Use Cases

CAR 2 CAR Communication Consortium

About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium. The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). The Consortium members represent worldwide major vehicle manufactures, equipment suppliers and research organisations.

Over the years, the CAR 2 CAR Communication Consortium has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. CAR 2 CAR members focus on wireless V2V communication applications based on ITS-G5 and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands. As a key contributor, the CAR 2 CAR Communication Consortium and its members work in close cooperation with the European and international standardisation organisations.

Disclaimer

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1 Introduction

Other (informational) **UC_00001**

The present document collects descriptions of C2C-CC reference C-ITS beyond Release 1 use cases realised based on Release 1 terminology and approach. Based on ongoing standardisation discussions it may be updated according to Release 2 terminology and approach later. The provided descriptions reflect in most of the cases developments proposed in pre-competitive R&D initiatives, often validated via prototypic proof-of-concept implementations. The described use cases adopt novel approaches going beyond those specified in current European C-ITS standards. Therefore, they can be used as input material for the ETSI TC ITS WG1 work item defining the basic set of applications (BSA) considered for the ETSI TC ITS Release 2 set of standards.

The C2C-CC use cases of this document are described using a common template specifically realized by the C2C-CC to highlight, in a consistent and harmonized way, some key aspects for the description of use cases. **This template adopts standard terms** defined in ETSI EN 302 665 [1] (ITS Service, ITS application, ITS-S Service, ITS-S application, …) **and explains how those terms shall be used** for describing use cases. The rest of the document is organized in the following way: Section 2 introduces the definitions of the main standard terms adopted; Section 3 describe the template used for the description of use cases: section 3 collects the C2C-CC use cases descriptions in sub-sections dedicated to specific use cases categories mapping ETSI BSA Rel2 ITS services.

2 Definitions

Other (informational) **UC_00002**

The ETSI EN 302 665 provides the following definitions that can be adopted for the definition of use cases:

ITS Station (ITS-S): functional entity specified by the ITS station (ITS-S) reference architecture (i.e. vehicle ITS-S, roadside ITS-S, central ITS-S, personal ITS-S)

ITS-S service: communication functionality offered by an ITS-S to an ITS-S application (e.g. Cooperative Awareness Service, Decentralized Environmental Notification Service, etc.)

ITS-S application: fragment of an ITS application available at an ITS station that uses ITS-S services to connect to one or more other fragments of the same ITS application (e.g. a stationary vehicle warning application running at a vehicle ITS-S detecting the stationary state and transmitting a notification using the DEN service)

ITS application: association of two or more complementary ITS-S applications (a stationary vehicle warning application composed of a transmitting and a receiving stationary vehicle warning ITS-S applications)

ITS Service: service provided by an ITS application to the user of ITS (e.g. road hazard signalling is an ITS service that can be provided by stationary vehicle warning applications, as well as by many other applications of the same category: slow moving vehicle-, weather condition warning, etc.)

By reusing the above standard definitions, **a “Use Case” can be defined here as a specific implementation of an ITS application to provide an ITS service to ITS users.**

Such definitions are to be considered in the rest of this document.

3 C2C-CC template structure for use case description

Other (informational) **UC_00003**

In the C2C-CC use case description template, use cases are always grouped under use case categories mapping ITS services listed in the ETSI BSA Rel2 document. Use cases falling under a given ITS service share the general goal of the ITS service. Each individual use case is then described in terms of its specific target, the possible system architectures, and the possible implementation options usable for its realization. The use case description template reflecting this approach is schematically represented in the following table. The use cases in Section 3 are described using this scheme.

ITS Service High level description of the ITS service; common goal and expected impact of the multiple use cases falling under this category	**UC1 description**	**High level description** Briefly describes the specific goal of this use case
		Possible system architectures Architecture A: describes the type of ITS-S involved in the execution of the use case, their role and the relationships to the other ITS-S (possibly use drawings) Architecture B…N: If alterative architectural options are possible, describe them as per Architecture1
		Possible implementation options: Implementation A: refers to one of the above architectures to briefly describe, for each of the involved ITS-S, the functions implemented by their ITS-S applications as well as the used ITS-S services (possibly use drawings) The ITS-S service description shall indicate what kind of messages are used and if extensions of existing messages are needed. Implementation B…N: if alternative implementation options are possible, describe them as per Option1
	UC2 description	As UC1 description
	…	…
	UCN description	As UC1 description

4 Use case specifications

4.1 Vehicles Coordination

Other (informational) **UC_COOP_00001**

Under this ITS service fall ITS applications that use ITS-S services to coordinate vehicle movements in terms of manoeuvres or trajectories. As the capability to plan possible future manoeuvres and trajectories is a prerogative of vehicles with higher automation levels (L3+), this ITS service is targeted at those vehicles. Several forms of coordination with different complexity are possible. For example, messages can be exchanged to allow vehicles follow, at a safe distance, the trajectory of other vehicles in front. Alternatively, vehicles can exchange messages to notify the intention to implement specific manoeuvres, enable cooperative manoeuvres as well as to acknowledge whether manoeuvre intentions of other vehicles' can be safely implemented. Coordination can run between vehicles or with the support of the road infrastructure. In this last case, roadside or central ITS-Ss might suggest vehicles to implement specific manoeuvres that in turn vehicles could decide to accept or not based for example on own safety constraints in the current driving environment. The manoeuvre suggestions could be common to several vehicles or specifically addressed to individual vehicles.

In any case, the expected impact of this ITS Service is to increase traffic safety and efficiency at the same time thanks to an explicit coordination of actions between cooperative highly automated vehicles. Knowing about each other "plans" would allow receiving vehicles to know in advance how to react (e.g. safely slow down when a vehicle ahead notifies the intention to merge on the ego-lane), but also to keep less conservative time gaps from the surrounding cooperative vehicles.

4.1.1 Cooperative Lane Merging (CLM)

UseCase **UC_COOP_00002**

A merging vehicle on a highway entry and one or more vehicles on the main highway participate in a cooperation process aimed at letting the merging vehicle merge on the highway safely (the gaps between the vehicles are always above safety thresholds) and smoothly (none of the involved vehicles abruptly decelerate or accelerate).

4.1.1.1 Possible system architectures

Architecture A

In this first architecture the CLM runs among vehicles only, by means of V2V communication. A merging vehicle A is present on the entry, and at least one vehicle B on the main highway conflicts with the merging manoeuvre of vehicle A.

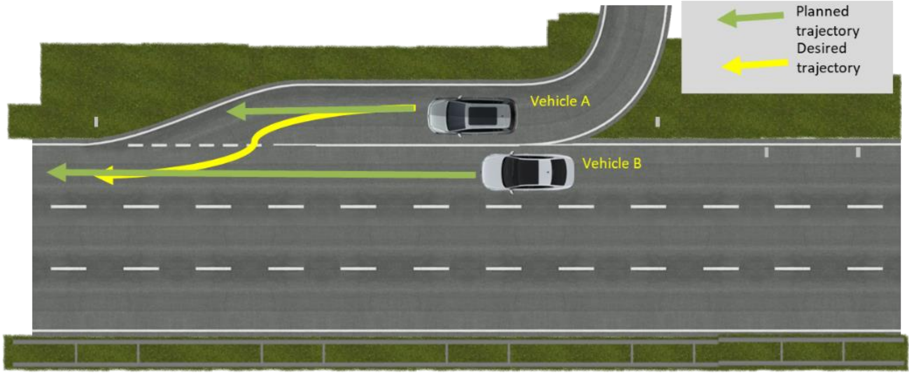
Architecture B

In this second architecture the CLM runs with the help of a roadside ITS-S. A merging vehicle A is present on the entry, and at least one vehicle B on the main highway conflicts with the merging manoeuvre of vehicle A. A roadside ITS-S is able to detect a possible conflict and communicate with the conflicting vehicles via I2V communication.

4.1.1.2 Possible implementation options

Implementation A

This implementation option refers to Architecture A. Both vehicles run a cooperative merging ITS-S application and an ITS-S service based on exchange of manoeuvre coordination messages (MCMs). Both vehicle A and B use these messages to continuously broadcast their respective planned trajectories (see Figure 1). At the merging section, vehicle A includes a desired trajectory in the message to notify the intention to merge on the highway. Vehicle B detects the merging needs of vehicle A and, if safely and smoothly possible, adapts its planned trajectory to accommodate it. Upon receiving vehicle's B adapted planned trajectory, vehicle A starts implementing its desired merging manoeuvre till completing it. Vehicle A planned trajectory is replaced by the previously transmitted desired trajectory.

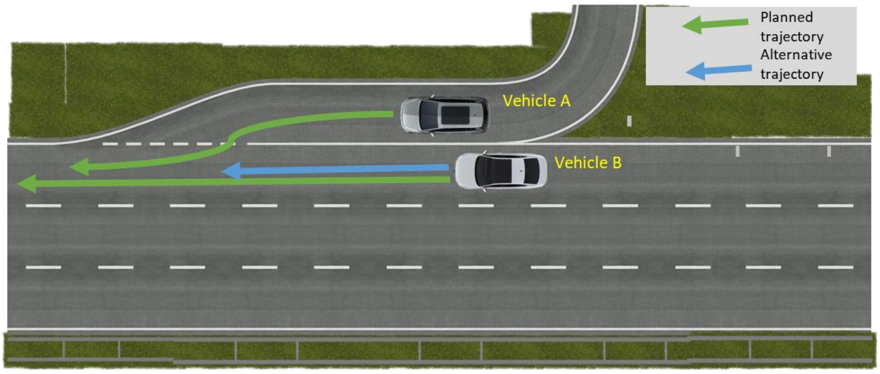


Source: Car2Car Communication Consortium

Figure 1: Example of distributed V2V cooperative merging scenario

Implementation B

This implementation option refers to Architecture A as well and is based on the use of alternative trajectories. Alternative trajectories are a new trajectory type demonstrated by the IMAGinE research project [2] which may be transmitted by cooperative vehicles as cooperation offer to another vehicle. Both vehicles run a cooperative merging ITS-S application and an ITS-S service based on exchange of manoeuvre coordination messages (MCMs). Both vehicle A and B use these messages to continuously broadcast their respective planned trajectories (see Figure 2). At the merging section, Vehicle B detects vehicle A's need for cooperation and includes an alternative trajectory in the message to offer a cooperative manoeuvre. Vehicle A accepts the cooperation offer and adapts its planned trajectory to merge on the highway. Upon receiving the adapted planned trajectory from vehicle A, vehicle B selects its alternative trajectory as planned trajectory and starts implementing its cooperative manoeuvre.

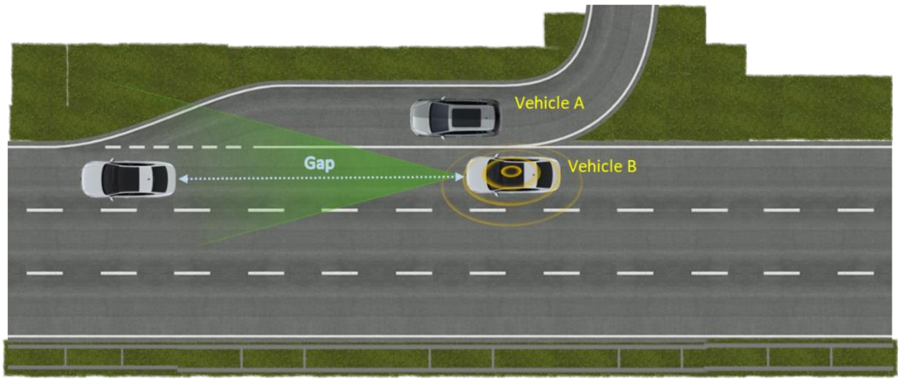


Source: Car2Car Communication Consortium

Figure 2: Example of distributed V2V cooperative merging via cooperation offer (IMAGinE project)

Implementation C

This implementation option refers to Architecture A as well. Vehicle A runs a cooperative merging ITS-S application and an ITS-S service based on exchange of collective perception messages (CPMs). Vehicle B sends CPMs to continuously broadcast data relative to the perceived objects with its on-board sensors (see Figure 3). At the merging section, vehicle A receives the CPMs from Vehicle B and can estimate the available gap(s) for merging on the highway. If a suitable large enough gap is identified, vehicle A adapts its trajectory to merge on the highway. Otherwise, vehicle A stays on the acceleration lane until a suitable gap (e.g., after vehicle B) can be found.



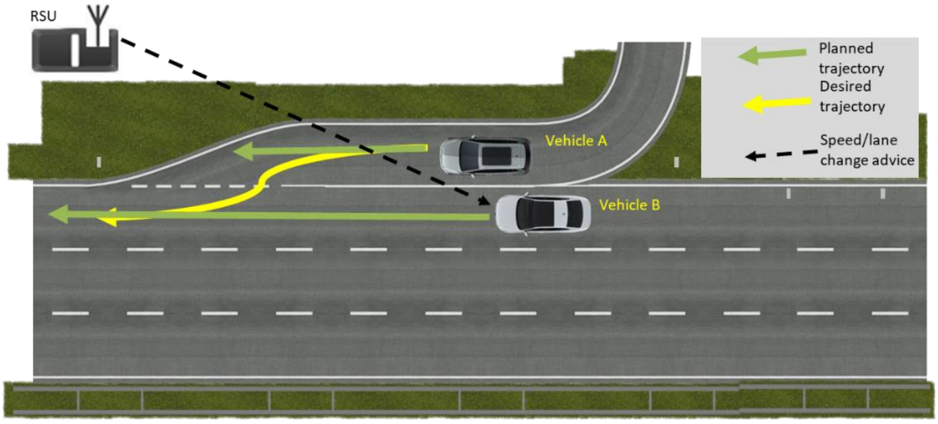
Source: Car2Car Communication Consortium

Figure 3: Example of distributed V2V highway merging via collective perception

Implementation D

This implementation option refers to Architecture B. Besides the vehicles, a roadside ITS-S is present and runs a centralized CLM application also making use of manoeuvre coordination messages. Both vehicles run a ITS-S cooperative merging application and an ITS-S service based on exchange of manoeuvre coordination messages (MCMs). Both Vehicle A and B use these messages to continuously broadcast their respective planned trajectories. At the merging section, vehicle A includes a desired trajectory in the message to notify the intention to merge on the highway. Vehicle B detects that the desired trajectory of vehicle A collides with its own planned trajectory but does not initially let vehicle A merge. If considered beneficial for traffic efficiency, the ITS-S application running at the roadside station uses its ITS-S manoeuvre coordination service to transmit messages suggesting vehicle B to adapt its speed or change lane to let vehicle A merge. If safely and smoothly possible, vehicle B adapts its planned trajectory to accommodate this merging. Upon receiving vehicle's B adapted planned trajectory, vehicle A starts implementing its desired merging manoeuvre till completing it. Vehicle A planned trajectory is replaced by the previously transmitted desired trajectory.

Lane- or speed change advices could be included in infrastructure-based MCMs as adopted in the EU H2020 TransAID project (see [3] [4]).

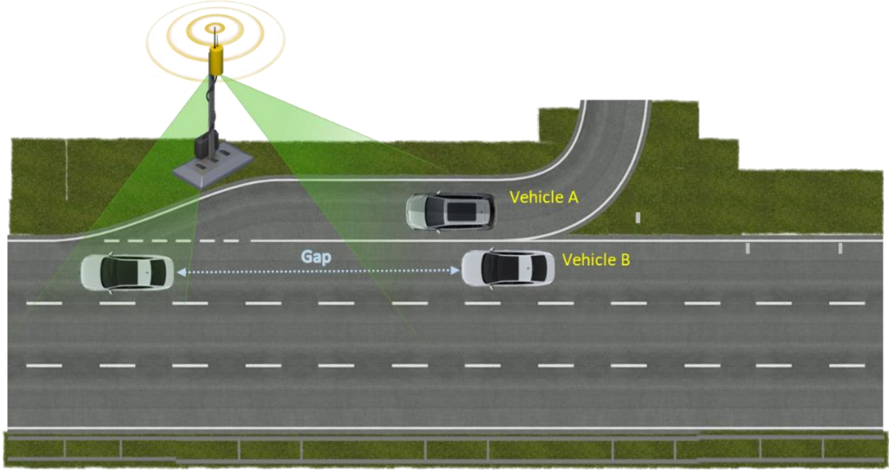


Source: Car2Car Communication Consortium

Figure 4: Example of Infrastructure-assisted cooperative merging scenario

Implementation E

This implementation option is similar to Implementation C but using Architecture B instead. Besides the vehicles, a roadside ITS-S is present and sends CPMs to continuously broadcast data relative to the perceived objects with its on-board sensors (see Figure 5). Vehicle A receives the CPMs from the roadside ITS-S and executes the merge manoeuvre analogously to Implementation C. This concept was successfully demonstrated in a test site in the German research projects MEC-View [5] and LUKAS [6].



Source: Car2Car Communication Consortium

Figure 5: Example of Infrastructure-assisted highway merging via collective perception (MEC-View and LUKAS projects)

4.1.2 Cooperative Transition of Control

UseCase **UC_COOP_00003**

For highly automated vehicles (L3+) a transition of control (ToC) is the process by which driving and monitoring tasks are handed over from the automated system to the human driver. It has been demonstrated by several studies that, depending on the level of attention of the driver, the first instants after the takeover might be critical and lead to an erratic driving behaviour, which in turn can be a risk for surrounding traffic. This phenomenon can imply even bigger risks at the so called “transition areas” where, due to multiple possible reasons (e.g. ODD violation), a big number of automated vehicles might want to give back control to their drivers in the same place at the same time. If takeovers fail at one or multiple vehicles, additional risks and inefficiencies (e.g. accidents or traffic jams) can be caused by minimum risk manoeuvres (MRM). To mitigate the possible negative effects of transition of ToCs and MRMs, cooperative transition of control ITS applications can be implemented. Vehicles can inform each other in a distributed way about imminent transition of control and minimum risk manoeuvres. Similarly, the road infrastructure can anticipate simultaneous occurrence of transitions of control in the same location and suggest incoming vehicles to trigger their transition at distinct points and times, in such a way not to concentrate the them in the same area.

Architecture A

In this first architecture the cooperative transition of control runs among vehicles only.

Architecture B

In this second architecture the cooperative transition of control runs with the help of a roadside ITS-S.

4.1.2.1 Possible implementation options

Implementation A

This first implementation option refers to Architecture A. Two or multiple highly automated vehicles are currently engaged in cooperative manoeuvring (e.g. executing a cooperative lane change, a cooperative merging, etc.). During the manoeuvre coordination process (i.e.

exchange of planned and desired trajectories), one of the two vehicles experiences the need of a ToC. As the ToC will be followed by human driving or, in an unfortunate case, by a MRM, the manoeuvre coordination might not successfully be completed in time (see Figure 6). To estimate the possibility for the process to be completed, or the necessity for aborting it, the other cooperating vehicle needs to know when exactly the ToC is going to happen and to which (lower) automation level the ToC vehicle will transit.

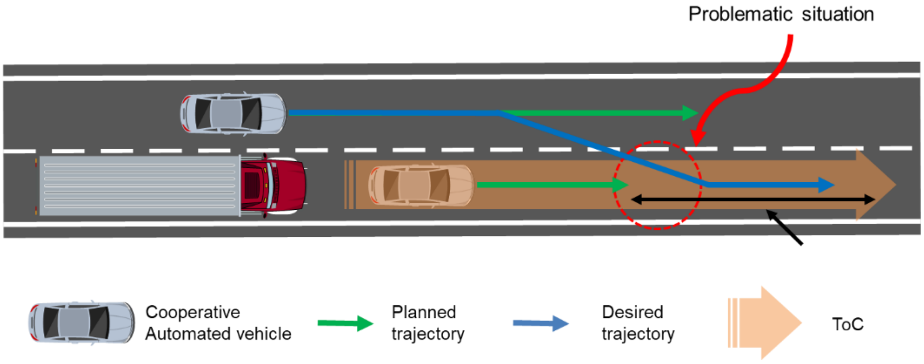


Figure 6: ToC during manoeuvre coordination (H2020 TransAID)

To cope with this need, both cooperating vehicles can extend their ITS-S manoeuvre coordination applications with functionalities to consider the occurrence of ToC and MRMs. The vehicles about to trigger a ToC can use an extended manoeuvre coordination ITS-S service with MCMs carrying ToC and MRM information (namely the estimated time of start of a ToC and eventually a MRM, plus the target automation level). Vehicles receiving this information can take it into account to implement according manoeuvre coordination decisions.

Implementation B

This second implementation option refers to Architecture B. Multiple highly automated vehicles are currently heading towards a no AD zone (i.e. a zone where due to multiple possible reasons, AD is not possible or not allowed at all by the road infrastructure operators). The highly automated vehicles inform the road infrastructure if they are currently driving in automated mode and, if yes, with which level. This information can be included in CAM message extensions. By collecting this, along with legacy CAM information (position, speed, acceleration, heading, etc.), a road infrastructure controller can run a ITS-S application to define the best strategy not to concentrate ToCs in the road segment directly before the No-AD zone (the no-AD zone might be a roadworks zone with only a reduced number of lanes available, and a vehicle in MRM blocking the lanes would very negatively impact the traffic flow). A possible strategy might be distributing the ToC of distinct vehicles at different locations upstream (see Figure 7). For this purpose, the RSU can use an extended infrastructure-based manoeuvre coordination ITS-S service where transmitted MCMs include vehicle-specific ToC advices or safe spot advices. The ToC advice indicates a specific road segment and range distance within which a ToC start is suggested. Similarly, a safe spot advice indicates where the vehicle can safely stop in case a MRM is necessary (see [4]). Upon receiving these infrastructure-originated MCMs, vehicles can decide whether to comply or not with the suggested advice based on internal AD policies and parameters. The advised vehicles can then use specific extensions of MCMs called AdviceResponses to acknowledge the road controller if a given suggestion is being followed. Collecting this information in real time is important for the road controller to understand if the ToC suggestion strategy shall be adapted or if a different assignment of safe spots shall be applied.

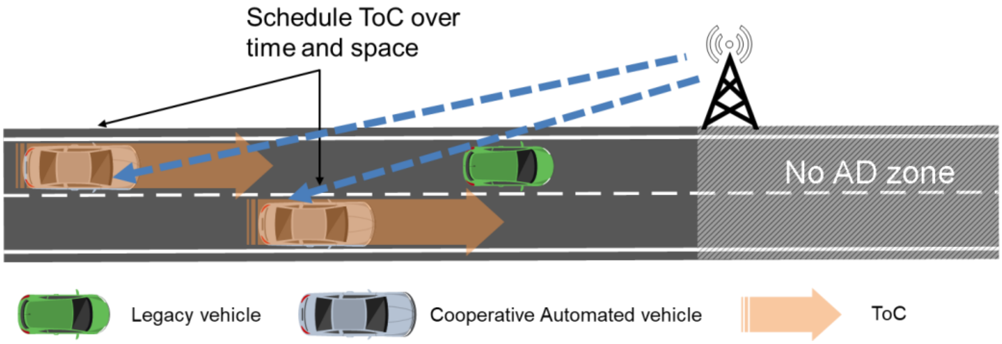


Figure 7: road infrastructure-originated distribution of ToC advices (H2020 TransAID)

4.1.3 Advanced Cooperative ACC (String) (AC-ACC S)

UseCase **UC_COOP_00004**

4.1.3.1 High level description

This use case is based on the use of V2X to obtain lead vehicle dynamics and general traffic ahead in order to enhance the performances of ACC and ACC string as defined in section xx. Compared to the normal CACC it includes support for lateral vehicle control in addition to longitudinal one. As a consequence, it will require usage of safety containers guaranteeing higher information quality. In case of a string of ACC vehicles, the control of the string is decentralized and differently from Platooning does not require a dedicated platoon control message. The infrastructure can play a similar role as for CACC and CACC-S using IVIM extensions. In this case IVIMs can additionally suggest lane changes. As this use case might be run by vehicles with high automation level IVIMs are expected to be as well complemented by safety containers (for functional safety reasons)

4.1.3.2 Possible system architectures

Architecture A:

One possible architecture for this use case operates on V2V communication only. At least one vehicle B follows a lead vehicle A. Vehicle B actuates both its longitudinal and lateral control based on the information received on vehicle A’s dynamics via CAM and/or CPM.

Architecture B:

A second architecture option is the additional inclusion of I2V communication. In this architecture, the actuation of longitudinal and lateral control of both the leading and following vehicle takes information and recommendations received through IVIM by the infrastructure into account.

4.1.3.3 Possible implementation options:

Implementation A:

The implementation for an Advanced C-ACC (S) builds upon the implementations of the basic C-ACC (S) for longitudinal control using the Architecture A. In the advanced case described here, additionally the lateral control is supported by extended CAM information. A following vehicle can use information on lateral manoeuvres received from a leading vehicle to actuate the lateral path planning and control. In addition to the CAM, the MCM can be used in the future to further enhance the service.

Implementation B:

This implementation builds on Architecture A. In the advanced case described here, the longitudinal and lateral control are supported by CAM and CPM information. A following vehicle can use CAM information (for detection of V2X-equipped vehicles) and CPM information (especially for detection of non-equipped vehicles) received from a leading vehicle to actuate the longitudinal and lateral path planning and control.

Implementation C:

This implementation option builds on Architecture B and, same as Implementation A, adds the lateral control component to the basic, infrastructure assisted C-ACC (S). In addition to the decentralized functionality based on V2V communication through extended CAMs only, the infrastructure provides support through additional information provided in (extended) IVIMs. As for the basic infrastructure assisted C-ACC (S), the infrastructure can still suggest how many vehicles should form a C-ACC string, and suggest timings a location for lane changes of the entire string or individual vehicles where advisable (i.e. recommend break-ups of the string).

4.2 Intersection Crossing Assist

Other (informational) **UC_CrosA_00001**

Under this ITS service fall ITS applications that use ITS-S services to assist vehicle movements at signalized and not signalized intersections. This service is targeted to vehicles capable to know about the intended navigation route to transit through an intersection (inbound-outbound intersection approaches and possibly lanes) and up to L3+ vehicles able to plan target manoeuvres and trajectories. Several forms intersection crossing assist with different complexity are possible as detailed in the use cases below. In any case, the expected impact of this ITS Service is to increase traffic safety and efficiency at the same time thanks to a more explicit and informed coordination of actions between cooperative vehicles or with the road infrastructure. Knowing about vehicles intended routes or “plans” can help vehicles to coordinate the intersection transit in an automated way at not signalized intersection. From the other end, it allows intersection control systems to develop extended algorithms (e.g. with AI) to better allocate traffic demands hence improving the traffic flow.

4.2.1 Automated Green Light Optimum Speed Advisory (A-GLOSA)

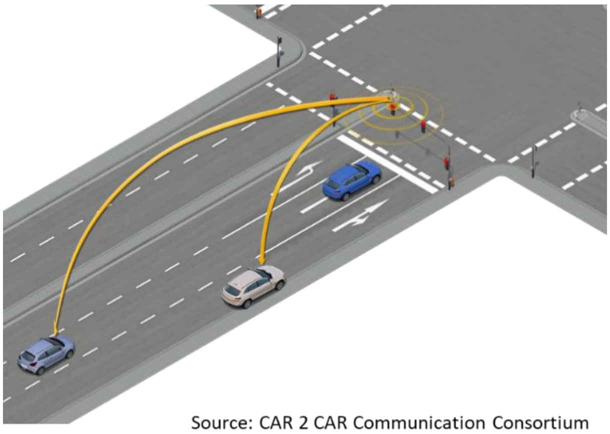
UseCase **UC_CrosA_00002**

Extends the GLOSA ITS application by implementing automated functions at the ITS-S application running on the vehicle. This function tries to automatically adopt the GLOSA speed, which can be either explicitly suggested by the infrastructure or computed by the ITS-S application running on the receiving vehicle. This use case might be run by vehicles with level of automation ranging from L1 to L5. The specific goal of this use case is to assist cooperative vehicles to automatically adapt their speed to pass the intersection at the green light on their intended route, or to smoothly decelerate and stop at the red light.

4.2.1.1 Possible system architectures

Architecture A

In this architecture the A-GLOSA runs with vehicle ITS-Ss helped by an intersection control system using a roadside ITS-S. One or multiple vehicle ITS-Ss approach the intersection on one or multiple inbound lanes. The intersection control system is able to detect incoming vehicles and uses an ITS-S service that provides topology- (MAPEM) as well as signal phase and time information (SPATEM) via the roadside ITS-S. (See Figure)



Source: CAR 2 CAR Communication Consortium

Figure 8: Example of A-GLOSA scenario

4.2.1.2 Possible implementation options

Implementation A

The first implementation option refers to Architecture A. Vehicles receive MAPEM and SPATEM information, calculate the GLOSA speed locally and apply it for intersection transit or stop. For doing so, they consider, besides the received SPAM and MAP information, their current position and dynamics as well as their target route at the intersection. As vehicles would heavily rely on SPATEM and MAPEM information, these messages se are expected to be complemented by safety containers expressing the quality and accuracy of the provided topological and timing information (for functional safety reasons).

Implementation B

This second implementation option also refers to Architecture A. Differently from the previous option, vehicles receive a GLOSA speed advice within the SPATEM. This advice is possibly applied by the vehicles for intersection transit or stop. As vehicles would heavily rely on the received speed advices, SPATEM messages se are expected to be complemented by safety containers expressing the quality and accuracy of the provided information (for functional safety reasons)

4.2.2 Optimized Traffic Light Information with V2I

UseCase **UC_CrosA_00003**

In proximity of signalized intersections, cooperative automated vehicle ITS-Ss (isolated or organized in strings (platoons or CACC)) continuously transmit information describing their status (e.g. the occurrence of a hazardous event), intentions (e.g. planned route for transiting intersection), targets (e.g. desired speeds), or characteristics (e.g. string size, current automation level, etc.). By collecting this explicit probing V2I information, the intersection control system (e.g. the traffic light controller) can run an ITS-S application to improve the safety and efficiency of the intersection. Depending on the applied strategy, the intersection control system will dynamically adapt the information transmitted to the vehicles in terms of SPATEMs and MAPEMs and possibly generate advices that vehicles can automatically apply at their ITS-S applications to transit the intersection while meeting the intersection control system's goals.

4.2.2.1 Possible system architectures

Architecture A

In this architecture, the use case runs with vehicle ITS-Ss helped by an intersection control system using a roadside ITS-S. One or multiple vehicle ITS-Ss approach the intersection on one or multiple inbound lanes. Vehicles can approach the intersection isolated or organized in strings (platoons or CACC string). The intersection control system runs an ITS-S application able to detect incoming vehicles and can establish with them, via a roadside ITS-S, a bi-directional communication.

4.2.2.2 Possible implementation options

Implementation A

The first implementation option refers to Architecture A. Vehicles affected by a hazard (e.g. broken-down situation) on a specific inbound or outbound lane run a ITS-S application detecting the problem and broadcasting a DENM containing an identifier of the lane where the hazard occurs. This detailed information is used by the ITS-S application of the intersection control system to dynamically update the allowed topological in/out connections and the associated sign and time information. The updated information is then reflected in the MAPEM and SPATEM information transmitted by the associated Roadside ITS-S. An example is highlighted in Figure 9. A broken-down vehicle blocks the right-turning traffic lane on the west approach of the intersection (approach C, lane 5). As a consequence, vehicles can only use the through traffic lane (approach C, lane 6) to turn right, which is not initially allowed. Without any additional intersection signaling information, automated vehicles would not understand the situation, they would get blocked and possibly request the driver to take over, with possible negative impacts on traffic flow.

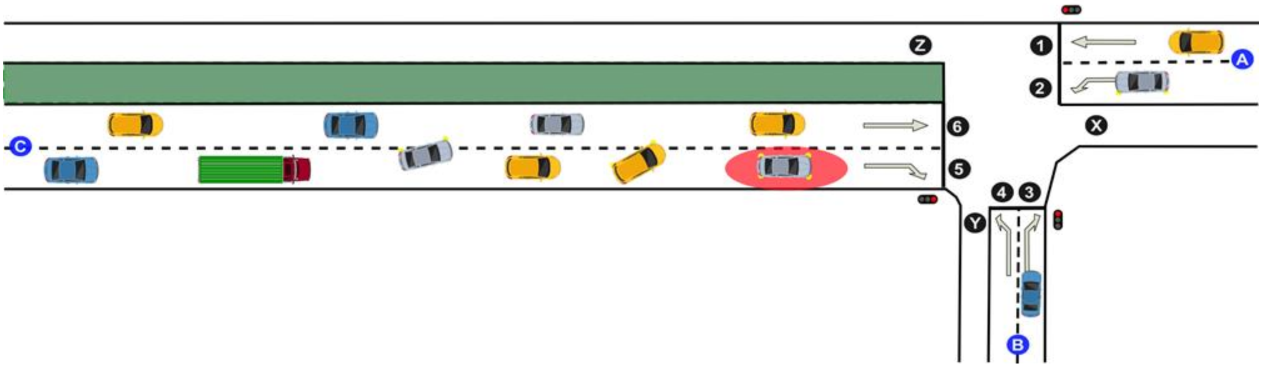


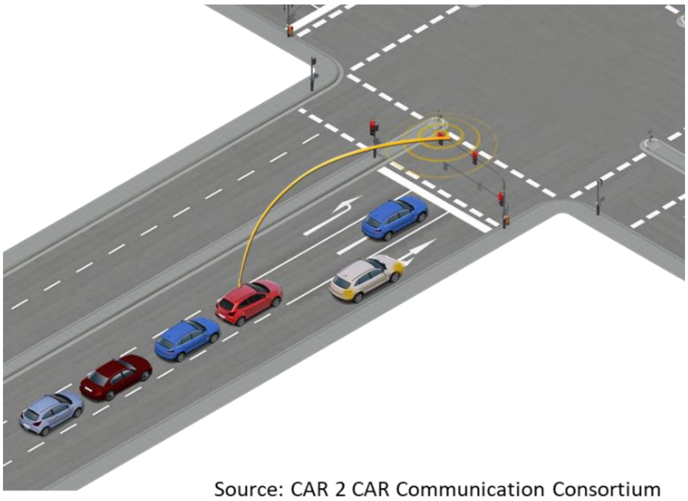
Figure 9: Broken-down vehicle blocking in/out connection at a signalized intersection [3]

To unblock the situation and minimize the associated negative effects on traffic flow, the following actions can be executed: the broken-down vehicle broadcast a DENM unambiguously indicating the blocked lane; the intersection control system receives the DENM and modifies the MAPEM and SPATEM information to inform all the incoming cooperative vehicles (automated and not) that the left lane can be used to turn right (optionally, and if necessary or useful, the sign and time information can be dynamically adapted to this situation).

In order for this use case to be realized, extensions to the DENM rel1 are needed so that it can explicitly and correctly refer to specific MAPEM intersection and lane identifiers. Moreover, as this implementation option implies dynamic modifications of consolidated intersection control programs by inclusion of external information received by vehicles via V2X, it is necessary that DENMs are complemented by safety containers expressing the quality and accuracy of the transmitted information (for functional safety reasons).

Implementation B

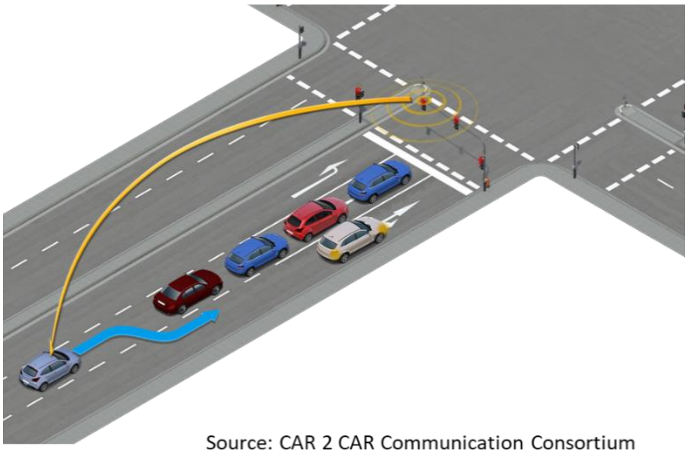
This second implementation option also refers to Architecture A. Isolated cooperative automated vehicles ITS-Ss and/or cooperative vehicles organized in strings (platoons or CACC strings) use a dedicated ITS-S to continuously broadcast one or multiple information among the following ones: their planned route for transiting the next intersection (in terms of in/out lane connections), the overall route to reach their destination (e.g. including other downstream intersections managed by the same controller), desired speed values (e.g. optimal speed), and vehicle/string characteristics (e.g. size of an incoming string of vehicles, current automation level, etc.). By collecting this explicit probing V2I information, the ITS-S application running at the intersection control system (e.g. the traffic light controller) can update its queue models and calculate more efficient traffic light phases and durations at all the intersections under its management. The results of these calculation are then reflected in dynamically updated SPATEM and MAPEM messages. As an example (see Figure 10), the intersection control system might extend a green light phase duration to let an entire string, approaching at a given target speed, pass the intersection before the red phase starts, in such a way not to “split” the string.



Source: CAR 2 CAR Communication Consortium

Figure 10: String of vehicles heading at a signalized intersection (H2020 MAVEN)

In another example (see Figure 11), the intersection control system might use the V2I probe information to detect that two ingressing lanes are very differently occupied by incoming traffic. In reaction, the ITS-S application running at the controller could either include lane-specific GLOSA advices in SPATEMs (e.g. assigning 2 distinct signal groups to the two lanes that initially would be associated to the same signal group), or suggest specific incoming vehicles to change to the less occupied lane.



Source: CAR 2 CAR Communication Consortium

Figure 11: Lane-specific GLOSA and lane change advices at signalized intersections (H2020 MAVEN)

The probe I2V information can be included in CAM extensions of different types (see [7]) and be broadcasted by vehicles of different automation levels depending on their capability to generate that information (e.g. in/out route at intersections might be available thanks to navigation systems also at vehicles with lower automation, while information about possible participation in a vehicle string might be only available at vehicles with higher automation). As for the previous one, this implementation option implies dynamic modifications of consolidated intersection control programs by inclusion of external information received by vehicles via V2X. As a consequence, it is necessary that future CAM extensions are complemented by safety containers expressing the quality and accuracy of the transmitted information (for functional safety reasons). Regarding the messages generated by the infrastructure, SPATEM and MAPEM messages would also require extensions for safety containers expressing the quality and accuracy of the provided topological, timing and speed advice information (this is again for functional safety reasons at the automated systems of receiving vehicles). Finally, lane change advices could be included in infrastructure-based MCMs as adopted in the EU H2020 TransAID project (see [3] [4])

4.2.3 Automated GLOSA with negotiation

UseCase **UC_CrosA_00004**

This use case and extends the approaches of the previously described A-GOLSA and Optimized Traffic light information with V2I. It is targeted to cooperative vehicles with high level of automation being capable to negotiate about the received speed or lane change advices with the intersection control system. Cooperative automated vehicles inform the controller in real time if the received advices are being followed or not. This additional feedback can be used by the ITS-S application at the intersection controller to further refine the traffic light phase and time algorithms and produce refined or alternative advices, such to further optimize the traffic flow at the intersection or at intersection corridors.

4.2.3.1 Possible system architectures

Architecture A

In this architecture, the use case runs with vehicle ITS-Ss negotiating with an intersection control system through a roadside ITS-S. One or multiple vehicle ITS-S approach the intersection on one or multiple inbound lanes. Vehicles can approach the intersection isolated or organized in strings (platoons or CACC string). The intersection control system runs ITS-S application that is able to detect incoming vehicles and establishes with them, via a roadside ITS-S, a real time bi-directional communication.

4.2.3.2 Possible implementation options

Implementation A

This implementation option refers to Architecture A. After having assisted the intersection controller with V2I probe data and upon receiving speed or lane change advices, the ITS-S application of cooperative automated vehicles inform the controller in real time if the received advices are being followed or not (i.e. if speed or driven lanes are being adapted as suggested, or if these adaptations cannot or do not want to be applied). This additional feedback can be used by the ITS-S application of the intersection controller to further refine the traffic light phase and time algorithms and in turn modify speed advices in SPATEM messages or lane change advices in Infrastructure-based MCMs. As an example, if a big string of cooperative automated vehicles acknowledged that the currently received speed advice is being followed, then the intersection controller would put high priority at keeping the duration of the green phase as long as needed for the string to pass the intersection. On the contrary, if the advice is not followed, then the time resources of the intersection controller could be better allocated at another in/out connection.

The feedback on the current compliance to a speed or lane change advise can be either included in extensions of CAMs (see [7]) or MCMs (see [3] [4]) transmitted by vehicles. As for the previous use cases, safety containers complementing messages transmitted by both vehicles and infrastructure units need to also express the quality and accuracy of the provided information for functional safety reasons.

4.3 Partial and high automation

Other (informational) **UC_Autom_00001**

ITS applications categorized under the ITS service "Partial Automation" make use ITS-S services to trigger and control automated reactions at vehicles with low- (i.e. L1-L2 vehicles where the driver is still in charge of driving and monitoring tasks) as well as high automation capabilities (L3+ vehicles where the driver is released partially or totally from his monitoring and driving responsibilities). In this context, wireless V2X communications and ITS-S services extend the capabilities of traditional ADAS and automated functions providing longer and non-line of sight detection ranges, as well as explicit communication of information between senders and receivers. Thanks to this extended and improved knowledge, ITS applications can apply and control more timely, informed and precise automated reactions, which in turn increases traffic safety and efficiency. Depending on the type of information exchanged and the ITS application reaction implemented, several forms of partial and high automation are possible. Some examples are listed below.

4.3.1 Hazardous Location Notification – Vehicle Assistance

UseCase **UC_Autom_00002**

The specific goal of this use case is to provide ITS-S applications at receiving vehicles with more time and information to better assist semi-automated (ADAS) or automated reactions in presence of unexpected road hazards. A transmitting ITS-S notifies incoming traffic about occurrence, details and evolution of a hazardous situation via DENMs. ITS-S applications at receiving vehicles process the information contained in DENMs, run a relevance check to understand if a given automated reaction is needed and, depending on the type and details of the hazards, the current vehicle status and relative dynamics, apply the most suitable reaction.

4.3.1.1 Possible system architectures

Architecture A

In this first architecture the use case runs among vehicles only. A transmitting vehicle triggers transmission of DENMs after detection of a hazardous situation and continuously updates the DENM content to describe possible evolution of the hazardous situation or its contextualization to the driving environment (e.g. lane, zone, road configuration where the hazard exists). One or multiple receiving vehicles approach the hazard location.

Architecture B

In this second architecture the use case runs with the help of a roadside ITS-S. the hazardous situation is detected, communicated and updated by a roadside ITS-S. A.

4.3.1.2 Possible implementation options

Implementation A

The first implementation option refers to Architecture A. The DENMs transmitted by the vehicle ITS-S reflect the type of hazard, the location where it applies, the area and traffic direction where vehicles have to be aware of it, possible additional information that can help receiving vehicles to take reaction decisions (e.g. lane or geographical zone where the event is occurring, the speed limit that should be applied when approaching the event, the road configuration of the road segments where the event happens). Besides this, the DENMs continuously inform the incoming traffic about temporal validity of the provided information (e.g. till when the information is considered to be valid), and dynamically communicate if any of the previously provided information has changed. ITS-S applications at receiving vehicle process the information contained in DENMs, run a relevance check to understand if a given automated reaction is needed and, depending on the type and details of the hazards, the current vehicle status and relative dynamics, apply the most suitable reaction. The reaction can be different also depending on the currently supported automated level. At vehicle currently running L1/L2, the reaction can be suggestion and/or direct execution of speed adaptations (e.g. when approaching a dangerous end of queue) or lane changes (to evade a lane blocked by a stationary vehicle) while the driver is still managing the monitoring tasks. At vehicles running higher automation levels (L3+) the reaction is very much depending on the presence of details describing the hazard. If these details are sufficient for the automated function to keep high automation through the hazard location with a target level of safety, then no human driver intervention will be requested. This can be the case when the received DENMs ensure with a sufficient level of confidence that the hazard is located on a very specific location (lane or zone of a known road configuration), that can be safely evaded by the automated function (e.g. a roadworks trailer or a stationary vehicle blocking the rightmost lane of a road segment configured with 4 lanes; in this case the vehicle might change lane to drive temporarily on the leftmost lanes). On the contrary, when the DENM does not contain sufficient details for the automated function to determine the safety of a given situation, a takeover request will be triggered for the human driver to re-engage his driving and monitoring tasks. This can be the case of a DENM informing of a hazard downstream but without further details on where on the road configuration this is actually happening.

To implement the above use case, safety container extensions of the DENM contents are needed to express the accuracy of the provided information for functional safety reasons. Moreover, additional containers would be beneficial to better describe with configurable shapes the areas where events are applicable (at the moment the hazard location can be expressed only with one geographical point, a set of consecutive points or one lane). Finally, an additional container describing unambiguously the road configuration (number of lanes and their type) of the segment where the hazard exist, can considerably help the receiving ITS-S application in apply meaningful and safe reactions.

Implementation B

This second implementation option refers to Architecture A. In this implementation option, a vehicle is currently engaged in higher automation levels (L3+) and has detected a violation of the ODD, which causes a takeover request to the driver anticipating a Transition of Control (ToC). If the ToC fails (the driver does not take over), a minimum risk manoeuvre (MRM) is executed. As sudden transition of control from high automated- to manual driving might imply an erratic driving behaviour of the vehicle in the first instants after the takeover, it is reasonable for the vehicle to run an ITS-S application that triggers transmission of a DENM informing other vehicles in the surrounding about the potential hazards associated to this event. Similarly, a minimum risk manoeuvre occurrence (e.g. a vehicle slowly decelerating and stopping in the ego-lane or on the emergency lane) can trigger transmission of a dedicated DENMs. This approach, proposed for the first type by the TransAID project foresees extension of the CDD “eventType” data element to include dedicated values accounting for “transition alert” and “MRM alert” (see [3]). Possible semi- of highly automated reactions at ITS-S applications at the receiving side are as in the Implementation A. In addition, manually driven vehicles might also benefit from knowledge of an ongoing ToC or MRM. An ITS-S application might be implemented to warn the driver, like in Figure 12, about the risk associated to an intended lane change to a lane where a vehicle is currently executing a ToC.

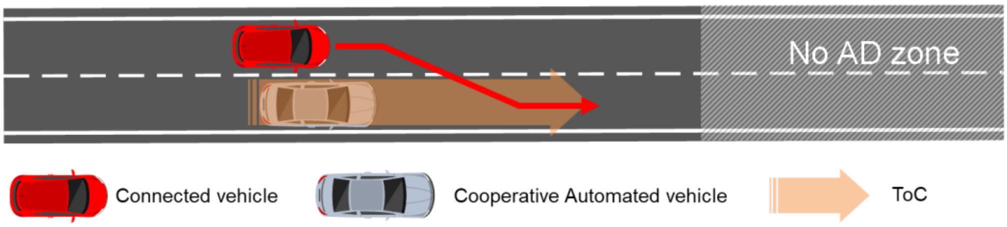


Figure 12:lane change in presence of a vehicle currently in ToC (H2020 TransAID)

In addition to additional information in DENMs in reaction to transition of control and minimum risk manoeuvre, the TransAID project proposes including dedicated information in extensions of CAM messages to continuously inform the surrounding vehicle about the currently supported automation level.

Implementation C

This second implementation option refers to Architecture B. Differently from the previous options, vehicles receive DENMs from a roadside ITS-S. The rest of the use case is as in Implementation A.

4.3.2 Cooperative Adaptive Cruise Control (CACC)

UseCase **UC_Autom_00003**

The Cooperative Adaptive Cruise Control (CACC) ITS application uses continuous communications from a target vehicle to a subject vehicle so that the subject vehicle can dynamically adapt its time gap to the target vehicle and keep it constant to a reduced value which would not be safely possible if only using inputs from front radars. Applying V2X as an additional real-time input to longitudinal control is demonstrated to improve traffic flow and driving convenience thanks to a reduction of unnecessary braking and throttle manoeuvres [1].

4.3.2.1 Possible system architectures

Architecture A

The first architecture foresees presence of only two communicating vehicles. A subject vehicle follows a so-called target vehicle and continuously receives from it messages containing real-time position, as well as current and predicted dynamics.

Architecture B

In this second architecture, the two vehicles are complemented by a roadside ITS-S that might provide information influencing their longitudinal control such as regulatory speed limits, speed suggestions, etc.

4.3.2.2 Possible implementation options

Implementation A:

In this implementation option based on Architecture A, the ITS-S application running at the subject vehicle is an extension of traditional ACC longitudinal controllers using distance from the vehicle in front and relative speed estimated by front radar measurements. This improved controller version, keeps the same control inputs, but calculates them based on the “measured” acceleration and “acceleration forecasts” both explicitly communicated directly by the target vehicle and continuously updated in real-time. In this way, by predicting the motion of the target vehicle, the longitudinal controller considers a “virtual target” that can be closer or further away than its actual physical location. As a result, earlier reactions can be triggered in the longitudinal controller, thereby reducing the overall reaction time. In turn this implies that the subject vehicle can adapt more quickly to acceleration and deceleration of the target vehicle and afford closer time gaps from it (see Figure 13).

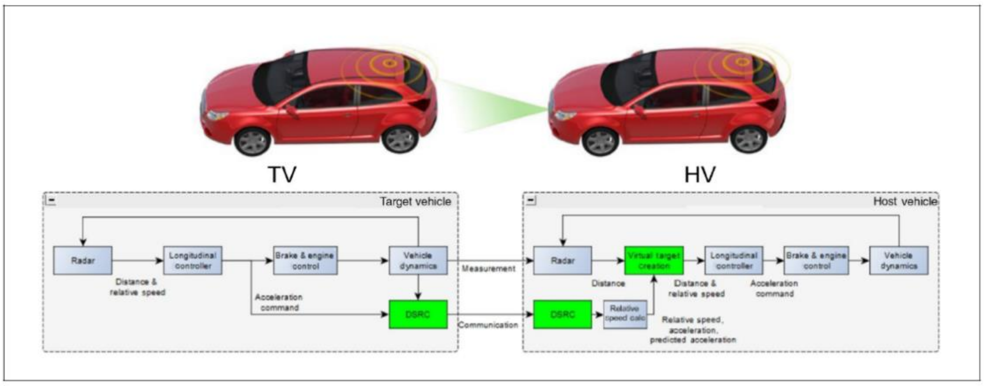


Figure 13: CACC longitudinal controller between Target Vehicle (TV) and Host Vehicle (HV) [8]

For this ITS application to be implemented, the Cooperative Awareness ITS-S service can be reused with some extensions. The CAM messages transmitted by Target vehicles shall contain an additional data element expressing the “acceleration forecast”, which in turn can be retrieved from the longitudinal controller before acceleration or braking commands are applied by the engine or braking system, respectively. Also, a very useful CAM extension would be the target vehicle-specific response time in implementing the command. This allows subject vehicles to estimate the acceleration response of the target vehicle much more accurately. More importantly, also in this case safety container extensions in CAM messages transmitted by the target vehicle are needed. These extensions shall express the accuracy of the provided information for functional safety reasons at the subject vehicle applying an automated adaptation of its dynamics in the longitudinal direction.

Implementation B

This second implementation option refers to Architecture B. Differently from the previous option, target and subject vehicle receive messages form a roadside ITS-S, which might influence their longitudinal controller decisions. These messages can be DENMs notifying about hazards downstream, IVIMs informing about applicable speed limits, or other messages suggesting adaptations of the longitudinal behaviour of the vehicles. The natural consequence of receiving these messages is a change in the measured and forecasted acceleration transmitted by the target vehicle, which in turn causes an according longitudinal adaptation at the receiving subject vehicle’s controller. Also, in this case, presence of safety containers in the message received from the roadside ITS-S, will be essential for the receiving vehicles to decide whether to apply automated reactions or not. So, extensions of infrastructure messages to carry safety containers reflecting the accuracy of the provided information will be needed.

4.3.3 CACC String

UseCase **UC_Autom_00004**

The Cooperative Adaptive Cruise Control (CACC) ITS application can be extended if the subject vehicle additionally considers information received from other vehicles preceding target vehicle directly in front of it. If more than two vehicles implement the CACC ITS-S application and each of them considers the information of the other vehicles in front, a string of CACC vehicles is realized. Considering other vehicles in front and in non-line of sight, considerably enhances the situational awareness of traditional ACC ADAS systems and makes it much more robust to perturbations in the front traffic. As an example, if a vehicle ahead in the string brakes, deceleration at the host vehicle may begin right away, without waiting for the braking manoeuvre to propagate along the string and make it instable (Typically without explicit communication from the vehicles ahead in the string, the deceleration required increases for each following vehicle, eventually bringing the entire string to a full stop [1]). Therefore, reducing the latency of the string response to perturbations has potential for a smoother, more consistent and denser traffic flow with consequent increased throughput.

4.3.3.1 Possible system architectures

Architecture A

In the first architecture multiple communicating vehicles run the CACC ITS application. A subject vehicle follows a so-called target vehicle and continuously receives messages from it as well as from the other CACC vehicles ahead in the string.

Architecture B

In this second architecture, the multiple vehicles are complemented by a roadside ITS-S that might provide information influencing their longitudinal control such as regulatory speed limits, speed suggestions, etc.

4.3.3.2 Possible implementation options

Implementation A:

In this implementation option based on Architecture A, the CACC ITS-S application running at the subject vehicle runs a Multi-Vehicle Look-Ahead functionality to consider the V2V data from several (if not all) preceding vehicles in the string (see Figure 14). Differently from the simple CACC, a subject vehicle in a string computes the 'virtual' target by considering V2V data from multiple preceding vehicles and weighting them based on distance, thereby enhancing the reaction times to traffic perturbations. To understand which of the preceding vehicles is actually in the same lane of the string vehicles, each subject vehicle includes in its messages the temporary identifier of its target vehicle. By overhearing this information from the vehicles ahead in the string, each subject vehicle can internally distinguish which vehicles shall the considered for the controller reactions.

Figure 14: Multi-Vehicle Look Ahead functionality of CACC strings [8]

For this ITS application to be implemented, the Cooperative Awareness ITS-S service can be reused with some extensions as the basic CACC. The only additional extension needed is the temporary identifier of the target vehicle.

Implementation B

This second implementation option refers to Architecture B and complements a CACC string in the same way as for the basic CACC.

4.3.4 Cooperative Automated Emergency Brake System (C-AEBS)

UseCase **UC_Autom_00005**

A subject vehicle applies an automated braking to avoid a crash with another road user, e.g., a hard braking vehicle. The situation is detected by messages received from target vehicles. The automated braking in the subject vehicle is issued when the time to collision falls below an application threshold. This is a semi-automated function, as the driver is requested to be in the loop. The messages from target vehicles are extended with safety containers for functional safety reasons.

4.3.4.1 *Possible system architectures*

Architecture A

A Target Vehicle (TV) is operating the Cooperative Awareness ITS-S service and potentially additional ITS-S services, sending messages containing data relevant for a Subject Vehicle (SV) to assess the situation whether a braking manoeuvre is need to avoid a collision with road users described in the messages of the TV, which can be the TV itself or other road users detected by the TV.

4.3.4.2 *Possible implementation options*

Implementation A:

The Target Vehicle (TV) is sending extended Cooperative Awareness Messages (extended CAMs) including safety containers which indicate a high level of reliability of a part of or all signals included in the CAM, like position, speed and heading.

The Subject Vehicle (SV) is approaching the TV and may collide if it continues its manoeuvre. It reacts automatically by initiating a braking manoeuvre based on a situation analysis. Potential hazards created by this manoeuvre (like getting rear-ended by other following traffic) are considered via Functional Safety mechanisms (like conducting a Hazard and Risk Analysis, HARA), resulting in requirements towards the data in the extended CAM of the TV which are not fulfilled by Release 1 CAMs.

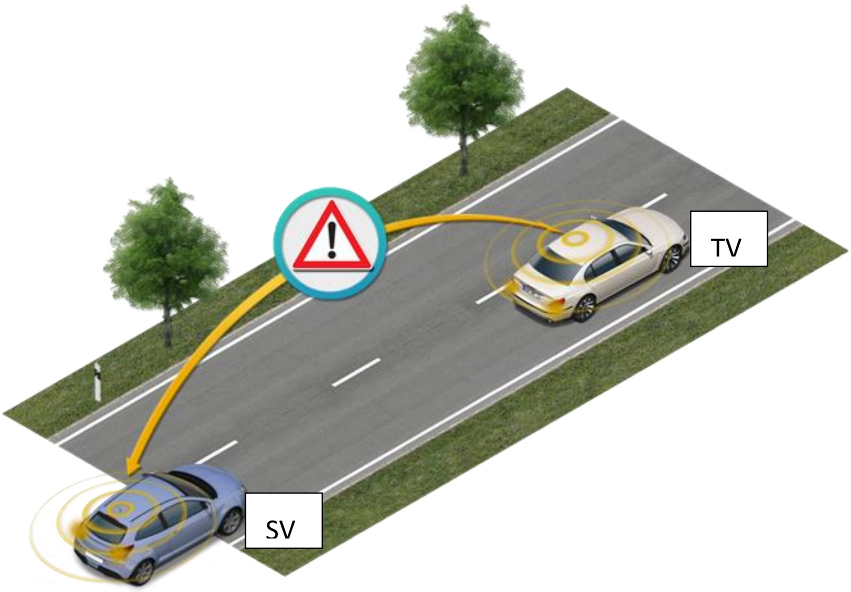


Figure 15: Cooperative Automated Emergency Brake System (C-AEBS)

Implementation B

The Target Vehicle (TV) detects information about preceding vehicles and operates the Collective perception ITS-S service. It is sending Collective Perception Messages (CPMs) including safety containers which indicate a high level of reliability of a part of or all signals included in the CPM. The Subject Vehicle (SV) uses this information as it uses the CAM information in Implementation A.

4.3.5 Advanced Pre-crash sensing

UseCase	**UC_Autom_00006**

This use case describes the process for information provided by a vehicle V1 or roadside unit R-ITS-S, when a critical situation is detected, via DENMs including use case specific extensions in an a-la-carte container. Each receiving vehicle may activate its Pre-Crash measures when it assumes itself to be under risk and the situation is considered as sufficiently critical.

For more details, see [9], [10], [11].

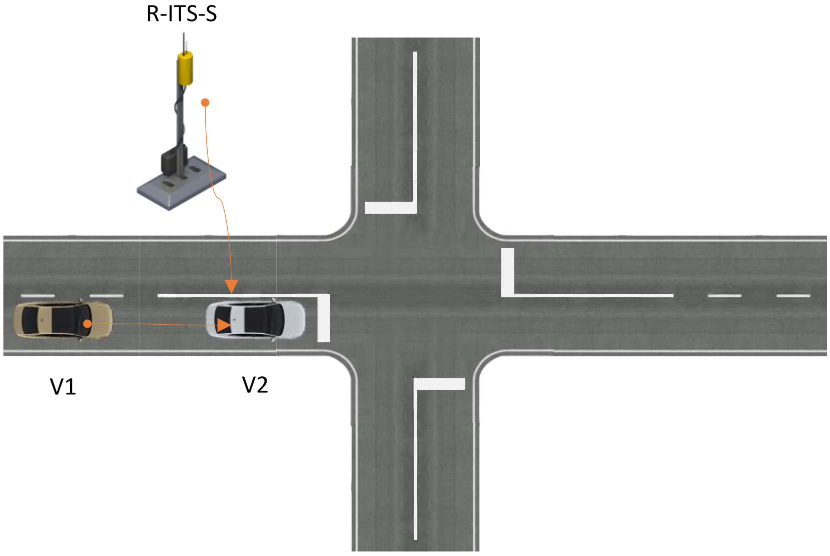


Figure 16: Advanced Pre-crash sensing overview. V2 is about to be hit by V1

4.3.5.1 Possible system architectures

Architecture A:

Vehicle 1 (V1) and Vehicle 2 (V2) are operating the Decentralized Environmental Notification ITS-S service and the Pre-Crash sensing ITS-S application.

Architecture B:

Vehicle 1 (V1) is not equipped with V2X. Vehicle (V2) and a roadside ITS station (R-ITS-S) are equipped with V2X and are operating the Decentralized Environmental Notification ITS-S service and the Pre-Crash sensing ITS-S application.

4.3.5.2 Possible implementation options:

Implementation A

Implementation A refers to Architecture A. When Vehicle 1 is about to have a collision with Vehicle 2, it sends out DENMs including details about the critical situation, allowing V2 to activate pre-crash measures based on the information in the DENMs. For longitudinal collision risks, this is especially useful if Vehicle 1 is equipped with front-facing sensors and Vehicle 2 is not equipped with rear-facing sensors.

Implementation B

Implementation B refers to Architecture B. The R-ITS-S obtains object information from stationary environmental sensors and detects a pre-crash situation between vehicles V2 and V1. It sends out DENMs in the same way as Vehicle 1 in Implementation A.

4.4 Advanced warning and information

Other (informational) **UC_AdWa_00001**

Release 2 use cases that advance similar Release 1 use cases

- by using Release 2 ITS-S services like Collective Perception,
- by extending the supported traffic scenarios or
- by extending the functionality on the receiver ITS station thanks to extended information

are part of the ITS service “Advanced warning and information”. These use cases aim at the goal to increase Road Safety by providing warnings and information to the driver.

4.4.1 Advanced Slow Vehicle Warning (ASVW)

UseCase **UC_AdWa_00002**

Extends the Day1 SVW with information about slow vehicles detected by other vehicles or infrastructure units (CPMs). This is particularly beneficial when the slow vehicle itself is not C-ITS equipped and cannot warn other road users about its presence.

4.4.1.1 Possible system architectures

Architecture A:

In addition to the CAMs sent out by slow vehicles, or when the slow moving vehicle is not C-ITS equipped at all, other vehicles and infrastructure provide object information through CPM which can be used to issue a slow vehicle warning if appropriate.

4.4.1.2 Possible implementation options:

Implementation A:

This implementation option refers to Architecture A. In addition to the dynamics information in CAMs and DENMs, vehicles can make use of object information received from other vehicles or infrastructure to activate the slow vehicle warning functionality. Thus, also warnings about non-cooperative slow vehicles can be issued and thus safety is fostered even more.

4.4.2 Advanced Intersection Collision Warning (AICW)

UseCase **UC_AdWa_00003**

By receiving information about non-cooperative vehicles detected by environmental sensors (CPMs), vehicles can detect the risk of an intersection collision and warn the driver accordingly.

4.4.2.1 Possible system architectures

Architecture A:

Cooperative vehicles and road-side infrastructure provide information on objected detected by their sensors through CPM. Receiving vehicles make use of this information in addition to the received CAMS to issue and intersection collision warning if appropriate.

4.4.2.2 Possible implementation options

Implementation A:

This implementation option refers to Architecture A. In addition to the dynamics information in CAMs, vehicles can make use of object information received from other vehicles or infrastructure to activate the intersection collision warning. Thus, also warnings about collision risks with non-cooperative vehicles can be issued and thus safety is fostered even more.

4.4.3 Filtering motorcycle.

UseCase **UC_AdWa_00004**

A motorcycle and a vehicle exchange messages to lower the collision risk when the presence of the motorcycle is not expected by the driver.

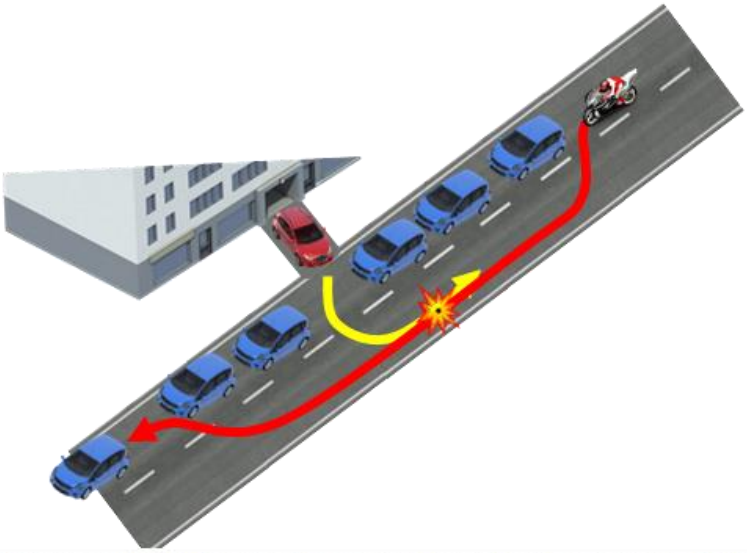


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Figure 17: Vehicle exiting property exit with left turn, motorcycle passes the vehicle queue

A motorcycle is passing a column of stationary traffic. The stationary traffic has deliberately left a gap in the queue to permit a vehicle to exit from a property on the right. The vehicle leaving the property enters the gap and assumes that they only need to look for vehicles approaching from their right, when in fact the motorcycle is approaching from the left. Issuing an alert to both vehicles informs the driver to look to the left, and the motorcyclist to be aware of a car exiting.

4.4.3.1 Possible system architectures

Architecture A

The MAI runs among the affected vehicles. The motorcycle, which may be filtering both when vehicles are and are not present in the oncoming traffic lane, will conflict with the car which is exiting from the property.

Architecture B

The filtering motorcycle as well as the gap created in the column of traffic is identified by ITS infrastructure and identify a potential conflict.

4.4.3.2 Possible implementation options:

Implementation A

The first implementation refers to Architecture A, both vehicles are running a collision avoidance application based on the exchange of CAM messages. Where a conflict is identified alerts are provided to both the car and the motorcyclist. Unlike a normal property exit the car has to first enter the main roadway, which gives a stronger indication of a conflict.

Implementation B

The second implementation refers to Architecture B. In this case the ITS-S is running a collision avoidance application receiving CAM messages from the vehicles involved. Where a conflict is identified alerts would be sent to the affected vehicles. (But what message would this be? A form of DENM message?)

4.4.4 Overtaking motorcycle

UseCase **UC_AdWa_00005**

A motorcycle and a vehicle exchange messages to lower the collision risk when the presence of the motorcycle is not expected by the driver.

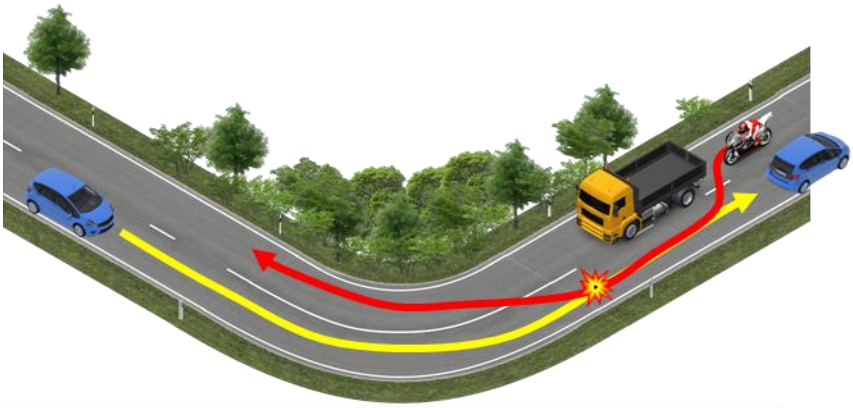

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Figure 18: Motorcyclist wants to overtake but has limited visibility

A motorcycle is behind a large and/or slow vehicle in a country road setting. The rider is keen to overtake but has limited visibility of the road ahead and there are frequently cars passing in the oncoming lane. The aim is to reduce the collision risk.

4.4.4.1 Possible system architectures

Architecture A: The MAI runs among the affected vehicles which are exchanging standard CAM messages.

Architecture B: The MAI runs among the affected vehicles which are exchanging CAM messages with future path prediction data.

4.4.4.2 Possible implementation options:

Implementation A

The first implementation refers to Architecture A, both vehicles are running a collision avoidance application based on the exchange of CAM messages. In this case the potential of a conflict can only be identified once the motorcycle has physically crossed into the opposing lane.

Implementation B

The second implementation refers to Architecture B. In this case both vehicles are computing their own future path prediction based on previous machine learning algorithms which have been monitoring the behaviour of both the rider and driver. As these algorithms have had the opportunity to learn from many driving data points they are in a position to predict more likely the probability of the manoeuvres. For example, the motorcycle will understand the typical behaviour seen by the driver when about to overtake – such as lane position, distance behind the following vehicle – gear selection + engine revs. It can then more readily predict if the rider is about to overtake and send an overtaking trajectory as path prediction points. This provides a greater warning window to both the vehicle and the rider. Currently future path information can be exchanged inside a VAM message.

The benefit is also available if the roles are reversed and the car is wishing to overtake – however in this case cars do not send VAM messages and thus the recommendation is that CAM messages also have the ability for every vehicle to pass on their future path information, and not just motorcycles. The host vehicle always understands better the behaviour of the driver, then a ‘foreign’ vehicle provided with 20 previous GPS points and the acceleration.

4.4.5 Overtaking motorcycle and turning vehicle

UseCase **UC_AdWa_00006**

A motorcycle and a vehicle exchange messages to reduce the risk of collision when the presence of the motorcycle is not expected by the driver.

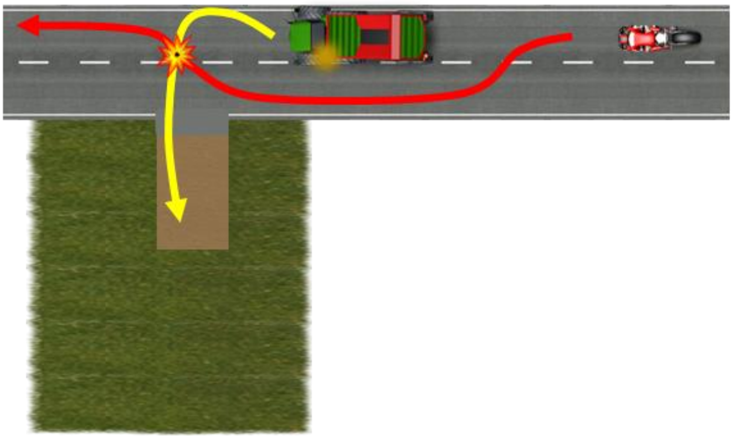

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Figure 19: Motorcyclist wants to overtake with a good view ahead but vehicle in front is turning left onto a field path, indicators are not visible

A motorcycle is on a rural road behind a vehicle with a wide body (farm equipment or larger trailers) so that the turn signals are obscured or are already blind that they can hardly be seen, and wants to overtake. The tractor driver wants to turn left onto a road or field, but the motorcycle is not visible in the mirror. The aim is to reduce the risk of collision between the possibly overtaking motorcycle and the turning vehicle.

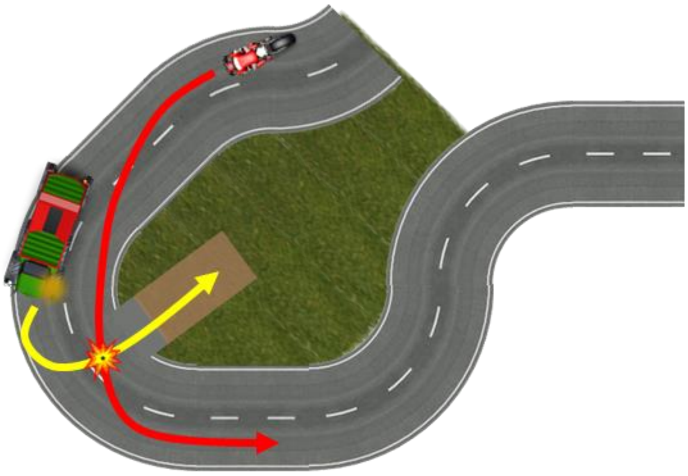

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Figure 20: Motorcyclist has clear view to the front and wants to overtake, vehicle ahead is turning left on a field path, but indicators are not visible

4.4.5.1 Possible system architectures

Prerequisite: Retrofit ITS-S for agricultural vehicles.

Architecture A

The MAI runs among the affected vehicles which are exchanging standard CAM messages.

Architecture B

The MAI runs among the affected vehicles which are exchanging CAM messages with future path prediction data.

4.4.5.2 Possible implementation options:

Implementation A

The first implementation refers to Architecture A, where both vehicles operate a collision avoidance application based on the exchange of CAM messages. In this case, a potential conflict can be detected when the motorcycle is behind a specific type of vehicle, accelerates and the behaviour equals a planned overtaking manoeuvres, right left sway. In addition, the indicators can also be included.

Option2

The second implementation refers to Architecture B. In this case both vehicles are computing their own future path prediction based on previous machine learning algorithms which have been monitoring the behaviour of both the rider and driver. As these algorithms have had the opportunity to learn from many driving data points they are in a position to predict more likely the probability of the manoeuvres. For example, the motorcycle will understand the typical behaviour seen by the driver when about to overtake – such as lane position, distance behind the following vehicle – gear selection + engine revs. It can then more readily predict if the rider is about to overtake and send an overtaking trajectory as path prediction points. This provides a greater warning window to both the vehicle and the rider. Currently future path information can be exchanged inside a VAM message.

4.4.6 Turning vehicle with PTW in the blind spot

UseCase **UC_ AdWa_00007**

A motorcycle and a vehicle exchange messages to reduce the risk of collision when the presence of the motorcycle is not expected by the driver

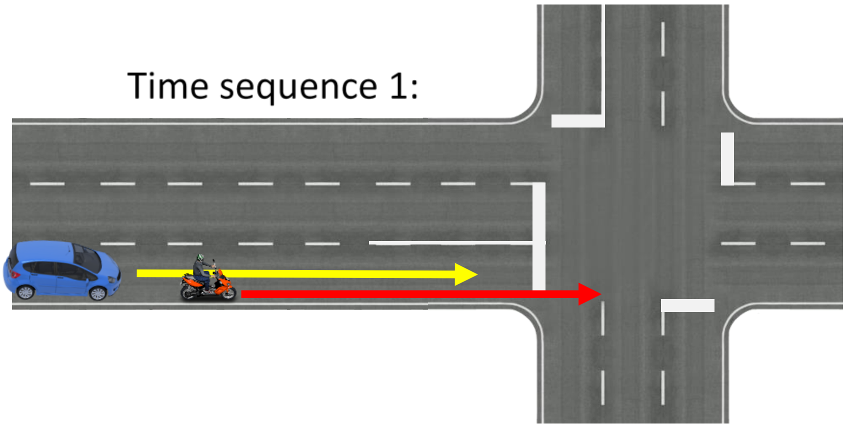

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Figure 21: Motor scooter is driving on the right side of the lane and wants to go straight

A motorcycle (mostly slow moving i.e. moped) driving on the right side of its lane. Another vehicle is overtaking the slow moving motorcycle. The overtaking vehicle driver decides to turn right after having overtaken. Due to the deceleration of the overtaking vehicle and an unchanged speed of the slower motorcycle a critical situation occurs, since the driver of the overtaking vehicle may not be aware of the proximity of the motorcycle due to blind spot or non-perception of the motorcycle.

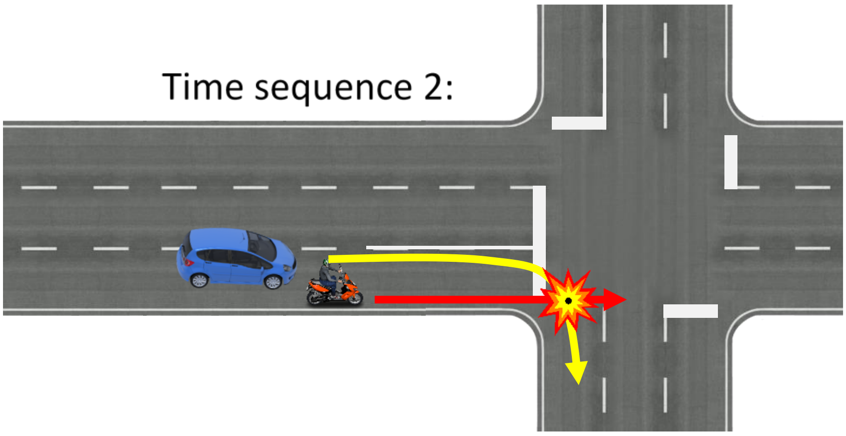

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Figure 22: A car overtakes and wants to turn right at the junction at short notice

4.4.6.1 Possible system architectures

Architecture A

The MAI runs among the affected vehicles, which are exchanging standard CAM messages.

Architecture B

The MAI runs in the overtaking vehicle based on information from a blind spot recognition system. This can either be based on on-board sensors or signaled via CAM messages.

4.4.6.2 Possible implementation options

Option 1

The first implementation refers to architecture 1, both vehicles are running a collision avoidance application based on the exchange of CAM messages. Where a conflict is identified, alerts are provided to both the car and the motorcyclist.

Option 2

The second implementation refers to architecture 2. In this case, the overtaking vehicle runs a blind spot recognition system. Information may come from on-board sensors and / or from CAM messages indicating the proximity and relative location of both vehicles. Alerts will be shown in the overtaking vehicle.

4.4.7 VRU Presence Awareness

UseCase **UC_ AdWa_00008**

VRUs (such as bicycles and pedestrians) and other traffic participants (such as cars and trucks) are informed about their mutual presence, especially in situation where their awareness is incomplete, e.g., due to reduced visibility towards each other.

4.4.7.1 Possible system architectures

Architecture A:

The VRU presence awareness can be enabled by traffic participants exchanging information related to the VRU’s driving environment (e.g., connected vehicles reporting about themselves or about other stations) and/or related to the VRU’s current and estimated future kinematic state (e.g., reporting by the VRU itself or external status assessment by other connected traffic participants).

Architecture B:

If available, VRU presence awareness can also be offered by means of infrastructure. The latter may detect the VRU and traffic participants in its vicinity with its sensors and warn them about the presences of each other.

Architecture C:

A third option to offer VRU presence awareness is by making use of the mobile communication network. Sensor data and data obtained by V2X communication from traffic participants related to the VRU and road users in its vicinity may be gathered and disseminated over Uu links to the involved stations.

4.4.7.2 Possible implementation options:

Implementation A:

This implementation option refers to Architecture A. In this implementation VRUs may make connected stations aware of their presence by sharing VAMs containing their current state and predicted trajectories. Connected vehicles may in turn inform the VRU about their kinematic states by transmitting CAMs or extended CAMs. Additionally, other connected traffic participants may make use of CPMs to share their perception related to the VRU and other road users in its vicinity sensed through their on-board sensors.

Implementation B:

This implementation option refers to Architecture B. In this implementation a RSUs may detect VRUs and traffic participants that are in or could come into interaction with the VRU. The RSU then sends out CPMs to inform the VRU about the other traffic participants and vice-versa. Additionally, to the description of the kinematic states of VRU and traffic participants the CPMs may include information about detected free spaces, further enhancing the awareness of connected stations.

Implementation C:

This implementation option refers to Architecture C. In this implementation the server gathering data with connected concerning VRUs and traffic participants in their surroundings may aggregate this data (e.g., dealing from sensors looking at the scene from different perspectives) and re-disseminate it over dedicated Uu links. This enables to send the relevant data only to the pertinent stations. The data may be encoded in CPMs disseminated on an IP-based protocol stack or use other (proprietary) formats. While this implementation may mitigate flooding of the V2X communication channel for VRU presence awareness, it is less suitable for VRU collision warning (Section 4.4.8) and VRU brake or steering intervention (Section 4.4.9) due to their much more stringent latency requirements.

4.4.8 VRU Collision Warning

UseCase **UC_ AdWa_00009**

VRUs and other human-driven traffic participants (i.e., of low automation level) are warned about possible collisions based on their current driving state.

4.4.8.1 Possible system architectures

Architecture A:

The VRU collision warning can be enabled by VRUs and traffic participants exchanging information related to their current or estimated future kinematic states. This may occur in the form of explicit collision warnings or by means of implicit information exchange based on the dissemination of the traffic participants’ kinematic states.

Architecture B:

VRU collision warning may also be enabled by RSUs tracking traffic participants in their environment and sending them implicit or explicit collision warnings.

4.4.8.2 *Possible implementation options*

Implementation A:

This implementation option refers to Architecture A. In addition to the kinematic information in CAMs and VAMs, road users can make use of object information received from other traffic participants by means of CPMs or in particular cases by DENMs to activate the VRU collision warning. Thus, warnings about collision risks with both cooperative as well as non-cooperative VRUs can be issued substantially contributing to traffic safety.

Implementation B:

This implementation option refers to Architecture B. In scenarios especially safety critical for VRUs, the installation of RSUs may substantially contribute to the VRU’s safety. High accuracy tracking of traffic participants is enabled by well-placed sensors covering the critical area. This allows for enhanced VRU collision warning by means of CPMs and DENMs, without requiring the presence of additional connected stations reporting the situation.

4.4.9 VRU Brake or Steering Intervention

UseCase **UC_ AdWa_00010**

In contrast to the VRU collision warning described in Section 4.4.8 for human driven or moderately automated traffic participants, higher automation levels allow for VRU brake or steering intervention. It is based on the information exchange between connected ITS-S related to VRUs and their driving environment.

4.4.9.1 *Possible system architectures*

Architecture A:

The VRU brake or steering intervention can be enabled by highly automated traffic participants receiving information from other connected traffic participants related to an imminent collision risk with a VRU. As for collision warning this may occur in the form of explicit collision warnings or by of implicit information exchange based on the dissemination of the traffic participants’ kinematic states.

Architecture B:

VRU brake or steering intervention may also be enabled by RSUs tracking traffic participants in their environment and sending them implicit or explicit information for automated or highly automated driving intervention for VRU protection.

4.4.9.2 *Possible implementation options:*

Implementation A

This implementation option refers to Architecture A. In addition to the kinematic information in CAMs and VAMs, road users can make use of object information received from other traffic participants by means of CPMs or, in particular cases, by DENMs to activate the VRU brake or steering intervention. An important difference to a simple collision warning is the higher relevance of functional safety considerations as supported by Day 3+ V2X services.

Implementation B

This implementation option refers to Architecture B. The equipment of RSUs with object tracking sensors in high-risk regions for VRUs allows to share this data by means of CPMs. This data can further be enhanced by including predicted trajectories of VRUs into CPMs or MCMs building a solid basis for VRU brake or steering interventions.

4.5 Agriculture specific use cases

Other (informational) **UC_Agri_00001**

4.5.1 Task data exchange

UseCase **UC_Agri_00002**

A job for an agricultural machine is usually described with a task data standardized within 11783 part 10. Within a ISO XML file relevant data (location, field boundary, guidance references lines, apply rate and others) is stored to define what to do on a field. Working on a field with multiple vehicles is much more efficient if this task data is available for all machines.

4.5.1.1 Possible system architectures

Any vehicle working on a field will offer relevant data of his job (defined within a task) to any other vehicle willing to collaborate. To ensure privacy of task relevant data only after joining a dedicated working group encryption of the data is possible.

4.5.1.2 Possible implementation options

Because agricultural machines usually working in rural areas, communication infrastructure is not always available. Therefore, a P2P approach will be used. That means every tractor with task data relevant for the job will offer this data to share with anyone willing to work at the same job.

4.5.2 Geo referenced data exchange

UseCase **UC_Agri_00003**

Working on a field is usually logged based on position data. Besides that, also control of the implement attached to an agricultural machine is often controlled by geo referenced data. This means that on the one hand the amount of applied goods or working intensity (fertilizer, seeding, depth of cultivator…) is defined within a prescription map or/and the area which is already worked, called coverage map, is stored. Based on this data the amount of applied goods, working state of tools is controlled or even stopped if an area would be worked twice.

To work with more than one machine on a field exchange of this georeferenced data is required to be highly efficient. Other than task data, which is usually defined once before the job begins, geo referenced data is gathered while working (coverage data) or could be modify while working (prescription data).

4.5.2.1 Possible system architectures

Any vehicle working on a field will offer relevant georeferenced data of his job to any other vehicle willing to collaborate. To ensure privacy of task relevant data only after joining a dedicated working group encryption of the data is possible. To ensure to have an equal revision of the map data all vehicle will share this data based on a distributed revision management system, enabling every member of the working group to identify status of his mapped data an asking for relevant updates from other to be up-to-date.

4.5.2.2 Possible implementation options

Because agricultural machines usually working in rural areas, communication infrastructure is not always available. Therefore, a P2P approach will be used. That means every tractor with task data relevant for the job will offer this data to share with anyone willing to work at the same job.

4.5.3 Agricultural Platooning

UseCase **UC_Agri_00004**

Agricultural vehicles are often working together in close proximity. Typically, this happens in unloading situation where one machine unload goods to a transport vehicle or when two machines doing the same practice like cultivating the field. To avoid collisions and/or lose of goods during unloading automation of steering and/or speed control is highly welcome within this kind of situation. In difference to automotive platooning ag machinery typically drives next to each other with variable lateral offset and only in few situation (starting a field) behind each other with a fixed lateral offset. Beside that the position offset is based on the desired hit point of the un loading set point and will move to ensure optimal usage of given transport volume.

4.5.3.1 Possible system architectures

The vehicle unloading goods or be in the front position will send desired position for vehicle receiving the goods or following. Based on the amount of unloaded goods the leading vehicle can notch the following vehicle to optimize use of the given transport volume.

4.5.3.2 Possible implementation options

After being manoeuvred in close proximity to the leading vehicle the operator of the following vehicle can hand over to automatic. The automatic will stay active as long as the leader or follower will decline automation or the follower will take over manual control again.

4.5.4 In field safety

UseCase **UC_Agri_00005**

Agricultural vehicles are often working together in close proximity. Also, not only being responsible for driving the vehicle but also for taking care for the working process means that the operator could be quite busy. Therefor there is always a certain danger of colliding with other vehicles being in the same field. This means warning the operator of a vehicle that there is another vehicle in close proximity moving towards each other could help to avoid dangerous situation.

4.5.4.1 Possible system architectures

Every vehicle will share his position, speed and direction of movement using some agricultural awareness message.

4.5.4.2 Possible implementation options

Receiving this kind of messages will enable every vehicle to judge if there are other participants moving around in close proximity and direction that a collision could be possible. Based on this a warning message could be display to the operator to make him aware of this situation.

4.5.5 Agricultural work awareness

UseCase **UC_Agri_00006**

Agricultural vehicles are often working next to public roads. This could effect in certain situation road users by dust or particles thrown into the air by agricultural working process. To enable road users to reduce speed or other measures to react on potential harmful situation the ag machine could sent on regular interval an awareness message enabling road users to judge by their own if that is from relevance for them.

4.5.5.1 Possible system architectures

Architecture A

Every vehicle in the field will share his position, speed and direction of movement using some agricultural awareness message.

4.5.5.2 Possible implementation options

Implementation A

Receiving this kind of messages will enable every vehicle to judge if there is a general potential of danger coming from this vehicle not being on the road and if that could be verified by other sensors (e.g. camera detecting dust). Based on that the operator could be warned or the automation system can react on this.

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