:

The broadcast mode is used at the level of the access layer. However, some multicast mode could be used at facilities layer level to identify the subject and targeted vehicles using their station ID (see clause A.1 presenting the French PAC V2X project approach).

For responding to an RSU, the unicast mode can also be used, but in such case, other participants will not be informed of the response of the considered vehicle.

5.6 Concept C1, C2V cooperation class "agreement seeking"

5.6.1 Overview

This new concept proposed by 5GAA is based on a manoeuvre coordination from a central station having the purpose to safely improve the traffic fluidity by suggesting manoeuvres coordination to a group of cooperative vehicles (group start) or more generally coordinating the manoeuvres of cooperative vehicles in more complex situations.

5.6.2 Description

Group Start:

The application was described in the documentation published in by 5GAA but has so far not been tested in an open environment.

When approaching a controlled intersection, all vehicles in a lane with red light are obliged to stop. However, when the light switches to green, vehicles will generally only accelerate once the vehicle in front of them has already started moving, which causes a delayed acceleration at the end of the lane. In intersections with very short green phases this can lead to vehicles waiting multiple phases before passing. By enabling vehicles to accelerate at the same time when the green phase starts this can fluidify traffic by increasing the number of vehicles that can pass through at one green phase, which in turn causes less congestion and shorter travel times.

This is where Group Start can provide an efficient solution. Self-driving or semi-automated vehicles form a group to start jointly at traffic lights. In a centralized implementation of this use case, a traffic control center provides tactical and strategic information to coordinate the activity, while a decentralized solution can be implemented with dedicated communication between the vehicles.

Hereafter the centralized implementation is described.

A traffic control center or Host Vehicle identifies several vehicles which intend to cross an intersection on a similar path at a similar time. The candidate vehicles are placed into groups following the same paths, guided through the intersection by their corresponding 'group lead' vehicle. After the manoeuvre is executed, the groups are dissolved. The lead vehicle reports the manoeuvre to the traffic control center. The coordination of acceleration and speed enables an efficient crossing which is adapted to all vehicles' capabilities.

Coordinated cooperative manoeuvres based on C-ACC:

The Use Case Cooperative Adaptive Cruise Control was already studied in ETSI TR 103 299 [i.4].

In highly dynamic environments where vehicles and drivers need to execute a vehicle movement it is sometimes dangerous to try and execute a manoeuvre. As the behaviours of surrounding vehicles are sometimes difficult to anticipate, drivers are not able to always execute their manoeuvre since it may pose a considerable safety risk. The manœuvre can be of the type "lane merging", lane changing, accessing exiting ramps, executing U-turns and so on. When drivers however can see or anticipate the behaviours of the surrounding drivers, such movements can be coordinated. An example of this would be using the flashing headlights to communicate an intent, or visual confirmation between the drivers.

The following needs to be considered:

- The use case itself contains different scenarios, such as U-Turn, lane merge and so on. Each of these will have individual differences which will need to be described in detail, as they will happen in different environments, different speeds and the number of involved participants will change.

- Additionally, the use cases can be implemented with actuation, enabling the manoeuvre of automated vehicles. Therefore, it needs to be considered, that the implementation stages of driver-operated or vehicle-operated movement can affect the implementation itself.
- There are differences between regions on how merges are to be executed in terms of access priorities, maximum speeds and if the manoeuvre is even allowed in certain areas. These situations all need to be considered when the use case is to be implemented.

An important requirement is that the vehicles can estimate and identify which communication partners in their communication ranges are also critical participants in the manoeuvre, as it is important the relevant partners are identified and addressed.

The most crucial aspect is that the communication between participants needs to be enabled in specific recognizable sequences, so that the different partners can identify each other to ensure the process.

5.6.3 Group Start use case

The group start use case is illustrated in Figure 13.

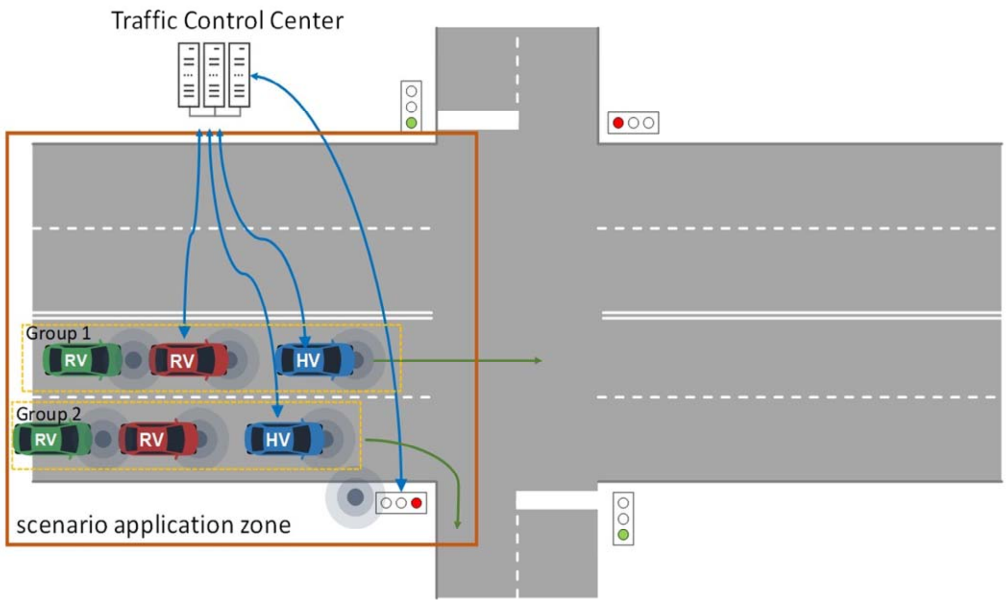

Figure 13: Illustration of the Group Start use case

5.6.4 Information flow diagram

Figure 14 shows a generic information flow diagram for the Coordinated Cooperation Manoeuvre use case (concept C1) above described.

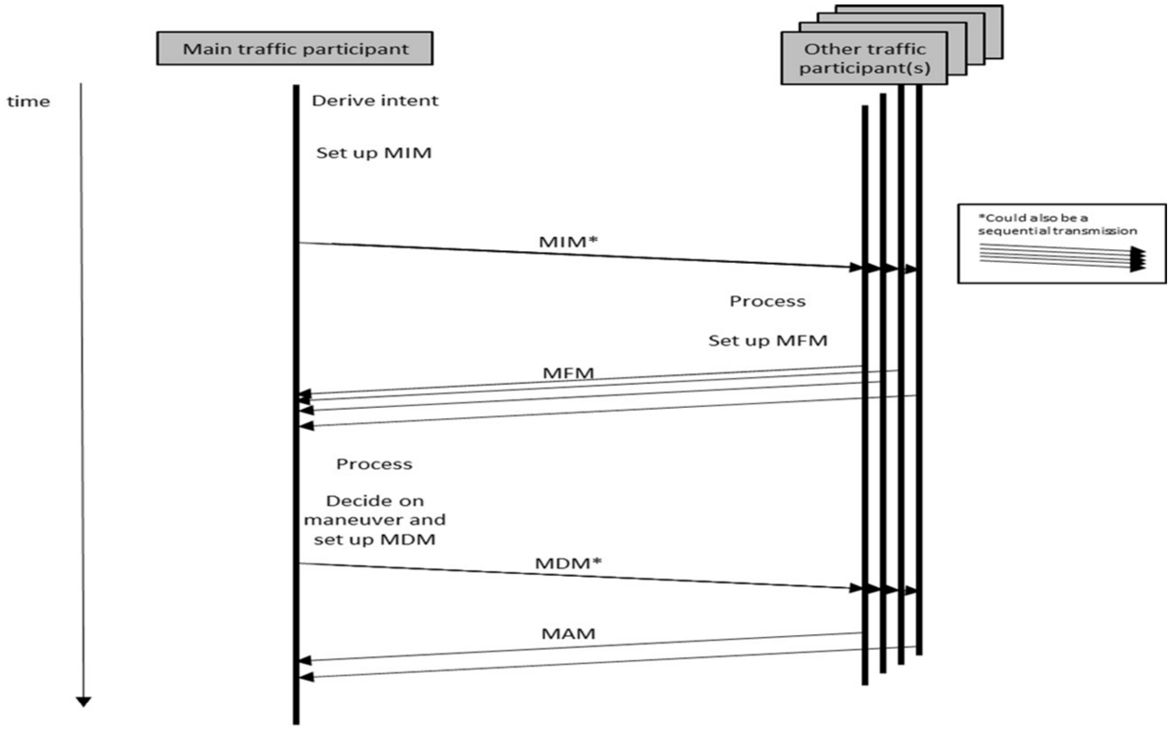

Figure 14: Information flow diagram for the coordinated cooperative manoeuvre

- A main traffic participant wants to perform a certain action (e.g. lane change, exit highway, U-turn, etc.).
- The Participant shares this intent with other traffic participants potentially involved in the manoeuvre.
- The traffic participants indicate to the main traffic participant whether they support or plan to decline the planned manoeuvre.
- The main traffic participant informs a superset of the traffic participants informed whether it plans to perform the manoeuvre.
- The vehicles then confirm the manoeuvre support, and the vehicles can all execute their individual manoeuvres to enable the planned manoeuvres by the initiating traffic participant.

5.6.5 Situation analysis

Needs of Group Start:

- A vehicle detects the benefit of the use case and its potential implementation at an intersection and initiates the use case.
- The traffic control centre identifies that multiple vehicles are approaching an intersection and intend to cross it on the same path and at a similar predicted time.

Constraints of Group Start:

- There is a mixture of vehicles which are capable and vehicles which are not capable of participating in the group start use case waiting at or approaching the traffic light. Vehicles without such capabilities are regarded as the group 'delimiter'. The next group, which is independent of the 'non-capable' one, is expected to start independently of the first group.
- The vehicles waiting at or approaching the traffic light have different capabilities (e.g. in terms of achievable acceleration, sensor equipment).
- There are more vehicles at the traffic light than can pass during one phase.
- All vehicles potentially participating in the group can securely communicate to each other.

- All vehicles potentially participating in the group can establish a secure connection with the appropriate traffic control centre.
- There is one dedicated traffic control centre for the given intersection.

Pre-conditions:

- Intersections benefiting from the use case need to be known to the initiating HVs (e.g. through prior communication or updates).
- The traffic control centre provides advice to the vehicles on how to approach the intersection and which path to take there (lane, relative position, or absolute position).
- The vehicles arrive at the intersection and wait at a red light.

The information required for Group Start includes Signal, Phase and Timing information, properties of the different involved vehicles and the properties of the group, the position, speeds, accelerations, yaw rates, and the planned path by the group and a timeout mechanism. Additionally, identifiers for the group, the vehicles, the sequence of messages and identifiers enabling separation of forming groups and the use case implementation will delimit the different forming groups and the reason for the forming of the group.

Needs of Coordinated Cooperative Manoeuvre:

- The main traffic participant needs to receive feedback messages from other traffic participants.

Constraints of Coordinated Cooperative Manoeuvre:

- The main traffic participant needs to be equipped with the means to inform other traffic participants about planned manoeuvres.
- Other traffic participants need to be able to signal confirmation/support/approval or denial/rejection of the planned manoeuvre.
- The main traffic participant needs to be able to process feedback received and needs to be able to inform surrounding traffic participants about the final decision regarding whether the manoeuvre will be performed or not.

Pre-conditions Coordinated Cooperative Manœuvres:

- The main traffic participant wants to perform a manoeuvre involving surrounding traffic participants.

5.7 Concept C2, C2V cooperation class "prescriptive"

5.7.1 Overview

This concept is dedicated to Centre - Vehicle (C2V) cooperation. Though this concept could be like the B2 concept above described, and developed, it is more appropriate for the supervision of fully automated vehicles (SAE level 4 and 5) which do not have a human driver in them (likely be mandatory by law all over Europe as it is already the case in France).

As this supervisor needs in some critical cases to teleoperate automated vehicles, its intent will correspond to a prescriptive class of collective actions.

5.7.2 Description

Actors and roles:

A central supervisor monitors in real time the evolution of relevant automated vehicles which are under its responsibility. In case of detecting a dangerous evolution of a vehicle, or receiving a vehicle request for support, or receiving a police vehicle interception/inspection request, the central supervisor will remotely act (teleoperate) on the relevant subject vehicle and may be also on other neighbour cooperative vehicles to resolve the reported or detected problem. Such manoeuvre coordination actions may be limited to the strict minimum required according to the central supervisor capabilities (perception and performances).

Release 2 cooperative vehicles moving in an automated mode without drivers could be remotely controlled by the central supervisor.

Release 2 cooperative vehicles in an automated mode with human drivers or in human driving mode may contribute to manoeuvre coordination initiated by the central supervisor.

Generally, all cooperative vehicles and cooperative RSE need to provide local information to the central supervisor with the objective to develop its perception of controlled local environments. This can be achieved using standard messages such as CAMs, DENMs, VAMs, and CPMs.

Goal:

The main mandatory goal of a central supervisor is to remote control fully automated vehicles (SAE level 4 and 5) moving without human drivers in them when it is judged necessary.

However, such central supervisor can be integrated in a central system which has other goals such as providing digital road infrastructure model for navigation purpose or/and traffic management.

Needs:

The central supervisor needs to be connected to cooperative vehicles and to the road infrastructure to collect local perception data and be able to remotely propose actions on automated vehicles. This connection could be via a cellular network (e.g. 4G or 5G) or via a local fibre optic network.

The supervised cooperative vehicle needs to be a release 2 cooperative vehicle moving in a fully automated mode without human driver in it. Such cooperative vehicle needs to support this class of MCS cooperative service.

It is expected that the density of release 2 cooperative vehicles be sufficient to achieve the targeted goal.

It is also needed that non-connected/cooperative vehicles do not take profit of the new created situation to exploit it to the detriment of the subject vehicle.

Geographic scope:

The geographic scope is depending on the central supervisor coverage. It could stay local to a cell or extended to a variable area according to the supervisor processing/memory capabilities and its performances in terms of end-to-end latency time.

Pre-conditions:

The central supervisor needs to obtain a full perception of the environments in which the subject vehicles are moving. It should be able to collect local contextual data and dynamic objects evolutions data (see Annex B of the present document).

The central supervisor should respect some minimum performance requirement for remotely proposing actions on subject vehicles which need its intervention.

The subject and target vehicles which are cooperating need to be standard release 2 cooperative vehicles.

5.7.3 Fully automated vehicles central supervision use case

Figure 15 shows the use case where a central supervisor (prescriptive cooperation class) located in the cloud or at the edge of the cloud and cellular networks (e.g. 4G or 5G) is used.

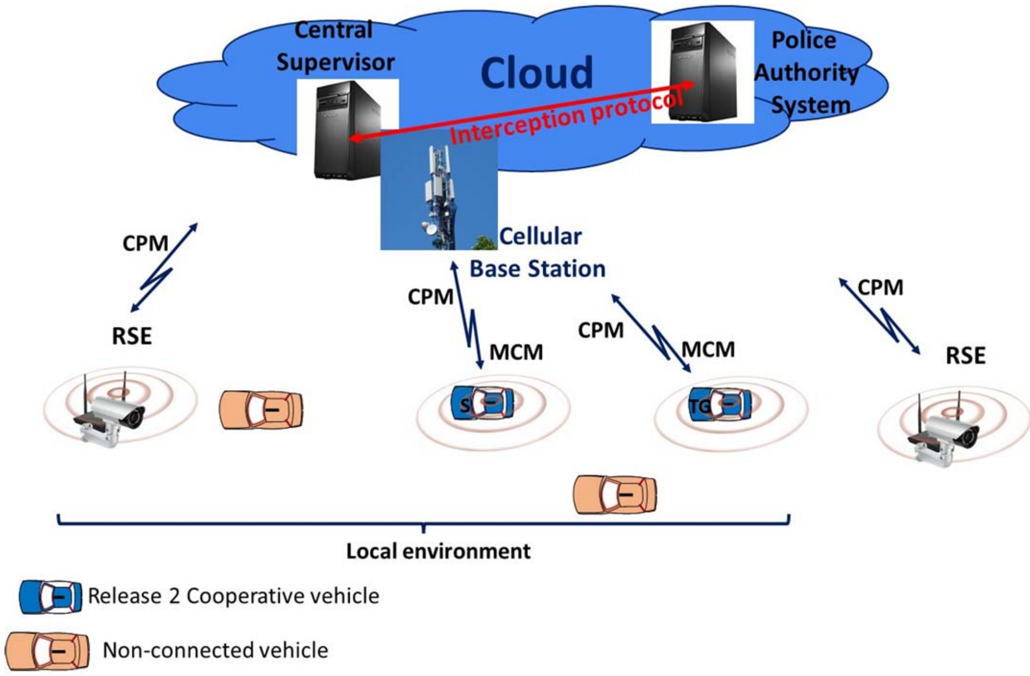

Figure 15: Overview of the concept C2 situation

The central supervisor coordinates the manoeuvre of the subject vehicle according to the level of perception it can collect from cooperative vehicles (from CAMs and CPMs) and local RSUs. It may be assisted by other release 2 cooperative vehicles if necessary.

Another architecture may include the supervisor located in a traffic management centre and linked to vehicles via a local optical fibre network and RSUs. Operated by a local road operator.

5.7.4 Information flow diagram

The information flow for this concept C2 above described is shown on Figure 16.

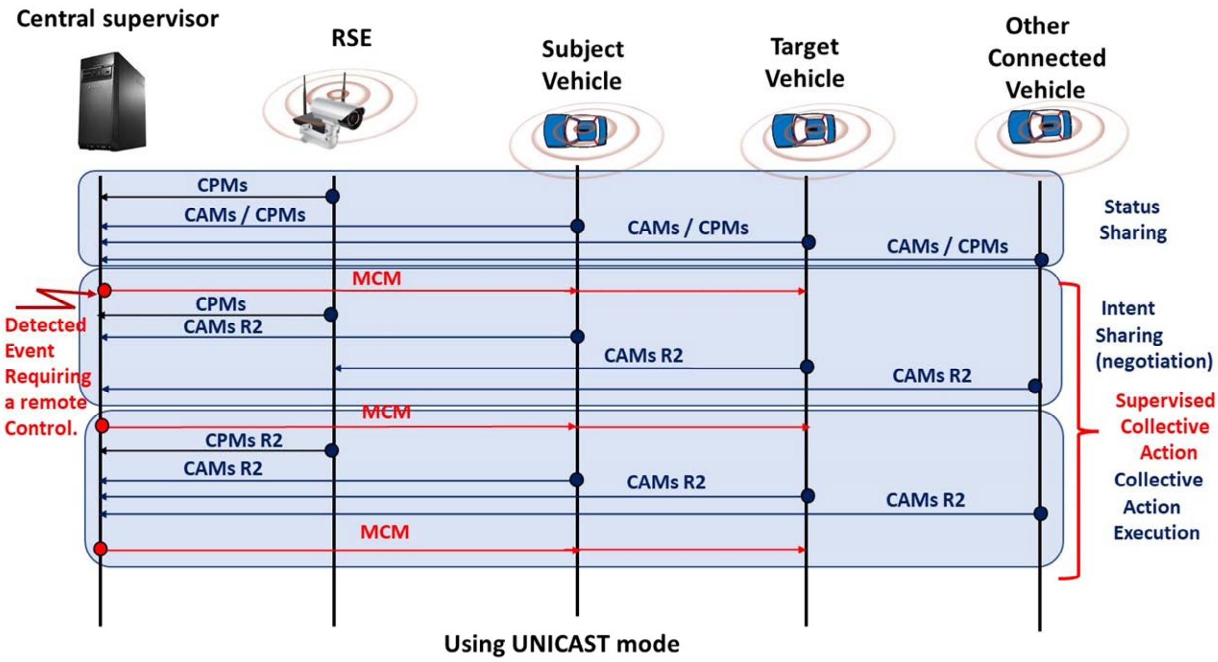

Figure 16: Information flow diagram for concept C2

5.7.5 Situation analysis

Hypothesis:

The central supervisor needs to be informed about the presence or not of a human driver able to take control of the vehicle when necessary. This could be achieved using CAM which needs to be forwarded to the central supervisor. The absence of a human driver in the vehicle is the only condition required for the central supervisor to monitor the evolution of the vehicle and remotely propose actions on it either under the detection of particular situations and on an interception request from a relevant authority.

When activated to supervise a particular automated subject vehicle, the central supervisor needs to have the capability to collect all relevant data elements (environmental context in which the vehicle is evolving, and vehicles' motion dynamics) which are necessary to detect a risk of collision, avoid the collision or mitigate it or act upon received interception requests.

When activated to supervise a particular automated subject vehicle, the central supervisor needs to know in what extend (permission level) it can propose remote actions on the automated vehicle relatively to its technical performance capacities (e.g. end to end latency time in worst cases situations).

Post-conditions:

The first phase of a vehicle remote control may consist in stopping the vehicle after leading it on a local safe parking place reducing as much as possible the local traffic disturbance.

However, this could be extended by another phase which may consist in leading the subject vehicle to a new destination where it can be inspected for a repair or any other purpose. Three solutions would be possible:

- A - The subject vehicle can be physically removed by another specialized, authorized vehicle.
- B - The subject vehicle can be required to move automatically to a new destination which is replacing its initial destination in its navigation system.
- C - The subject vehicle can be instructed to follow another authorized vehicle (follow-me), so forming a small vehicles' string, until reaching their destination.

In the cases B and C, the subject vehicle should have all its technical capacities to move in an automated mode and should have the necessary remaining energy to reach its destination. This last requirement may lead to indicate in CAM or in responding MCM the level of remaining energy (autonomy) in the subject vehicle for the central supervisor to be able to select the best solution to use.

Information requirement:

A central supervisor needs to collect all information which are necessary to take a decision to coordinate or not the manoeuvre of a subject vehicle (environment contextual data, subject vehicle motion dynamic, neighbour vehicles motion dynamics).

A central supervisor addresses or broadcasts manœuvre coordination instructions to be executed by relevant vehicles (subject and target) during the manoeuvre coordination process. The choice of the communication mode depends on the communication capacities which are available at the level of the used network.

Relevant cooperative vehicles update their CAMs which will reflect the received manoeuvres coordination execution.

Communication mode:

An addressed mode (unicast) or a broadcast mode can be used according to the capabilities of the long-range communication network which is used.

6 Conclusions

6.1 Introduction

CAM can be used for status sharing before the initiation of a collective action. CAM can be also used to provide an implicit response to MCM if a new container is added for communicating the vehicle reference trajectory. Other data elements could be added to enable an efficient cooperation between vehicles involved in a collective action.

Then functional and performance requirements are analysed to identified future standard evolutions which can be necessary for the development of this new manoeuvre coordination service.

6.2 Identified impacts on CAM

For partly and fully automated vehicles, CAMs can be used to provide information about the vehicle ADAS capabilities and activation and on ADAS which are necessary for the vehicle to be able to move safely in a flow of vehicles, such as:

- Active Cruise Control (ACC) maintains the vehicle in a regulated distance from its front vehicle.
- Automated Emergency Braking System (AEBS) triggers an automated emergency braking.
- Active Lane Keeping (ALK) enables the vehicle to stay in its lane according to the road infrastructure horizontal marking.
- Cooperative ACC (C-ACC) enables a significant reduction of the required minimum distance between the subject vehicle and the vehicle moving in front of it.
- Intelligent Speed Adaptation (ISA) enables to adjust the maximum speed limit of the subject vehicle according to its environmental context or according to the human driver vigilance level.

It could be also necessary that the CAM indicates if the subject vehicle is in a complete automated driving mode or stays in a partly human driven mode.

In some cases, for the manoeuvre coordination between several vehicles it would be necessary that the involved vehicles and other participants be informed of the vehicles' reference trajectories. This can be mandatory to examine if a release 2 cooperative vehicle can be helping in a particular manoeuvre coordination and then if this is the case, to monitor its trajectory evolution to verify that its manoeuvre reflect what is expected by the other vehicles.

When a cooperative vehicle initiates an MCS, the best way to identify its intent is to provide its reference trajectory evolution. This can be achieved at the level of CAMs (according to its release 2 evolution) or at the level of MCMs.

NOTE: A confusion is possible between the "path prediction" (which may optionally include dynamic information) and the "trajectory". These two data elements should be reconsidered and clarified in the CDD.

6.3 Potential requirements

6.3.1 Functional requirements

The functional requirements can be derived from the main concepts which are proposed in the present document:

- Concept A1, V2V cooperation class "agreement seeking". This concept includes the two introduced situations (V2V Cooperation Request, V2V Cooperation Offer).
- Concept A2, V2V cooperation class "prescriptive".
- Concept B, I2V cooperation class "agreement seeking" and "prescriptive".
- Concept C, C2V cooperation class "agreement-seeking" and "prescriptive".

FR01: A collective action is initiated by an ITS-S which has an intent (e.g. agreement-seeking class) or a mission (prescriptive class) needing the support of cooperative vehicles to achieve a pre-defined goal. Receiving vehicles need to obtain more information about the originating vehicle intent (development of the "Cost" concept) or mission (e.g. type of mission and its value). Triggering conditions of a collective action need to be refined according to main actors' needs.

The manoeuvre coordination service is supported by a functional pipeline which can be constituted of functions located in the four functional categories of an ITS reference architecture such as represented in Figure 1. Such a functional pipeline is discussed in annex B of the present document. All these functions/applications constitute the overall functional capabilities of the Intelligent Transport System which are complemented by communication capabilities (short range and long-range communication capabilities). These ITS capabilities should be monitored and maintained to be able to use safely the Manoeuvre Coordination Service.

FR02: An Intelligent Transport System (ITS) is a distributed system composed of 4 functional categories which are interacting together via communication networks. It is then necessary to specify and standardize the protocols and messages which are used to support these interactions which may have minimum performance requirements.

NOTE: The cooperative ACC as the platooning management (creation and disbanding) could be considered as a collective action supported by MCS. The same applies to AVP. Consequently, it should be studied if this MCS could also cover these different types of use cases.

FR03: A collective action may remain active during a long period of time (for example: - platooning synchronization, -AVP movement, -dedicated corridor management, etc.). It is then needed to distinguish several phases of manoeuvre coordination to cover a collective action (e.g. for platooning: -platooning creation, -platooning maintenance, -platooning disbanding, etc.). Elementary MC actions can be identified as in SAE J3186 [i.5].

Even if it is the complete responsibility of the application, it should be beneficial to clarify what is called a "collective action" and its interaction with the manoeuvre coordination service.

FR04: It is necessary to specify the interactions between a local "collective action management" application (or its proxy) and the Manoeuvre coordination basic service of the local ITS-S during all the duration of the collective action.

6.3.2 Functional Safety and Security requirements

The security of the overall ITS for the use of the Manoeuvre Coordination Service is a key feature which needs to be considered with a high level of attention especially in "prescriptive" cooperation class.

Even if in all cases, the receiving vehicles remain responsible of accepting or not a collective action initiation via an explicit intent, if accepted, the receiving vehicles movements will be actively impacted by received MCMs.

FSR01: It seems highly necessary to reinforce the security of cooperative vehicles contributing to a collective action, relatively to a risk of manipulation (masquerade) with the objective to avoid that an attacker takes the control of the vehicle.

Vehicles, road-side equipment, and central equipment which can directly or remotely propose actions to a subject vehicle and on its neighbours has to get the required permission for this purpose. Then, the process for getting the right level of permission needs to be secured.

FSR02: Several categories of ITS-Ss can be involved in a collective action. These ITS-Ss (including vehicles) will have a diversity of roles and responsibilities which need to be reflected in granted permission.

Nobody should have the possibility to remote control (teleoperate) any vehicle without having the right permission level.

FSR03: The required security level needs to be ensured independently of the used communication profile especially during teleoperation.

In all cases, the subject and target vehicles which receive coordination manoeuvre data need to have the possibility to accept them or not after the required analyses (consistency, integrity, plausibility, etc.). This is like the situation when a SPAT message indicating a red phase is received which requires that all relevant vehicles stop until a change of phase to green.

FSR04: Receiving vehicles need to be able to detect misbehaviour and report it to the security system and local collective action partners.

The negotiation phase which is initiated by an intent/mission and an associated reference trajectory proposal is a key phase which needs to be secured especially for the prescriptive class.

Several intent/mission classes need to be defined according to the roles and responsibilities of the using stakeholders.

Functional Safety such as defined by ISO 26262 [i.6] (Fusa), derived from IEC 61508 [i.7] defines requirements and measures to ensure a safe operation of safety-critical vehicle systems and appropriate reactions to prevent hazards in the case of failures. Several causes of failures may occur (hardware defects, software defects, cyberattacks on hardware, software and data causing defects, etc.).

FSR05: As a cyberattack can be the cause of a functional safety problem (attack on hardware, software, data, etc.), the respective contribution of the security countermeasures to the functional safety of the system needs to be established.

Redundancy can be a measure to overcome functional failures related to hardware, software, and data. But relatively to cyberattacks other solutions need to be developed to prevent cyberattacks and if not completely possible to detect and eliminate them.

FSR06: Several perceptions means will cohabit in an ITS (e.g. -autonomous perception of vehicles and RSEs, -local and global connectivity, -local digital map, etc.), so constituting a redundant system enabling the detection of inconsistency between resulting data and then facilitating the detection of a functional problem or cyberattack.

Furthermore, the security system with changing ITS-S ID might negatively impact cooperative manoeuvres due to the time limit on use of an ITS-S ID. If the manoeuvre happens to coincide with an ITS-S ID change this would cause problems and means of circumventing the regulation for purpose such as cooperative manoeuvres would be needed. This could be in terms of a keep-alive indication to ensure the stations keep the same ID for a timed period for example.

FSR 07: Frequent changes of the ITS-S ID could impact the performances of a collective action. Consequently, a specific management of the ITS-S ID changes needs to be specified during the achievement of a collective action.

6.3.3 Minimum performance requirements

Some minimum performance requirements need to be specified especially at the level of end-to-end communication latency time and processing time.

End-to-end communication means from the real time update of relevant data used at the perception level to the manoeuvre coordination actions which result from their analysis.

All processing times associated to the functions which are part of the processing pipeline need to be considered. The overall processing time will be the sum of all processing times spent in the various functional categories which are cooperative to achieve the targeted objective.

Figure 17, Figure 18 and Figure 19 provide examples of end-to-end latency time computations relatively to the three main concepts (A, B, C) which are considered in the present document.

Additionally, the domain of sequential action previously acquired information immediately prescribes a form of implementation. It is therefore important to have the accurate requirements of critical information order and separate them from implementation. Potentially, a use case implementation cannot be decoupled, and an industry consensus driven implementation for individual use cases might be necessary.

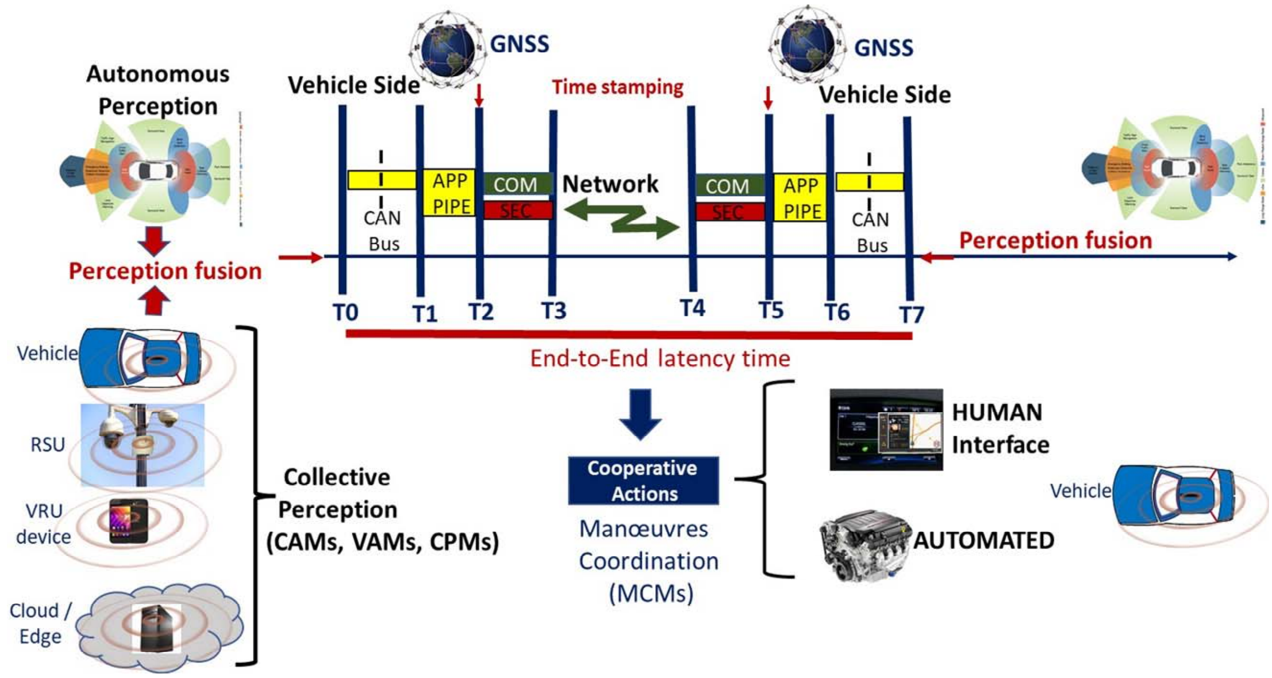

Figure 17: Example of End-to-End latency time computation for the concept A

In the example shown in Figure 17, the end-to-end delay will be as follows:

- T0 and T7 are the times of availability of local perception data (autonomous from local sensors and collective from exchanged of messages). These data are used to elaborate an exchange with other vehicles for their manoeuvres' coordination.
- T1 - T0 and T7 - T6 are the processing times necessary for obtaining data which can be used by the Applications Pipeline to analyse the respective situations of cooperative vehicles and then decide on the next cooperation steps.
- T2 -T1 and T6 - T5 are the processing times necessary to elaborate the decision for progressing in the on-going cooperation of the manoeuvre coordination process.
- T3 - T2 and T5 - T4 are the times necessary to execute standard communication and security protocols used by the network.
- Network (T4 - T3) is the latency time of the local ad-hoc network used between vehicles (V2V concept).

This is a symmetric situation, and the End-to-End latency time can be computed between the transmitting source and the receiving source by adding:

(T1 - T0) + (T2 - T1) + (T3 - T2) + (T4 - T3) + (T5 - T4) + (T6 - T5)

In this concept A, only standard local ad-hoc networks are used enabling a low latency time at network access level (a few milliseconds for the exchange of standard messages).

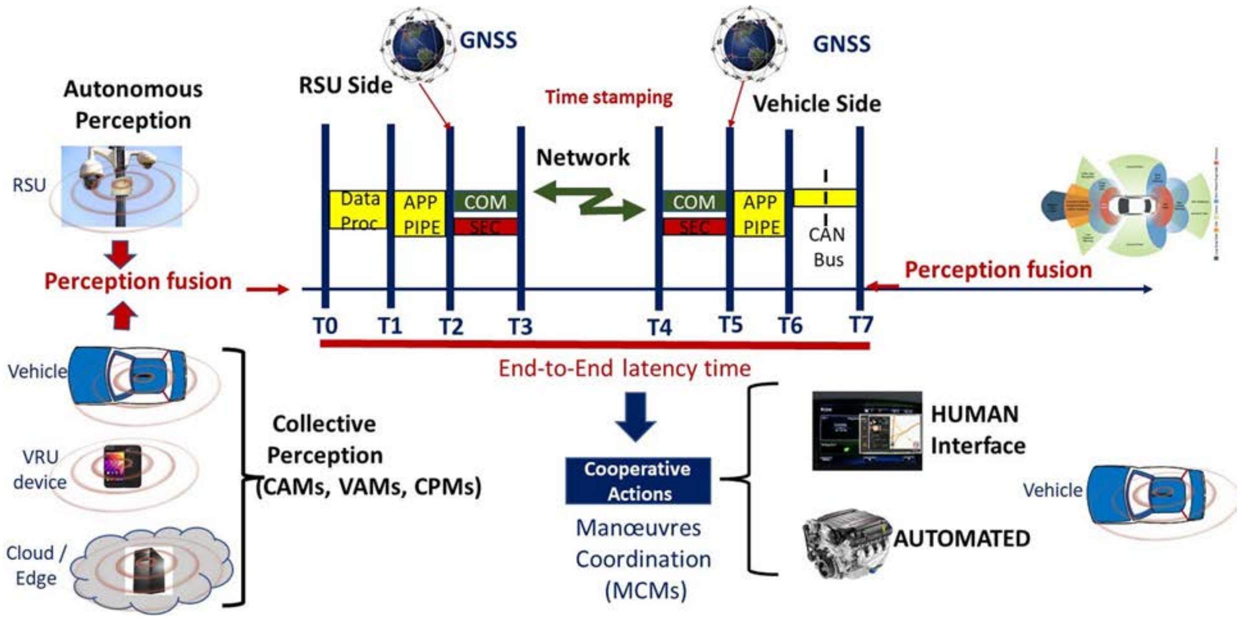

Figure 18: Example of End-to-End latency time computation for the concept B

In the example shown in Figure 18 the end-to-end delay will be as follows:

- T0 and T7 are the times of availability of the local perception data respectively at the level of the RSU and cooperative vehicle. The autonomous perception of the RSU enables the collect of data in short time delay. For the reception of collective perception data, the use of a standard local ad-hoc network limits the End-to-End latency time for this collect to a few ten milliseconds (a few milliseconds for the local ad-hoc access network.
- T1 - T0 and T7 - T6 are the processing times necessary for obtaining data which can be used by the Applications Pipeline to analyse the respective situations of relevant cooperative vehicles for their manoeuvres' coordination steps.
- T2 - T1 and T6 - T5 are the processing times necessary to elaborate the decision for progressing in the on-going cooperation of the manoeuvres' coordination process.
- T3 -T2 and T5 - T4 are the times necessary to execute standard communication and security protocols used by the network.
- Network 1 (T4 -T3) is the latency time of the local ad-hoc network used between the RSU and vehicles (I2V concept).

This can be considered as a symmetric situation (RSU and vehicles have to sense and process local data), and the End-to-End latency time can be computed between the transmitting source and the receiving source by adding (from the RSU to the vehicle):

$$(T1 - T0) + (T2 - T1) + (T3 - T2) + (T4 - T3) + (T5 - T4) + (T6 - T5)$$

In this concept B, only standard local ad-hoc networks are used enabling a low latency time at network access level (a few milliseconds for the exchange of standard messages).

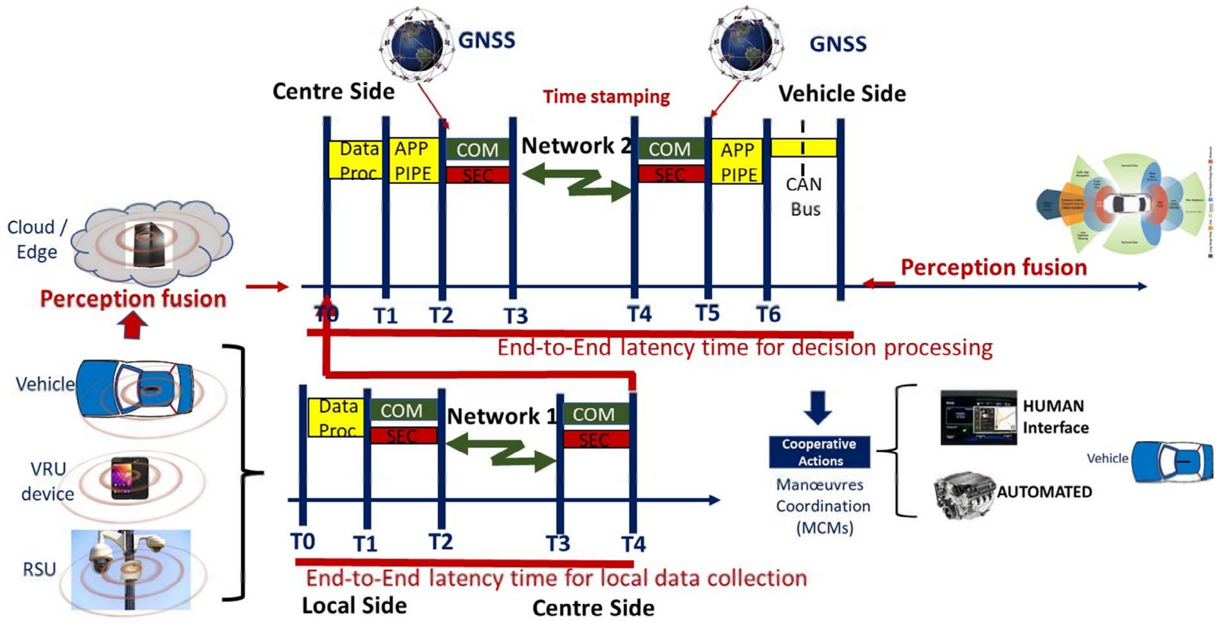

Figure 19: Example of End-to-End latency time computation for the concept C

In the example shown in Figure 19, at least three different cases for long-range networks (impacting the End-to-End latency time) can be considered:

- The central system is located at the edge of the cloud in the cellular base station. In such case, the network latency can be reduced to the cell access network latency and likely for 5G technology approaching the local ad-hoc network latency (a few milliseconds). But this means that all cells need to support the applications pipelines which are necessary for cooperative vehicles supervision and control in case of necessity, and that the relevant cell technology be deployed everywhere cooperative vehicles have to move.

- The central system is in the cloud. In such case, the global network which is used (e.g. Internet) needs to be connected to concerned local environments using relevant cellular access networks. The network latency time needs to add the cellular access network latency time to the internet latency time.

- The central system is in the road infrastructure controlled by the road operator. This can be achieved using a high-speed fibre optic network interconnecting the ITS RSUs. In such case, the latency time of the long-range network can also be drastically reduced to a few milliseconds.

The concept C needs to consider the two processes which are necessary at a central level:

- The local data collection process via the long-range network 1.

- The decision process including the applications pipe using the long-range network 2 to communicate the result of the decision process to vehicles which need to coordinate their manoeuvres (actions).

The End-to-End latency times computations are the same as previously, adding the communication and processing times which are necessary at the level of each process.

Considering the End-to-End latency time for local data collection, this one impacts the timeliness of collected highly dynamic data and then can make them obsolete if too long.

Moreover, the two End-to-End latency times need to be added for each new manoeuvre coordination which is decided.

Annex A:
Example of MC Messages

A.1 Introduction

This annex presents the results of 3 (clauses A.3, A.4 and A.5) National and European research projects which specified and experimented a Manoeuvre Coordination Service and its associated message.

An attempt to develop a joint proposal for MCM format is provided in clause A.2.

However, this proposed ASN.1 coding is only supplied as an initial contribution which needs to be further developed considering new emerging research project results and the possibility of some harmonization with SAE J3186 [i.5].

A.2 Joint proposal for MCM format

A Manoeuvre Coordination Message format proposal to implement the previously described manoeuvre coordination concepts can be defined including the message generation time, reference position and heading of the MCM sender, and one or two containers: A *Vehicle Manoeuvre Container*, which includes a list of possible manoeuvres for the sender vehicle, or a *Manoeuvre Advice Container*, which contains manoeuvre recommendations for other vehicles.

Vehicle Manoeuvre Container

The *Vehicle Manoeuvre Container* is exchanged periodically among nearby vehicles via V2X communication, to implement the manoeuvre coordination concept A1 "V2V cooperation - agreement seeking". It contains mainly a list of trajectories with cost values. The trajectories represent possible driving paths for the ego-vehicle with a time horizon about 30 seconds in the future. The cooperation cost C expresses how favourable the trajectory is for the ego vehicle, and they allow the relative prioritization of the transmitted trajectories. Three types of trajectories are considered:

- *Reference trajectory*: corresponds to the target trajectory being currently driven by the vehicle. Reference trajectories of all cooperating vehicles remain collision free and potential collisions are solved according to the traffic rules. The reference trajectory cost indicates the extent of the ego-vehicle's necessity for cooperation (when $C > 0$) or its willingness to cooperate with other vehicles (when $C < 0$). A cost $C = 0$ indicates that the vehicle neither is looking for cooperation nor it is willing to cooperate with other vehicles.

- *Alternative trajectory*: represents a cooperation offer from the ego-vehicle to another vehicle. i.e. a trajectory that the vehicle would be ready to drive to improve another vehicle's situation. The cost of an alternative trajectory is higher that the reference trajectory cost.

- *Request trajectory*: expresses that the ego-vehicle has a need for cooperation from another vehicle in order to achieve its objective. Its cost is lower than the reference trajectory cost.

The *Vehicle Manoeuvre Container* includes the current vehicle automation state, which indicates whether the vehicle is currently driving in automated mode longitudinally, laterally, or both, and a trajectory list. The first trajectory in the list is the reference trajectory, which is always included. Optionally, one or more possible cooperation offers (alternative trajectories) and/or cooperation petitions (request trajectories) for other vehicles are also included. All trajectories have a common format, consisting of a unique trajectory ID, the future vehicle path of the vehicle (position over time), an optional category to signalize special cases, such a high-priority trajectory sent by an emergency vehicle, the cooperation cost value, and an optional cooperation timeout.

Manoeuvre Advice Container

The *Manoeuvre Advice Container* is sent periodically by vehicles or roadside units via V2X communication, to implement the manoeuvre coordination concept A2 "V2V cooperation - prescriptive", B1 "I2V cooperation - agreement seeking" or B2 "I2V cooperation - prescriptive" or C-C2V cooperation and prescriptive. It contains mainly a list of advised manoeuvres for different vehicles. Each manoeuvre contains a manoeuvre ID, the station ID, position and heading of the vehicle that needs to execute the manoeuvre, the manoeuvre path, and the automation state in which the manoeuvre should be driven.

In the manoeuvre coordination concept A2, the *Manoeuvre Advice Container* is transmitted by special vehicles, such as a police car, to indicate nearby vehicles to follow a given manoeuvre. In the concepts B1 and B2, the *Manoeuvre Advice Container* is transmitted by a roadside unit with the objective to improve the driving safety and efficiency of nearby vehicles. The vehicles for which a manoeuvre is specified in the *Manoeuvre Advice Container* respond by transmitting periodically MCMs with a *Vehicle Manoeuvre Container,* which contains its reference trajectory and a category that indicates their acceptance or decline of the received manoeuvre advice. If at least one vehicle declines the manoeuvre advice, the advised manoeuvres may be updated in subsequently transmitted *Manoeuvre Advice Containers*.

Representation of trajectories

Several formats for representing a trajectory could be imagined. One well-known variant is to use a simple list of points each consisting of a geographic location and a timestamp. However, this has several disadvantages especially for manœuvre coordination of vehicles. One is that semantic information e.g. the occurrence of a lane change is not explicit.

Therefore, a different format is suggested. This is based on the topology of the lanes around the vehicle. Each lane defines a Frenet Coordinate System. The x-coordinate of the Frenet coordinate system follows the center line of the lane. The y-coordinate gives the distance perpendicularly to the center line. The trajectories are encoded by providing the used Frenet systems (i.e. the used lanes) and a definition of the x/y coordinates within each frenet system/lane.

The definition of x/y coordinates uses polynomials. Using polynomials has several advantages, like (theoretical) infinite accuracy and easy calculation of dynamic information by means of derivation, like velocity and acceleration. The longitudinal part of the Frenet trajectory is encoded as x(t). The lateral part as y(x).

Advantages of using Frenet coordinates based on lanes and polynomials are the following:

- Availability of semantic information of the planned manœuvres, like lane-changes or turn manœuvres.
- Effective encoding of curved trajectories (following a curved lane is the most often use case).
- Effective encoding of trajectories with high accuracy, also on longer distances.
- Robustness against localization errors, especially as regards heading and lateral displacement.
- A special case of polynomials are polynomials of 0th grade (which is a point). So also lists of points are supported if needed.

The final representation of a Frenet trajectory contains:

- A list for used Frenet systems/lanes. The initial Frenet system is defined by an absolute geographic position. From this initial system, a description of the necessary changes defines the next Frenet systems. The following is an example for getting an impression:
  - Starting lane: most right of 3 at position *lat/lon*
  - (lane change to left) new lane: second right of 3
  - (very left lane disappears) new lane: very left of 2
  - (entering intersection) new lane: very right of 1
  - (leaving intersection) new lane: very right of 2, new heading 145°
  - (end of trajectory): position *lat/lon*
- A list of trajectory segments for each Frenet system. A segment contains a polynomial for x(t) and a polynomial for y(x).

To properly encode and decode Frenet trajectories, a local map is necessary in each equipped ITS station. This could be derived from a navigation map (e.g. that used for manœuvre planning) or also from a simple lane topology detected by a local sensor (e.g. video camera). The receiver of a MCM needs to first match the description of the Frenet system to its own map and is then able to convert the trajectory coordinates to its internal representation. The absolute position at the end of the received trajectory allows to check if the map matching was correct.

The process of matching requires some sort of flexibility. For instance, the location of a lane topology change may not be identical for different maps and the position of the lane center, or the lanes width might differ.

Using different maps in the sending and receiving ITS stations adds some inaccuracy to the interpretation of received Frenet trajectories. On the other hand, this inaccuracy would nevertheless be part of the trajectories, if it is assumed that most manœuvre planers use some kind of map for their long-term planning (> 2 seconds). Since the semantic map topology is part of the transmitted trajectory, the chance is given to compensate the map differences at the receiver.

In some special situations, such as on parking spaces, no lanes are available. For this case, an alternative description is provided by using so called off-road points. Off-road points are geo-referenced points with timestamp, which can be used in places where a Frenet trajectory cannot be defined.

ASN.1 Description of MCM Format

```
MCM ::= SEQUENCE {
    header ItsPduHeader,
    mcm ManoeuvreCoordination
}

ManoeuvreCoordination ::= SEQUENCE {
    generationDeltaTime GenerationDeltaTime,
    mcmContainer McmContainer
}

McmContainer ::= CHOICE {
    vehicleManoeuvreContainer VehicleManoeuvreContainer,
    manoeuvreAdviceContainer ManoeuvreAdviceContainer
}

VehicleManoeuvreContainer::= SEQUENCE {
    currentPoint McmStartPoint,
    mcmTrajectories SEQUENCE SIZE(1..16) OF McmTrajectory,
    automationState McmAutomationState OPTIONAL
}


McmTrajectory ::= SEQUENCE {
    trajectoryID INTEGER (0..65535),
    trajectory Trajectory,
    categories SEQUENCE SIZE(1..4) OF McmCategory OPTIONAL,
    cost CooperationCost
}

McmStartPoint ::= CHOICE {
    intermediatePointReference IntermediatePointReference,
    intermediatePointOffroad IntermediatePointOffroad
}

McmCategory ::= SEQUENCE {
    type McmCategoryType,
    objectID StationID OPTIONAL,
    referencedTrajectoryID INTEGER (0..65535) OPTIONAL
}

McmCategoryType ::= INTEGER {none(0), emergency(1), cooperationOffer(2), cooperationDecline(3),
cooperationAcceptance(4)}

McmAutomationState ::= SEQUENCE {
    longitudinalAutomated BOOLEAN,
    lateralAutomated BOOLEAN
}

CooperationCost::= INTEGER { zero(0), oneThousandth(1) } (-1000..1000)

ManoeuvreAdviceContainer ::= SEQUENCE(SIZE(1..16)) OF Manoeuvre

Manoeuvre::= SEQUENCE {
    manoeuvreID INTEGER (0..65535),
    executantID StationID,
    executantPosition ReferencePosition,
    executantHeading Heading,
    trajectory Trajectory,
    automationAdvice McmAutomationState OPTIONAL
}
```

ASN.1 Description of Trajectory Format

```
Trajectory::= SEQUENCE {
    intermediatePoints SEQUENCE SIZE(1..10) OF IntermediatePoint,
    longitudinalPositions SEQUENCE SIZE(1..11) OF Polynom,
    lateralPositions SEQUENCE SIZE(1..11) OF Polynom,
    headings SEQUENCE SIZE(1..11) OF Polynom OPTIONAL
}

IntermediatePoint ::= CHOICE {
    reference IntermediatePointReference,
    lane IntermediatePointLane,
    intersection IntermediatePointIntersection,
    offroad IntermediatePointOffroad
}

Polynom ::= SEQUENCE {
    coefficients SEQUENCE SIZE(1..6) OF PolynomCoefficient,
    start PolynomStartX,
    end PolynomEndX,
    xOffset PolynomXOffset
}

IntermediatePointReference::= SEQUENCE {
    referencePosition ReferencePosition,
    referenceHeading Heading,
    lane Lane,
    timeOfPos TimeOfPos
}

IntermediatePointLane::= SEQUENCE {
    lane Lane,
    reason Reason,
    timeOfPos TimeOfPos
}

IntermediatePointIntersection::= SEQUENCE {
    exitLane SEQUENCE {
        lanePosition LanePosition,
        laneCount LaneCount
    },
    exitHeading Heading,
    timeOfPosEntry TimeOfPos, -- time on the trajectory when the intersection will be entered
    timeOfPosExit TimeOfPos   -- time on the trajectory when the intersection will be leaved
}

IntermediatePointOffroad::= SEQUENCE {
    referencePosition ReferencePosition,
    referenceHeading Heading,
    timeOfPos TimeOfPos
}

Lane::= SEQUENCE {
    lanePosition LanePosition,
    laneCount LaneCount -- total number of lanes at the position
}

PolynomCoefficient::= REAL
PolynomStartX::= INTEGER (0..2097151) -- Unit: 0.001 meter or seconds
PolynomEndX::= INTEGER (0..2097151)   -- Unit: 0.001 meter or seconds
PolynomXOffset::= INTEGER (-8000000..8000000) -- Unit: 0.001 meter or seconds

-- Basic types

LaneCount::= INTEGER (1..16) -- Number of Lanes

TimeOfPos::= INTEGER(0..65535) -- Unit: 0.01 seconds

Reason::= ENUMERATED {
    none(0),
    laneOpening(1),
    laneClosing(2),
    laneChange(3)
}
```

It could be possible to use, the predicted path of a CAM release 2 as reference trajectory rather than sending an MCM. Then means should be taken so that all the reference trajectory information needed is part of the predicted path (which may optionally contain dynamic information such as the vehicle heading and speed variations) and that the necessary relation of request trajectories to the reference trajectory is still possible.

NOTE: The current definition of PathPoint in CDD overlaps with the definition of trajectory (see clause 3.1) when the pathDeltaTime option is selected. The pathDeltaTime option enables the computation of vehicle dynamic (heading and speed variations between two PathPoints).

A.3 French PAC V2X project proposal

The French PAC V2X (Perception Augmented via Cooperation V2X) project [i.2] has developed a proprietary MCM (Manoeuvre Coordination Message) which has been validated through several use cases during the project.

Figure A.1 shows the structure and content of this message.

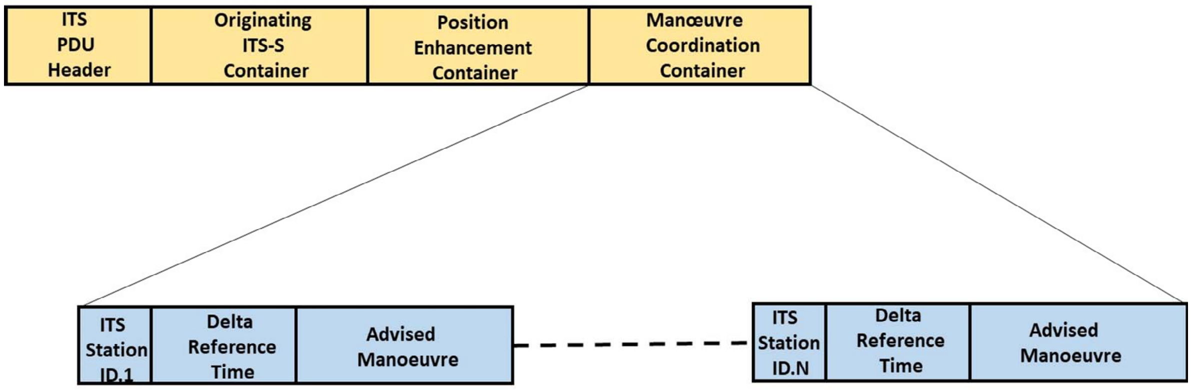

Figure A.1: Structure and content of the MCM used in the French PAC V2X project

In PAC V2X, this MCM is broadcasted by the roadside units (concept A or B).

The ITS PDU Header and the Originating ITS-S container respect the structure and content of other existing ETSI standard messages.

The position enhancement container has been added to increase the accuracy of vehicles' positions from the Roadside Unit.

The MCM is mainly provided by the Manoeuvre Coordination Container which contains:

- One sub-container by relevant ITS Station (subject and target vehicles) which are involved in the manoeuvre coordination. Then each sub-container contains:
  - The ITS Station ID (ex: ID.1 to ID. N) which is concerned by the advised manoeuvres.
  - The delta reference time to be added to each way point of the proposed trajectory.
  - The list of waypoints that is recommended to the identified vehicle(s).

NOTE 1: Indeed, the succession of waypoints associated to the vehicle dynamic which can be calculated from time information constitute the vehicle trajectory (see its definition in clause 3.1).

The association of the delta time to each identified waypoint enables to control the speed of each vehicle while controlling its trajectory. This approach is like the path prediction which is already considered in the VBS.

Some possible actions are anyway missing, for example:

- Transit from a human driving mode to an automated mode.
- Transit from an automated mode to a human driven mode.

- Follow-me, consisting, from the subject vehicle to follow a requesting vehicle (e.g. a police vehicle, or a road operator vehicle authorized one) in case of necessity so forming a small platoon, the subject vehicle executing the reference trajectory of the leading vehicle with a prescribed minimum inter-distance.
- Trigger an emergency brake.
- Activates your active lane keeping.

NOTE 2: A DENM signals an event but do not propose an action to a vehicle. Only individual decided actions are achieved.

Here, the multicast addressing mode at the level of the facilities layer is used, which means:

- The MCM is broadcasted and then received by all vehicles being in the ad hoc local area network of the RSU.
- The received MCM are forwarded to the facilities layer using the standard communication layers protocol of the selected communication profile (here ITS-G5).
- The facilities layer checks the consistency, integrity and plausibility of the message and decides to process it or not.

If the receiving ITS-S is in the list of the identified ITS Stations in the manoeuvre coordination container, then the ITS-S needs to process the received manoeuvre coordination data and decide if it executes them or not. If executed, this will be automatically reflected in the next CAMs which can be considered as an acknowledgement from the identified ITS Station. The execution of the planned manoeuvre is therefore indicated with a CAM at the time the planned manoeuvre is prescribed by the Roadside unit. During the time between the reception of the MCM and the execution of the manoeuvre, an acknowledgement is not explicitly sent.

If the receiving ITS-S is not in the list of the identified stations in the Manoeuvre Coordination Container, this one may still use the information for its own purpose as the proposed manoeuvre coordination could be also impacting it if being in the neighbouring of relevant ITS-Stations.

Further aspects like security or misuse have not been investigated in this project proposal.

A.4 German IMAGinE project proposal

The cooperation protocol designed in the IMAGinE research project [i.3] is based on periodic transmission of trajectories with cost values via V2X communication. The trajectories represent possible driving paths for the considered vehicle with a time horizon about 30 seconds in the future. The trajectory costs C express how favourable the trajectory is for the ego vehicle and they allow the relative prioritization of the transmitted trajectories. The following types of trajectories are considered:

- *Reference trajectory*: corresponds to the target trajectory being currently driven by the vehicle. Reference trajectories of all cooperating vehicles remain collision free and potential collisions are solved according to the traffic rules. The reference trajectory cost indicates the extent of the ego-vehicle's necessity for cooperation (when $C > 0$) or its willingness to cooperate with other vehicles (when $C < 0$). A cost $C = 0$ indicates that the vehicle neither is looking for cooperation nor it is able to cooperate with other vehicles.
- *Alternative trajectory*: represents a cooperation offer from the ego-vehicle to another vehicle (i.e. a trajectory that the vehicle would be ready to drive to improve another vehicle's situation). The cost of an alternative trajectory is higher that the reference trajectory cost.
- *Requested trajectory*: express that the ego-vehicle is willing to cooperate with another vehicle to achieve its objective. Its cost is lower that the reference trajectory cost.

These trajectories are exchanged periodically among nearby vehicles via V2X communication in Manoeuvre Coordination Messages (MCM). An MCM format specified in IMAGinE contains mainly three containers (see Table A.1 for details). First the message header includes basic message information such as its generation time or the current vehicle automation state, which indicates whether the vehicle is currently driving in automated mode longitudinally, laterally, or both. The second container indicates the vehicle current position in WGS84 format, including its lane in the case of a multi-lane road. Last, a trajectory list includes a reference trajectory, 0 to N alternative trajectories and 0 to M requested trajectories. In other words, the MCM always contains the vehicle current trajectory, optionally followed by at least one possible cooperation offer (alternative trajectory) or cooperation petition (requested trajectory) for other vehicles. All trajectories have a common format, consisting of a unique trajectory ID, the path of the vehicle (position and heading) relative to its lane over time, information on road topology changes, the trajectory cost value, and an optimal category to signalize special cases, such a high-priority trajectory sent by an emergency vehicle.

Table A.1: Format of the Manoeuvre Coordination Message proposed by the IMAGinE project

Container	Description	Data Fields
Header	Basic message information	• ITS PDU Header, protocol version, message ID and station ID • Message presentation time • Vehicle automation state
Current position	Position of the sending vehicle	• Reference position (WGS84, with confidence ellipse) • Current lane position
Trajectories	List of MCM trajectories	• Trajectory ID • Trajectory course (vehicle position reference to lane over time) • Changes in road topology (e.g. number of lanes intersection) • Category (optional e.g. cooperation offer, or decline for a specific vehicle)

A.5 European TransAID project proposal

The TransAID proposal for MCM supports the coordination of manoeuvres between cooperative automated vehicles, as well as the transmission of suggestions from the infrastructure for the coordination of these vehicles, in such a way to increase the overall traffic safety and efficiency. Figure A.2 shows the proposed structure and content for the MCM which contains different containers for vehicles and RSUs.

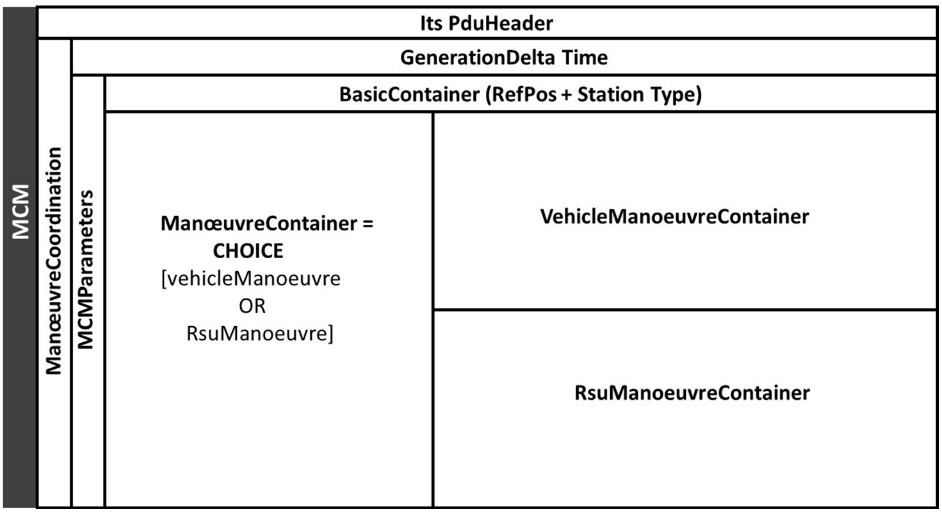

Figure A.2: Structure and content of the MCM used in the TransAID project

The MCMs transmitted by vehicles include a VehicleManoeuvreContainer (see Figure A.3), which mainly includes the vehicle planned and/or desired trajectory, the vehicle dynamics, information about transitions of control and an acknowledgement of received advice.

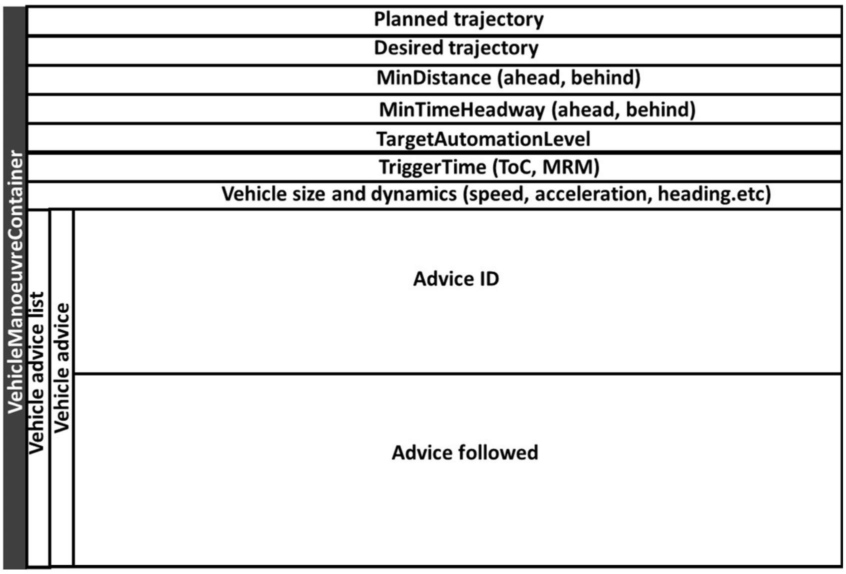

Figure A.3: Structure and content of the VehicleManoeuvreContainer used in the TransAID project

The MCM transmitted by vehicles include an RsuSuggestedManoeuvreContainer (see Figure A.4), which includes a manoeuvre advice for a connected automated vehicle. This suggestion can be related to a target driving lane, following a specific vehicle, schedule a transition of control toward the human driver or changing lane to occupy a safe spot.

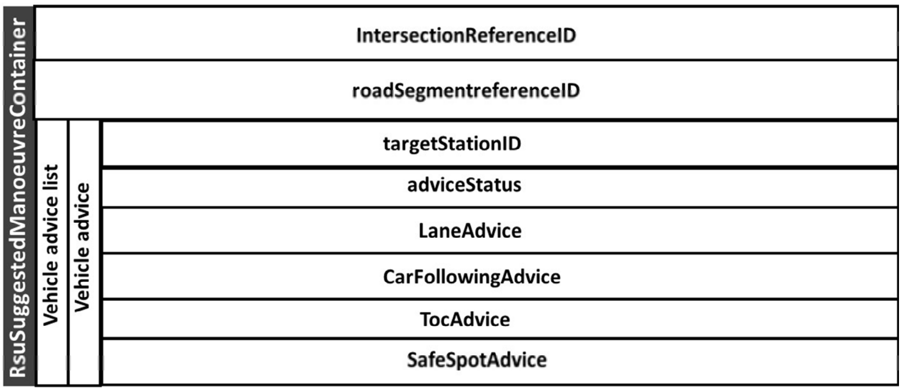

Figure A.4: Structure and content of the RsuSuggestedManoeuvreContainer used in the TransAID project

A.6 SAE J3186 Maneuver Sharing and Coordination Service

SAE developed and published a first version of the J3186 [i.5] standard which is also considering a manoeuvre sharing and coordinating service.

This SAE initial version is limited to V2V cooperation but could evolve toward other types of ITS-S cooperations as currently considered in ETSI.

In SAE J3186 [i.5], the roles of a service session initiator and participants are defined as Host Vehicles respectively, and the roles regarding performing the intended manoeuvre or only needing responses are defined as Executant Vehicles and Affected Vehicles respectively.

In addition, in SAE J3186 [i.5] a manoeuvre is described as one or more sub-manoeuvres, and each sub-manoeuvre is described with the ID of Executant Vehicle, IDs of Affected Vehicles, current state data of Executant Vehicle, Traget Road Resource, Temporal characteristics, and kinematic characteristics.

Unlike the present document introduced only the trajectory-based description for the geographical characteristics of a manoeuvre, SAE J3186 [i.5] adopted three ways for describing the geographical characteristics of a manoeuvre with a message field named TRR (Traget Road Resource). The TRR can be one of the three different types where the Type 1 represents a box-shaped area expressed by mainly positioning attribute, the Type 2 represents a box-shaped area expressed by mainly one or two vehicles surrounding the area, and Type 3 represents a trajectory-based area.

These differences will be considered by the Technical Specification work following the present document in ETSI, and more generally by both organizations during their standardization harmonization attempt.

Annex B:
Examples of an applications pipeline using the MCS

The Manoeuvre Coordination Service is mainly used to collectively coordinate manoeuvres between several human driven and partly/fully automated vehicles whatever the environmental context in which these vehicles move. The knowledge of the environmental context may support a decision to use or not the MCS.

EXAMPLE: If the context is too complex or risky (e.g. adverse weather conditions, high density of vulnerable road suers, chaotic traffic, etc.) the MCS will not be triggered restricting temporarily the possibility of a collective action.

Including Vulnerable Road Users (VRUs) in this context increases the complexity of the overall system due to the diversity of humans' behaviours related to their types and associated risk factors.

When a subject vehicle needs to change its motion dynamic (trajectory and/or velocity), this one can only do it in the respect of the traffic code and considering the environmental context in which it is moving. The main environmental context factors are:

- The human factors (e.g. density, types, crowd behaviour, etc.).
- The meteorologic factors (visibility and stability).
- The traffic factors (fluid, chaotic, jam, etc.).
- The technical factors (loss of technical capabilities such as perception or communication).

In addition to the environmental context, each neighbouring object (static and mobile) needs to be perceived by the subject vehicle in each time so that a manoeuvre can be safely completed. For perceived mobile objects, the prediction of their motion dynamics needs to be done considering the environmental context in which they are moving.

In summary, the environmental complexity and uncertainty (stochastic aspect) are favourable to the use of Artificial Intelligence particularly to avoid collision when vehicles' manoeuvres are judged necessary.

Figure B.1 shows a possible use of AI for collision risk analysis in the considered applications pipeline.

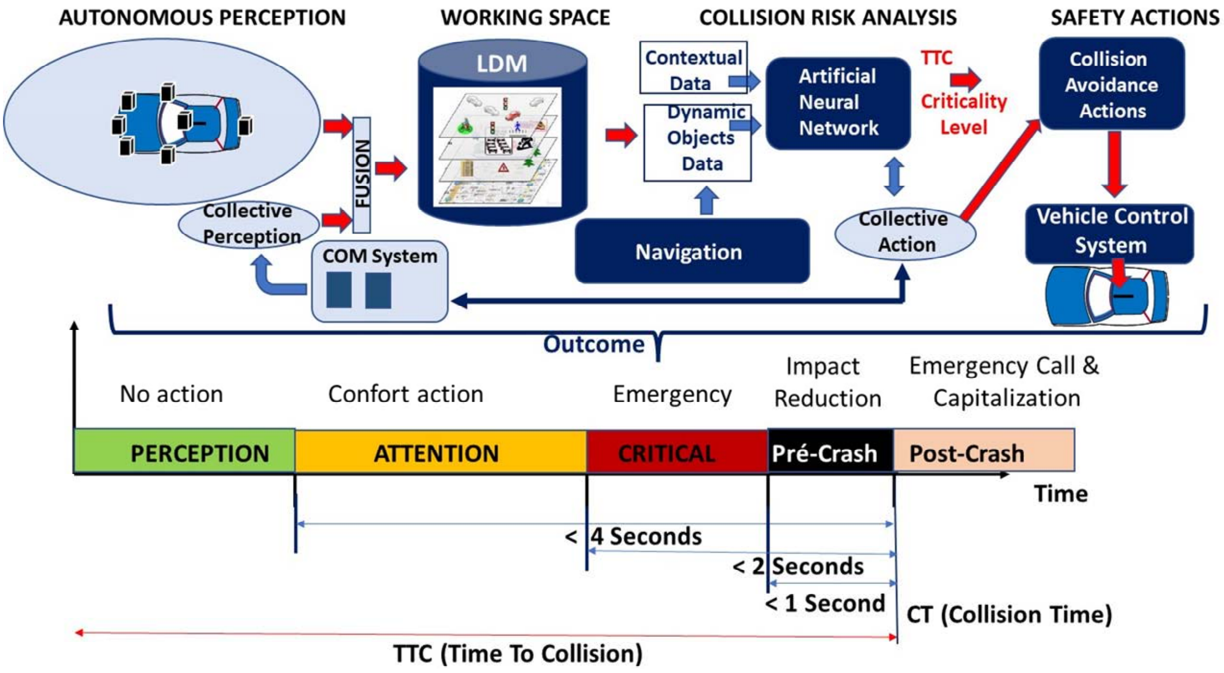

Figure B.1: Collision avoidance application pipeline and its outcome

Manoeuvres are necessary for a vehicle navigation on the road infrastructure along a selected itinerary enabling it to travel from an origin to a destination. An automated vehicle knows the succession of waypoints it will have to pass through to reach its destination except in the case of unexpected road hazard which may disturb its selected itinerary. Manoeuvres are also necessary to satisfy objectives in terms of comfort, delays, respect of the environment and so forth. As shown in Figure B.1, it is necessary to collect two types of data:

Contextual data:

- Road infrastructure data - Topology of the road, number of lanes, local traffic regulations…etc. which are part of the ODD and are signalled by horizontal marking and vertical signing.
- Technical ITS capabilities data - Mainly the perception, communication and processing capabilities of the ITS and the distribution of these capabilities in the 4 functional categories. Of course, it is necessary to know the state of the ITS in terms of availability of all expected capabilities (functional safety).
- Traffic data - Classification of the traffic situation, impacting the velocity of road users (vehicles and VRUs). For example, this could be represented by changing speed limitations in school zones over holiday periods.
- Meteorological data - Which can be severely impacting the road infrastructure availability (flooding, fires, etc.) but also the visibility or stability of road users.
- Human factors data - An overall state of the density and safety risk of the road users which are present in the area. The traffic situation as the meteorologic state may of course impact the human factors.

Objects data:

There are static and dynamic objects on the road. The position of static object is only meaningful when interacting with the trajectory of a mobile object. Data relevant to objects are:

- The type of object, its dimension/coverage (shape).
- The position of the object (reference point) and the position accuracy.
- When the object is mobile (vehicle, VRU), its trajectory (succession of positions), its velocity and stability.
- When the object is mobile, the predictability of its motion dynamic.

For the collision risk analysis function, two set of data are required to be able to anticipate a collision (detect a risk) and generate actions to avoid it:

- The evidence data set which provides real data elements collected in real time.
- The prediction data set which provides anticipated data elements for a predefined time in the future. This anticipation depends on the knowledge of the situation and its evolution (evolution of the context and evolution of the motion dynamic of the relevant mobile objects).

The data are collected according to a sampling period which currently could be between 100 milliseconds and 1 second depending on the implemented technology capabilities. This periodicity is necessary at the level of mobile object data (highly dynamic) while it could be less for contextual data.

NOTE: It is expected in the future that the technology will enable a higher sampling period to better analyse the dynamic of vehicles (for example, a vehicle running at 100 km/hour travels almost 3 meters in 100 milliseconds).

A comparison between the Evidence data set and the Prediction data set can be made to verify if the predictions are corresponding to the reality (measure of the errors). If the error is judged too important, the neuronal synaptic weights can be corrected accordingly (retro-propagation of the error gradient). For that an activation function can be used (e.g. the normal (gaussian) law with an adjustment of the mean and standard deviation for reducing the error).

The outcome of the collision risk analysis function is firstly an overall safety situation related to the ego object (collision avoidable, possible precrash mitigation, crashed with an identified kinetic energy level estimation). Then, this overall situation can be decomposed into one or several collision risks between the ego object and other objects in its vicinity. This decomposition may also indicate if other release 2 cooperative vehicles could be used either to avoid a collision when starting a new manoeuvre or to mitigate an identified collision by initiating precrash mitigation actions at the level of release 2 cooperative vehicles which could be impacted by the predicted collision.

The outcome of the collision risk analysis function is also the possibility to build a knowledge base to identify more precisely the cause of accidents (black box) and to improve the system capabilities to better predict the motion dynamic evolutions of road users (vulnerability profiles of vehicles' drivers and VRUs).

History

Document history		
V2.1.1	April 2024	Publication