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Part 1: Use Cases definition;
Release 2

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Foreword

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

The present document is part 1 of a multi-part deliverable covering Vulnerable Road Users (VRU) awareness as identified below:

Part 1: "Use Cases definition";

Part 2: "Functional Architecture and Requirements definition";

Part 3: "Specification of VRU awareness basic service".

Modal verbs terminology

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Executive summary

Technological developments and research activities in C-ITS have primarily focused on motorized transport to improve safety and environmental impacts by advancing equipment of vehicles and infrastructure. For this C-ITS, V2V, I2V and V2I use cases and applications have been identified in the Basic Set of Applications (BSA).

Additional use cases are being developed to cover applications such as Platooning, Cooperative Adaptive Cruise Control (C-ACC), Cooperative Perception Service (CPS) and Manoeuvre Coordination Service (MCS). Vulnerable Road Users (VRUs) related use cases can make use of these specifications and applications and should be taken into account. Interoperability between vehicle-based and portable safety devices is of paramount importance to improve the overall safety and decrease the fatalities in both urban and non-urban areas. There is therefore the need to develop VRU related specifications in order to allow the deployment of VRU safety applications.

The objective of the present document is to provide the material to help identify improvements of current specifications and the content of additional specifications based on ongoing VRU developments. VRU applications extend the awareness of and/or about Vulnerable Road Users such as motorcycles, bicycles, pedestrians and more impaired traffic participants in the neighbourhood of other traffic participants. They enable further improvement of traffic safety and management based on both direct ITS station-to-ITS station communications and via a third party ITS station (e.g. vehicle or road-side equipment).

The present document is the first part of a three-part standard:

- Part 1 (the present document) describes the VRU system and the use cases related to Vulnerable Road Users such as pedestrians, bicyclists and road workers.
- Part 2 [i.17] specifies the VRU related requirements; as well as the functional architecture of the VRU system. In addition, it analyses the impact on existing standards (for instance the CAM European Norm).
- Part 3 [i.18] specifies the communication protocols, message format, semantics and syntax as well as key interfaces and protocol operation for the VRU awareness service.

The present document starts with a definition of what is considered as a VRU, its possible configurations and its environment.

The next clause introduces a categorization of the potential use cases involving VRUs, classified based on the different stakeholders involved in the C-ITS system which could contribute to prevent a risk of collision with the VRU. Each of these categories has its own specificities. The categories will help develop the structure and prepare the specification of the VRU system functional architecture in ETSI TS 103 300-2 [i.17].

A set of exemplary use cases is then described, where VRUs encounter a risk of collision and how this risk could be mitigated by the C-ITS system. These use cases have been analysed and one of the outcomes of this analysis is that depending on the use case and the actors involved, different elements of the architecture may be mandatory or optional (for example functions in the cloud). This is also closely linked to the deployment level of the different features of the C-ITS system.

Finally, the deliverable concludes with the outcome of the analysis of the use cases, discussing the different challenges identified in the use case descriptions that need to be taken into account when specifying the VRU basic awareness service in ETSI TS 103 300-2 [i.17] and ETSI TS 103 300-3 [i.18]. Part of the main challenges are the unpredictable behaviour from the VRU and a VRU profiling proposal, positioning aspects, resource usage, in terms of spectrum, power and functions, performance parameters, security and privacy and roadmap for a progressive system development of the VRU architecture.

Introduction

VRU applications extend the awareness of and/or about Vulnerable Road Users such as motorcycles, bicycles, pedestrians and more impaired traffic participants in the neighbourhood of other traffic participants. They enable further improvement of traffic safety and management based on both direct ITS station-to-ITS station communications and via a third party ITS station (e.g. vehicle or road-side equipment).

1 Scope

The present document describes and categorizes typical use cases relevant to traffic safety that involve Vulnerable Road Users (VRUs) i.e. road users such as pedestrians, bicyclists, e-scooters, motorcycles and road workers and are enabled by Cooperative Intelligent Transport Systems.

Each use case contains an associated flow chart which shows the interaction between the involved actors, i.e. at least one VRU and other ITS stations.

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] ETSI TR 102 638: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions".

[i.2] ETSI EN 302 637-2: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.3] ETSI EN 302 637-3: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[i.4] SAE J2735 (March 2016): "Dedicated Short Range Communications (DSRC) Message Set Dictionary".

[i.5] ISO/TS 19091: "Intelligent transport systems -- Cooperative ITS - Using V2I and I2V communications for applications related to signalized intersections".

[i.6] ETSI EN 302 665: "Intelligent Transport Systems (ITS); Communications Architecture".

[i.7] SAE J2945/9 (March 2017): "Vulnerable Road User Safety Message Minimum Performance Requirements".

[i.8] Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles.

NOTE: Available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0168&from=EN.

[i.9] ETSI TS 103 301: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services".

[i.10] ETSI TS 101 539-1: "Intelligent Transport Systems (ITS); V2X Applications; Part 1: Road Hazard Signalling (RHS) application requirements specification".

[i.11] Regulation (EC) No 661/2009 of the European Parliament and of the Council of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefore. Article 10: Advanced vehicle systems.

[i.12] Commission Regulation (EU) No 347/2012 of 16 April 2012 implementing Regulation (EC) No 661/2009 of the European Parliament and of the Council with respect to type-approval requirements for certain categories of motor vehicles with regard to advanced emergency braking systems.

[i.13] ISO/TS 17426: "Intelligent Transport Systems (ITS) -- Cooperative systems -- Contextual speed".

[i.14] VRUITS Deliverable D2.1: "Technology potential of ITS addressing the needs of Vulnerable Road Users".

[i.15] PROSPECT Deliverable D2.1: "Accident Analysis, Naturalistic Observations and Project Implications".

[i.16] ETSI TS 103 097: "Intelligent Transport Systems (ITS); Security; Security header and certificate formats".

[i.17] ETSI TS 103 300-2: "Intelligent Transport System (ITS); Vulnerable Road Users (VRU) awareness; Part 2: Functional Architecture and Requirements definition; Release 2".

[i.18] ETSI TS 103 300-3: "Intelligent Transport System (ITS); Vulnerable Road Users (VRU) awareness; Part 3: Specification of VRU awareness basic service; Release 2".

[i.19] IEEE 802.11n™: "IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput".

[i.20] M/546 Commission Implementing Decision C(2016)808 of 12.2.2016 on a standardisation request to the European standardisation organisations as regards Intelligent Transport Systems (ITS) in urban areas in support of Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

emergency braking: phase directly starting when the AEBS emits demand for at least 4 m/s² deceleration to the service braking system of the vehicle

manoeuvres: specific and recognized movements bringing an actor, e.g. pedestrian, vehicle or any other form of transport, from one position to another within some momentum (velocity, velocity variations and vehicle mass)

Post-Encroachment-Time (PET): time between the passing of first road user and arrival of second road user at a conflicting space. It measures the potential risk of collision

road: way allowing the passage of vehicles, people and/or animals. It is made of none, one or a combination of the following lanes: driving lane, bicycle lane and pavement

personal ITS-S: ITS-Station in a nomadic ITS sub-system in the context of a portable device

Time to Collision (TTC): value of time obtained by dividing the distance between the subject vehicle and the target (e.g. VRU) by the relative speed of the subject vehicle and the target at an instant of time

traffic conflict: situation involving two or more moving users or vehicles approaching each other at given velocities in such a way that a traffic collision would occur unless at least one of the users or vehicles performs an emergency manoeuvre

NOTE: Traffic conflicts are defined by the following parameters:

- traffic conflict point (time and space) where the trajectories intersect;
- time-to-collision, distance-to-collision, post-encroachment time, and angle of conflict.

vehicle: road vehicle designed to legally carry people or cargo on public roads and highways such as busses, cars, trucks, vans, motor homes, and motorcycles

NOTE: This does not include motor driven vehicles not approved for use of the road, such as forklifts or marine vehicles.

velocity: momentum (in physics)

NOTE: The velocity takes into account the mass of the vehicle and its speed. The braking distance will therefore be more a function of the velocity than of the speed.

Vulnerable Road Users (VRU): non-motorized road users as well as L class of vehicles (for example mopeds or motorcycles, etc.), as defined in Annex I of EU regulation 168/2013 [i.8]

VRU application: application extending the awareness of and/or about Vulnerable Road Users such as motorcycles, bicycles, pedestrians and less impaired traffic participants in the neighbourhood of other traffic participants

VRU device: portable device used by a VRU integrating a standard ITS station

NOTE: The definition of an ITS station is given in ETSI EN 302 665 [i.6]. A VRU device can also integrate applications interfacing the ITS-S. For example, an application can improve the VRU trajectory prediction by learning continuously from its behaviour when sharing the space with other road users.

VRU system: ensemble of ITS stations interacting with each other to support VRU use cases, e.g. personal ITS-S, vehicle ITS-S, roadside ITS-S or Central ITS-S

user: equipped or un-equipped road user such as driver, pedestrian, service provider or authority

3.2 Symbols

Void.

3.3 Abbreviations

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

ABS	Antilock Braking System
AD	(vehicles)
AEBS	Advanced Emergency Braking System
AI	Artificial Intelligence
BSA	Basic Set of Applications
C-ACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CEN	Comité Européen de Normalisation (European Committee for Standardization)
C-ITS	Cooperative ITS
CPM	Cooperative Perception Message
CPS	Cooperative Perception Service
CSM	Contextual Speed limit Messages
DENM	Decentralized Environmental Notification Message
DoS	Denial of Service
EEBL	Emergency Electronic Brake Light
FVRU	Few VRUs
FYL	Functional Years Lost

GN	GeoNetworking
GNSS	Global Navigation Satellite System
HMI	Human-Machine Interface
ISA	Intelligent Speed Adaptation
ISO	International Organisation for Standardization
ITS	Intelligent Transport System
ITS-S	ITS Station
LOS	Line of Sight
MAI	Motorcycle Approach Indication
MAW	Motorcycle Approach Warning
MCM	Manoeuvre Coordination Message
MCS	Manoeuvre Coordination Service
MEC	Mobile Edge Computing
MVRU	Many VRUs
NLOS	Non-Line of Sight
PAC	Perception Augmentée par Coopération
PET	Post-Encroachment-Time
PHY	Physical (layer)
PoTi	Position Time
PSM	Personal Safety Messages
PTW	Powered Two Wheelers
R-ITS-S	Roadside ITS Station
RLAN	Radio Local Area Network
RSE	Road Side Equipment
RX	Receive
SAE	Society of Automotive Engineers
SDO	Standards Developing Organization
SPaT	Signal Phase and Timing
TRO	Transport Regulation Order
TTC	Time-To-Collision
TX	Transmit
UC	Use Case
UWB	Ultra WideBand
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle-to-everything
V-ITS-S	Vehicle ITS Station
VRU	Vulnerable Road User

4 Vulnerable Road User system description

4.1 Background

Cooperative Intelligent Transport Systems (C-ITS) have been developed to enable an increase in traffic safety and efficiency, and to reduce emissions and fuel consumption.

Initial focus was on road traffic safety and especially on vehicle safety. For this C-ITS, V2V, I2V and V2I use-cases and applications have been identified in the Basic Set of Applications (BSA), ETSI TR 102 638 [i.1]. Specification and information exchanges such as ETSI EN 302 637-2 [i.2] (CAM), ETSI EN 302 637-3 [i.3] (DENM), SAE J2735 [i.4] (SPaT-MAP), ISO/TS 19091 [i.5] and ETSI TS 103 301 [i.9] have been developed as part of ETSI ITS Release 1.

Additional use cases are being developed to cover applications such as Platooning, Cooperative Adaptive Cruise Control (C-ACC), Cooperative Perception Service (CPS) and Manoeuvre Coordination Service (MCS). VRU related use cases can make use of these specifications and applications. The objective of the present document is to provide the material to help identify improvements of current specifications and the content of additional specifications based on ongoing VRU developments.

4.2 Vulnerable Road Users

The following types of road users are considered as Vulnerable Road Users (see also the classification in Annex 1 of Regulation (EU) 168/2013 [i.8]):

- Pedestrians (including children, elderly, joggers).
- Emergency responders, safety workers, road workers.
- Animals such as horses, dogs down to relevant wild animals (see note below).
- Wheelchairs users, prams.
- Skaters, Skateboards, Segway, potentially equipped with an electric engine.
- Bikes and e-bikes with speed limited to 25 km/h (e-bikes, class L1e-A [i.8]).
- High speed e-bikes speed higher than 25 km/h, class L1e-B [i.8].
- Powered Two Wheelers (PTW), mopeds (scooters), class L1e [i.8].
- PTW, motorcycles, class L3e [i.8];
- PTW, tricycles, class L2e, L4e and L5e [i.8] limited to 45 km/h;
- PTW, quadricycles, class L5e and L6e [i.8] limited to 45 km/h.

NOTE: Relevant wild animals are only those which present a safety risk to other road users (VRUs, vehicles).

Persons carrying a personal device and transported as driver or passenger in a vehicle not listed above, such as a car (equipped with C-ITS or not), a truck, a public transport (i.e. bus, urban train, train, etc.) are not considered as VRUs and are out of scope of the present document. However, there is a grey zone during the time when the user is entering a vehicle and should be still considered as a VRU. For example, a person entering a car with the car presents a safety risk while the car door is open. The challenge associated with the change of role of the VRU device and this grey zone is considered in clause 7.2 and will be further analysed in ETSI TS 103 300-2 [i.17].

Use cases defined in ETSI ITS protocols already consider motorbikes as vehicle ITS stations, together with other motorized road vehicles such as cars, trucks or buses. However, they can also be considered as VRUs. Accordingly, VRUs may belong to both categories of vehicle ITS stations or personal ITS stations, as defined in ETSI EN 302 665 [i.6].

A VRU is described by its type, vulnerability state, legal state and situation.

4.3 VRU system

The Vulnerable Road User system (VRU system) defines the ITS artefacts that are relevant for the use cases and scenarios of clause 6, including the primary components and their configuration, the actors and their equipment, relevant traffic situations and operating environments.

The present document considers use cases and scenarios in which VRUs are particularly vulnerable to road hazards due to potential traffic conflicts with other road users, and in which VRU applications, as a subset of C-ITS applications, can increase the safety of the VRUs.

VRU applications can exist in any ITS-S, meaning that VRU applications can be found either in the VRU itself or in non-VRU ITS stations, for example cars, trucks, buses, road-side stations or central stations. These applications aim at providing VRU-relevant information to actors such as humans directly or to automated systems. VRU applications can increase the awareness of vulnerable road users, provide VRU-collision risk warnings to any other road user or trigger an automated action in a vehicle. VRU applications make use of data received from other ITS-Ss via the C-ITS network and may use additional information provided by the ITS-S own sensor systems and other integrated services.

The VRU systems considered in the present document are Cooperative Intelligent Transport Systems (C-ITS) that comprise at least one Vulnerable Road User (VRU) and one ITS-Station with a VRU application. The ITS-S can be a Vehicle ITS-Station or a Road side ITS-Station that is processing the VRU application logic based on the services provided by the lower communication layers (Facilities, Networking & Transport and Access layer as specified in ETSI EN 302 665 [i.6]), related hardware components, other in-station services and sensor sub-systems.

A VRU system may be extended with other VRUs, other ITS-S and other road users involved in a scenario such as vehicles, motorcycles, bikes, and pedestrians. VRUs may be equipped with ITS-S or with different technologies (e.g. IoT) that enable them to send or receive an alert. The VRU system considered is thus a heterogeneous system.

4.4 VRU system configuration

A strict definition of a VRU system is used to identify the system components that actively participate in a use case and behaviour scenario. The active system components are equipped with ITS-Stations, while all other components are passive and form part of the environment of the VRU system.

A vulnerable road user is an actor that interacts with a VRU system in a given use case and behaviour scenario:

- If the VRU is equipped with a personal device, then the VRU can directly interact via this device with other ITS-Stations and/or other VRUs.
- If the VRU is not equipped with a device, then the VRU interacts indirectly, as the VRU is detected by another ITS-Station in the VRU system via its sensing devices such as sensors or cameras. However, such VRUs cannot detect another VRUs (for instance a bicycle).

Table 1 identifies the four types of VRU equipment.

Table 1: VRU equipment types

VRU equipment type	Description of VRU equipment
(unequipped) VRU	VRU is unequipped.
VRU-Tx	VRU is equipped with an ITS station, having only a transmitter (no receiver) that broadcasts awareness messages or beacons about the VRU.
VRU-Rx	VRU is equipped with an ITS station, having only a receiver and an HMI to receive messages from other ITS-S and can act upon the information received, e.g. inform or warn the VRU.
VRU-St	VRU is equipped with an ITS-Station that includes the VRU-Tx and VRU-Rx functionality.

The use cases and behaviour scenarios consider a wide set of configurations of VRU systems based on the equipment of the VRU and the presence or absence of Vehicle ITS Station (V-ITS-S) and/or Road side ITS Stations (R-ITS-S) with a VRU application. This results in the VRU system configurations described in Table 2. This table presents the types of ITS stations present in the configuration. There can be one or more instances of each type in a configuration.

Table 2: VRU System Configurations

VRU System Configurations												
C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
VRU	VRU-Tx	VRU-Rx	VRU-St	VRU	VRU-Tx	VRU-Rx	VRU-St	VRU-Rx	VRU-St	VRU-St	VRU	VRU-Tx
				R-ITS-S	R-ITS-S	R-ITS-S	R-ITS-S	R-ITS-S	R-ITS-S		R-ITS-S	R-ITS-S
V-ITS-S	V-ITS-S	V-ITS-S	V-ITS-S	V-ITS-S	V-ITS-S	V-ITS-S	V-ITS-S					

4.5 Traffic situations

4.5.1 Introduction

Three types of traffic situations are distinguished:

1) An immediate safety risk of a VRU due to an imminent conflict or collision with another road user.

2) Safety of a VRU can be increased by raising awareness of the presence of the VRU to avoid a conflict situation proactively.

3) Traffic efficiency can be increased for a VRU with special needs.

The environment of the following traffic situations may be diversified, for example with the presence of a zebra crossing, whether road users travel in the same lane or in separate lanes, a vehicle is opening its door, the intersection is signalised, or whether the Line Of Sight (LOS) is occluded (see clause 4.6).

4.5.2 Collision risks

4.5.2.1 General considerations

A vulnerable road user is particularly vulnerable in traffic situations where there is a potential conflict with another road user. The traffic conflict point is the intersection of the trajectories of the VRU and the other road user. A conflict, or collision, occurs if both the VRU and the other road user reach the conflict point at about the same time. The collision can be avoided if either or both respond with an emergency manoeuvre and appropriately adapt their speed or/and path.

The VRUITS project reported in their deliverable D [i.14] the result of the analysis of a range of databases to identify critical scenarios for VRU's. According to this analysis, the accident between **pedestrians** and vehicles with the highest frequency occurs when the pedestrian was crossing the road at mid-block, occluded or not by a parked car. The majority of **cycling** accidents were found to occur at junctions/intersections. One of the most common scenarios involve vehicles pulling out into the path of the on-coming cyclist at an intersection. For **PTW**, the most common scenario was found to be the PTW being hit by a vehicle (mainly passenger car) initially heading in the same direction and then turning across the path of the PTW. Another scenario involves vehicles pulling out from intersections into the path of the PTW. Most accidents occur within urban environments.

The safety risk for the VRU can be measured from the speed difference, distance or time period between the VRU and the other road user when passing the conflict point and expressed in safety measures such as the Time-To-Collision (TTC) or Post-Encroachment-Time (PET).

Traffic conflicts can be categorized by the road topology and the direction of travel of the VRU and other road user(s). They have been studied intensively in research projects such as PROSPECT [i.15] and are considered in the example use cases described in the present document (see clause 6.1).

4.5.2.2 Mid-block situations

A VRU and another road user are travelling on the same straight or bended road; i.e. not near a crossing or intersection. The VRU and the other road user can travel in different directions:

1) The VRU is crossing the road of another road user at mid-block or jay walking. The VRU may approach the road from the same side of the road as the other road user, or from the opposite side.

2) The VRU is being approached and/or overtaken by another road user travelling in the same direction.

3) The VRU is overtaking another (stationary or slow moving) road user on the inner side of the lane or road.

4) The VRU is overtaking another (stationary or slow moving) road user on the outer side of the lane or road.

5) The VRU is potentially colliding with another road user travelling in the opposite direction (e.g. overtaking scenarios with approaching VRU/road user; roads with limited width).

4.5.2.3 Crossing or intersection situations

A VRU can cross the trajectory of another road user at a road crossing or intersection from different directions, while each road user maintains its direction of travel:

1) The VRU is crossing the intersection perpendicular to the direction of the other road user. The VRU may approach the intersection from the same side as the other road user, or from the opposite side.
2) The VRU is being overtaken by another road user travelling in the same direction.
3) The VRU is overtaking another (stationary or slow moving) road user on the inner side of the lane or road.
4) The VRU is overtaking another (stationary or slow moving) road user on the outer side of the lane or road.
5) The VRU is potentially colliding with another road user travelling in the opposite direction.

Additional conflict situations may arise if a VRU is turning while the other road user maintains its course:

1) The VRU and other road user travel in the same direction. The VRU turns in front of the other road user.
2) The VRU and other road user travel in opposite directions. The VRU turns in front of the other road user.
3) The VRU and other road user travel in perpendicular directions. The VRU turns in front of the other road user in the same direction.
4) The VRU and other road user travel in perpendicular directions. The VRU turns in front of the other road user and in opposite directions.

Additional conflict situations may arise if a VRU maintains its course while the other road user is turning ahead of the VRU:

1) The VRU and other road user travel in the same direction. The other road user turns in front of the VRU.
2) The VRU and other road user travel in opposite directions. The other road user turns in front of the VRU.
3) The VRU and other road user travel in perpendicular directions. The other road user turns in front of the VRU in the same direction.
4) The VRU and other road user travel in perpendicular directions. The other road user turns in front of the VRU in opposite directions.

4.5.3 VRU awareness

Other road users can be made aware of the presence of a VRU to avoid the risk of collisions proactively in the traffic situations introduced in clause 4.5.2. In parallel, VRU could be also made aware of the presence of other road user to proactively initiate protective actions. Simultaneous awareness both of the VRU and other road user may increase VRU safety. Awareness is particularly relevant in the following situations:

- Black spot locations such as bus stops, schools.
- Traffic light conflicts between VRUs and turning vehicles.
- Zebra crossings or other VRU crossings.
- Position of the VRU is inside an unexpected area (e.g. pedestrian on a highway or on a cycle lane).

4.5.4 Traffic efficiency

Traffic efficiency of VRUs is primarily related to controlled intersections. Two situations can be distinguished:

- Traffic light status information can be provided to VRUs.
- VRUs can request priority or signal state changes.

4.5.5 Collision Avoidance

Collision avoidance between a vehicle and a VRU can be achieved in an active manner at the level of the vehicle or VRU device which may have several strategies:

- Slowing down the vehicle when detecting a VRU with its own frontal camera (ex: Front assist), or when receiving an alert from another vehicle or road side unit.
- Changing its trajectory when detecting a VRU with its own frontal camera or when receiving an alert from another vehicle or road side unit.
- Slowing down or changing the trajectory of VRU when detecting a collision risk with a vehicle or other road user.
- In all cases in extreme condition, an emergency braking can be triggered by the subject vehicle when receiving some instruction from an authorized road side unit (for example using the Manoeuvre Coordination Service).

This type of solution is possible for human driven vehicles or automated vehicles (SAE levels 4 &5) in extreme cases:

- If the human driver is in a hypo-vigilance state following some health problem.
- Under a cyberattack of the vehicle.
- If an automated vehicle without human driving capabilities is in a failure mode.

Collision avoidance action may be triggered locally by a vehicle or a VRU device detecting a risk of collision or remotely by an authorized road infrastructure equipment or police vehicle. This second case would be relevant in case of terrorist attack or police roadblock forcing.

4.6 Environment

4.6.1 Introduction

The environment in which the VRU system operates determines the ability and performance to detect VRUs, to communicate relevant information, the required behaviour of VRU applications and the ITS possible action on dangerous vehicles. The environment consists of detection and communication equipment at the road side, in vehicles or VRU devices, and obstacles that affect the detection or communication. An ITS-S that is not equipped with a VRU application that could be used for VRU detection and communication can also be considered as part of the VRU system environment.

The environment has a large impact on the potential safety risks in the traffic conflict situations described in clause 4.5. A large set of scenarios could be defined by varying the environments per use case. The objective of clause 4.6, however, is to provide a structure for identifying the most critical scenarios in terms of detection, communication and action performances of VRUs. The following clauses categorize elements in the environment of a VRU system as described in clause 4.4.

4.6.2 Road layout

A road layout determines the subset of traffic conflicts and conflict points in real situations for the topologies defined in clause 4.5:

- The presence of pavements or cycle lanes, borders and horizontal and vertical road markings, for example, reduces the potential conflicts on mid-block situations, and at best increases the separation distance between the VRU and other road users.
- Signalisation at crossings and intersections also intends to reduce the number of traffic conflict situations.

The road layout also defines traffic rules and legal road use in a given situation, which determines the expected functionality, the type of awareness, warnings and actions of VRU applications. The examples below identify the situations in which VRUs are expected to cross the trajectory of vehicles and when not:

- Awareness of VRUs in the vehicle's lane is more critical than that of VRUs on designated VRU areas.
- Warnings may be given when VRUs cross a zebra or un-signalised VRU crossing.
- Red light violation warnings may be given when a VRU or a vehicle crosses against a red light.
- Add uncontrolled traffic situations.

Besides the road layout, critical situations may arise from unexpected driving manoeuvres, e.g. when a vehicle enters a designated VRU area, for example due to its speed.

The VRU applications should take scenarios into account where road users may violate or abuse the road layout, and scenarios where traffic legislation differs between countries.

4.6.3 Road side equipment

Road side equipment can contribute to VRU safety in different modes of operation:

- Passive VRU detection: the presence of the VRU is detected by an IoT device (e.g. presence detector, camera) and reported to the VRU application in the Road ITS-Station.
- Active VRU detection: the road side equipment receives messages from transmitting VRUs and forwards them to the VRU application.

In both cases, the information is processed in the VRU application, which may send event notifications in case of a safety issue (e.g. red-light violation detection, pedestrian or animal crossing detection, road workers, etc.).

4.6.4 Vehicle equipment

The use cases consider different types of equipment in the neighbouring vehicles:

- Vehicle with communication device and VRU application, but no pedestrian detection system (sensors).
- Vehicle with communication device and VRU application, equipped with pedestrian detection system.

NOTE: Whether the neighbouring vehicle communication device is embedded in the vehicle or is a personal device playing the role of vehicle ITS station has no impact on the VRU use cases and is considered as an implementation topic.

Vehicles without any communication device and/or without VRU application are also considered in the use cases, taking into account the progressive system deployment. Furthermore, according to the development level, the equipped vehicles may support warning to their drivers only (i.e. ETSI ITS Release 1 services) or CPS and MCS capability.

4.6.5 Obstacles

Different types of obstacles can exist in the VRU environment for C-ITS:

- Obstacles that (partially) degrade the detection of VRU by road side or vehicle detectors.
- Obstacles that (partially) degrade the communication between ITS-S and the VRU communication devices.
- Obstacles on the road (i.e. other road users - are typically moving objects).
- Obstacles at the road side (road infrastructure, bridges, buildings, trees, etc.).
- Obstacles due to the larger dimensions of vehicles, for example the load on agriculture vehicles, trucks especially when complemented with trailers, caravans, motorhomes.

5 Categorization of use cases

Use cases can be classified according to the structure of the VRU system being used such as represented in Figure 1 below. This classification leads to six categories (A to F) of use cases. For each category some examples (in most of the cases provided by national or European projects) illustrating the interactions (behaviour scenarios) between the elements of the VRU system are proposed. It should be noted that the use cases do not focus on a specific environment, such as rural, urban or highway, and that most of them could be applicable to more than one environment. Accordingly, the categorization presented below can be considered environment independent.

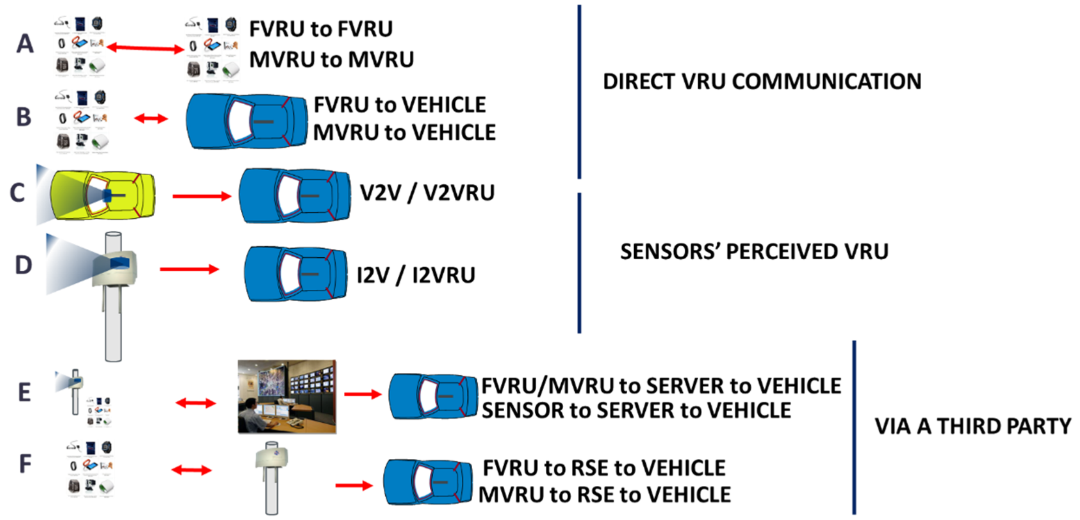


Figure 1: Proposed categories of use cases

In some situations, there may be a large and/or dense crowd of VRUs that are identified in the figure above as Many VRUs (MVRU). In other cases, there are only a Few VRUs (FVRU), for example less than 10 in total.

Table 3: Proposed categories of use cases

Use case category	Description
Category A	Direct VRUs communication. In this case, the VRUs are equipped with a device (VRU-Tx, VRU-Rx, or VRU-St configuration) embedding at least one ITS-S, as described in ETSI EN 302 665 [i.6] and potentially other types of applications.
Category B	Direct VRU to vehicle communication. The VRU is equipped with a device (VRU-Tx, VRU-Rx, or VRU-St configuration) embedding at least one ITS-S; the vehicle is also equipped with an ITS-S compliant with the relevant VRU standards.
Category C	Assistance of a third party (a vehicle) detecting a hidden VRU and signalling it to other vehicles. The VRU may not be equipped (VRU or VRU-Tx configuration) while the vehicles have an ITS-S complying with the VRU standards.
Category D	Assistance of a third party (a Road Side Equipment or RSE) detecting a hidden VRU and signalling it to approaching vehicles. The VRU may not be equipped (VRU or VRU-Tx configuration) while the RSE and vehicles are equipped with ITS-S complying with VRU standards.
Category E	Assistance of a third party (a control centre or cloud server) monitoring the evolution of VRUs. The VRUs may be equipped with an ITS-S (VRU-Tx, VRU-Rx, or VRU-St configuration) complying with VRU standards, detecting risks of collisions with monitored vehicles and then acting to avoid collision (sending alarm or collision avoidance instructions). RSE and vehicles are equipped with ITS-S complying with VRU standards.
Category F	Assistance of a third party (an RSE) monitoring the evolution of VRUs equipped with an ITS-S (VRU-Tx, VRU-Rx, or VRU-St configuration) complying with VRU standards, detecting risks of collisions with monitored vehicles and then acting to avoid collision (sending alarms or collision avoidance instructions). RSE and vehicles need to be equipped with ITS-S complying with VRU standards. Edge computing is part of this category.

Table 4 shows how the most dangerous traffic situations that have been identified by European projects such as PROSPECT can be mapped to the use case categories proposed in Table 3.

NOTE: Table 4 refers to the use cases described in clause 6 by their names: UC-XY where X is the letter referring to the use case category and Y is the number of the use case in the category.

Table 4: Proposed categories of use cases

Use Case category (right) vs. traffic situations (below)	**A - vru2vru**	**B - vru2v**	**C - V2V**	**D - I2V**	**E - server2v**	**F- vru2i2v**
Pedestrian/bicycle crossing the road, vehicle going straight * This UC is mapped to UC-B2 (i.e. vru2v), and can be possibly combined with other UCs like UC-C1, UC-D2, and UC-E1. (***UC-B2**, UC-C1, UC-D2, UC-E1)		X	X	X	X	
Pedestrian/bicycle crossing the road, vehicle turning at intersection * This UC is mapped to UC-B2 (i.e. vru2v), and can be possibly combined with other UCs like UC-C1, UC-D2, and UC-E1. (***UC-B2**, UC-C1, UC-D2, UC-E1)		X	X	X	X	
Pedestrian/ bicycle crossing the road, PTW going straight * This UC is mapped to UC-A2 (i.e. vru2vru), and can be possibly combined with other UCs like UC-D2. (***UC-A2**, UC-D2)	X			X		
Pedestrian/bicycle crossing the road, PTW turning at intersection * This UC is mapped to UC-A2 (i.e. vru2vru), and can be possibly combined with other UCs like UC-D2. (***UC-A2**, UC-D2)	X			X		
PTW/bicycle and vehicle in longitudinal traffic flow (same direction or opposite) * This UC is mapped to UC-B2 (i.e. vru2v), and can be possibly combined with other UCs like UC-D2. (***UC-B2**, UC-D2)		X		X		
Pedestrian and bicycle in longitudinal traffic flow (same direction or opposite) * This UC is mapped to UC-B2 (i.e. vru2v), and can be possibly combined with other UCs like UC-D2. (***UC-B2**, UC-D2)	X			X		
Road workers in roadwork zone * This UC is mapped to UC-B1 (i.e. vru2v), and can be possibly combined with other UCs like UC-D1. (***UC-B1**, UC-D1)		X		X		
Group of pedestrians in protected area * This UC is mapped to UC-F1 (i.e. vru2i2v), and can be possibly combined with other UCs like UC-D1. (***UC-F1**, UC-D1)				X		X
Motorbike rider on the road * This UC is mapped to UC-B3 (i.e. vru2v), and can be possibly combined with other UCs like UC-C1 and UC-D2. (***UC-B3**, UC-C1, UC-D2)		X	X	X		
Emergency Electronic Brake Light * This UC is mapped to UC-B4 (i.e. vru2v), and can be possibly combined with other UCs like UC-D2. (***UC-B4**, UC-D2)		X		X		
Unequipped Animal/pedestrian on the road * This UC is mapped to UC-D2 (i.e. i2v), and can be possibly combined with other UCs like UC-C1 and UC-E2. (***UC-D2**, UC-C1, UC-E2)			X	X	X	

Use Case category (right) vs. traffic situations (below)	**A - vru2vru**	**B - vru2v**	**C - V2V**	**D - I2V**	**E - server2v**	**F- vru2i2v**
Equipped Animal/pedestrian on the road * This UC is mapped to UC-B2 (i.e. vru2v), and can be possibly combined with other UCs like UC-A2, UC-C1, UC-D2 and UC-F2. (***UC-B2**, UC-A2, UC-C1, UC-D2, UC-F2)	X	X	X	X		X
Motorcycle Approach Indication/Motorcycle Approach Warning * This UC is mapped to UC-B5 (i.e. vru2v), and can be possibly combined with other UCs like UC-A2, UC-C1, UC-D2. (***UC-B5**, UC-A2, UC-C1, UC-D2)	X	X	X	X		

6 Description of example use cases

6.1 General considerations for the use case descriptions

Clause 6 provides examples of typical use cases per categories as identified in clause 5 with the objective to increase the understanding of the interactions and associated system behaviour scenarios being applied during the system operation. Each use case is analysed and provides inputs to the summary and challenges presented in clause 7. System requirements and architecture of the VRU system as described in ETSI TS 103 300-2 [i.17] will be based on the use cases described in the present document.

The use cases hereafter presented are illustrative and display realistic cases with corresponding VRUs, that may even have been demonstrated in previous activities and tests, rather than generic VRU and their devices, which would be less meaningful to extract requirements for the specification of the VRU functional architecture. Since VRUs include different types of road users (see clause 4.2) the use cases may also be applicable to road users different from the ones used as an example. For example, a bicycle could face the same risk of collision as a pedestrian in the situation of a specific use case.

The messages mentioned when describing the use cases are also just examples of possible messages. The decision on which specific messages and their content will be described in ETSI TS 103 300-2 [i.17], together with the specification of requirements and VRU architecture. Notably, a compromise will have to be sought in order to control the possible congestion of the channel and avoid its saturation.

The assumption is that there is at least one mechanical device in the scenarios (e.g. no pedestrian-to-pedestrian risk of collisions).

6.2 Category A: VRU to VRU direct cooperation

6.2.1 UC-A1: Sharing pavement between pedestrian and cyclists

6.2.1.1 Description

This is typically a VRU to VRU cooperation. Each VRU is equipped with an ITS-S complying with VRU standards. The VRUs are exchanging constantly standard messages enabling the detection of a risk of collision between them. When relevant, an action (in this case, an alert) can be triggered to avoid the collision.

Use case category: A	

6.2.1.2 Actors

The actors are several VRUs (at least two) sharing a given space which can be organized or not into separate dedicated lanes.

6.2.1.3 Pre-conditions

VRUs are all equipped with a portable device integrating an ITS-S compliant with the VRU standards. These devices are power supplied and configured properly according to their applications. VRUs are positioned in the communication range of the C-ITS network.

6.2.1.4 Triggers

When a risk of collision between two or more VRUs is detected, a collision avoidance action (e.g. an alarm with a possible recommendation) is provided to the VRUs of types VRU-Rx or VRU-St.

6.2.1.5 Normal flow

Assumptions: The cyclist and pedestrians are equipped with Release 2 services only. The flow considers all cases, independently of timing constraints (see the time constraints analysis in clause 6.2.1.9).

The normal information flow is represented on Figure 2.

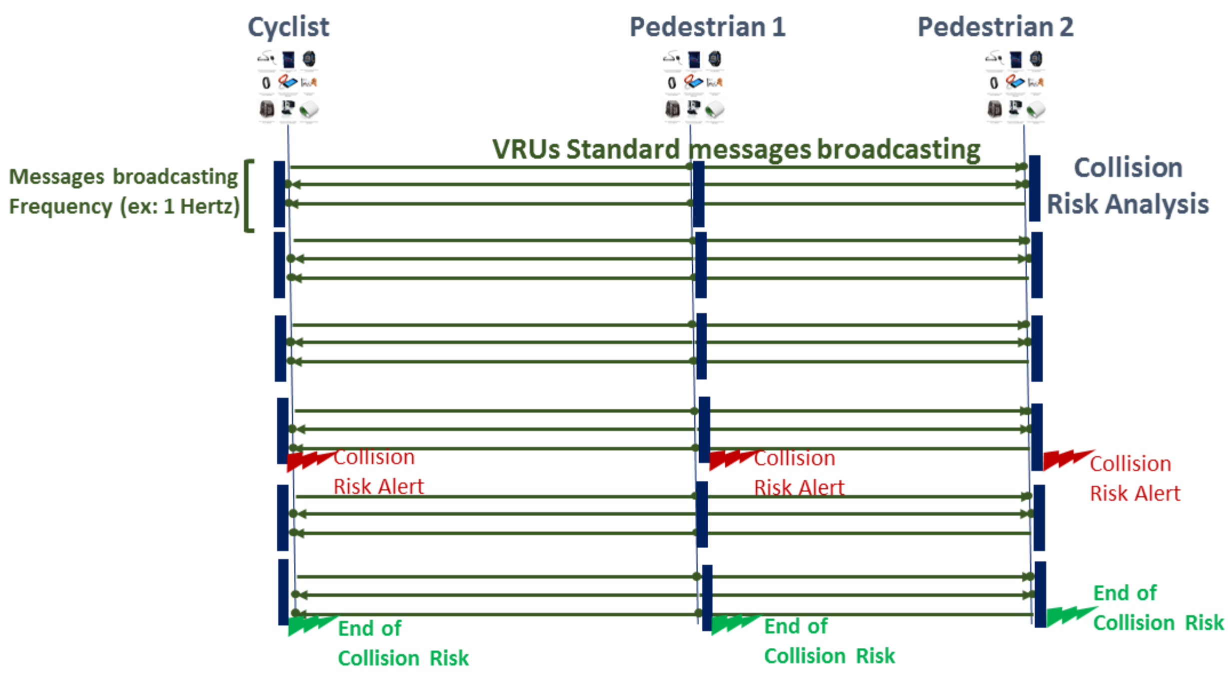


Figure 2: Flow diagram for UC-A1 where VRUs share the pavement

1) VRU standard messages are continuously broadcasted by VRUs devices at a configurable frequency (for example at 1 Hz maximum).

2) Received messages are processed by ITS-S for collision risk analysis.

3) A risk of collision is detected by one or several devices.

4) According to ITS-S configurations (e.g. VRU-Rx and VRU-St) the devices alert the VRUs of a collision risk, providing an alarm and complementary recommendations advices to avoid collision between the two VRUs (e.g. cyclist & pedestrian).

5) Other cyclists and pedestrian being in a similar collision risk situation (and receiving the warning notification) are also advised.

6.2.1.6 Alternative flow

The normal flow already considers a deployment based on Release 2. Consequently, there is no alternative flow.

6.2.1.7 Post-conditions

Once a collision risk has been processed, the system is going back to its monitoring state, broadcasting standard messages and analysing their content to detect a new risk of collision until being deactivated by the VRU.

6.2.1.8 High Level Illustration

Figure 3 shows an illustration of the considered use case.

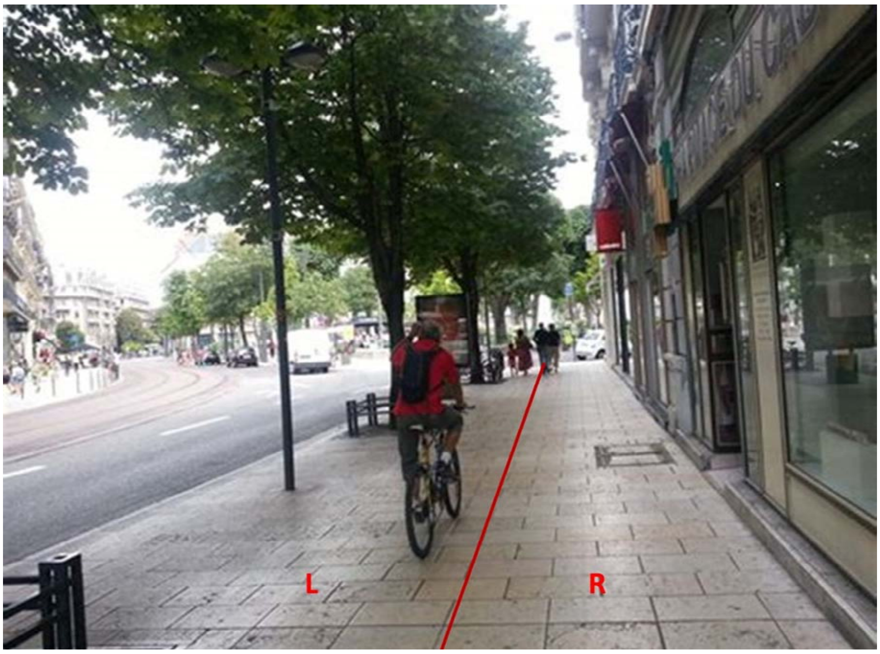


Figure 3: VRU to VRU use case illustration

In case of a detected collision risk, provided alerts need the use of audio-visual messages:

- Advising pedestrian to move on their right (see R sign in the illustration) for example.
- Advising cyclist to slow down if its speed is judged excessive.

6.2.1.9 Use case analysis

This category of use cases does not consider a direct automated action on VRUs and their mobility means. Only alerts and advices (on trajectory or momentum) are foreseen.

In this case, the security level of the system does not need to be consolidated as the risk is low in case of a cyberattack.

If there are many VRUs in the system, an ad hoc local area network congestion problem may happen.

The precision of the geo-position is an essential point of this use case (e.g. better than 20 centimetres accuracy).

The latency time of the system is less critical than when a motorized vehicle is involved. However, the periodicity of exchanged messages needs to remain as much as possible consistent with the required positioning accuracy and VRU behaviour.

This use case could be considered in the same manner with a motorcycle instead of a bicycle. Another analysis should be developed due to the velocity of the motorcycle, its noise and its electronic equipment (VRU device) which can be very different of the bicycle:

- The velocity will impact the latency time requirements of the message exchanges as the TTC may be reached faster than with a bicycle.
- The interaction between the motorcycle HMI and the VRU needs to be more carefully designed in terms of alerts, considering the velocity and noise associated with the motorcycle.

The same applies to further use cases showing bicycles, e-scooters, PTW, etc.

6.2.2 UC-A2: Pedestrian crossing a road with an e-scooter approaching

6.2.2.1 Description

In this use case, one (or several) equipped VRU(s) able to receive and transmit V2X messages, i.e. in VRU-St configuration, is (are) positioned at a crossroad while an electric scooter is approaching. The e-scooter is equipped with a VRU device as well. One of the VRU ITS-S has sufficient processing capabilities to perform a risk assessment.

Use case category: A	 **FVRU to FVRU** **MVRU to MVRU**

As an example, this use case shows the electric e-scooter being equipped with a VRU-Tx ITS-S only, while the pedestrian about to cross the road is equipped with a VRU-St ITS-Station which has the capability to perform the risk assessment. Another possibility could be to have the e-scooter equipped with a VRU-St ITS-S while the pedestrians are equipped with VRU-Tx ITS-S only. In this case, the e-scooter could perform an automatic emergency brake to avoid a risk of collision with an elderly person for example.

The risk assessment assists in controlling the frequency of communication in order to reduce network congestion. The risk assessment can be based on context perception (detection if the VRU is participating to traffic, using public transport, walking indoors), and/or on building a dynamic map from the signals received from other road users.

The VRU standard messages are received by other VRUs and vehicle ITS-S stations. In case of potential risk, the VRU-St ITS-S warns its user and is able to broadcast a warning message to passing-by vehicles.

6.2.2.2 Actors

- Pedestrian equipped with a VRU-St.
- Electric scooter equipped with a VRU-Tx.

6.2.2.3 Pre-conditions

- VRU-St and VRU-Tx support V2X and VRU application.
- VRU-St is able to broadcast VRU standard messages.
- Both VRUs are in proximity i.e. within each other's V2X communication range.

6.2.2.4 Triggers

The VRU-St assesses the level of risk based on context perception, e.g. presence of other road users transmitting C-ITS messages and/or participation to traffic with increased risk of collision (e.g. intent to cross a road).

It identifies potential collision with a TTC less than 5 seconds.

6.2.2.5 Normal flow

1) The VRU-St and the VRU-Tx broadcasts VRU standard messages.

2) Based on context perception, the risk assessment at the VRU-St identifies that both VRUs are on a collision course.

3) The VRU-St warns its user (pedestrian) at the appropriate time to wait before crossing the road. It may also broadcast a warning message to passing-by vehicles.

6.2.2.6 Alternative flow

In this specific case, no alternative flow was identified.

6.2.2.7 Post-conditions

After the electric scooter has passed, the pedestrian can cross the road in safety.

Both VRU ITS stations carry on transmitting VRU standard messages, while the risk assessment function in the VRU-St resumes its operation.

6.2.2.8 High Level Illustration

Figure 4 shows an illustration of the considered use case.

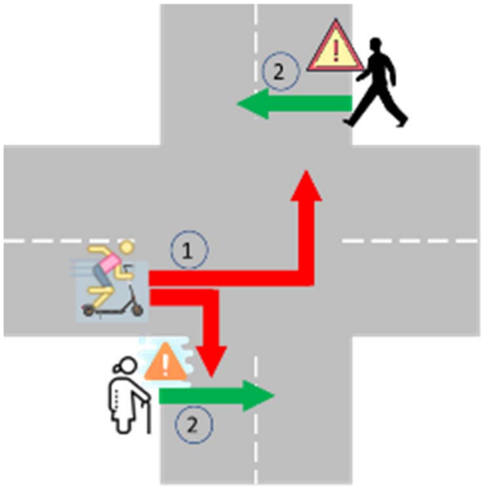


Figure 4: E-scooter to pedestrian use case illustration

6.2.2.9 Use case analysis

This use case highlights several challenges:

- Positioning aspects. It can be achieved only if the positioning is sufficient to determine that both trajectories have a chance to collide.

- Evaluation of the expected behaviour of the VRU. The risk of collision can only be assessed if the knowledge of the VRU context, especially in the case of the pedestrian, is sufficient to understand that its user intends to cross the road.

- This use case may also be considered with a motorbike replacing the e-scooter. In this case, performance figures should be modified accordingly to evaluate the risk of collision (PET, TTC), as explained in clause 6.2.1.9.

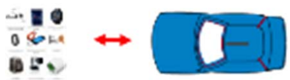
6.3 Category B: VRU to Vehicle direct cooperation

6.3.1 UC-B1: Active Roadwork

6.3.1.1 Description

By active roadwork it is meant that human workers are present and active on the roadwork zone.

The VRUs to vehicles cooperation can be achieved by VRUs using a device including an ITS-S complying with VRU standards. In such case, the devices' ITS-S are continuously broadcasting VRU standard messages providing dynamic data elements related to their positions and movements. Vehicles are also equipped with an ITS-S complying with VRU standards and so are capable of receiving VRU standard messages and then of detecting and avoiding collision with active workers.

Use case category: B	 **FVRU to VEHICLE** **MVRU to VEHICLE**

6.3.1.2 Actors

- Actives workers on the roadwork zone.
- Vehicles (human driven or automated).

6.3.1.3 Pre-conditions

VRUs are all equipped with a portable device integrating an ITS-S compliant with the VRU standards. Vehicles are also all equipped with an ITS-S complying with VRU standards. All ITS-S are power supplied and configured properly according to their applications. VRUs and vehicles are positioned in the telecommunication range of the C-ITS network.

6.3.1.4 Triggers

When a risk of collision between at least one VRU and a vehicle is detected, a collision avoidance action is triggered.

6.3.1.5 Normal flow

Assumptions: The road workers are equipped with Release 1 services only, having the capability to broadcast DENMs. Vehicles are equipped with Release 1 service, broadcasting CAMs. The flow considers all cases, independently of timing constraints (see use case analysis in clause 6.2.1.9 for timing constraints).

The normal information flow is represented in the flow diagram shown in Figure 5.

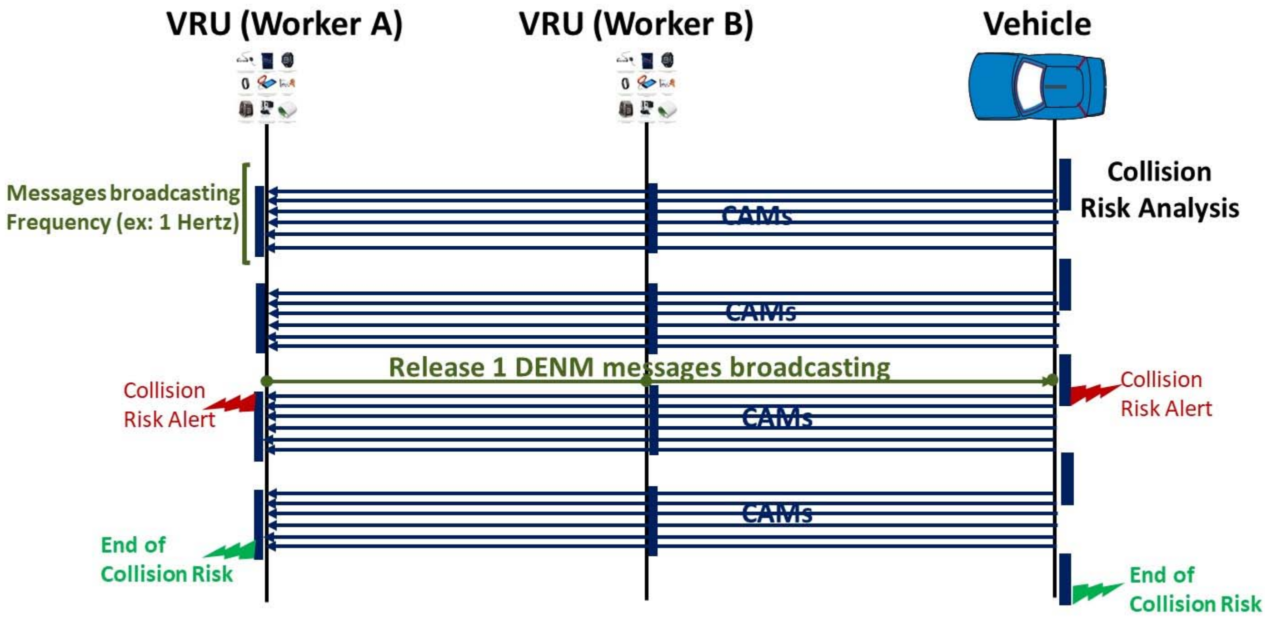


Figure 5: Flow diagram for UC-B1 - Active Roadwork

1) Release 1 compliant vehicles are constantly broadcasting CAMs.

2) CAMs sent by vehicles are processed by VRU devices (VRU-Rx, VRU-St) for collision risk analysis.

3) A risk of collision is detected by one or several devices.

4) According to ITS-S configurations (e.g. VRU-Rx and VRU-St) the devices alert the road worker of a collision risk, providing an alarm and complementary recommendations advices to avoid collision between the road worker and one vehicle.

5) VRU devices detecting a risk of collision broadcast DENMs to vehicles.

6) Upon reception of DENMs, vehicles act according to the estimated TTC, either sending a warning to the driver, triggering an emergency braking or a post-crash action.

7) In parallel, active road workers can receive a signal indicating a dangerous vehicle and encouraging them to protect themselves.

This normal flow could also have the VRUs send CAM messages and both devices performing the risk assessment in parallel. The option provided here is just an example of possible messages and takes into account that a compromise will have to be sought in order to control the possible congestion of the channel, avoiding to saturate it. The same applies to the alternative flow. The decision on the messages to be used and their content will be described in ETSI TS 103 300-2 [i.17], together with the specification of the requirements and VRU architecture.

6.3.1.6 Alternative flow

Assumptions: Road workers (VRUs) and vehicles are equipped with Release 2 services (ex: VRU service and VRU service processing at the vehicle level) and potentially enhanced collision avoidance system. The flow considers all cases, independently of timing constraints (see clause 6.3.1.9):

1) Release 2 compliant vehicles are constantly broadcasting CAMs or enhanced CAMs (see note).

2) Release 2 VRU devices ITS-S (VRU-Rx, VRU-St) process received messages for collision risk analysis.

3) As soon as a collision risk is detected, VRU devices broadcast VRU service messages and signal this risk of collision with a vehicle to the VRU.

4) Vehicles receiving VRU service messages process them for TTC calculation and collision avoidance action according to the TTC value.

NOTE: Enhanced CAM could add some trajectory/velocity prediction data elements (in particular vehicles being in an automated mode may provide such prediction), thus enabling the VRU devices to better identify a risk of collision.

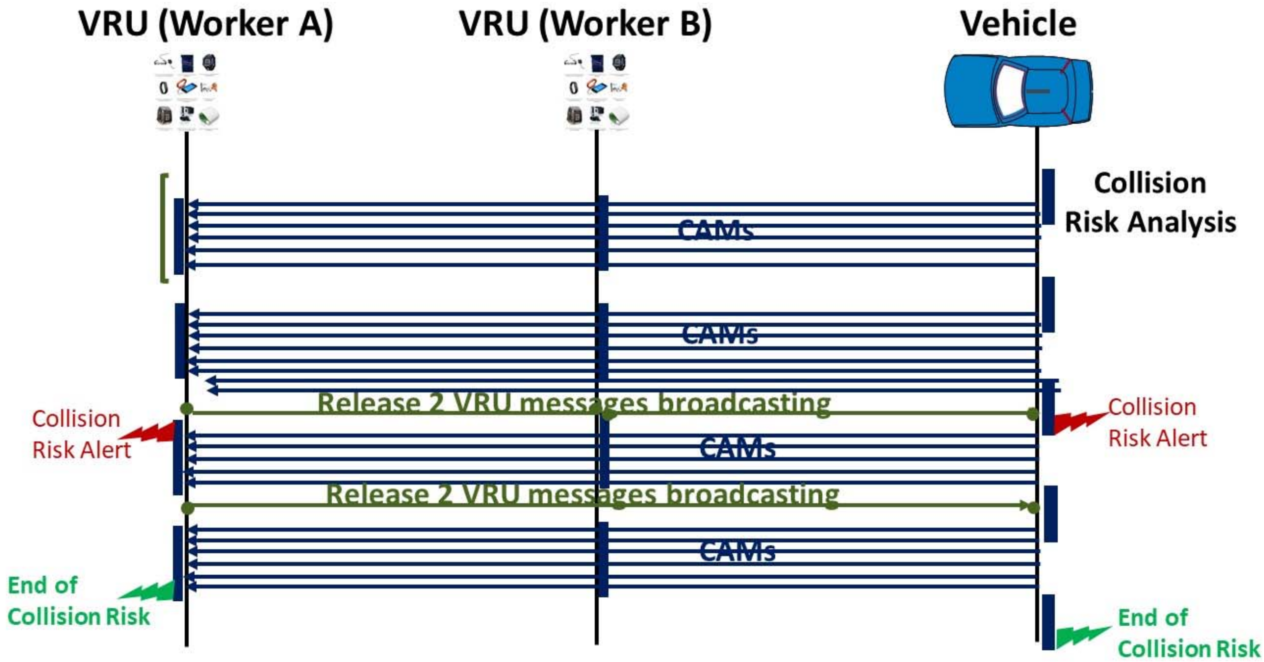


Figure 6: Alternative flow diagram for UC-B1 - Active roadwork

6.3.1.7 Post-conditions

Once a collision risk has been processed, the system resumes its monitoring state, broadcasting VRU standard messages and analysing their content to detect a new risk of collision until being deactivated by the VRU.

If the vehicle has been stopped before the stop line, it needs to perform a manoeuvre to change its lane and enter the first open lane.

6.3.1.8 High Level Illustration

Figure 7 shows an illustration of the considered use case.

If the vehicle A is decelerated and stopped before the "do not pass" line, it will have to insert itself in the traffic flow of the left open lane, respecting the minimum vehicles' inter-distance in conformity with the traffic code.

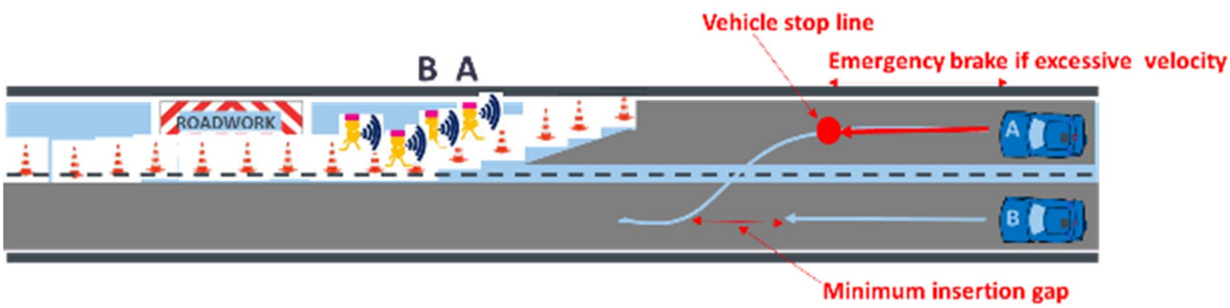


Figure 7: Active Roadwork use case illustration

6.3.1.9 Use case analysis

The possibility of alerting the VRU, the driver or acting directly on the vehicle depend on the device's capabilities (e.g. deployment level), but also on the TTC available when the risk of collision is detected.

As soon as a risk of collision is detected, a VRU device needs to broadcast VRU service messages at a frequency of at least 1 Hz.

Vehicles broadcast CAMs or enhanced CAMs at a frequency of at least 10 Hz (see note).

NOTE: At the receiving side, the sampling period (related to broadcasting frequency) and communication latency will influence the age of data elements (freshness). If a sampling period of 100 millisecond (10 Hz) is used, the data elements accuracy (e.g. positioning) may show an error higher than 20 cm (according to vehicle relative velocity) if there are no correction facilities (trajectory and velocity prediction). Normally, an ad-hoc local area network has a latency approaching the millisecond (in case of no network congestion), so not really contributing to the increase of the age of data elements.

Direct actions on vehicles (e.g. emergency braking) if needed by TTC value lead to the securing of the messages being broadcasted by the VRUs.

This type of direct action can be mandatory in the case of a terrorist attack or a police roadblock forcing (use case similar to this one but with workers replaced by policeman willing to intercept a given vehicle). In this case, a specific certificate can be necessary.

If there are many VRUs in the system, an ad hoc local area network congestion problem may happen and needs to be solved. This could be achieved by developing a relevance check algorithm which authorizes only, for example the three more relevant equipped VRUs broadcasting their movements. Such algorithm could be based on the collision risk levels comparisons between all VRUs which are broadcasting VRU messages. Only the three having the highest risk could be authorized to continue to broadcast their messages.

6.3.2 UC-B2: VRU crossing a road

6.3.2.1 Description

In this use case, one (or several) equipped VRU(s) able to receive and transmit V2X messages, i.e. in VRU-St configuration, are crossing a road. In the normal flow, the VRU is (are) positioned at a crossroad. There are two possible approaches:

- Approach 1 (A1): the VRU ITS-S has limited processing capabilities, and sends continuously VRU standard messages, but does not perform any risk assessment.
- Approach 2 (A2): the VRU ITS-S has sufficient processing capabilities to perform a risk assessment. The risk assessment assists in controlling the frequency of communication in order to reduce network congestion.

The VRU standard messages are received by other vehicle ITS-S stations. In case of potential risk, the V-ITS-S broadcasts a warning message, which is received by the VRU-St.

This use case has been described by the VRUITS project.

Use case category: B	

6.3.2.2 Actors

- One or several V-ITS-S.
- One or several VRU ITS-S, in VRU-St configuration.

6.3.2.3 Pre-conditions

- VRU-St and V-ITS-S support V2X and VRU application.
- V-ITS-S broadcast periodically vehicle awareness messages.
- VRU-St is able to broadcast VRU standard messages, either periodically (Approach A1) or in case of increased risk (Approach A2).
- V-ITS-S and VRU-St are in proximity i.e. within each other's V2X communication range.

6.3.2.4 Trigger

Approach A1: The V-ITS-S makes a risk assessment, based on the VRU standard messages received and on behavioural models of the VRUs, and identifies potential collision with a TTC less than 5 seconds.

Approach A2: (In addition to the vehicle risk assessment), the VRU-St assesses the level of risk based on context perception, e.g. presence of other road users transmitting C-ITS messages and/or participation to traffic with increased risk of collision (e.g. intent to cross a road).

6.3.2.5 Normal flow

Vehicle is equipped with Release 1 services only:

1) The VRU-St broadcasts VRU standard messages, either (A1) continuously, (A2) at higher risk based on context perception.
2) The risk assessment at the VRU-St or the V-ITS-S identifies that both road users are on collision course, and warns the ITS-S users.
3) A collision warning is sent using C-ITS to the relevant road users.
4) The relevant ITS-S stations receive the C-ITS warning, and warn the ITS-S user at the appropriate time.

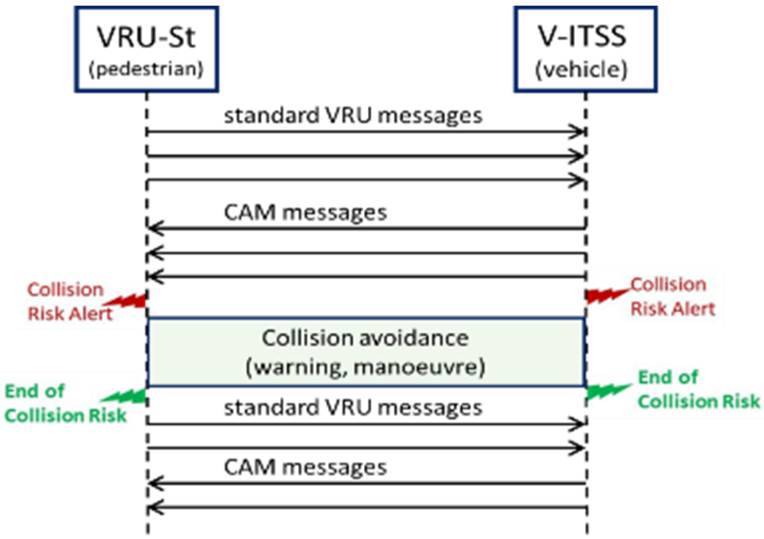


Figure 8: Flow diagram for UC-B2 - VRU at crossroad

6.3.2.6 Alternative flows

Alternative Flow 1

Vehicle is equipped with other Release 2 services, for example CPS and MCS services:

1) The VRU-St broadcasts awareness messages, either (A1) continuously, (A2) at higher risk based on context perception.

2) The risk assessment at the VRU-St or the V-ITS-S identifies that both road users are on collision course, and warns the ITS-S users.

3) A collision warning is sent using C-ITS to the VRU.

4) Action, potentially from a received MCM message, is performed on the vehicle, for example by triggering an emergency braking or a slowing down of the vehicle according to its velocity level.

Alternative Flow 2

In this use case, one VRU is crossing a road on a bridge, while another VRU is crossing directly on the road. The trigger is only applied if the risk of collision is identified on the same vertical position. Otherwise, that would be a false positive. Different vertical position means that the pedestrian or other VRU's can be at the same location in the horizontal plane, but at different vertical positions (see Figure 9).

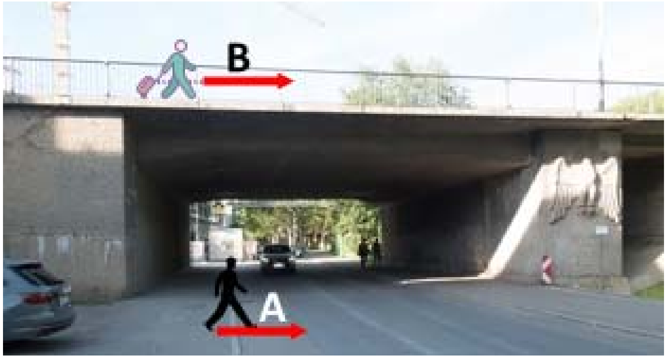


Figure 9: Illustration VRU on a bridge

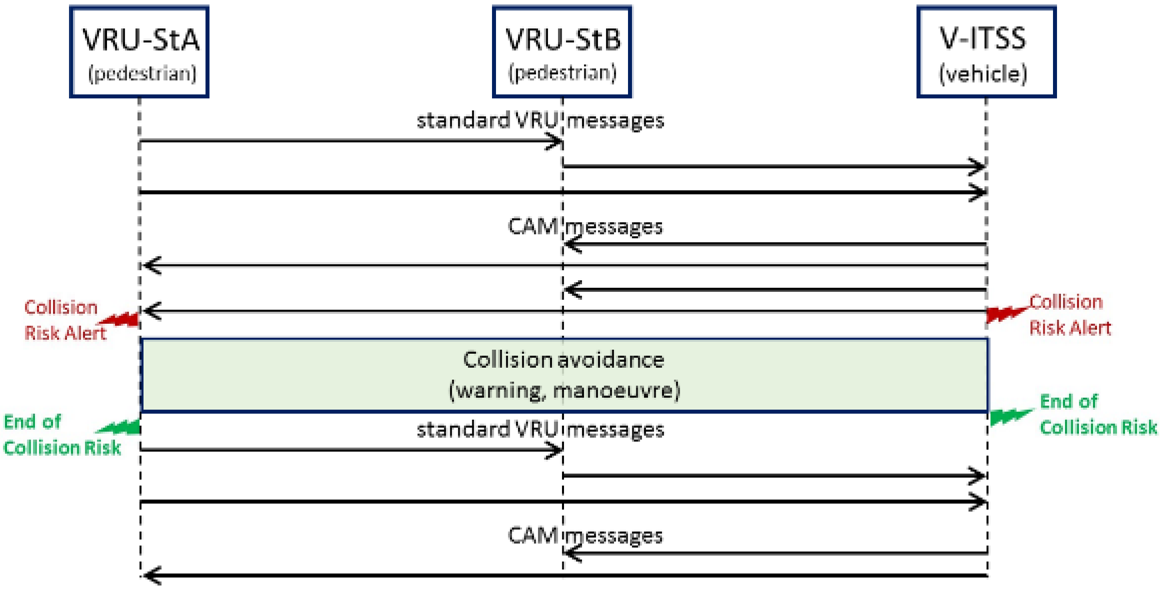


Figure 10: Flow diagram for UC-B2-alt - VRU crossing on a bridge

On Figure 10, only the VRU A is detected as being in a risk of collision because of its proximity to the vehicle:

1) The VRU-StA and VRU-StB broadcast VRU standard messages.

2) The risk assessment at the VRU-StA or the V-ITS-S identifies that both road users are on collision course, and warns the ITS-S users.

3) A collision warning is sent using C-ITS to the relevant road users.

4) The relevant ITS-S stations receive the C-ITS warning, and warn the ITS-S user at the appropriate time.

5) No risk of collision is identified for VRU-StB.

6.3.2.7 Post-conditions

V-ITS-S driver and VRU take appropriate action to avoid or mitigate a collision. If this is achieved, the system goes back to its monitoring state, broadcasting VRU standard messages and analysing their content to detect a new risk of collision until being deactivated by the VRU.

6.3.2.8 High Level Illustration

Figure 11 shows an illustration of the considered use case.

Figure 11: UC-B2 - VRU at crossroad illustration

6.3.2.9 Use case analysis

This use case highlights several challenges:

- Resources available at the VRU, especially in terms of battery if it broadcast a VRU awareness message.
- Channel occupancy which may become critical if there is a large number of VRUs broadcasting and may lead to useless channel congestion (see Figure 11).
- Evaluation of the expected behaviour of the VRU, which is linked to a sufficient precision of positioning data.
- The collision risk analysis requires the information about vertical position. An action (alerting, manoeuvre) should be triggered only in the case where the VRU and vehicle are on the same vertical level (altitude). However, the accuracy of the position is important, and may be inaccurate for reasons such as message repetition too low, difficulty to obtain a sufficient confidence due to high buildings or overpass in a city street, VRU rapidly changing level using an elevator (e.g. to go up on the bridge).

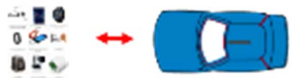
6.3.3 UC-B3: Rider is ejected from his motorbike

6.3.3.1 Description

A person riding a motorbike falls on a slippery road and is ejected at a certain distance from the motorbike.

Approaching vehicles equipped with a V-ITS-S need to avoid running on the rider and crash the motorbike instead if the TTC is too short to brake efficiently.

This use case assumes that a technical mechanism is available to pair the VRU device of the rider with the VRU device on-board of the motorbike when they are sufficiently close to each other. Such a mechanism may use existing protocols such as Bluetooth for example.

Use case category: B	 **FVRU to VEHICLE** **MVRU to VEHICLE**

6.3.3.2 Actors

- Motorbike equipped with a VRU-St.
- Rider equipped with a VRU-St.
- One or several vehicles equipped with ITS-S.

6.3.3.3 Pre-conditions

- Both VRU-St and V-ITS-S support V2X and VRU application.
- Both VRU devices are paired together, forming a single VRU device.
- V-ITS-S broadcast periodically vehicle awareness messages.
- Both VRU-St are able to broadcast VRU standard messages. Before the trigger, only one of them (e.g. the motorbike device) is broadcasting the message.
- V-ITS-S and VRU-St are in proximity i.e. within each other's V2X communication range.

6.3.3.4 Triggers

The motorbike falls on the ground, for example because of gravels on the road. The motorbike continues progressing for a few meters, while the rider is ejected and stays where it fell. A vehicle that was behind the motorbike arrives at a high speed.

6.3.3.5 Normal flow

- Both VRU-St detect that they are not associated anymore and start sending independently VRU standard messages. The VRU-St hosted by the rider start sending pedestrian VRU standard messages.
- The V-ITS-S receives both messages.
- The V-ITS-S makes a risk assessment, based on the VRU standard messages received and on behavioural models of the VRUs, and identifies potential collision with a TTC less than 5 seconds.
- The V-ITS-S is able to identify that one of the VRU-St is from a machine, while the other one is from a pedestrian (new role of the rider). The V-ITS-S is also able to determine the position and orientation of the motorbike and of the rider.
- According to its level of autonomy, the vehicle displays an alert to the driver signalling the pedestrian on the road or, if capable, takes the direction of the motorbike to avoid a collision with the fallen rider.
- The rider's VRU-St also signals a risk of collision to its owner, who may be able to move off the road.
- The V-ITS-S driver or the vehicle takes appropriate action to avoid or mitigate a collision with the fallen rider.

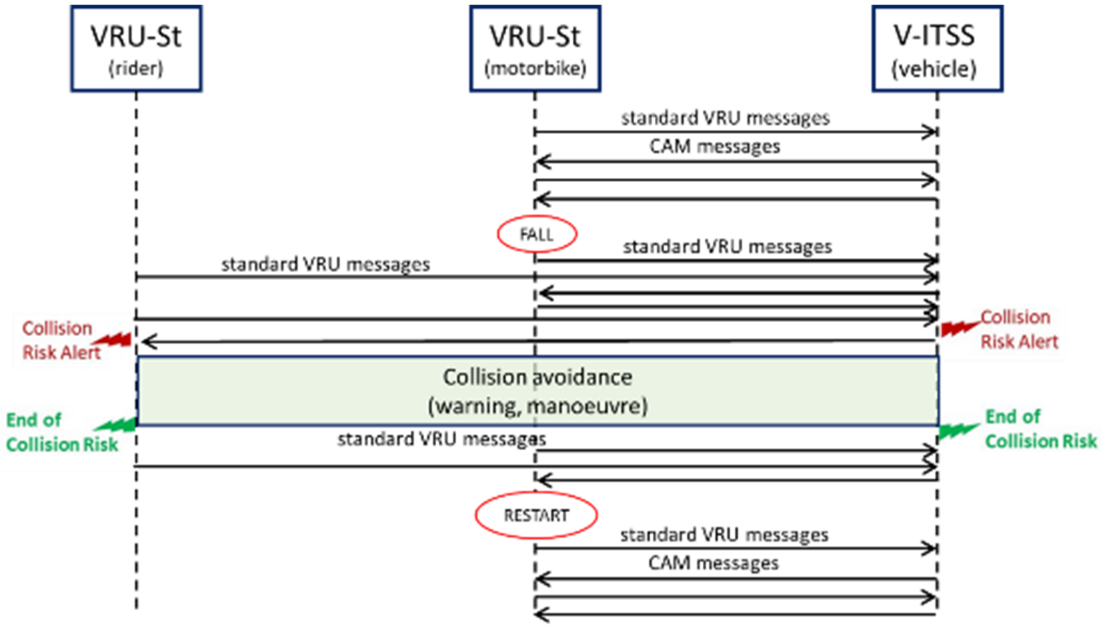


Figure 12: Flow diagram for UC-B3 - Rider is ejected from his motorbike

6.3.3.6 Alternative flow

No alternative flow.

6.3.3.7 Post-conditions

Hitting the motorbike rider could be avoided. If the collision could be avoided with the motorbike as well, both VRU-St continue broadcasting VRU standard messages. The rider is not hurt and can restart. Both VRU-St re-aggregate, the system goes back to its monitoring state, broadcasting VRU standard messages as one VRU, analysing the content of received messages to detect a new risk of collision until being deactivated by the VRU.

6.3.3.8 High Level Illustration

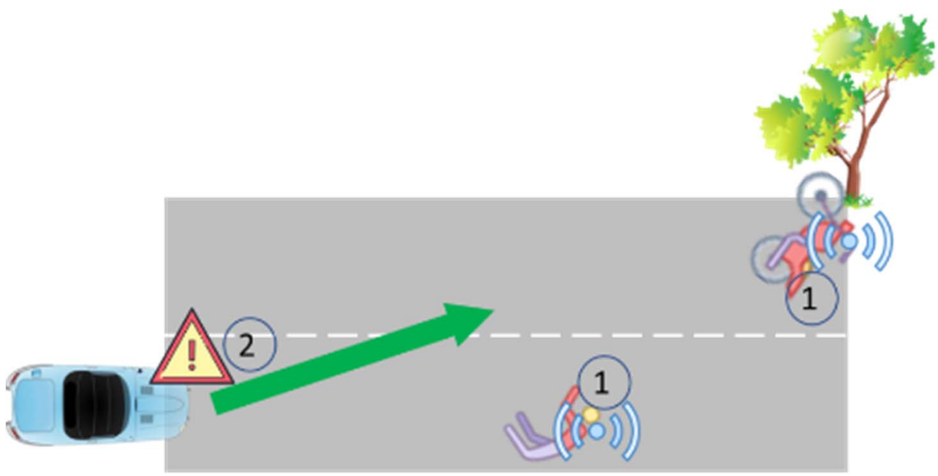


Figure 13: Fallen motorbike use case illustration

6.3.3.9 Use case analysis

Potential challenges are:

- How to aggregate/differentiate the VRU-St of the rider personal device and the VRU-St of the motorbike.

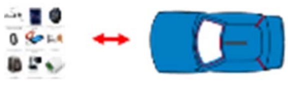
- The identification of one VRU as being a motorbike, while the second one, hosted by the rider can take different roles.
- The positioning accuracy required to differentiate them, as well as the orientation of both VRUs, which should be notified together with their dimensions.

6.3.4 UC-B4: Emergency Electronic Brake Light

6.3.4.1 Description

The Emergency Electronic Brake Light (EEBL) application enables a vehicle to broadcast its own emergency braking situation to the surrounding vehicles, including those that have their LOS obstructed by other vehicles or bad weather such as fog or rain.

In case there are multiple vehicles driving behind each other, and the first vehicle would have to perform an emergency braking, this application eliminates the delay in reaction time by subsequent vehicles: Each driver/rider is informed immediately, and collision danger could be avoided.

Use case category: B	 FVRU to VEHICLE MVRU to VEHICLE

6.3.4.2 Actors

C-ITS equipped motorcycles and other connected vehicles (human driven or automated).

6.3.4.3 Pre-conditions

Motorcycles and vehicles involved are all equipped with a C-ITS device compliant to relevant standards which includes the EEBL application. All C-ITS devices are power supplied, enabled and configured properly according to the EEBL application. Motorcycles and vehicles are positioned within their C-ITS telecommunication range.

6.3.4.4 Triggers

- If the motorcycle performs an urgent deceleration, an emergency braking event is broadcasted to the surrounding vehicles. vehicle acceleration $\leq$ -7,0 m/s^2.
- Second alternative criteria to send an EEBL warning is an ABS interaction.

6.3.4.5 Normal flow

The information flow from a car to a motorcycle is represented on Figure 14. When a car performs an emergency braking, DENM message are broadcasted by C-ITS device on the car. Received messages are processed for warning to rider.

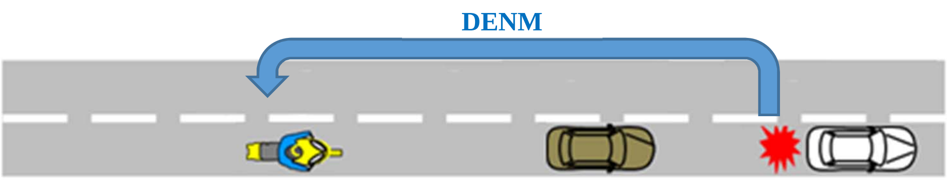


Figure 14: EEBL Use case flow diagram

6.3.4.6 Alternative flow

Alternatively, the motorcycle will inform the surrounding vehicles of the emergency brake event by the braking action itself.

6.3.4.7 Post-conditions

Once an EEBL DENM information is received, the receiving vehicle device should determine the relevance of the broadcasted message and address the information to the driver or the rider of the vehicle.

6.3.4.8 High Level Illustration

Figure 15 shows an illustration of the considered use case.

This application alerts drivers/riders of any hard braking that is performed by vehicles in front.

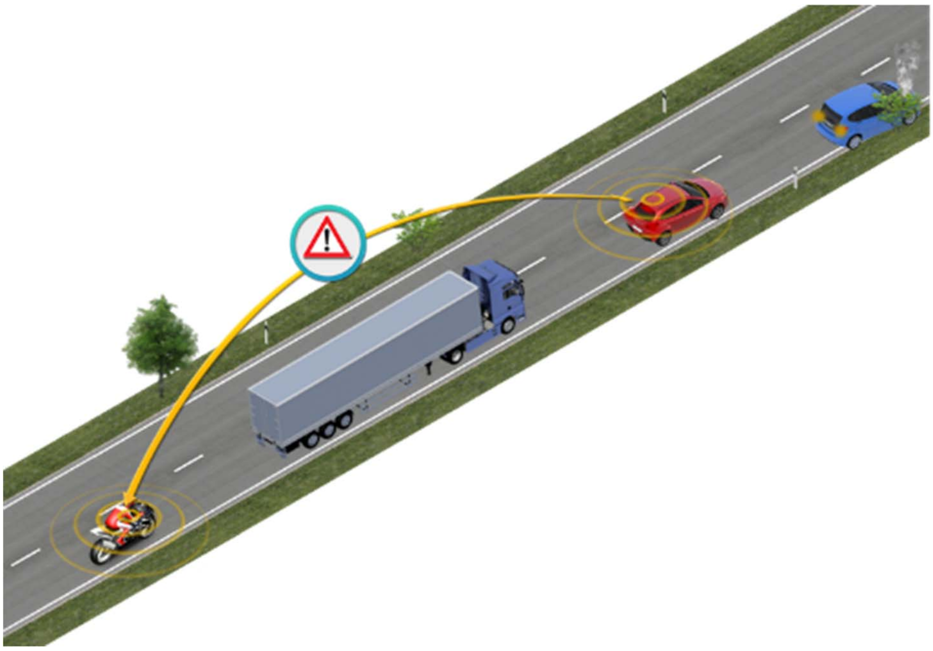


Figure 15: Example of receiving an EEBL message

6.3.4.9 Use case analysis

The example shows three vehicles driving behind each other. In case of an action that causes the first vehicle to perform an emergency braking, the other vehicles behind the first vehicle should react immediately. This can be complicated in situations with limited visibility, such as above-mentioned adverse weather conditions, but also in particular when the driver's LOS is obstructed by other vehicles.

In Figure 15, the motorcycle only sees the brake lights of the truck in front. Therefore, the stopping distance of the motorcycle is directly affected by the reaction time of the truck driver. The higher the number of vehicles in between, the higher the delay becomes for noticing the obstacle ahead. The EEBL application eliminates this problem by enabling the vehicle to broadcast a self-generated emergency brake event to the surrounding vehicles with DENM information. Upon receiving the event information, the receiving vehicle determines the relevance of the event and if appropriate, provides a warning to the driver/rider in order to avoid a possible collision. By doing so, the driver/rider is informed before being able to see the incident ahead and is able to avoid the risk of collision.

6.3.5 UC-B5: Motorcycle Approach Indication/Motorcycle Approach Warning

6.3.5.1 Description

Motorcycle Approach Indication (MAI) is an application that informs a vehicle driver that an approaching motorcycle is nearby, even if the driver cannot see the motorcycle.

If, based on dynamics information from both vehicles, a possible crossing with the motorcycle is detected or the relative distance between the two vehicles decreases below a given margin, an information is issued to the vehicle driver.

The Motorcycle Approach Warning (MAW) application warns a vehicle driver who has a potential risk to collide with a motorcycle. This goes beyond the general notice that a motorcycle is approaching such that the MAI application provides. The MAW application is more sophisticated, because it also calculates the risk of collisions and only provides warnings to the vehicle driver if a collision is likely to occur.

Use case category: B	

6.3.5.2 Actors

C-ITS equipped motorcycles and other connected vehicles (human driven or automated).

6.3.5.3 Pre-conditions

- Motorcycles and vehicles involved are all equipped with a C-ITS device compliant to the relevant standards which includes the MAI/MAW application.
- All C-ITS devices are power supplied, enabled and configured properly according to the MAI/MAW application.
- Motorcycles and vehicles are positioned within their C-ITS telecommunication range.

6.3.5.4 Triggers

MAI: When the calculated driving trajectory of a motorcycle and a car have a point in common, i.e. they intersect each other or when the distance between a motorcycle and a vehicle falls below a certain point, a collision indication is triggered.

MAW: When a risk of collision between at least one motorcycle and a vehicle is detected, a collision avoidance warning is triggered.

6.3.5.5 Normal flow

The normal information flow is represented on Figure 16.

VRU standard messages are continuously broadcasted by C-ITS device on the motorcycle at a configurable frequency (e.g. 10 Hz maximum). CAM standard messages are also continuously broadcasted by vehicle C-ITS Stations. Received messages are processed for collision risk analysis.

In the case where an approaching motorcycle is nearby, the vehicle C-ITS device will inform the driver of this situation by providing complementary information. When the vehicles are in a collision risk situation, the driver will also be advised of it. Once the collision risk disappears, this is also signalled to the driver.

If a collision is likely to occur, vehicle C-ITS devices will warn the driver, and additionally to this, the motorcycle devices will also warn the rider.

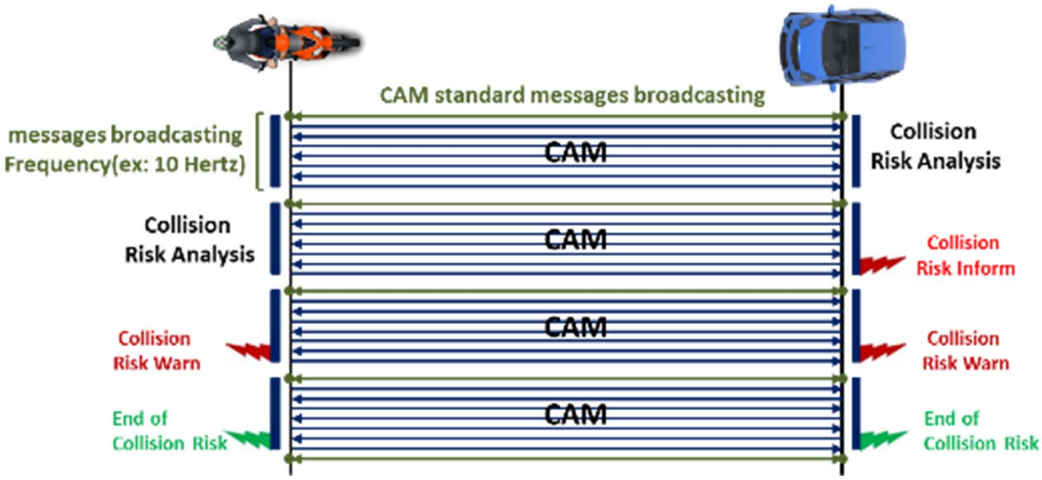


Figure 16: MAI/MAW use case flow diagram

6.3.5.6 Alternative flow

No alternative flow.

6.3.5.7 Post-conditions

Once a collision risk and the respective avoidance measure have been processed, the system goes back to its monitoring state, broadcasting and receiving CAM standard messages, and analysing their content to detect a new risk of collision.

6.3.5.8 High Level Illustration

The figure below is an illustration of the considered use case.

This use case scenario shows a possible collision at an intersection. A vehicle drives to an intersection in which a motorcycle has right of way.

As the vehicle is intending to stop at the intersection, the C-ITS device on the vehicle combines the received motorcycle's CAM messages with the ego vehicle data, using their relative distance and speed, in order to predict possible collision types, e.g. crossing collision or left turn collision.

After predicting the collision type, the critical Time To Collision (TTC) is calculated. If the time becomes less than a predefined criterion, e.g. 8 seconds, the C-ITS device on the vehicle will inform the driver that a motorcycle is approaching.

If the vehicle still not reduced its speed in order to prevent the collision, the time becomes less than severe criteria (e.g. 3 seconds), vehicle devices will warn driver, add to this, motorcycle devices will warn rider.

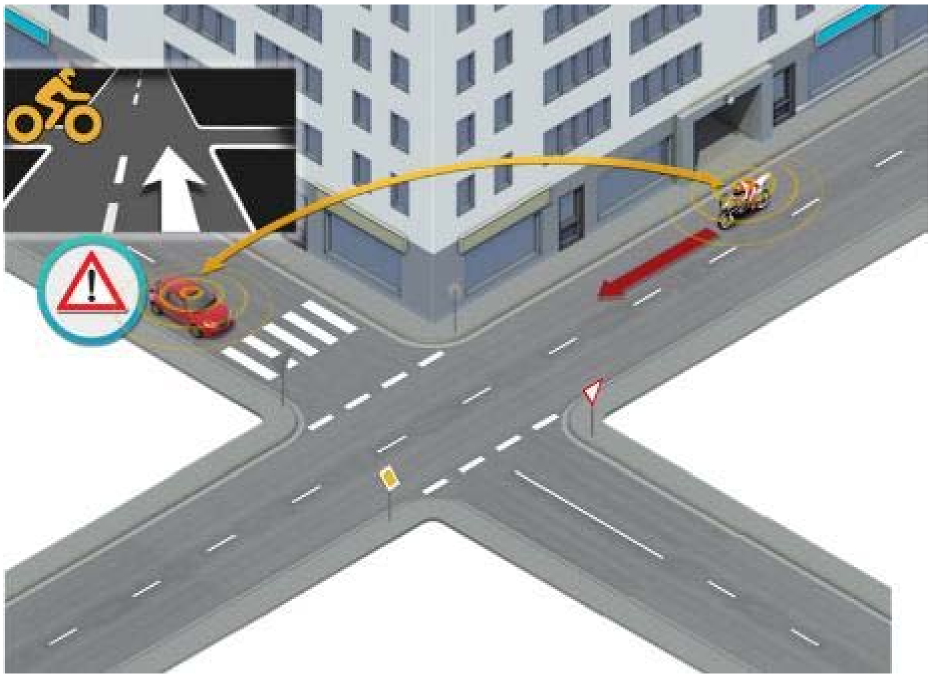


Figure 17: Motorcycle to Vehicle use case illustration

6.3.5.9 Use case analysis

Direct actions on vehicles (e.g. hard braking) need the securing of the messages being broadcasted by the motorcycles.

If there are many motorcycles in the C-ITS system, an ad hoc local area network congestion problem may happen and needs to be solved. This could be achieved by developing a relevance check algorithm which authorizes only, for example the three more relevant equipped motorcycles broadcasting their movements. Such algorithm could be based on the collision risk levels comparisons between all motorcycles which are broadcasting messages. Only the three having the highest risk could be authorized to continue to broadcast their messages.

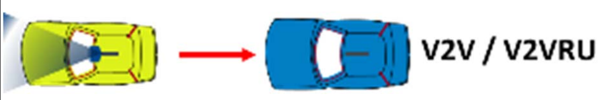
6.4 Category C: V2V direct cooperation

6.4.1 UC-C1: Signalling VRU hidden by an obstacle

6.4.1.1 Description

This use case has been demonstrated during the ITS World Congress 2015 in Bordeaux.

Some vehicles are equipped with a front sensor (e.g. a camera) and a perception function capable of analysing collected video and detecting VRU. When a sensor-equipped vehicle is detecting a VRU starting to cross a road, it broadcasts a standard message (e.g. DENM or CPM) signalling to other vehicles being in the C-ITS network that a hidden VRU is crossing. Receiving vehicles will act according to their relative speed and distance to the VRU.

Use case category: C	

6.4.1.2 Actors

A non-equipped VRU crossing a road.

A vehicle equipped with a frontal sensor, an associated VRU perception capabilities and one relevant ITS-S.

A second vehicle equipped with an ITS-S capable of receiving and processing standard messages broadcasted by the first vehicle.

6.4.1.3 Pre-conditions

The vehicle detecting a VRU is equipped with an active frontal sensor (e.g. a camera with image processing capabilities) and an active compliant ITS-S. It has the capability to broadcast standard messages signalling the perception of a VRU (DENM or CPM).

The second vehicle is equipped with an active ITS-S capable of receiving and processing standard messages related to the VRU signalling. The second vehicle is also capable of analysing a risk of collision with a signalled VRU and then acting to avoid the collision (alert to the driver or direct action on the vehicle).

6.4.1.4 Triggers

Two triggering conditions need to be considered:

- The first one is a detection by the first vehicle of a VRU engaging to cross the road. This detection triggers the broadcasting of standard messages such as DENM or CPM.
- The second one is the result of the collision risk analysis with the signalled VRU by the second vehicle. If the result is positive, a collision avoidance action has to be started (communication to the driver or direct action on the vehicle).

6.4.1.5 Normal flow

Assumptions: Vehicles are equipped with Release 1 services only, having the capability to broadcast DENMs and CAMs. The flow considers all cases, independently of timing constraints (see clause 6.4.1.9).

The normal information flow is represented on Figure 18.

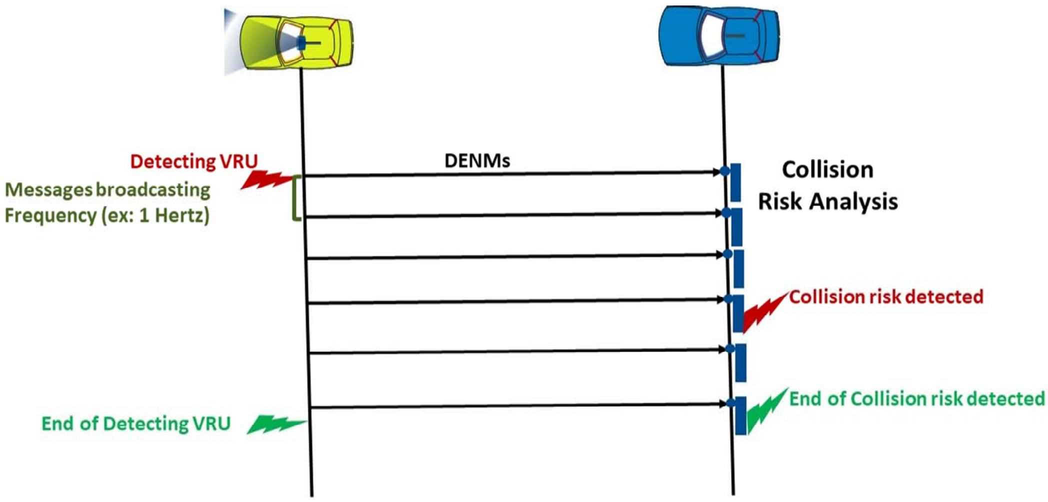


Figure 18: Flow diagram for UC-C1: VRU hidden by an obstacle

1) Release 1-compliant vehicle is detecting by means of its front camera one or several VRUs which can be hidden by a vehicle.

2) The vehicle detects one or several hidden VRU and starts broadcasting DENMs.

3) Receiving vehicles analyse relevant DENMs for collision risk analysis.

4) If a risk of collision is detected, the subject vehicle starts a collision avoidance action according to the calculated TTC.

6.4.1.6 Alternative flow

Assumptions: Vehicles are equipped with Release 2 services (for example, CPS/MCS) and potentially enhanced collision avoidance system. The flow considers all cases, independently of timing constraints (see clause 6.4.1.9):

1) Release 2-compliant vehicles constantly broadcast CAMs or enhanced CAMs (see here above) and CPS/MCS.

2) As soon as a collision risk with a hidden VRU is detected, the vehicle equipped with a front camera broadcast CPMs or MCMs thus assisting other equipped vehicles in avoiding a collision with the hidden VRU(s). This broadcasting can be conditioned by the reception of CAMs signalling the presence of equipped vehicle(s) in the ad hoc network.

3) Vehicles receiving CPS/MCS messages process them for TTC calculation and collision avoidance action according to the TTC value.

The flow diagram is similar to the normal flow, except that DENMs are replaced by Release 2 messages such as CPM/MCM which are better adapted to collision avoidance and partly/fully automated vehicles.

6.4.1.7 Post-conditions

Once the VRU is not detected anymore by the first vehicle and that the collision avoidance with the VRU has been eliminated, the two vehicles go back to their normal monitoring states.

6.4.1.8 High Level Illustration

Figure 19 shows an illustration of the considered use case.

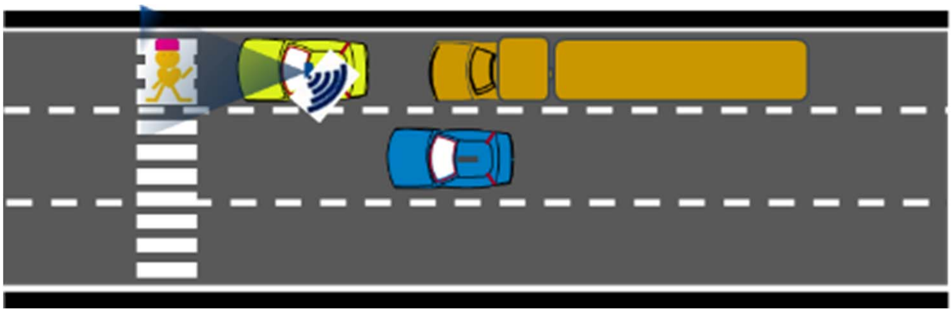


Figure 19: Illustration of UC-C1: VRU hidden by an obstacle

6.4.1.9 Use case analysis

A similar use case could apply when involving animals, for example in a curb of a rural area.

Vehicles broadcast CAMs or enhanced CAMs at a frequency of at least 10 Hz.

As soon as a risk of collision is detected with a hidden VRU, the detecting vehicle broadcasts CPS/MCS messages at a frequency of at least 10 Hz (if able to do so).

Direct actions on vehicles (e.g. emergency braking) need the securing of the messages being broadcasted by the first vehicle.

The most appropriate message to be used (CPM, MCM or another) should be selected according to the automated level of the second vehicle (see note) (SAE from 0 to 5).

NOTE: Enhanced CAM may also indicate the level of SAE automation and if the vehicle is in a human-driven or automated mode.

It is necessary to avoid false positive and false negative detection.

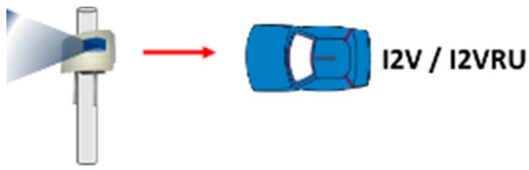
6.5 Category D: I2V direct cooperation

6.5.1 UC-D1: Signalled few VRUs in a protected area

6.5.1.1 Description

Part of this use case is being tested and demonstrated in the scope of the French research project YELLOW. It is also tested in the scope of the French PAC V2X (Perception Augmentée par Coopération V2X). The ETSI CPM (Collective Perception Message) and a PAC V2X proprietary MCM (Manoeuvre Coordination Message) are part of the test.

VRUs are evolving in a protected area (ex: pedestrian zone, roadwork, police control, etc.). The arrival of vehicles with an excessive speed is detected by means of a static or mobile Road Side Equipment (RSE) via its own sensors (i.e. camera). This RSE may signal the arrival of a vehicle in an excessive speed relatively to its short distance to the protected area. The RSE may also broadcast standard messages to the approaching vehicle(s) signalling the protected area. Optionally, the RSE may trigger an emergency braking at the level of a vehicle presenting a risk of collision with VRUs in the protected area.

Use case category: D	

6.5.1.2 Actors

VRUs which can be equipped or not with portable devices including an ITS-S.

Road Side Equipment monitoring the approaching of vehicles to the protected area. This road side equipment is including an ITS-S relevant to the system configuration being targeted.

Vehicles equipped with an ITS-S capable of processing standard messages broadcasted by the RSE and then to avoid the collision.

6.5.1.3 Pre-conditions

All the system elements are activated and are in the ad hoc network of the local system.

6.5.1.4 Triggers

At least one vehicle is detected as approaching the protected area with an excessive speed from a distance which, if overpassed, would present a risk of collision with VRUs located in the protected area (risk analysis result).

6.5.1.5 Normal flow

Assumptions: Vehicles are equipped with Release 1 services only, having the capability to broadcast DENMs and CAMs. RSE may also broadcast DENMs or CSM (Contextual Speed limit messages). The flow considers all cases, independently of timing constraints (see clause 6.5.1.9):

1) Release 1 compliant RSE is detecting, via its CAMs reception, the arrival of a vehicle at a relatively short distance (e.g. < 100 m to be adjusted according to vehicle velocity) and with an excessive velocity (higher that the speed limit).

2) The RSE also detects the presence of VRUs in the protected area.

3) The RSE then broadcasts DENMs signalling the presence of VRUs in the area.

4) Receiving vehicles analyse the relevant DENMs for collision risk analysis.

5) If a risk of collision is detected, the subject vehicle starts a collision avoidance action according to the calculated TTC.

6) In parallel, VRUs receive signals from a local siren indicating a risk and encouraging them to protect themselves. The local siren is controlled by the RSE.

The normal information flow is represented on Figure 20.

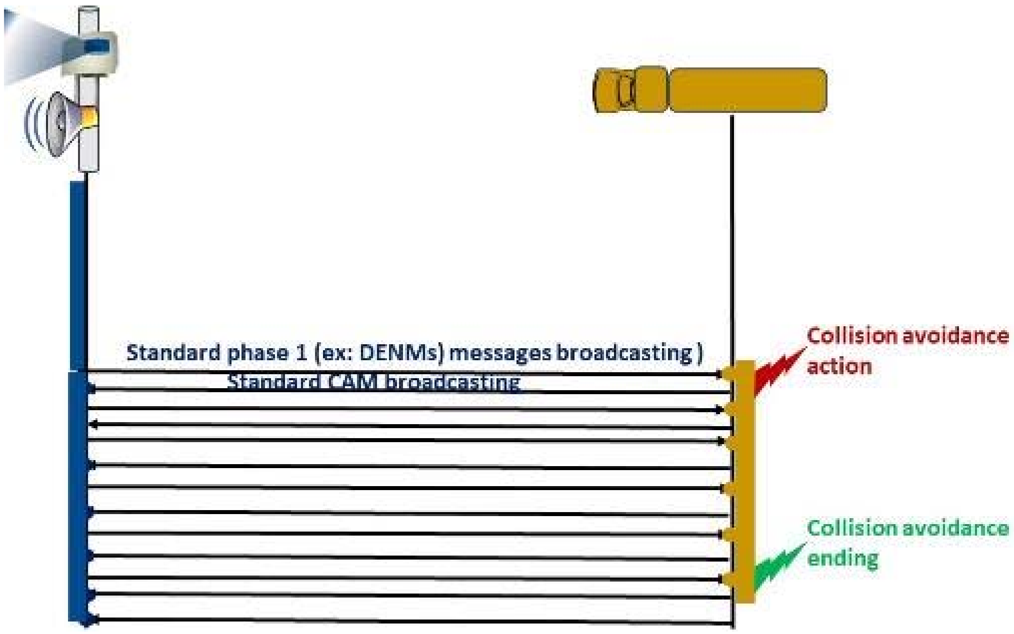


Figure 20: Flow diagram for UC-D1: Few VRUs in a protected area

This flow could also have the RSE broadcast DENM messages whenever it has detected VRUs in the protected area. The option provided here is just an example of possible messages and takes into account that a compromise will have to be sought in order to control the possible congestion of the channel, avoiding to saturate it. The decision on which specific messages and their content will be described in ETSI TS 103 300-2 [i.17], together with the specification of requirements and VRU architecture.

6.5.1.6 Alternative flow

Assumptions: Road workers (VRUs) and vehicles are equipped with Release 2 services (ex: VRU service and VRU service processing at the vehicle level) and potentially enhanced collision avoidance system. The flow considers all cases, independently of timing constraints (see clause 6.5.1.9):

1) Release 2 compliant vehicles constantly broadcast CAMs or enhanced CAMs.

2) Release 2 VRU devices (VRU-Rx, VRU-St) constantly broadcast VRU standard messages, received by the local RSE.

3) As soon as a collision risk is detected by the RSE, it starts broadcasting Release 2 messages (CPM or MCM) to support the concerned vehicle for its collision avoidance strategy.

4) The RSE also broadcasts Release 2 standard messages to signal a risk of collision to the relevant VRUs and then the end of this risk of collision. An alternative solution may be also the use of a controlled siren.

5) Vehicles receiving the messages process them for TTC calculation and collision avoidance action according to the TTC value.

NOTE: This flow diagram depends on the communication strategy being selected between the three ITS-S types: Vehicles, RSEs, and VRU devices. Here, a separate ad hoc network between the RSE and the VRU devices is considered.

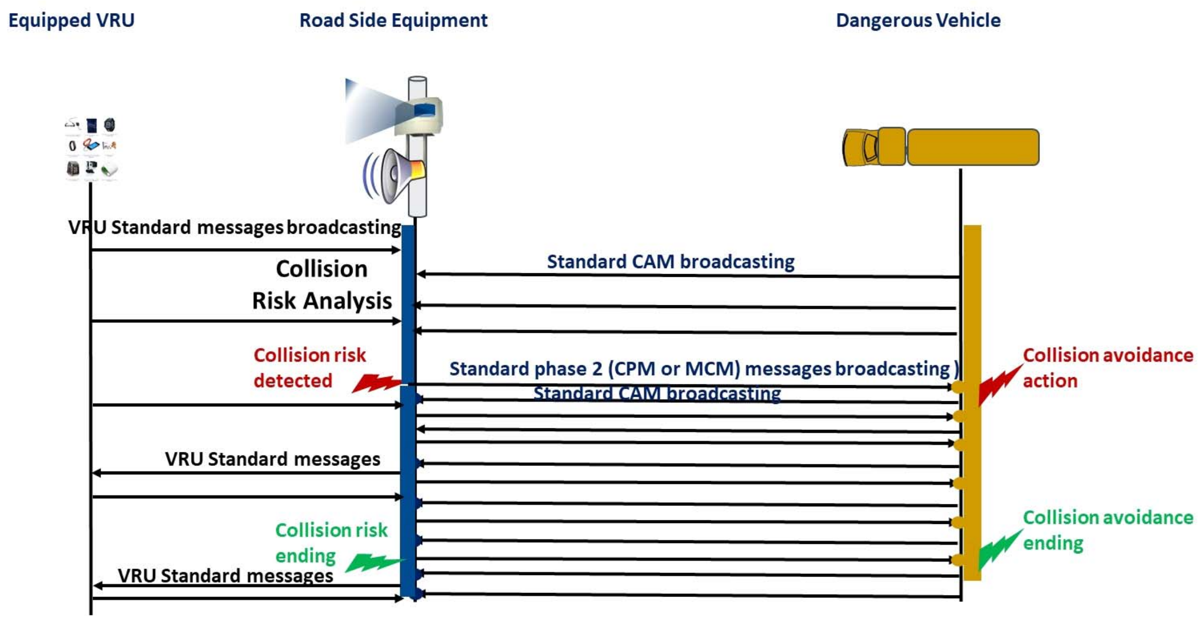


Figure 21: Alternate flow diagram for UC-D1: few VRUs in a protected area

6.5.1.7 Post-conditions

Once a collision risk is not anymore detected by the Road Side Equipment, the system can return to an observation state with the objective to continue detecting a risk of collision between a vehicle and VRUs.

If the dangerous vehicle has been stopped or slowed down (the action being detected by the RSE sensor and the vehicle CAMs), this one may expect some more assistance to leave the work zone lane and join the first open lane available (lane change assist).

If some VRUs are equipped with portable devices including an ITS-S, once having received a standard message signalling an end of collision alert, they continue indicating their presence in the local ad hoc network of the RSE as long as being present.

6.5.1.8 High Level Illustration

Figure 22 shows an illustration of the considered use case.

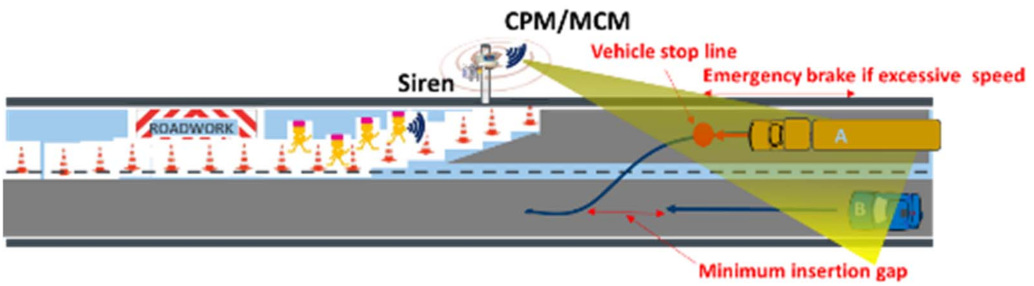


Figure 22: Illustration of UC-D1: Few VRUs in a protected area

6.5.1.9 Use case analysis

In the normal flow, the following operational aspects need to be considered:

- DENMs cause and sub-cause may be updated.
- DENMs broadcasting is only triggered when a VRU device detects a risk of collision by prediction of a collision spot.

- The DENMs frequency is at least 10 Hz.
- The latency time at the application level does not exceed 300 millisecond.

In the use case alternative flow, the following operational aspects need to be considered:

- VRU service messages are specified on purpose to avoid overloading one C-ITS channel. In such case they can be broadcasted at a frequency of 1 Hz. Several VRU standard messages may be specified for the RSE to signal an imminent risk of collision or its ending.
- The end to end latency time between the RSE and the signalling to VRU needs to not exceed 300 millisecond.
- CPM or MCM need to be broadcasted at least at 10 Hz.

Direct actions on vehicles (e.g. emergency braking) can result from DENMs, CPM or MCM reception (depending on vehicle implementation).

This type of direct action can be mandatory in the case of a terrorist attack or a police roadblock forcing (use case similar to this one but with workers replaced by policeman willing to intercept a given vehicle). In this case, a specific certificate may be necessary.

It is necessary to select the most appropriate message to be used (DENM, CPM or MCM) according to the automated vehicle level (SAE from 0 to 5).

6.5.2 UC-D2: Non equipped VRUs crossing a road

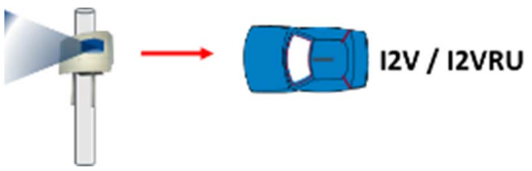
6.5.2.1 Description

This use case is also tested in PAC V2X project using ETSI CPM and a project proprietary version of the MCM.

VRUs are non-equipped children crossing a road after leaving/boarding their scholar bus waiting for them at the bus station. Before crossing, they can be hidden by the bus itself.

Vehicles intending to overtake the bus cannot perceive the hidden VRUs.

A Road Side Equipment (RSE) senses the presence of one or several VRUs ready to cross the road and signals this risk to the vehicle (DENM or CPM) or provides them with manoeuvre instruction to overtake the bus when a risk of collision with a VRU does not exist anymore.

Use case category: D	

6.5.2.2 Actors

Non-equipped VRUs.

A Road Side Equipment monitoring the arrival of vehicles close to the crossing area. This road side equipment includes an ITS-S relevant to the system configuration being targeted.

Vehicles equipped with an ITS-S capable of processing standard messages broadcasted by the RSE and then of avoiding the collision.

6.5.2.3 Pre-conditions

The RSE and vehicles have their ITS-S activated and are in the ad hoc network of the system.

6.5.2.4 Triggers

At least one vehicle is detected as approaching when the VRUs start to cross the road through the reception of Release 1 or Release 2 messages broadcasted by the RSE.

6.5.2.5 Normal flow

Assumptions: Vehicles are equipped with Release 1 services only, having the capability to broadcast CAMs. RSE may also broadcast DENMs or CSM (Contextual Speed limit messages). The flow considers all cases, independently of timing constraints (see clause 6.5.2.9):

1) Release 1 compliant RSE is detecting, via its CAMs reception, the arrival of a vehicle at a relatively short distance (e.g. < 100 m to be adjusted according to vehicle velocity) and with an excessive velocity (higher that the speed limit).

2) The RSE also detects one or several VRUs starting to cross the road.

3) The RSE then broadcasts DENMs, signalling the presence of VRUs on the road.

4) Receiving vehicles analyse the relevant DENMs for collision risk analysis.

5) If a risk of collision is detected, the subject vehicle starts a collision avoidance action or triggers an alert to the driver.

The normal information flow is represented on Figure 23.

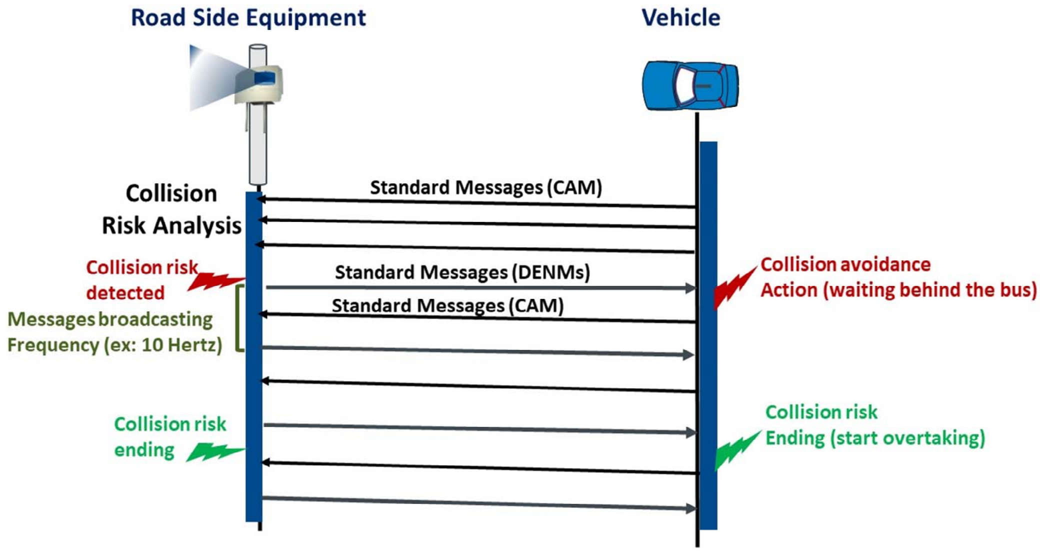


Figure 23: Flow diagram for UC-D2: non-equipped VRUs at a pedestrian crossing

This flow could also have the RSE broadcast DENM messages whenever it has detected VRUs in the protected area. The option provided here is just an example of possible messages and takes into account that a compromise will have to be sought in order to control the possible congestion of the channel, avoiding to saturate it. The decision on which specific messages and their content will be described in ETSI TS 103 300-2 [i.17], together with the specification of requirements and VRU architecture.

6.5.2.6 Alternative flow

Assumptions: Vehicles are equipped with Release 2 services only, having the capability to broadcast CAMs, enhanced CAMs and processing CPM/MCM. RSE is equipped with Release 2 and able to broadcast CPM/MCM. The flow considers all cases, independently of timing constraints (see clause 6.5.2.9):

1) Release 2 compliant RSE detects, via its CAMs reception, the arrival of a vehicle at a relatively short distance (e.g. < 100 m to be adjusted according to vehicle velocity) and with an excessive velocity (higher that the speed limit).

2) The RSE also detects one or several VRUs starting to cross the road.

3) The RSE then broadcasts CPMs or MCMs, signalling the presence of VRUs in the area.

4) Receiving vehicles analyse relevant Release 2 messages for collision risk analysis.

5) If a risk of collision is detected, the subject vehicle starts a collision avoidance action according to the calculated TTC.

The alternative information flow is similar to the normal flow diagram (Figure 23), replacing DENMs by CPMs/MCMs.

6.5.2.7 Post-conditions

Once a collision risk is not detected anymore by the Road Side Equipment, the system can return to an observation state with the objective to continue detecting a risk of collision between a vehicle and VRUs.

If the dangerous vehicle has been stopped or slowed down (the action being detected by the RSE sensor and the vehicle CAMs), this one may expect assistance to leave the waiting area behind the bus and start overtaking the bus (lane change assist).

6.5.2.8 High Level Illustration

Figure 24 shows an illustration of the considered alternative use case.

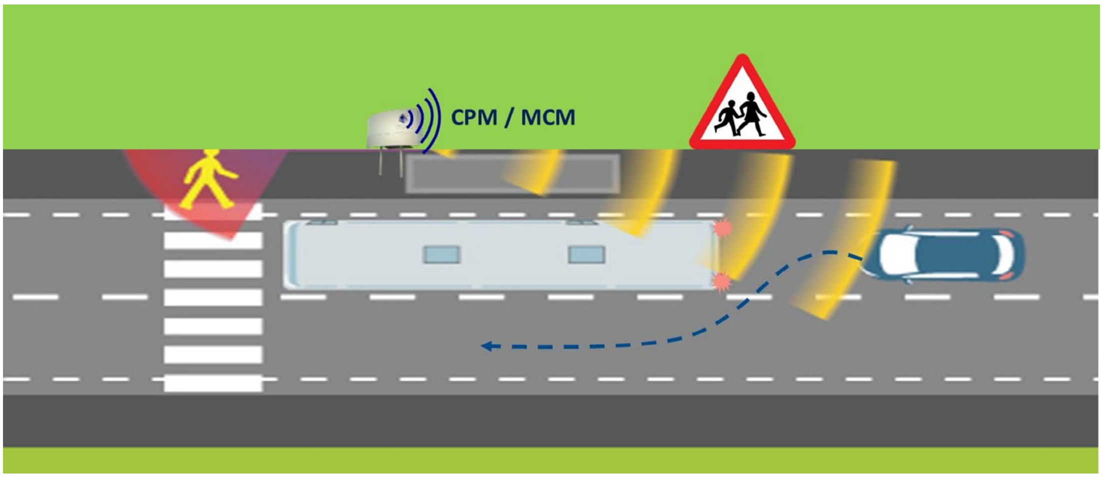


Figure 24: Illustration of UC-D2: non-equipped VRUs at a pedestrian crossing

6.5.2.9 Use case analysis

A similar use case could apply when involving animals, for example in a curb of a rural area.

As the VRU does not own a specific device, the collision avoidance is only possible at the vehicle level when receiving Release 1 or Release 2 messages.

CAM messages are broadcasted at a frequency between 1 and 10 Hz.

CPM or MCM messages are also broadcasted at a frequency between 1 and 10 Hz.

The end to end latency time needs to be limited to 300 millisecond between the RSE and the vehicle.

Direct actions on vehicles (e.g. emergency braking) need the securing of the messages being broadcasted by the RSE.

This type of direct action can be mandatory in the case of a terrorist attack. In this case, a specific certificate can be necessary.

The most appropriate message to be used (DENM, CPM or MCM) should be selected according to the automated vehicle level (SAE from 0 to 5).

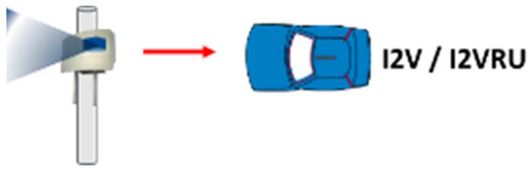
MCM may be continuously broadcasted, informing passing-by vehicles that the area is monitored for VRUs protection. In such case, the MCM may not contain particular instructions to vehicles if VRUs are not perceived as starting to cross the road.

6.5.3 UC-D3: VRUs crossing at a zebra protected by a traffic light

6.5.3.1 Description

This use case is also tested in PAC V2X project for giving the priority to special vehicles (e.g. Public transport, emergency) under the condition that VRUs are not engaged in a zebra road crossing.

At a crossroad, traffic lights are regulating the traffic and equipped with ITS-S. A traffic light detects the approach of a priority vehicle (ex: a public transport) via its broadcasted CAMs. Before changing its phase from red to green, the traffic light verifies with an appropriate sensor that no VRU is engaged on the zebra crossing area. If it is the case, the traffic light phase can be changed, if not, the traffic light is waiting that all engaged VRUs have finished crossing before changing the traffic light phase.

Use case category: D	

6.5.3.2 Actors

One traffic light equipped with one sensor (ex: camera) monitoring the zebra crossing area.

One Road Side Equipment in case the traffic light has not the capability to detect the VRU crossing or/and the arrival of a priority vehicle.

One intersection controller managing the intersection traffic lights.

One priority vehicle and other vehicles waiting at the level of the red traffic light.

Possibly one or several VRUs being engaged on the zebra crossing area.

6.5.3.3 Pre-conditions

A priority vehicle is moving in direction of a traffic light being in the red phase. This priority vehicle is detected by the traffic light which has the capability to change its red phase to green to ease the passing of the priority vehicle under the condition that no VRU is crossing the road.

6.5.3.4 Triggers

Detection of a priority vehicle approaching the traffic light being red.

6.5.3.5 Normal flow

Assumptions: Vehicles are equipped with Release 1 services only, having the capability to broadcast CAMs. Traffic light/RSE may also broadcast DENMs and SPAT/MAP. The flow considers all cases, independently of timing constraints (see clause 6.5.3.9):

1) Release 1 compliant Traffic light/RSE is detecting, via its CAMs reception, the arrival of a priority vehicle.

2) The Traffic light/RSE also detects one or several VRUs starting to cross the zebra area.

3) The Traffic light delays the signal phase change from red to green until the engaged VRUs are in a secured area.

4) Optionally, the RSE may also broadcast DENMs signalling the presence of VRU in the zebra area.

5) Upon receiving DENMs, vehicles analyse relevant DENMs for collision risk analysis.

6) If a risk of collision is detected, the subject vehicle starts a collision avoidance action or triggers an alert to its driver.

The normal information flow is represented on Figure 25.

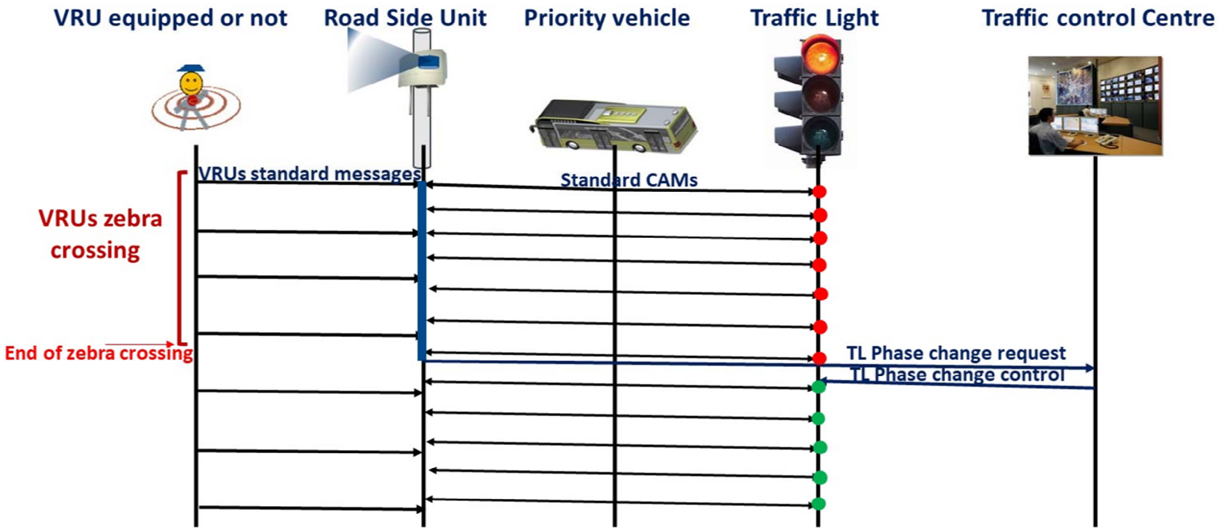


Figure 25: Flow diagram for UC-D3 - VRUs at a pedestrian crossing with a traffic light

The road side unit receives the priority vehicle CAMs indicating a public transport vehicle in activity which has priority. However, at the same time, the RSE detects (by its own sensor or by the portable device of the VRU) that one or several VRU(s) is starting to cross the road in the zebra area. The RSE waits until all crossing VRUs are safe on the side of the road before requesting a change of the traffic light phase from red to green to give priority to the public transport vehicle.

6.5.3.6 Alternative flow

Assumptions: Vehicles are equipped with Release 2 services, having the capability to broadcast CAMs, enhanced CAMs and processing CPM/MCM. RSE is equipped with Release 2 being able to broadcast CPM/MCM. Some VRUs are also equipped with devices complying to Release 2 VRU services. The flow considers all cases, independently of timing constraints (see clause 6.5.3.9):

1) Release 2 compliant Traffic light/RSE detects, via its CAMs reception, the arrival of a priority vehicle.

2) The Traffic light/RSE also detects one or several VRUs starting to cross the zebra area.

3) The Traffic light delays the change of its signal phase from red to green as long as all engaged VRUs are not in security.

4) Optionally, the traffic light/RSE then broadcasts CPMs or MCMs, signalling the presence of VRUs in the area.

5) Release 2 receiving vehicles analyse relevant Release 2 messages for collision risk analysis.

6) If a risk of collision is detected, the subject vehicle starts a collision avoidance action according to the calculated TTC.

The alternative information flow is similar to the normal flow diagram above but adds the detection of VRUs via the Release 2 VRU services standard messages in complement to the RSE sensors.

6.5.3.7 Post-conditions

Once the zebra crossing area is empty of VRUs, the traffic light phase can be changed from red to green to leave the priority vehicle go ahead.

6.5.3.8 High Level Illustration

Figure 26 shows an illustration of the considered use case.

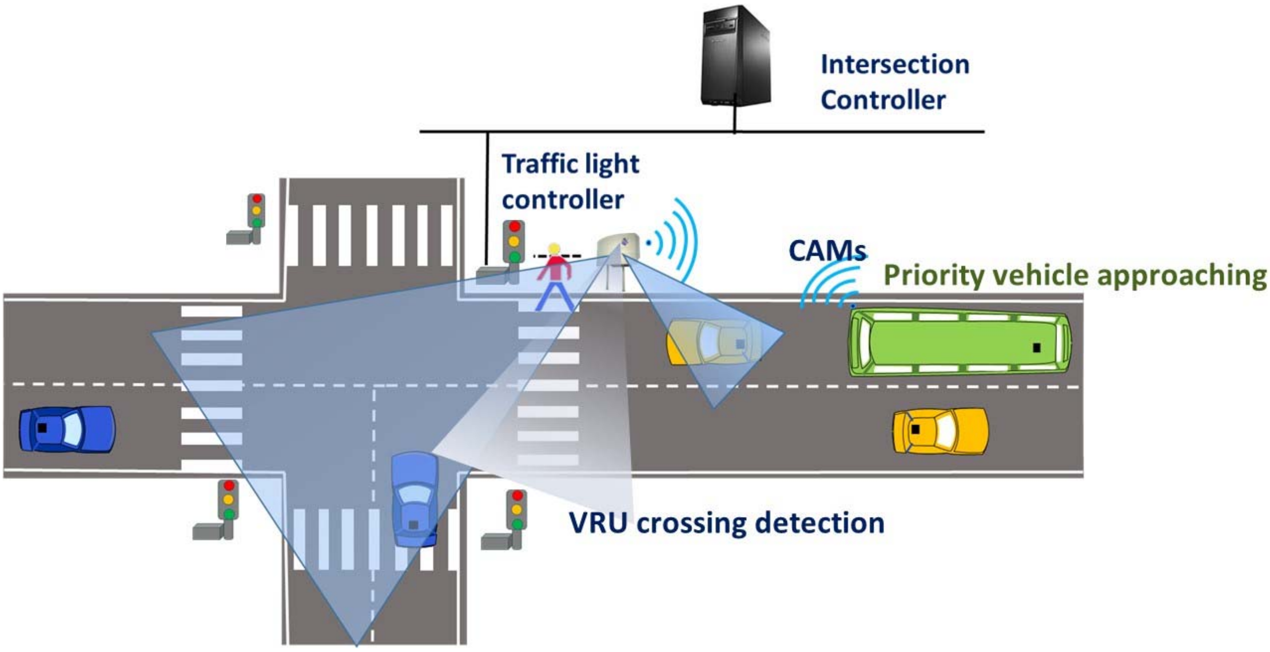


Figure 26: Illustration of UC-D3 - VRUs at a pedestrian crossing with a traffic light

6.5.3.9 Use case analysis

This use case considers a situation in which two different needs are conflicting:

- The need for one or several VRUs to be able to cross a road in full safety.
- The need to facilitate the mobility of Public Transport.

VRUs need to be protected until they have left the zebra crossing area.

It is probably preferable to use an RSE with a relevant sensor to verify that the zebra crossing area is not occupied by VRUs rather than to rely on the VRU devices, knowing that not all VRUs will be equipped with such devices.

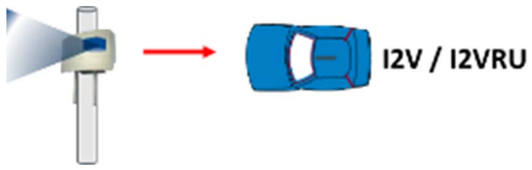
If the traffic light is controlled by a traffic management centre, the centre needs to be involved in the traffic light phase change.

The end to end latency time of the VRUs devices needs to be less than 300 millisecond, though for this use case, the VRU positions and data ages are not so critical.

6.5.4 UC-D4: Scooter/Bicyclist Safety with Turning Vehicle

6.5.4.1 Description

In this use case a typical critical situation is considered, where a vehicle turns right and oversees an approaching scooter or bicyclist, that intended to go straight. A similar situation is considered with a vehicle approaching from the opposite direction and wants to turn left. The driver oversees the scooter or bicyclists and a collision of both road users is possible.

Use case category: D	

6.5.4.2 Actors

The actors are one Road Side Equipment equipped with a sensor (e.g. a camera), a non-equipped VRU (scooter or bicyclist) and a vehicle equipped with an HMI for receiving warning messages.

6.5.4.3 Pre-conditions

One Road Side Equipment which is able to broadcast VRU standard messages. Vehicles equipped with an ITS Station are able to receive warning messages.

6.5.4.4 Triggers

- VRU (scooter or bicyclist) and car are close to the intersection.
- VRU (scooter or bicyclist) goes straight through the intersection.
- Vehicles driving in the same direction as the VRU, turn right at the crossroads or turn left at the crossroads in the opposite direction.

6.5.4.5 Normal flow

- The RSE detects VRUs (scooter or bicyclist) approaching intersection by the sensors (e.g. cameras, radar, etc.).
- The RSE performs collision detection through path prediction for VRU and vehicles near the intersection.
- The RSE broadcasts warning messages to vehicles in the area via CAM or CPM.
- The right-turning vehicle in the same direction as the VRU gets the collision avoidance message.

Figure 27 and Figure 28 illustrate possible collision situations under this flow.

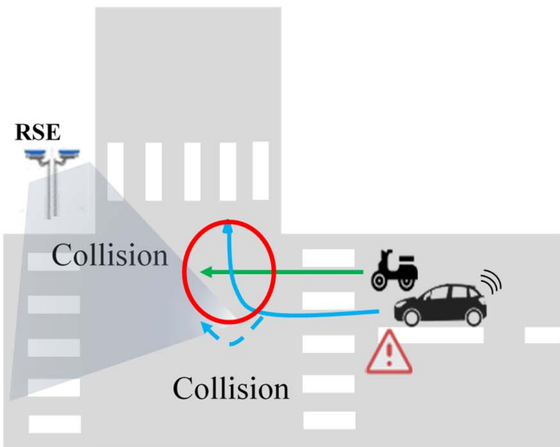


Figure 27: Scooter/Bicyclist Safety with Turning Vehicle use case flow diagram

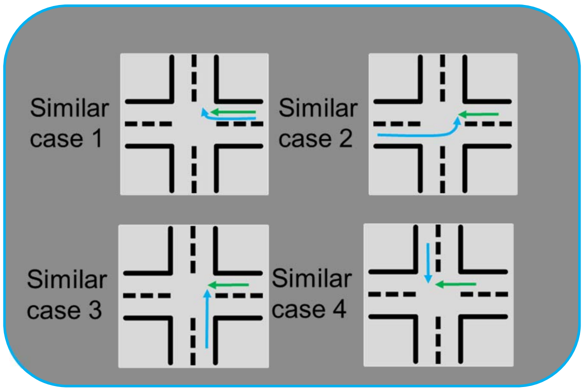


Figure 28: Possible collision situations

6.5.4.6 Alternative flow

Path prediction and collision detection may be moved to MEC for acceleration. In addition, if the VRU is equipped with a VRU-Rx, he can also receive a warning message.

6.5.4.7 Post-conditions

Car driver is alerted of potential collisions, and takes appropriate action to avoid or mitigate a collision.

6.5.4.8 High Level Illustration

Figure 29 is an illustration of the considered use case. At the intersection, ambient sensors (e.g. cameras, radar, etc.) are integrated with an RSE. At the RSE the data from the sensors is fused and utilized for a joint object detection and classification, focusing on road users and their dynamics. If the vehicle tries to turn right, and there is a scooter that is going straight in the same direction, the RSE will broadcast a warning message to the vehicle when it detects a collision risk. The warning message should be sent five seconds before the vehicle or the scooter arrives at the edge of the red circle as shown in Figure 29, and the HMI on the car will provide a warning message to the driver. In addition, as shown in the figure, when the vehicle driving in the different direction tries to turn left, the warning message will be broadcast when the RSE detects that a collision may occur.

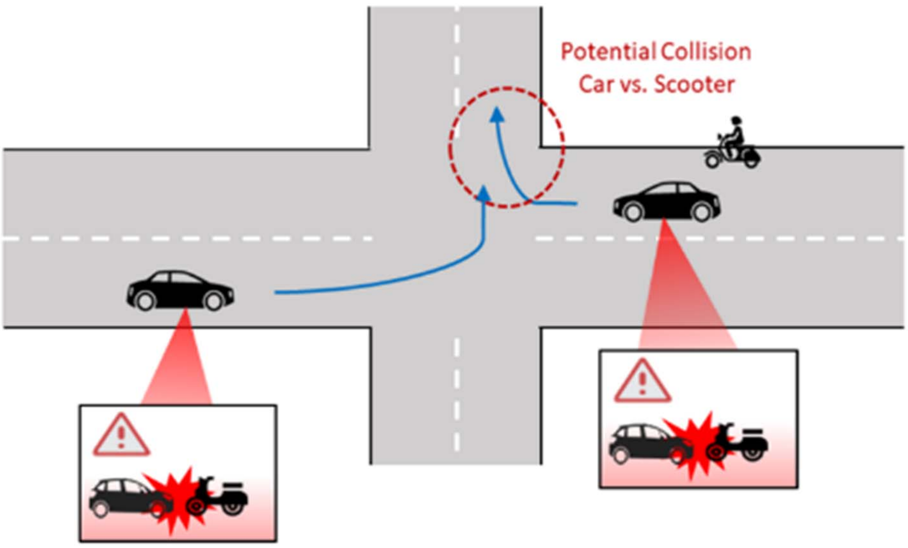


Figure 29: Scooters Safety with Turning Vehicle

6.5.4.9 Use case analysis

Path prediction and collision detection play a very important role in this use case. However, it is difficult to balance the real time delivery of warning messages and high accuracy of path prediction and collision detection. After all, whether the warning message can be received by vehicles or VRUs before the accident is the most important thing to improve the safety of this use case.

6.6 Category E: Equipped VRU via a third-party Centre

6.6.1 UC-E1: Network assisted vulnerable pedestrian protection

6.6.1.1 Description

Use case derived from contribution ITSWG1(18)044003 by 5GCAR project (adapted to become technology-agnostic).

This use case is focused on situations where a VRU is moving close to the street or crossing the street. Thanks to exchange of positioning via a global navigation satellite system (GNSS), radio based positioning, and local sensor/camera information between users and the network via wireless communications, the network assisted VRU protection system will determine the road user position. All this information is processed for multiple road users for alert generation to vehicle drivers or AD vehicles. Complementing GNSS and in-vehicle equipment with radio-based positioning is crucial in situations where GNSS reception is highly inaccurate or even impossible (tunnel, parking garage) and where in-vehicle equipment becomes unreliable because of non-line-of-sight (NLOS) between vehicle and VRU or bad weather conditions.

Goal: To detect the presence of vulnerable road users in proximity of a vehicle with the help of the network and deliver such information to the vehicle and the VRU to avoid the potential collision with the help of accurate positioning technology.

Use case category: E	

6.6.1.2 Actors

- Actor 1: The third-party centre located in the cloud is able to provide a broadcast signal to the Vehicle with V-ITS-S device and to the pedestrian with a VRU station device. Using V2C/V2I communication, localization data (x, y) and alert information are provided from Actor 1.
- Actor 2: Pedestrian VRU station can provide supporting information like GNSS position to Actor 1.
- Actor 3: Vehicle ITS-S can provide supporting information like GNSS position, speed, yaw rate to Actor 1.

6.6.1.3 Pre-conditions

A pedestrian is crossing a road in bad visibility conditions. The vehicle involved is equipped with communications capabilities. The equipped pedestrian user is carrying a VRU ITS station device that is registered in the infrastructure network and a location server with enhanced positioning algorithm and data fusion.

6.6.1.4 Triggers

A risk for the pedestrian safety is detected by the third-party centre when crossing the road in proximity to the approaching vehicle.

6.6.1.5 Normal flow

- Equipped car able to connect via communications channel to infrastructure and location server to warn the driver or decide consequently driving corrections (avoid collision).

- Actor 1 controls the communication of V-ITS-S and VRU stations, and exchanges status of these users.
- Actor 2 manages independently to come close to the street and stop or cross the street with the VRU station. Optionally, the network will communicate the VRU station position and/or stop alert to the VRU which will decide by itself how to react.
- Actor 3 is connected to the network infrastructure and gets the status of other ITS stations for monitoring. The network will communicate the VRU position and/or stop alert to the vehicle, which will decide by the vehicle itself how to react.

6.6.1.6 Alternative flow

No alternative flow.

6.6.1.7 Post-conditions

Potential collision is avoided and the pedestrian user safely crosses the street.

6.6.1.8 High Level Illustration

Figure 30 shows an illustration of the considered use case.

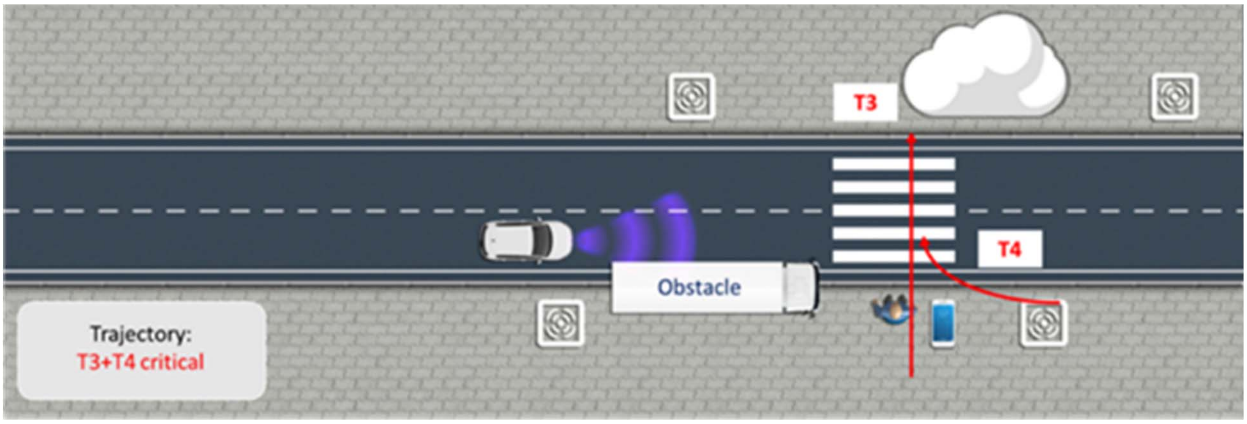


Figure 30: Pedestrian crossing behind an obstacle to be avoided by network assistance

6.6.1.9 Use case analysis

- Impact on performance of the transfer and risk assessment in the cloud. This may be improved if edge servers are available.
- The server in the cloud needs a comprehensive perception of the area to make a decision.
- Impacts on network load, priority of VRU message, problem of latency, problem of privacy.

6.6.2 UC-E2: Detection of an animal or pedestrian on a highway

6.6.2.1 Description

Highways are now equipped with cameras at strategic locations, which monitor the road traffic as well as events that may happen on the highway and put vehicles at risk. Such event can be the detection of the presence of a pedestrian, or even an animal on the side of the road, likely to enter the driving lanes. These cameras are monitored in a control centre, where the decision is made to trigger an alert to passing-by vehicles in a certain area, covered by a cluster of road-side units.

Use case category: E	

6.6.2.2 Actors

- Animal or pedestrian (equipped or not) walking on the highway.
- Cameras located on the side of the road and connected to the control centre (through any type of medium).
- Monitoring operator or AI in the control centre.
- One or several vehicles equipped with ITS-S.

6.6.6.3 Pre-conditions

The highway or normal road is equipped with monitoring systems (cameras, radar) which are connected to a central controlling and management unit. This control centre has access to local road side ITS-S and can trigger messages to be broadcasted by these ITS-S.

6.6.2.4 Triggers

Monitoring equipment detects the presence of a VRU on the road.

6.6.2.5 Normal flow

- The monitoring equipment forwards a notification to the control centre.
- A road network operator or AI detects the presence of the VRU constitutes a road hazard and triggers an alert.
- The location of the event is obtained from the information and identification of the monitoring equipment.
- An alert is distributed to the cluster of road side ITS-S. These stations start broadcasting the alert in their respective areas.
- The vehicle drivers in the area receive an alert and can slow down to avoid crashing the VRU.
- If equipped (e.g. adult pedestrian), the VRU is notified by its device and able to move behind guard rails. If not equipped (e.g. wild animal) only the vehicle drivers can react.

6.6.2.6 Alternative flow

- The monitoring equipment is directly connected to the closest road side ITS-S, which immediately evaluates the risk of collision and starts broadcasting an alert. This is beneficial when the two devices are collocated.
- The monitoring equipment also forwards a notification to the control centre, which takes the same steps as in the normal flow.

6.6.2.7 Post-conditions

When the situation has been cleared (e.g. the VRU is no longer on the road) a corresponding information can be send to the control centre. The control centre can initiate the required messages to be sent by the road side ITS-S.

6.6.2.8 High Level Illustration

Figure 31 shows an illustration of the considered use case.

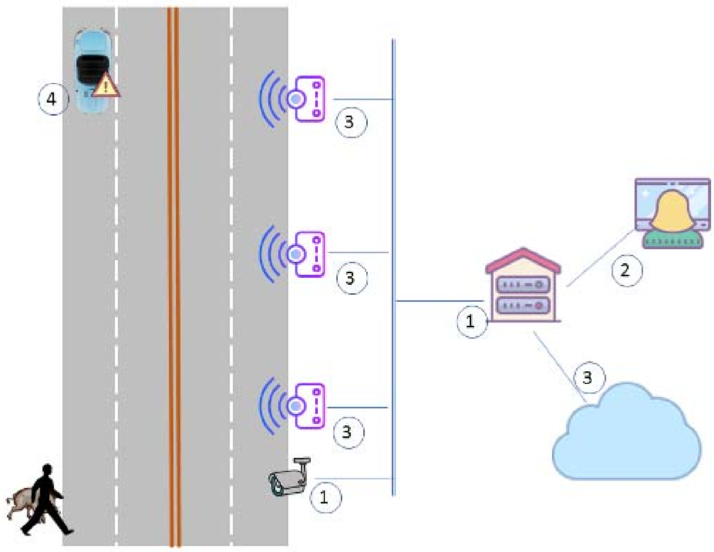


Figure 31: Pedestrian/Animal on highway use case illustration

6.6.2.9 Use case analysis

Potential challenges are:

- Capability to interact with and alert the VRU walking on the road from the control centre.
- Positioning accuracy required to ensure the VRU is inside the highway property.
- Capability to deploy an alert on a large area.

6.7 Category F: Equipped VRU via a third party RSE

6.7.1 UC-F1: Signalled Many VRUs in a protected area

6.7.1.1 Description

In an urban environment, many times VRUs are moving in protected VRU areas and sometimes crossing roads at unprotected points according to their points of interest. If many VRUs are equipped with a portable device including an ITS-S, this may create a local ad hoc network congestion problem. This can be limited if this issue is considered during the design of the overall system. Several possible approaches need to be further explored in the next parts of the present standard.

Use case category: F	

6.7.1.2 Actors

Many equipped VRUs which are evolving in the same ad hoc network.

One or several Road Side Equipment in active cooperation with equipped VRUs.

Vehicles which are moving in the same area as the VRUs.

6.7.1.3 Pre-conditions

All the portable devices of the equipped VRUs are activated and are in the same ad hoc network as at least one RSE.

The RSE is equipped with a relevant ITS-S, is activated and is in the same ad hoc network as vehicles equipped with an ITS-S.

6.7.1.4 Triggers

The portable devices of the VRUs keep broadcasting VRU standard messages to signal their movements. When a risk of collision between at least one VRU and a vehicle is detected by the RSE, this one triggers the broadcasting of standard messages (e.g. DENMs, CPMs, MCMs) according to the type of vehicle being detected (via its CAMs). The relevant vehicle can act according to the content of the received messages.

6.7.1.5 Normal flow

Assumptions: Vehicles are equipped with Release 1 services only, having the capability to broadcast CAMs and process DENMs and Contextual Speed Messages (CSM). RSE is also equipped with compliant Release 1 services enabling the broadcasting of DENMs and CSMs.

1) Release 1 compliant RSE detects, via its CAMs reception, the arrival of one or several vehicle(s) which trajectory and velocity create some collision risk with several VRUs evolving in the area.

2) The RSE then broadcasts Release 1 messages (DENMs or CSM) signalling the presence of VRUs and asking for a speed reduction.

3) Receiving Release 1 vehicles react according to received instructions (e.g. authorized contextual speed limit) and recommendations, considering the calculated TTC.

4) If a risk of collision is detected, according to the TTC value, the subject vehicle starts a collision avoidance action.

The normal information flow is represented on Figure 32.

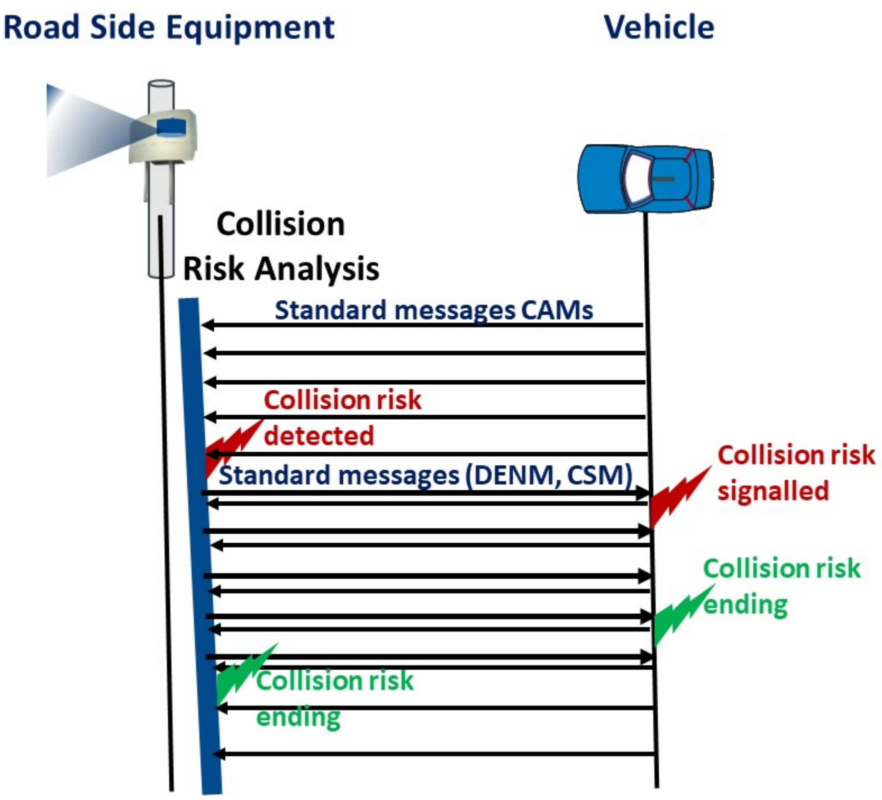


Figure 32: Flow diagram for UC-F1 - Many VRUs in a protected area

6.7.1.6 Alternative flow

Assumptions: Vehicles are equipped with Release 2 services, having the capability to broadcast CAMs, enhanced CAMs and processing CPM/MCM. RSE is equipped with Release 2 and able to broadcast CPM/MCM. Some VRUs are also equipped with devices complying with Release 2 VRU services. The flow considers all cases, independently of timing constraints (see clause 6.5.3.9):

1) Release 2 compliant RSE detects, via its CAMs reception, the arrival of one or several vehicles which may create a risk of collision with one or several VRUs.

2) The RSE also detects one or several VRUs engaged in the crossing of the road. This is achieved either via the own RSE sensors or via standard communication with VRUs being equipped of devices complying with Release 2 VRU services.

3) The RSE broadcasts Release 2 standard messages (CPM or MCM) enabling vehicles which may create a risk of collision to act according to the calculated TTC.

4) Receiving vehicles analyse relevant Release 2 messages for collision risk analysis.

5) If a risk of collision is confirmed, the subject vehicle starts a collision avoidance action according to the calculated TTC.

The alternative information flow is represented on Figure 33.

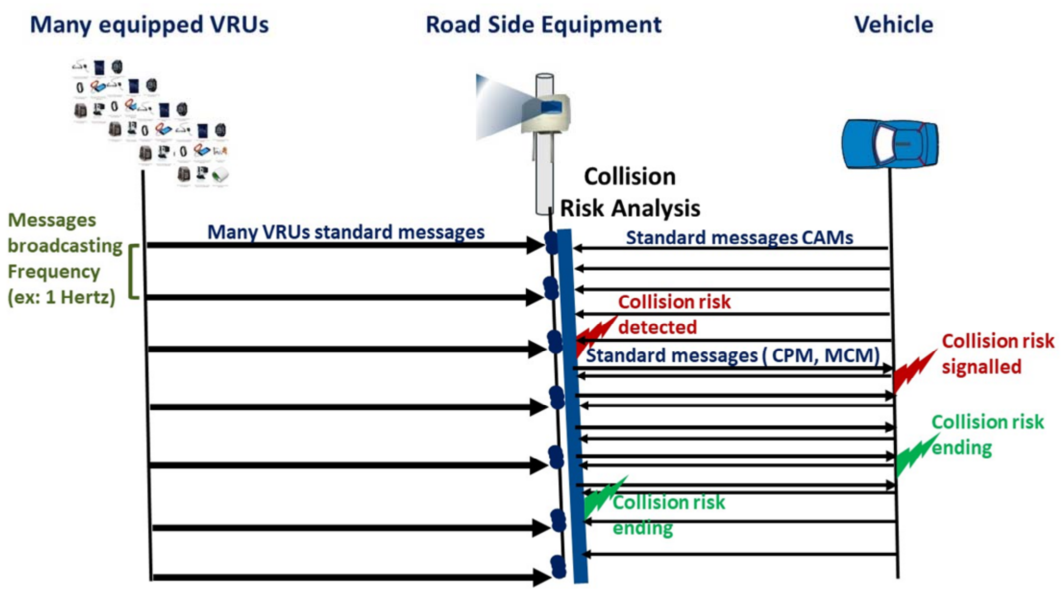


Figure 33: Alternative flow diagram for UC-F1 - Many VRUs in a protected area

6.7.1.7 Post-conditions

Portable devices of equipped VRUs continue to broadcast VRU standard messages indicating their movements.

The Road Side Equipment continues to assess a risk of collision.

6.7.1.8 High Level Illustration

Figure 34 shows an illustration of the considered use case.

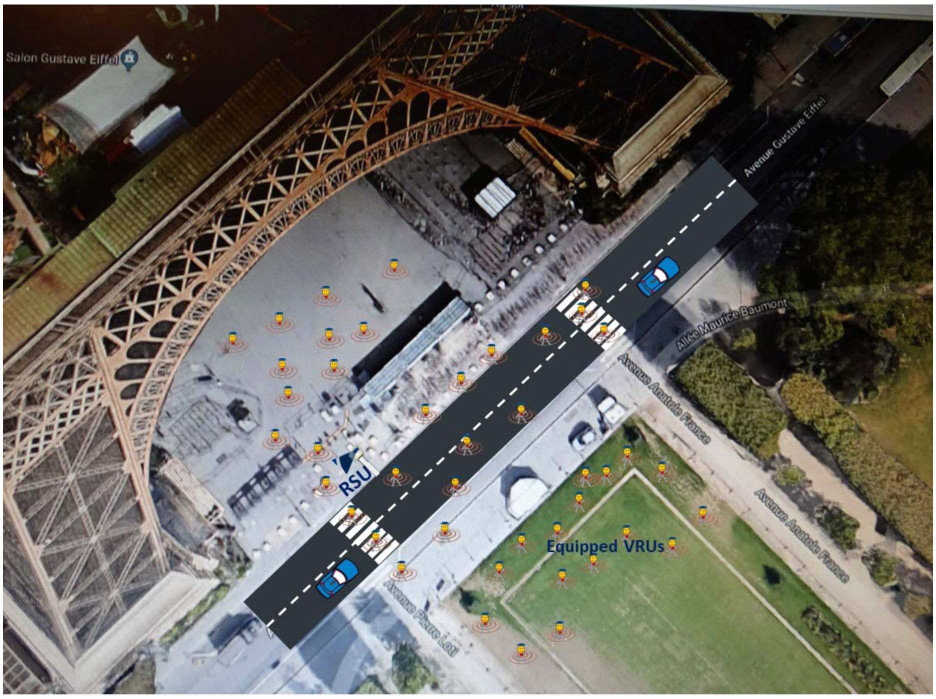


Figure 34: Illustration of UC-F1 - Many VRUs in a protected area

6.7.1.9 Use case analysis

The main challenge relevant to this use case is the possibly high number of equipped VRUs leading to a congestion of the ad hoc network being used between them and the RSE. For this reason, one of the possible solutions is to have a separate ad hoc network different of the one being used by the vehicles.

In case of many VRUs, it is not possible to provide the trajectory of each one. Consequently, it is necessary to consider an area which is populated with VRUs and to be capable of geo-delimiting this area in broadcasted CPM/MCM. The minimum frequency of the VRU Service messages needs to be at least 1 Hz. The total end to end (applications level) latency time needs to be better than 300 millisecond to be able to maintain a relative age of dynamic data elements not too far from the reality.

6.7.2 UC-F2: Intelligent traffic lights for all (P2I2V)

6.7.2.1 Description

This P2I2V cooperation is achieved by each VRU using a portable device including an ITS-S complying with VRU standards. In such case, the portable devices' ITS-S are continuously broadcasting standard message providing dynamic data elements related to their positions and movements. Infrastructure (traffic lights in this case) and vehicles are also equipped with an ITS-S complying to VRU standards and so are capable of transmitting and receiving VRU standard messages and then detecting and notifying the traffic light change setting adjustment.

Use case category: F	

6.7.2.2 Actors

The actors are VRUs crossing the zebra area, traffic lights infrastructure, and vehicle(s) near the zebra crossing.

6.7.2.3 Pre-conditions

- VRUs are all equipped with a portable device integrating an ITS-S compliant to the VRU standards.
- Vehicle(s) and traffic lights infrastructure are also all equipped with an ITS-S complying with VRU standards.
- All ITS-S are power supplied and configured properly according to their applications.
- The VRU should be certified as an 'social-weak' or very vulnerable person (e.g. pregnant, elderly, kids, person with special needs) and this fact should be indicated in the static element of the VRU standard message.
- VRUs and Infrastructures are positioned in the communication range of C-ITS network. Infrastructures and vehicles are also positioned in the communication range of the ad hoc network.

6.7.2.4 Triggers

When VRUs like a pregnant woman or an elderly cross at the zebra crossing, intelligent traffic lights detect it and automatically extend the signal if they fail to cross within the initial time limit and inform the surrounding vehicles.

6.7.2.5 Normal flow

The normal information flow is represented on Figure 35.

Standard messages including signal information are continuously broadcasted by Infrastructure at a configurable frequency (ex: minimum 1 Hz, 10 Hz maximum).

Standard messages are continuously broadcasted by VRUs portable devices at a configurable frequency (e.g. 1 Hz maximum). CAM standard messages are also continuously broadcasted by vehicle ITS stations.

Received messages are processed by the infrastructure for crossing status analysis. In case of a detected crossing failure and signal extension, according to the ITS-S configuration, vehicles being in a signal extension situation will be advised of the signal extension alert.

Once VRUs completely cross the zebra area, the information is transmitted from the infrastructure to the vehicles nearby.

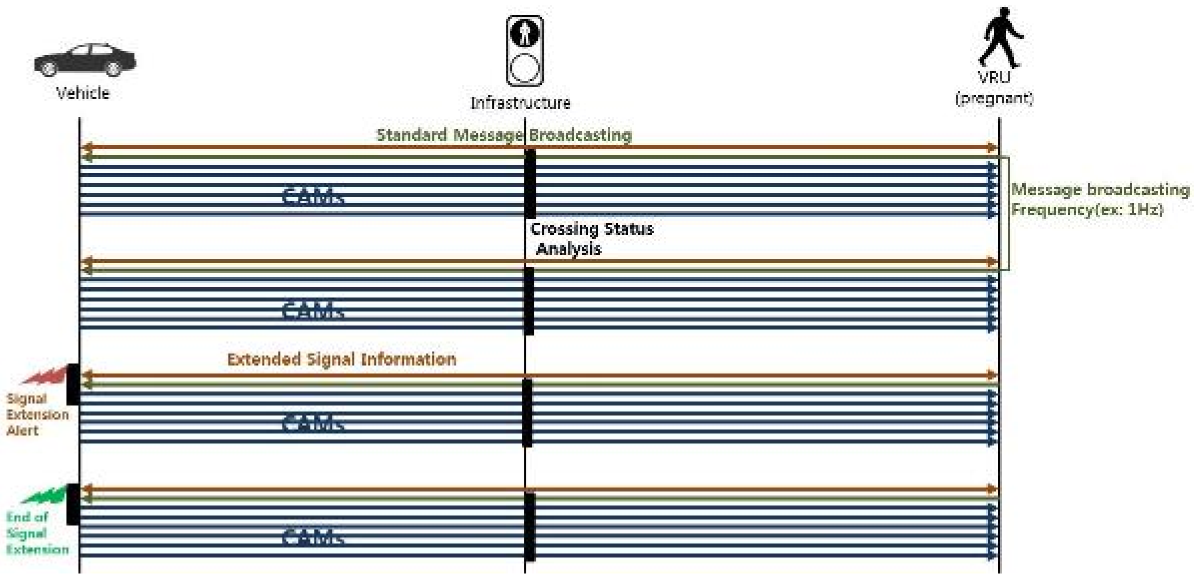


Figure 35: Use case UC-F2 flow diagram

6.7.2.6 Alternative flow

No alternative flow.

6.7.2.7 Post-conditions

Once VRUs completely passed the crossing, the infrastructure broadcasts standard messages including signal time information to inform the green light change to the vehicles.

6.7.2.8 High Level Illustration

Figure 36 shows an illustration of the considered use case.

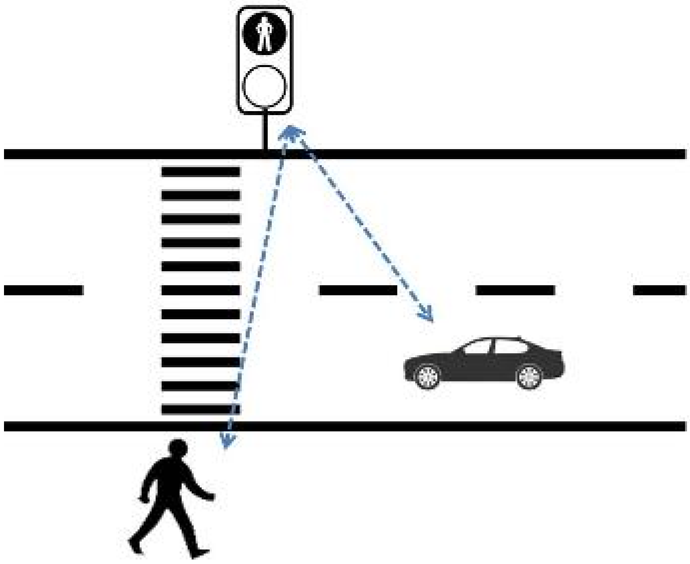


Figure 36: Illustration of UC-F2 - Intelligent traffic lights for all (P2I2V)

6.7.2.9 Use case analysis

This category of use cases does not consider a direct automated action on VRUs and their mobility means. Only alerts and advices (on trajectory or momentum) are foreseen. As a result, the user safety risk is low in case of a cyberattack. Nevertheless, there may be a need to consider some mechanism to prevent abusing this solution e.g. maximum traffic light change extension limit. If there are many VRUs in the system, an ad hoc local area network congestion problem may happen.

7 Summary and conclusion

7.1 General overview

Clause 4 has presented a definition of what is considered to be a VRU and its environment.

Clause 5 has introduced a categorization of the potential use cases involving VRUs classified based on the different entities involved in the C-ITS system which could contribute to prevent a risk of collision with a VRU. Each of these categories has its own specificities. The categories will help develop the structure and prepare the specification of the VRU system functional architecture.

Clause 6 has described a set of exemplary use cases where VRUs encounter a risk of collision and how this risk could be mitigated by the C-ITS system. These use cases have been analysed and one of the outcomes of this analysis is that depending on the use case and the actors involved, different elements of the architecture may be mandatory or optional (for example functions in the cloud). This is also closely linked to the deployment level of the different features of the C-ITS system. In this analysis, some challenges to be addressed in ETSI TS 103 300-2 [i.17] and ETSI TS 103 300-3 [i.18] have been highlighted.

The following clauses introduce the different challenges identified in clause 6 that need to be taken into account when specifying the VRU basic awareness service.

7.2 Unpredictable behaviour from the VRU - profiling

A key characteristic of a collision avoidance system is its capability to predict movements (trajectories and momentum (velocity associated to the mobile object mass)) with the objective to be capable of acting on time (changing trajectory/reducing velocity) in such a way to avoid the collision. This is of course applicable to all types of moving objects (VRUs and vehicles). When a predicted behaviour is indicated, it will be necessary also to provide the level of confidence associated to this prediction. This level of confidence can be of course related to some movement parameters (example: the mobile object velocity), but also to the knowledge that may be acquired (learning) of frequent behaviours of VRUs. This is why it is necessary to classify VRUs according to their possible behaviours and derived prediction level.

The different types of VRUs have been defined in clause 4.2. They can be globally split into three groups or VRU profiles, each of them raising challenges for their introduction in the C-ITS system and the prevention of false positive and false negative estimation of collision situations.

VRU profile 1 is mainly concerned with pedestrians, i.e. road users not using a mechanical device for their trip. It includes for example pedestrians on a pavement, but also children, prams, animals, blind persons guided by a dog, riders off their bikes. They trigger the following behaviour challenges:

- Unpredictable behaviour, as whether they will stay on pavement or enter the road, in particular for young children and (wild) animals. Their trajectory and intentions cannot be easily predicted and depend on their context and environment. The behaviour also depends on their culture and habits.
- Their velocity range is limited, e.g. from 0 to 4 m/s for an adult pedestrian, 0 to 1 m/s for an older or disabled person.
- Their capabilities to react to warnings/avoid collision, the amount of time they will need to react and the types of user interface to be used, for example sound alarms rather than visual alarms, wearables, augmented reality, etc. Indeed, this also applies to the other VRU profiles described below. VRUs in this profile may or may not have the capability to react to a warning.
- They may take passive or active roles in the C-ITS systems.
- They may be gathered in a large and/or dense group or travel isolated. In the case of travelling in large groups, should all of them take part actively (i.e. transmitting) to the C-ITS? The ITS-S may be overloaded by the number of messages received. However, in any case, this should be re-evaluated as soon as they get isolated. A related challenge for this topic is to determine the conditions in which they are travelling/behaving as a group and what is the number threshold to consider that they are isolated or not.
- They may change their role in the road traffic and become passengers of a public transport vehicle (bus, urban train, train), riders of a motorbike, walking indoors, entering a car, etc. Some means needs to be defined to determine the role of an active device in the C-ITS system and whether it should be considered as a VRU or not.

VRU profile 2 is mainly concerned with light vehicles, possibly with an electric engine. It includes bicycles, but also wheelchair users, skaters, scooters, Segway's, etc. They can move on the pavement or directly on the road and often have lower speeds. They trigger the following behaviour challenges:

- They often move at a low speed, but higher than that of a standard pedestrian (for example 0 to 10 m/s for a bicycle), which means that they represent a safety issue for the actual pedestrians if they travel on the pavement. On the other hand, their speed is often slower than that of regular vehicles, which constitutes a safety issue for their riders.
- Their behaviour is easier to predict than for regular pedestrians, yet it is still subject to random movements.
- They have the same ability to react to a warning as a regular adult pedestrian.
- If the light vehicle has an active C-ITS device and the rider has one as well, which may have slightly different positions, then both of them should be aggregated from the C-ITS point of view (or one of them be given the priority) and split again when they separate. This applies for example to the case where the rider has fallen on the ground and lies a few meters away from the bicycle.
- They are difficult to perceive (e.g. no correct lighting). They may travel in groups and often do not follow traffic regulations. So, it is necessary to make them electronically visible for vehicles.

NOTE: Even though it is not a mechanical device, a horse carrying a rider is considered as part of that VRU profile.

VRU profile 3 is concerned with motorbikes, which are equipped with engines that allow them to reach speeds similar to other vehicles such as cars, buses or truck. They normally take part in the road traffic and are already included in the C-ITS system, able to send CAMs when equipped with the proper device. They trigger the following behaviour challenges:

- Same as for light vehicles, their behaviour is easier to predict than for regular pedestrians, yet it is still subject to random movements.
- They have the same ability to react to a warning as the driver of a vehicle.
- Same as for light vehicles, aggregation and separation of C-ITS stations should be envisioned when they mount or step down from the motorbike.
- Their perception (noise in the road) and visibility from other vehicles. Accident statistics show that often car drivers do not see the motorcycle.

An important challenge raised here is the notion of grey zone, referring to the transition of the actual role of the VRU user, from one profile to another. It is necessary to make the difference between a VRU as a pedestrian, pushing a bicycle, riding a motorbike or passenger in a car and especially when it is changing roles. This could also fit in a legal framework. This will be further analysed in ETSI TS 103 300-2 [i.17].

As each VRU may have a specific behaviour profile, it can be constantly learned by the personal device with the objective to refine the velocity range and the confidence level that can be associated with its trajectory prediction. Accordingly, provided velocity ranges could be considered as initial figures (calibration) which may be updated by a learning mechanism in the VRU device.

VRU devices may be static (for example in helmet, wearable, belt, watch, etc.) or dynamic (for example smartphone) vs. the VRU reference position. If mobile, it is more difficult to position properly the VRU since the correction to be applied to calculate its deviation to the reference position is not accurately calculable.

VRU actions are difficult to predict depending on their types, but also on their capability to act properly in critical situations. Some VRUs may not have the capability to act to avoid an accident (children, animals, disabled/elderly persons, etc.).

A VRU may have several devices not consistent in terms of positioning (different reference positions). In this case, they may cooperate to select only one reference device which could mark out a complete secure area (a safety shield, for example circle, ellipse) around the group, providing a single reference position.

7.3 Positioning aspects

For the positioning of VRUs specific considerations are required in order to cover the different use cases presented in the present document.

In general, a significant higher precision and accuracy of the positioning information are required for a typical VRU use cases. Depending on the specific use case, a precision of 0,5 m or less is needed.

VRUs are smaller in size and more unpredictable in behaviour. Furthermore, the VRU device might be a portable device which is not installed in a fixed position.

A VRU position reference point needs to be specified (e.g. gravity centre) for the purpose to correct the VRU position according to the place where the portable device is integrated. The portable characteristic of the typical VRU devices will also lead to time variant roles of the device, e.g. a smart phone as VRU device can be used as a bicycle VRU when on a bicycle whereas as soon as the person walks away from the bicycle it becomes a pedestrian VRU.

The bicycle example also shows the issue with the path prediction of these portable VRU devices. Since the VRU devices might change their roles from one message to another, it is a challenge to predict the future trajectory of the VRU device.

The orientation of the VRU is also an important factor, especially in the case where it has fallen on the ground after an accident and constitutes a non-moving obstacle to other road users. This parameter should complement the dimensions of the VRU in the VRU message.

Even if in most of the cases it is possible to consider only two dimensions for the analysis of VRUs trajectories and momentums, in some situations, for example when using a bridge to cross a road, three dimensions (longitude, latitude, altitude) should be considered to avoid false negative notification when VRUs are crossing the road using a bridge or VRUs dedicated footbridge. This challenge is also related to a lack of accuracy of the altitude value as given by commercial positioning systems which may not be able to discriminate a VRU crossing the road under the bridge from one crossing the road on the bridge.

Summary:

- Positioning accuracy requirements for VRUs are significantly higher than for traditional C-ITS participants.
- Positioning reference point is an important aspect to be defined having in mind the portable characteristics of a typical VRU device.
- VRUs position is specified for the three spatial dimensions with the same level of accuracy. This is necessary in a short term to avoid false positive when VRUs are crossing a road using a bridge. This will be necessary also in the future when flying vehicles will be deployed (e.g. automated taxis).
- Due to the portable characteristic of the VRU device, the VRU can change roles. This leads to a challenge in path and trajectory prediction and its level of confidence.
- In some use cases, a single VRU device might have different roles, e.g. walking beside a bicycle.

These specific aspects need to be taken into account in the functional architecture definition and the specification of the message content of the VRU messages.

More details can be found in the POsition TIme (PoTi) Facilities layer service.

7.4 Resource Usage

7.4.1 Introduction

The operation of the VRU equipment in the C-ITS domain will be subject to limited available resources. The considered resources are:

- Spectrum resource in the relevant frequency bands and used communication systems.
- Batterie resources as an important subject for portable devices used by VRUs.
- Implementation complexity for portable devices.

The spectrum resource issue is a general issue and not dependent on the type of ITS device. The two other topics are mainly important for the considerations related to portable devices. Fixed devices and devices implemented in vehicles with power supply capabilities will have less issues with these two resource constraints. Having in mind that the overall ITS protocol has mainly been developed for vehicle and infrastructure usage, these topics have to be considered in detail for VRU devices which will mainly be portable devices.

7.4.2 Spectrum resource constraints

In order to identify the main constraints of the spectrum resource usage, the VRU communication has to be split into two approaches:

- Direct mainly ad hoc communication between the VRUs and the C-ITS network performed in the allocated spectrum for safety related C-ITS communication in the band 5 875 MHz to 5 925 MHz.
- Indirect communication between the equipped VRUs and the C-ITS system communication counterparts like vehicles and infrastructure using RLAN, cellular networks or other wireless communication channels operated in spectrum band not used by or allocated to C-ITS ad hoc systems.

For the case of a direct communication using the safety related spectrum resources, Table 5 depicts an example of the estimation of the spectrum usage for a typical pedestrian VRU deploying direct broadcast-based communication. Here an average periodic message similar to a CAM is assumed for the calculation of the required safety related spectrum. Under the assumptions given in Table 5, up to 4,24 MHz spectrum in urban and suburban environments is needed to support a broad deployment of these kind of messages by pedestrians. These estimations need to be updated as soon as the detailed parameters of the messages (length, average number per second) to be deployed are specified.

Table 5: Example estimation of pedestrian spectrum resource usage

Environment	Parameter	Value	Comment
Urban	Packet size (bytes)	350,00	Including security and higher layer overhead, e.g. GN
	Average TX periodicity (Hz)	1,00	pedestrian messages 1 per seconds
	ITS pedestrian stations in relevance area	500,00	Urban crossing: 50 m from centre, area 8 000 m^2, minus street area (4 000 m^2) minus building area (3 000 m^2) density 0,5 persons/m^2 --> 500
	Spectrum efficiency (bits/Hz)	0,55	6 MBit/s minus PHY header and overhead in 10 MHz
	Maximum channel load	0,60	Maximum load for periodic messages
	Spectrum requirements (MHz)	**4,24**	
Sub-Urban	Packet size (bytes)	350,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	1,00	medium moving traffic
	ITS pedestrian stations in relevance area	10,00	Sub-Urban crossing: 50 m from centre, area 8 000m^2, minus street area (4 000 m^2) minus building area (3 000 m^2) density 0,01 persons/m^2 --> 10
	Spectrum efficiency (bits/Hz)	0,55	6 MBit/s minus PHY header and overhead in 10MHz
	Maximum channel load	0,60	Maximum load for periodic messages
	Spectrum requirements (MHz)	**0,08**	

Typical highway use cases have not been considered here since it can be assumed that the required resources for pedestrians is very limited in these environments. Additional applications will add up and increase the spectrum requirements in the safety related bands. A more detailed analysis needs to be performed based on the message definition and the functional architecture.

When an indirect communication link is used (RLAN, Mobile Radio, UWB, etc.), the spectrum resource usage in the band of the used indirect communication system has to be evaluated. A similar approach like the one presented in Table 5 can be used.

7.4.3 Power and complexity constraints

Especially for portable ITS devices mainly deployed for VRUs (pedestrians, pets, bicycles, etc.) without power supply, the power consumption for the active participation in the ITS communication has to be considered carefully. The battery capacities used by these systems are very limited.

The following cases have to be considered separately:

- TX only devices (i.e. VRU-Tx as defined in Table 1).
- RX only devices (i.e. VRU-Rx as defined in Table 1).
- Full transceivers. (i.e. VRU-St as defined in Table 1).

For TX only devices the main factors to be considered are:

- TX power derived mainly from the required relevance range of the supported applications.
- Duty cycle of the messages.
- Modulation scheme deployed.

- Etc.

For RX only devices the following factors are relevant:

- Duty cycle of the messages.
- Modulation scheme deployed.
- Receiver complexity and performance.
- Etc.

For transceiver systems, all of these parameters have to be considered:

- TX power derived mainly from the required relevance range of the supported applications.
- Duty cycle of the messages (depending on the access technology).
- Modulation scheme deployed.
- Receiver complexity and performance.
- Ratio between TX and RX.
- Etc.

The main factors to be taken into account are dependent on the message definitions (length, repetition rate), the functional architecture and the used access layer protocol. The consumption and complexity can be significantly reduced by taking these constraints into account in higher layer building blocks like the facilities layer and network layers.

7.4.4 New functional constraints

VRU portable devices as well as vehicles' ITS-S may face an increase of their complexity due to the introduction of new functions and evolution of existing functions.

New functions can be justified to optimize the network bandwidth being used for the interactions between the different C-ITS components (vehicles, VRUs devices, RSE, Centres). For example, interactions may be developed (triggering conditions) only when a risk of collision between one or several VRUs and vehicle(s) is detected. A new function for "Risk Analysis" is introduced that would decide at VRU ITS-S and vehicle ITS-S level which collision avoidance strategy (change of trajectory or/and act on the mobile momentums) to use, based on the knowledge of the local traffic pattern (density and predictability of the traffic). Moreover, the mobile paths prediction may be needed to develop a specific function in charge of characterizing their behaviours based on some criteria such as the VRUs profiles (ex: an animal's behaviour is different from a human's) and their potential momentums (the speed of changing trajectory depends on mobiles' velocities and their masses).

Evolution of existing functions is related to the increase of positioning performances (accuracy) and the need to include additional positioning augmenting functions considering terrestrial corrections (see the PoTi specification). The VRU device may also have to consider enhanced security functions which could come out as a result of the security study.

According to the ITS architecture, new functions together with their associated algorithms (AI) and data may be distributed taking into account the scenarios which are considered in ETSI TS 103 300-2 [i.17].

7.5 Performances of the VRU system

In order to guarantee the support of the uses cases and corresponding applications depicted in the present document, the VRU devices need to be able to support the required performance criteria. As part of the definition of the functional architecture of the VRU system (as part of C-ITS), the following performance criteria need to be considered:

- Latency:
    - Initial access latency, information update latency.

- Resource usage:
  - Batterie usage, spectrum usage, etc.
- Reliable range:
  - Communication range for a given system parameter setting like TX power, Coding rate, Modulation scheme, etc.
- Number of supported devices under given spectrum resource constraints and congestion control mechanisms:
  - In C-ITS a large number of devices needs to be supported to increase the benefits of the system.
  - Congestion needs to be managed in order to guarantee a reliable communication range.
- Positioning accuracy and reliability:
  - VRUs are typically small, positioning has to be more accurate and reliable than in vehicular ITS.
  - VRUs are less predictable (uncertainty, trajectory prediction).
  - Limited sensor data fusion capabilities.
  - Fixed indirect VRU detection could increase positioning accuracy and provide additional positioning support.
  - VRUs positioning is provided by means of VRU-to-X messages broadcasting. The age of the data elements contained in messages evolves with time and is then related to the periodicity of broadcasted messages. Consequently, the message periodicity needs to be adjusted according to the velocity of the VRU if consistency needs to be maintained between the VRU positioning accuracy and the received positioning data elements evolution. For example, if a VRU moves at 2 meters per second, in 100 milliseconds it will have progressed by 20 centimetres thus creating an error of 20 centimetres which can be equivalent to the expected positioning accuracy. However, if the periodicity of messages is reduced in order to avoid channel congestion, the positioning error increases which can undermine VRU safety. In such case, interpolation of received data elements can be achieved if there is a good confidence in the VRU trajectory prediction.

In the final analysis of the use cases and the mapping onto the functional architecture, these performance criteria need to be defined. These criteria will significantly influence the implementation choices of the VRU system. This analysis will be performed in ETSI TS 103 300-2 [i.17].

7.6 Security and privacy of the VRU application

VRU applications share many security and privacy considerations with other C-ITS applications based on mobile devices.

At a high level, there are security concerns around false positives and false negatives:

- A false positive means that a receiver thinks there is a situation that requires a reaction when in fact there is no such situation. This occurs if a receiver believes a message in the VRU system to be true, but the message is false. This can lead to the receiver taking an action in the real world that negatively affects system users, for example by reducing their safety. For example, a false VRU message might give a driver the incorrect impression that a child was running out in front of their car, causing the driver to brake suddenly and increasing the chance of a rear-end collision.
- A false negative means that a receiver does not think there is a situation that requires a reaction when in fact there is such a situation. This occurs if the receiver does not receive a message alerting them to a situation, or if the receiver receives the message but also receives contradictory messages and as a result chooses not to believe the true message. For example, a denial of service (DoS) attack might lead to a receiver not receiving any messages from VRUs.

To avoid false positives, a communications design should include cryptographic protection for the messages, using credentials that are only issued to trustworthy devices. Existing communications security standards such as ETSI TS 103 097 [i.16] specify mechanisms for providing this cryptographic protection.

Protection against false negatives is harder to provide via communications security mechanisms alone. A DoS attack cannot be prevented, but it can potentially be detected and the authorities alerted to physically remove the source of the attack. An attack based on contradictory messages can be mitigated by communications security mechanisms, as these can be used to make it harder for an invalid sender to create contradictory messages that will be accepted by a receiver.

Since all VRU applications produce data about VRUs and potentially about other private users of roads, those applications also create privacy concerns. Participants in the system may generate messages that reveal personal information about them, either as individual messages or when the messages are aggregated. In the case of VRUs, this is especially relevant as the use cases show that their protection often involves edge or cloud components of the system.

A strategy to mitigate privacy concerns should include both technical measures to reduce personal information leakage form messages (for example, by simply not including a number such as a National ID number in the message; or by periodically changing temporary identifiers that are associated with the sender so that two messages generated by the same sender at different times do not reveal that they were generated by the same sender). It should also include data management policies about retention of and access to data generated by these applications. It is thus important to consider how much information about itself the VRU should provide to the C-ITS system, especially in cases like scenario F2 which considers 'social-weak' or very vulnerable person (e.g. pregnant, elderly, kids, person with special needs).

7.7 Architecture to support progressive system deployment (roadmap)

As presented in previous clauses, the Intelligent Transport System (ITS) being required to support the targeted VRU safety service may be composed of several interacting elements. These interacting elements need to be interoperable and then, for this purpose, respect the C-ITS exchange profiles being selected by the successive deployment phases foreseen in Europe. At the time of this study, it is expected that a new type of message, or container in other C-ITS messages (e.g. CAM, DENM, CPM, etc.) is introduced to fully enable the VRU application. Harmonisation with new services is taken into account in ETSI TS 103 300-2 [i.17].

1. Phase 1 deployment:

From Release 1 delivered by ETSI and CEN in the scope of the M /453 European Commission Mandate, the Road Hazard Signalling (ETSI TS 101 539-1 [i.10]) application already specifies one use case related to VRU protection (see clause 6.3.1). This is V2V cooperation leading to the broadcasting of DENM standard messages when a stationary vehicle, in a dangerous environment (e.g. on a highway), detects that one of its occupants is leaving the vehicle.

The contextual speed (Contextual Speed Message, CSM) standard (ISO/TS 17426 [i.13]) may also be used to request the speed adaptation (Intelligent Speed Adaptation, ISA) of vehicles when one or several VRUs are detected moving and potentially crossing their trajectories.

DENMs may be slightly adapted to qualify the situation (cause and sub-cause levels) of VRUs evolutions associated to the category of VRU.

2. Phase 1.5 deployment:

Phase 1 deployment is considered not sufficient to cover urban areas, so the European Commission issued a new mandate (M/546 [i.20]) to European SDOs for the development of complementary standards applicable to urban areas. This enables the development of new VRU service standards exploiting exchanged profiles of cooperative vehicles from the phase 1 deployment. Consequently, new VRU services can be integrated with existing Release 1 services such as cooperative awareness services.

3. Phase 2 deployment:

Phase 2 deployment focuses on the support of automated vehicles from SAE level 2 to SAE level 4 and 5 (fully automated vehicles). Collision avoidance capabilities will be enhanced via the development of new standard messages such as CPM (Collective Perception Messages) and MCM (Manoeuvre Coordination Messages) associated to new electronic automatic capabilities (example: Advanced Emergency Brake System) which could be available on new vehicles types.

The focus on automated vehicles will lead to the development of new functions which need to be considered in the ITS architecture reference model, even if primarily at the level of the applications layer:

- It becomes highly necessary to predict the movement of the vehicle to anticipate a risk of collision. In principle, the automated vehicle navigation application already knows the path to follow to reach its destination. This knowledge enables the provision of the path prediction. An automated vehicle also knows the regulated speed limits and respects them. Accordingly, these data elements can be added in a new dedicated container of the CAM. In order to flexibly act on the periodicity and nature of broadcasted messages, it would be useful to know the versions, automated levels and capabilities of C-ITS enabled vehicles present in the local ad hoc network. Then new data elements could also be added in the CAM for a better use of the available network and vehicles' capabilities.

- The collision risk analysis becomes an important function necessary to select the most appropriate collision avoidance strategy and its operational application. The collision risk analysis uses the augmented perception (autonomous perception fused with remote perception received from other C-ITS-S). The collision risk analysis is also based on mobiles' trajectory and velocity evolutions which need to be predicted. The augmented perception is more and more based on the use of artificial neuronal networks and the trajectory/velocity prediction can be learned by a continuous analysis of mobiles' behaviours being associated with their respective categories. This is where AI will have an important role to play. This prediction is applicable to all mobiles present in the vicinity of the ego ITS-S. Some of these mobiles may not be C-ITS enabled, or even connected. This is where roadside equipment could have an important role to play to increase the level of perception of automated vehicles.

- In some particular circumstances, the collision avoidance application itself can be the fusion of collision avoidance strategies proposed by two or more different ITS-S according to their own perception of the situation, especially, when vehicles are defective or cannot have the expected level of autonomous perception.

An ITS-S can fall in one of 4 categories of elements:

- vehicles;

- personal devices;

- road side equipment;

- central station.

Collision avoidance is a local problem, meaning that a centre located anywhere on Earth would not be the best one to resolve on time this local problem. But a centre at the edge of the cloud, with broadcasting capabilities may have such capability if being capable to develop a full perception of the local areas being concerned by some risk of collision. Such centre at the edge of the cloud would also need to respond with the required operational performance specifications, independently of its load.

Moreover:

1) The deployment of Road Side Equipment (RSE), at strategic area locations with regard to VRUs movements, may accelerate the deployment of VRU services, in cases where VRUs are not equipped with VRU devices, which is practically always the case today given the diversity of VRUs but may change in the future i.e. with expected integration of personal ITS-S in new mobile devices. RSE may detect the VRUs movements using their own sensors (for example, thermal video cameras or presence detectors). They also can detect VRUs who are already equipped with standard devices complying with ETSI ITS VRU service standards (Release 1.5). If the device is not directly equipped with ITS access technologies (for example, using IEEE 802.11n [i.19] or IoT), the RSE may act as a gateway to be able to broadcast C-ITS compliant messages to vehicles. The RSE may also be used to reduce the C-ITS channels load by using dedicated protocols to manage critical situations involving a large amount of detected VRUs. One way to overcome this critical situation would be to use a Local Area Network offering a large bandwidth (for example, IEEE 802.11n [i.19]) for VRUs to RSE cooperation, the RSE acting as a relay for transferring a resulting summary into the C-ITS system.

2) The deployment acceleration may also be achieved by developing retrofit (ex: phase 1 evolution to phase 1.5 and evolution to phase 2) and aftermarket solutions (directly phase 2 after market devices for VRUs and vehicles) for the dynamical evolution management of in-service vehicles.

3) One risk is the fragmentation of the market by the introduction of new access technologies creating interoperability problems. Such an introduction needs to be anticipated for the deployment of migration roadmaps avoiding such fragmentation problem.

7.8 Heterogeneity of in-service vehicles

For a long time, several categories of vehicles will be sharing the road infrastructure:

- Non-connected vehicles as it is still often the case today. It is impossible to act on these vehicles as it is not possible to communicate with them. In such case it is only possible to act on VRUs via their portable devices.
- Connected vehicles using a cellular network to access centre in the cloud. Some communications are then possible if some centre in the cloud or at the edge of the cloud has the capability to perceive the complete environment of the VRUs and the performances (latency time) required to inform/act on time on relevant vehicle(s).
- Human driven cooperative vehicles equipped with the services necessary to, at least, alert the driver of a risk of collision with one or several VRUs.
- Human driven cooperative vehicles having an emergency brake capability. In such case it is expected to have the possibility to remotely act on the vehicle to avoid a collision. Such action, for example via an MCS, can be overtaken in emergency situation if the TTC is less than 2 seconds.
- Automated vehicle being controlled by its electronic. In such case, according to the TTC, the vehicle may receive some augmented perception via the CP service or directly remotely controlled in case of an emergency situation (TTC < 2 seconds).

NOTE: Considering the evolution and life cycle of portable devices, it is possible that the C-ITS market penetration rate in portable VRU devices will increase in parallel to that of vehicles. When this is the case, a vehicle may thus be connected to the C-ITS through an embedded ITS-S device or through an aftermarket solution, for example using the VRU device for that purpose. However, it is important to consider that in this case, the VRU functionality of the device is switched off after the device owner enters the vehicle and cannot be considered any more as vulnerable, thus leaving the transition phase (also called grey zone in the present document) between the two roles of the device (VRU device vs. aftermarket solution). This new role of the portable device (or any other) is out of scope of the present document, as outlined in clause 4.2. Only the transition phase will be considered in ETSI TS 103 300-2 [i.17].

7.9 Passive versus active collision avoidance action

When a risk of collision is detected, the system may inform either only one of the involved mobiles (ex: the vehicle) or both of them. The information may consist in providing relevant data (warning, alarm) to the human (VRU or/and vehicle driver) which has then the complete responsibility to trigger at the right time the right action to avoid the collision. This also applies to motorcycles which may receive alerts to avoid another vehicle.

The VRUs and vehicles may take together actions for crash avoidance, but such actions need to be consistent. A VRU action is only relevant to some categories of VRUs according to their behaviour prediction and capability to act securely. Such behaviour prediction can be learned progressively by observing the VRU trajectories and velocity evolutions in different situations.

At vehicle level, possible actions are related to the level of implementation of C-ITS services (e.g. phase 1 limited to driver awareness/alerts) and direct actions on its electronic capabilities (ex: emergency brake). A direct action depends on the criticality level of the situation, but also on the level of confidence to be given to local and remote perception data elements.

Relying only on human is well known to present the risk that it may not have the capability to act properly especially at the level of the VRU which may have limited capabilities understanding and achieving the requested recommendations. The VRU capability to understand and act is related to its profile. The following VRUs may then pose a challenge to ensure they can understand properly and act:

- VRUs non equipped with a VRU-Rx or VRU-St device.

- Animals.
- Childs.
- Elderly.
- Disabled persons.
- Etc.

Consequently, in many situations, it could be preferable to act at the level of the vehicle. As identified before, this can be achieved via the human driver if the vehicle has one, and if not, acting on the electronics of the vehicle.

Acting on the electronics of the vehicle can be left to the vehicle itself, but this does not preclude the possibility for an authorized third party (RSE, police vehicle, centre) to broadcast instructions (using new messages under development such as CPM or MCM) requesting an immediate action (ex: slowing down/emergency brake). Receiving such instructions, the vehicle becomes responsible of the situation in case of non-execution. A black box (as in aircraft) can be used to identify the responsibilities in case of collision between the vehicle and VRU(S).

In some cases, when the TTC does not allow to trigger a collision avoidance action, a pre-crash action reducing the impact of the crash can be started. But in such case, it is necessary that the vehicle be equipped with a dispositive reducing the impact of the crash (e.g. at bumper level).

The TTC value for triggering a pre-crash or an automated action on the vehicle is depending on:

- The speed of the vehicle when approaching the collision spot with the VRU.
- The conditions of the road (e.g. slippery or not).
- The state of the vehicle's tyres.

7.10 Harmonization with existing standards (SAE, etc.)

SAE International published J2945/9 [i.7] in 2017 to provide recommendations of safety message minimum performance requirements between a VRU and a vehicle. Since J2945/9 [i.7] was developed with a plan of future revision and corresponding increased release, it was limited to a very simple communication scenario, i.e. including a VRU to a vehicle only; described requirements and mechanisms were assumed to be refined or revised in future research. It is, however, recommended that the set of VRU-related standards of ETSI ITS including the present document are properly harmonized with the relevant aspects of J2945/9 [i.7].

Two use cases of "VRU crossing the road while vehicle is approaching" and "VRU travelling along the road" were selected as the subject scenarios for J2945/9 [i.7] due to their high portions in the total functional years lost (FYL). J2945/9 [i.7] addresses the transmission of Personal Safety Messages (PSM), which is defined in J2735 [i.4] and profiled in the J2945/9 [i.7], from road user devices carried by pedestrians, bicycle riders and public safety personnel towards vehicles, to provide driver and vehicle system awareness and potentially to offer safety alerts to VRUs. Functional and performance requirements for positioning and timing, PSM contents and transmission, security and privacy, etc. are specified in clause 6 of J2945/9 [i.7].

NOTE: FYL is a non-monetary approximation of life lost resulting from a fatal injury and the years of functional capacity lost caused by a nonfatal injury.

Clause 7 of SAE J2945/9 [i.7] shows the preliminary values assigned to the parameters identified in the standard. The parameters and assigned preliminary values can be taken into account to determine the performance criteria and the specific requirements of the present document (defined in ETSI TS 103 300-2 [i.17]). For example, 1 second of vruTransmitStartTime and 4,5 seconds of vruSituationAwareTime can be referenced for the latency performance criteria. 3 meters of vruPersonalClusterRadiusDef can be considered for the number of supported devices performance criteria in the congestion situation by a large number of VRU devices. 1,5 meters of vruPosAccuracy can be referenced for the positioning accuracy and reliability performance criteria.

More details can be found in the SAE J2945/9 [i.7] specification.

7.11 Considerations on Access Technology

Two types of considerations can be made when discussing the access technology for the VRU system:

- the technology to be used; and
- how the technology can be used.

The objective of the present document is to prepare the specification of the VRU basic service at Facilities layer level. Accordingly, the specification of the VRU system is agnostic of the access technology used. The messages which are considered at the level of the Facilities layer are independent of the access technology being used. These messages may be transferred directly between the ITS-S (direct communication mode) or through the network, e.g. when an IoT device detects the presence of a VRU on the road. Considerations and impact of both modes are evaluated in ETSI TS 103 300-2 [i.17].

Regarding the way the technology can be used, it is necessary to distinguish two different types of addressing modes which will impact the VRU awareness basic service:

- Broadcasting/multicasting consists in providing messages to all ITS-S which are in the communication area of the message sources. In this addressing mode, it is necessary to verify (at the facilities layer level) the received messages relevance to the receiving ITS-S (Relevance check function). For example, if a DENM message signals a road hazard which is not on the trajectory of the receiving ITS-S, the message is ignored as being not relevant to the Station, thus avoiding providing a "false positive information to the driver".
- Unicast consists in addressing a specific ITS-S. This means that, in order not to overload the global network with large number of messages which are not relevant to the addressed stations, it is necessary that an ITS-S using unicast implements at its level the relevance check function, with the objective to send only relevant messages to the addressed ITS-S.

Consequently, the addressing mode will impact the processing capabilities being necessary at the level of the Facilities layer of an ITS-S:

- If the broadcast/multicast mode is used, the Facilities layer needs to have a relevance check function to filter the received messages according to their relevance.
- If the unicast mode is used, the relevance check needs to be achieved at the level of the transmitting ITS-S with the objective of avoiding flooding the network with messages which are not relevant to the destinations.

7.12 Regulation and Liability

Contextual speed limits:

The dynamic change of speed limits according to local contexts requires an authority organization which is agile enough to authorize dynamically the speed limit evolution according to some contextual changes.

Contextual changes can be automatically detected by sensors, road side equipment and traffic management centres. For examples:

- In case of adverse weather conditions (low visibility, low stability).
- VRUs on the road (pedestrians, cyclists, workers, emergency/police people, animals, etc.).
- Dense traffic (support for traffic regulation).
- Pollution.
- Etc.

UK is planning to regulate the use of speed limiters. For this purpose, even for the sake of modifying the speed limits or the road charging, they consider that they need to improve their agility at the level of their TRO (Transport Regulation Order). For this purpose, they have been starting a specific project "DISCOVERY". The same problem exists in France (authorization from the prefect authority) and in other European members' states.

Consequently, if the C-ITS system wants to benefit from the use of dynamic contextual speed limits, it will be necessary to provide some automatic speed limit evolutions authorizations (in well-defined limits and with their associated rules) to management centres which may reflect them at the level of RSE/or directly to vehicles.

Emergency brake triggered by a third party:

In the scope of the EC regulation, n° 661/2009 [i.11] and 347/2012 [i.12], a new auxiliary brake system (AEBS: Advanced Emergency Braking System) is considered by the European Commission for vehicles of the category N1*, N2*, M2*, M3*, to be mandatory on new vehicles since 2018:

- *N2: Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 3,5 tonnes but not exceeding 12 tonnes.
- *N3: Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 12 tonnes.
- *M2: Passengers car comprising more than 8 seats in addition to the driver's seat and having a maximum mass of 5 tonnes.
- *M3: Passengers car comprising more than 8 seats in addition to the driver's seat and having a maximum mass exceeding 3,5 tonnes.

The regulation for N1* and M1* vehicle category of the AEBS is under study:

- *N1: Vehicles designed and constructed for the carriage of goods and having a maximum mass of 3,5 tonnes.
- *M1: Passenger cars comprising no more than 8 seats in addition to the driver's seat.

In all cases, the vehicle type approval is considering a well-defined target vehicle which is not related to a VRU. Consequently, when triggering an emergency braking to avoid a collision with a VRU, the vehicle type approval should be considering a target related to a VRU.

Moreover, the emergency brake triggering conditions are not fully defined. It is then recommended to consider a triggering condition being issued from a third party (an RSE or a Centre) under the condition that it reinforces as much as necessary the system security.

Manoeuvre coordination from a third party:

Automated vehicles of SAE level 4 & level 5 may not have a human driver or may have a not vigilant human driver inside. In such cases, these vehicles may be remotely controlled from a control centre. This means that for such automated vehicles being currently under experimentation (see for example the French PACTE law) it will be necessary to develop some form of manoeuvre coordination messages for their trajectory and momentum control. This also means that the control centre needs to obtain a complete perception of the automated vehicle environment from the automated vehicle itself, from other vehicles and potentially from roadside equipment in environments which present some perception difficulties. In particular, a control centre may be required to act remotely to avoid a collision between the vehicle and a detected VRU not perceived by the automated vehicle.

Consequently, the responsibility and liability are shared between the automated vehicle, the control centre and in some cases one or several roadside equipment.

Establishing a collision responsibility could be achieved by means of "incident indicator devices" (some form of black box) being located in the automated vehicle, the control centre and the road side equipment. In such case, this function is just storing for a small time, dynamic data elements related to the local traffic and to the exchanges which have been achieved between the elements of the system just before a collision.

Respective responsibilities between the automated vehicle, the control centre and possibly roadside equipment need to be clarified beforehand. Furthermore, if the VRU is equipped with an ITS-S, it may be considered for sharing the liability in case of a collision.

History

Document history		
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