ETSI TS 101 539-2 V1.1.1 (2018-06)

Intelligent Transport Systems (ITS);
V2X Applications;
Part 2: Intersection Collision Risk Warning (ICRW) application requirements specification

Reference
DTS/ITS-0010015

Keywords
application, interoperability, ITS

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

The present document is part 2 of a multi-part deliverable. Fulls details of the entire series can be found in part 1 [i.4].

Modal verbs terminology

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

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1 Scope

The present document provides Intersection Collision Risk Warning Application requirements and specifies the necessary parameters and conditions to operate the application using CAM [1], DENM [2] and the intersection service messages [4]. It includes the specifications of functional requirements and operational requirements of the LCRW application.

2 References

2.1 Normative 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.

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The following referenced documents are necessary for the application of the present document.

[1] ETSI EN 302 637-2 (V1.3.2): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[2] ETSI EN 302 637-3 (V1.2.2): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[3] ETSI TS 101 539-3 (V1.1.1): "Intelligent Transport Systems (ITS); V2X Applications; Part 3: Longitudinal Collision Risk Warning (LCRW) application requirements specification".

[4] ETSI TS 103 301 (V1.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services".

[5] ETSI TS 102 636-4-2 (V1.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; Sub-part 2: Media-dependent functionalities for ITS-G5".

2.2 Informative references

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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 302 665 (V1.1.1): "Intelligent Transport Systems (ITS); Communications Architecture".

[i.3] ETSI TS 102 894-1 (V1.1.1): "Intelligent Transport Systems (ITS); Users and applications requirements; Part 1: Facility layer structure, functional requirements and specifications".

[i.4] ETSI TS 101 539-1 (V1.1.1): "Intelligent Transport Systems (ITS); V2X Applications; Part 1: Road Hazard Signalling (RHS) application requirements specification".

3 Definitions and abbreviations

3.1 Definitions

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

age of data: difference between the time of a data element value setting at the originating ITS-S and the time the same data element value is used to undertake an appropriate action at a receiving ITS-S

NOTE: The age of data is an important quality parameter reflecting the freshness of highly dynamic data elements in particular when a collision risk is assessed at vehicles' receiving levels.

conflict zone: zone of an intersection where the trajectory paths of vehicles and other traffic participants (e.g. pedestrian, bicycles, vehicles) may cross

primary road safety application: ITS-S application which purpose is to prevent a collision

stop line: pavement marking line extending across lanes to indicate the point at which a stop is intended or required to be made

3.2 Abbreviations

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

BSA	Basic Set of Applications
CA	Co-operative Awareness
CAM	Co-operative Awareness Message
CCH	Control Channel
DCC	Decentralized Congestion Control
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
HMI	Human Machine Interface
ICRW	Intersection Collision Risk Warning
ITS	Intelligent Transport Systems
ITS-S	ITS Station
IVI	Infrastructure to Vehicle Information
IVIEM	In Vehicle Information Extended Message
IVIM	Infrastructure to Vehicle Information Message
LCRW	Longitudinal Collision Risk Warning
MAPEM	Message with detailed road topology information used by RLT service
MAT	Maximum Action Time
MDRT	Maximum Driver Reaction Time
MLT	Maximum Latency Time
OEM	Original Equiment Manufacturer
OR	Operational Requirements
RHS	Road Hazard Signalling
RLT	Road and Lane Topology
SPAT	Signal Phase And Timing
SPATEM	Signal Phase And Timing Extended Message
TLM	Traffic Light Maneuver
TTC	Time To Collision
VRU	Vulnerable Road User

4 Conforming ITS-S performance class definition

Intersection Collision Risk Warning (ICRW) application is considered as a primary road safety application. As introduced in clause 4 of ETSI TS 101 539-3 [3], primary road safety applications are ITS applications that target at reducing the risk of collision and thus improving the road safety. An ICRW application provides intersection collision risk warning to drivers. The warning indicates the risk of potential intersection collision risk that requires an immediate action of the driver.

NOTE: It is not excluded to implement the ICRW with automatic assistance system, such as automatic braking system. In this case, the automatic assistance system will react directly on the braking system for the driver, enabling a quicker reaction towards the collision risk.

The ICRW application relies on the processing of Cooperative Awareness Message (CAM) as specified in ETSI EN 302 637-2 [1] and Decentralized Environmental Notification Message (DENM) as specified ETSI EN 302 637-3 [2] transmitted from vehicle ITS-Ss or road side ITS-S. If applicable, an ICRW application may in addition rely on the roadside infrastructure services such as Traffic Light Maneuver (TLM) service, Road and Lane Topology (RLT) service and Infrastructure to Vehicle Information (IVI) service as specified in ETSI TS 103 301 [4]. These messages enable a receiving vehicle ITS-S be informed of the movement status of other vehicles in the intersection as well as the traffic light status, intersection access priority status, and topology of the intersection. This receiving ITS-S is therefore able to estimate the potential collision risk and inform driver when necessary.

The ICRW application requires a short end-to-end latency time. This latency time is the time difference between T0 and T6 and shall be as defined in ETSI TS 101 539-3 [3] and illustrated in Figure 1, in order to provide timely warning to driver. T0 is denoted as time at which the vehicle data is available at the vehicle electronic systems. For message transmitted from road side ITS-S, T0 is denoted as time at which the data is available at data source e.g. traffic light status data available at traffic light controller system. T6 is denoted as time at which the warning is presented on the vehicle HMI or time at which a direct action is requested to the vehicle electronic system, if applicable. Typically, 300 ms end to end latency time is required.

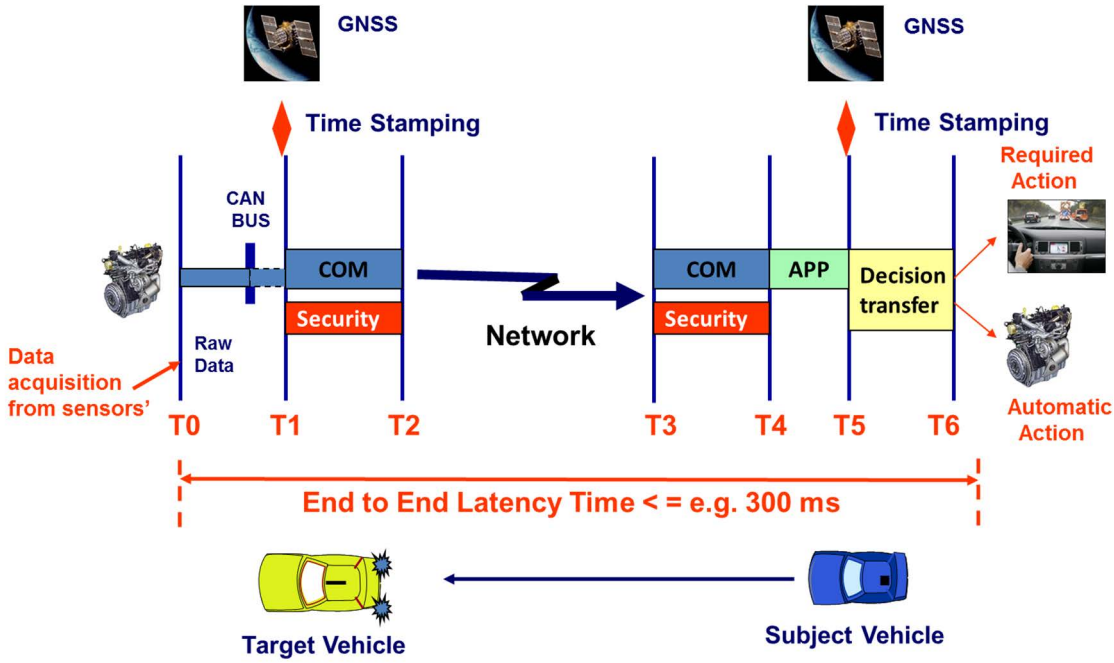


Figure 1: Application end to end latency time

In particular, time difference from T0 to T1 reflects the freshness of the data provided by a message with regards to the message time stamp. ETSI TS 101 539-3 [3] has defined two performance classes (class A and class B) based on this time difference, indicating the capability of a vehicle ITS-S to provide up-to-date information in CAM and DENM within a threshold value (e.g. 150 ms).

Road side ITS-S mounted within an intersection provides up-to-date information on intersection traffic light status (SPATEM), road topology (MAPEM) and infrastructure to vehicle Information (IVIM) in order to enable the receiving ITS-S be informed about the allowed maneuvers, the access rights to execute the maneuvers (e.g. "green", "yellow", "red"). The freshness of road side information may vary depending on the information update rate. Typically, such update rate is configured by road side ITS-S application, as described in ETSI TS 103 301 [4].

5 Intersection Collision Risk Warning application overview

5.1 ICRW in the ITS architecture

5.1.1 Overview

The objective of an ICRW application is to detect potential collision risk between two or more vehicles or obstacles inside an intersection area. In addition, the ICRW may detect potential traffic sign violation at an intersection area. When a collision risk or traffic sign violation risk is detected, the vehicle may issue a warning to the driver.

If the collision risk is detected by the roadside ITS-S, it may trigger the transmission of corresponding collision risk warning DENM to approaching vehicles. A vehicle receiving such DENM may issue a warning to driver, when the information is estimated relevant. One example use case is that a road side ITS-S equipped with sensors capable of detecting the intersection collision risk or traffic sign violation risk may transmit an intersection collision risk warning DENM to vehicles approaching to or inside the intersection area.

ICRW is an application layer entity that implements at least one intersection collision risk use case. In one possible implementation, an ICRW may implement more than one intersection collision risk use cases into one ITS-S application entity. The present document does not specify any implementation structure of the ICRW application.

Figure 2 presents an ICRW application in the ITS-S architecture as defined in ETSI EN 302 665 [i.2] as well as its logical interfaces with other entities and layers.

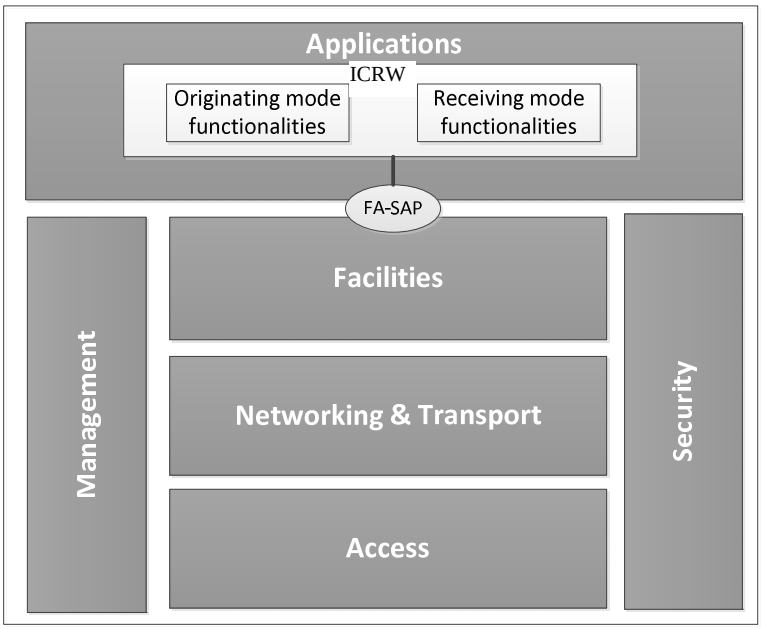


Figure 2: ICRW and logical interfaces

The ICRW application functionalities are distributed in conforming ITS-Ss. The following functional modes of the application are included:

- Vehicle ITS-S originating mode: This mode refers to functionalities implemented by a vehicle ITS-S, including the triggering of DENM transmission as specified in ETSI EN 302 637-3 [2] upon the detection of an intersection collision risk or traffic sign violation risk, and the transmission of CAM according to the CAM transmission rules as specified in ETSI EN 302 637-2 [1]. Some functional requirements are provided in ETSI TS 102 894-1 [i.3] for traffic situations which may be leading to an intersection collision.

- Minimum Vehicle ITS-S receiving mode: This mode refers to functionalities implemented by a vehicle ITS-S, including the processing of received ICRW DENM and providing warning to the driver in case based on the evaluation of the DENM.

- Full Vehicle ITS-S receiving mode: This mode refers to functionalities implemented by a vehicle ITS-S, including the processing of received CAM, DENM, SPATEM, MAPEM and IVIM for the analysis of intersection collision risks and provides warning to the driver in case of a detected risk. A driver warning issued by an ICRW application is a strong advice that requires an immediate action from the driver to avoid an imminent intersection collision.

- Road side ITS-S originating mode: This mode refers to functionalities implemented by a road side ITS-S, including the triggering of DENM transmission upon detection of potential collision risk at intersection.

- Road side ITS -S receiving mode: This mode refers to functionalities implemented by a road side ITS-S, including the processing of received CAM, DENM and/or sensor data for the detection of potential collision risk at intersection.

A vehicle ITS-S implementing ICRW shall comply with one of the following compliance levels:

- Level 1: the minimum vehicle receiving mode functionality shall be implemented.

- Level 2: according to Level 1 and the full receiving mode functionality shall be implemented.

- Level 3: according to Level 2 and the vehicle ITS-S originating mode functionality shall be implemented.

A road side ITS-S implementing ICRW shall comply with both the road side ITS-S originating and receiving mode functionalities.

The present clause describes ICRW functionalities of both modes.

ICRW may include use cases as defined in Basic Set of Applications (BSA) ETSI TR 102 638 [i.1], with their functional requirements defined in ETSI TS 102 894-1 [i.3]. In summary, the following collision risks may be considered as intersection collision risks:

- Crossing collision: the collision risk is detected between vehicles whose trajectories may cross in the conflict zone. In most cases, the crossing collision results in a lateral collision. The vehicle may issue a warning to the driver if it detects crossing collision. An immediate action e.g. emergency brake is required for the driver of the vehicle to avoid the collision.

- Traffic sign violation: the traffic sign violation at an intersection area refers to either a traffic light violation at a signalled intersection, or a priority violation at a non-signalled intersection (e.g. stop sign violation). The conditions under which a violation is considered to be true may vary according to regional regulations. Therefore, the violation risk detection algorithm of the ICRW should be compliant to such regulations.

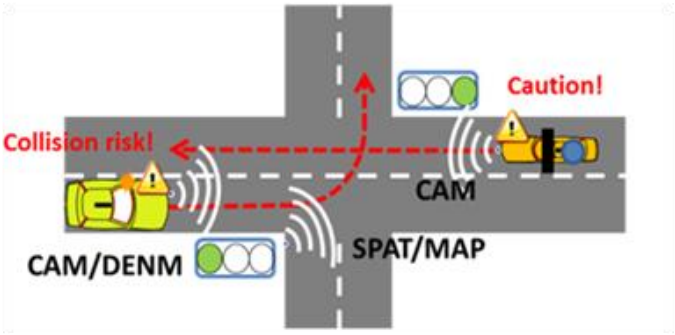
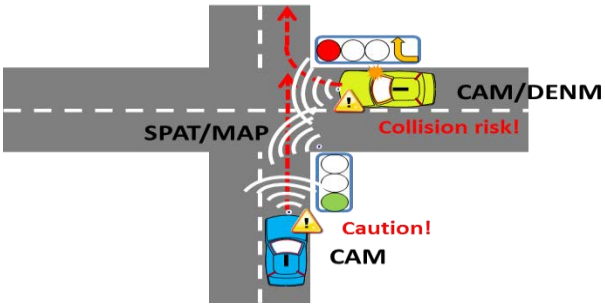
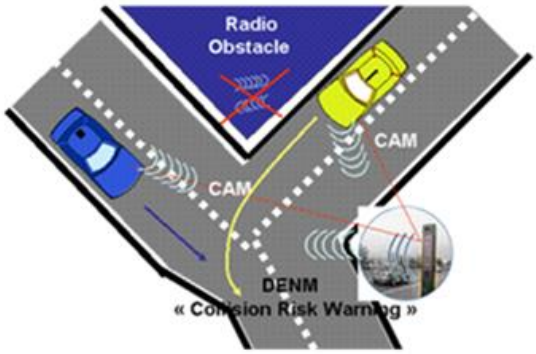
- Collision involving Vulnerable Road Users (VRU): this collision risk refers to risk of collisions between vehicles and Vulnerable Road Users e.g. bicycles, pedestrians inside the intersection area. A warning may be issued to the vehicle driver if a collision risk is detected. If the VRU is equipped with ITS-S implementing the ICRW e.g. a personal ITS-S, a warning may also be issued.

- Rear end collision: rear end collision may happen inside or near an intersection area, for example, at intersection queues.

5.1.2 Crossing collision warning

The considered use cases related to crossing collision warning are summarized in Table 1 and described below.

Table 1: Relevant use cases description for crossing collision risk warning

Use case	Scenario illustration
Turning collision risk warning	
Merging collision risk warning	
Collision risk warning for vehicles with missing radio connectivity	

Turning collision risk warning:

Detection by vehicle:

The collision risk is detected between vehicles, whose trajectories cross in the conflict zone of an intersection. In the example scenario as presented in Table 1, a first vehicle is turning to the left and another vehicle is going straight across the intersection. Both vehicle ITS-Ss receive SPATEM and MAPEM from road side ITS-S, allowing both of them entering the intersection area. Both ITS-Ss transmit CAMs. The left turning vehicle is able to monitor continuously the straight driving vehicle and calculates the associated Time Proximity Vector / Safety Shield (see annex A) with it. Once the value is within a limit (the straight driving vehicle is within the safety shield), the left turning vehicle may increase the CAM generation and transmission rate. Similar estimation may be done at straight driving vehicle, who in its turn increases the CAM generation and transmission rate. Cooperatively, two vehicles are able to monitors more precisely each other's kinematics status changes and detects the potential collision risk. If the collision risk probability reaches a predefined threshold, a warning is issued to the driver.

In one other possible ICRW implementation, the vehicle detecting the potential crossing collision risk (e.g. using embedded sensors) may trigger a DENM transmission. Other vehicle ITS-S receiving such DENM may evaluate the collision risk with transmitting vehicle ITS-S and accordingly issue a warning to the driver.

NOTE: In regions where left hand traffic rules apply, the turning collision may be detected between right turn vehicles with other vehicles.

Detection by roadside:

The roadside ITS monitors the straight driving and left turning trajectories of the two vehicle. Thus the roadside ITS is able to estimate a potential collision risk in real time. Upon detection of collision risk the roadside ITS shall issue a DENM to the traffic participants (e.g. vehicles, pedestrians, bicycles).

Merging collision risk warning:

Detection by vehicle:

The merging collision risk is detected between a vehicle with at least one other vehicle whose trajectory is merging with the trajectory of the first vehicle. In the example scenario as presented in Table 1, the right turning vehicle is authorized to make right turn with yellow phase, and the other vehicle is going straight across the intersection. Both vehicles receive SPATEM and MAPEM from road side ITS-S, allowing the entrance to the intersection. The straight driving vehicle is able to monitor (based on CAMs) constantly the turning vehicle and assess the collision risk probability. If the collision risk probability reaches a predefined threshold, the vehicle issues a warning to the driver requesting immediate action to avoid the collision.

Detection by roadside:

The roadside ITS monitors the straight driving and right turning trajectories of the two vehicles. Thus the roadside ITS-S is able to analyse the potential collision risk in real time. Upon detection of collision risk the roadside ITS shall issue a DENM to the traffic participants (e.g. vehicles, pedestrians, bicycles) within the intersection area.

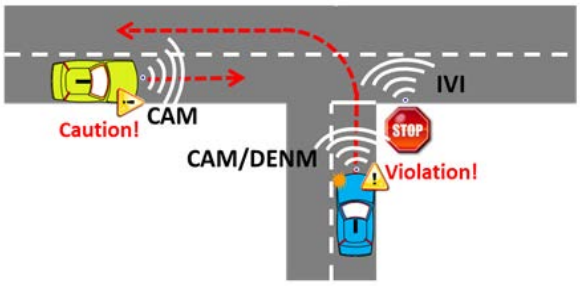
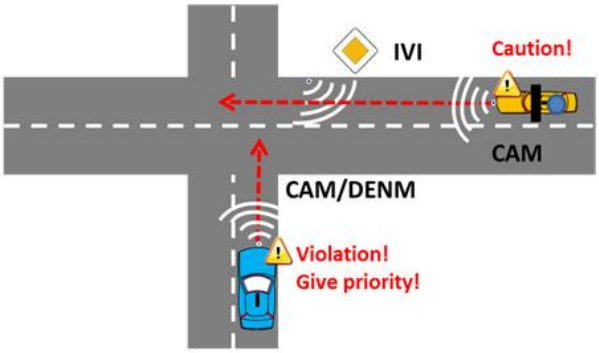
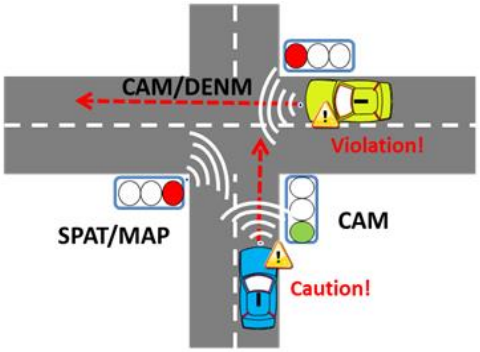
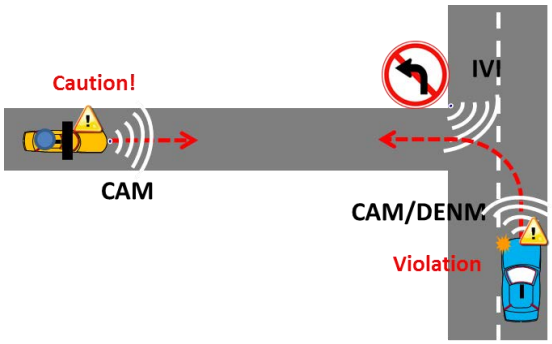
Collision risk warning for vehicles with missing radio connectivity:

In this use case, an roadside ITS-S detects collision risk between at least two other vehicles inside the intersection area and transmits a collision risk warning DENM. In the example scenario as presented in Table 1, a vehicle cannot receive CAM from other vehicles because of non-line-of sight radio propagation due to obstacle. A road side ITS-S is positioned at the intersection that has a line-of-sight condition with all road sections of the intersection. This road side ITS-S receives CAMs from vehicles at both directions, enabling it to detect the collision risk of these two vehicles. Optionally the roadside ITS-S uses additional technical means to detect the collision risk (e.g. radar, camera). Upon the detection of a collision risk, the ICRW application of the roadside ITS-S triggers the transmission of "collision risk warning" DENMs until the collision risk is eliminated. Upon reception of a DENM, a vehicle ITS-S may estimate the relevance of the collision risk with its own trajectory and movement state, and triggers a warning to driving if applicable.

5.1.3 Traffic sign violation warning

The considered use cases related to traffic sign violation are summarized in Table 2 and described below.

Table 2: Relevant use cases description for traffic sign violation warning

Use case	Scenario illustration
Stop sign violation warning	
Priority violation warning	
Traffic light violation warning	
Turning regulation warning	

Stop sign violation warning:

In this use case, a stop sign violation risk is detected against a vehicle approaching to an intersection from a road segment where a short stop is required before entering the intersection. In the example scenario as presented in Table 2, a vehicle is approaching to the intersection from south. It receives an IVIM message from road side ITS-S and is informed that a stop is required. The ICRW application (based on the vehicles speed) computes the distance required to stop the vehicle and compares it with the remaining distance to the stop line. If a brake is required for the vehicle to stop before the stop line or the violation cannot be avoided, a warning may be issued to the driver to brake or an action is taken automatically by the in-vehicle system (e.g. automatic braking) in order to avoid the potential violation.

Optionally the ICRW of the roadside ITS, which tracks continuously the movement of the vehicle trajectories, will compute a potential risk for stop sign violation and potential collisions.

The ICRW of the vehicle, which is about to violate the stop sign, or the roadside ITS may trigger a DENM warning. It enables a receiving ITS-S to estimate the collision risk and accordingly triggers a warning to driver. In this case, this use case is linked with the crossing or merging collision risk warning use cases as described in clause 5.1.2.

Priority sign violation warning:

In this use case, a priority violation risk is detected against a vehicle approaching to an intersection from the road segment where it should give priority to traffic of other road segments before entering the intersection. In the example scenario as presented in Table 2, the vehicle approaching from south, receives an IVIM message from the roadside ITS and is informed that traffic on est-west road segment has higher priority. Additionally the vehicle receives CAMs from the approaching vehicle from the east. The ICRW application may issue a warning to the driver, reminding him/her, that a vehicle is approaching on the main road and that the priority should be given to the this vehicle, or an action is taken automatically by the in-vehicle system (e.g. automatic braking).

Optionally the ICRW of the roadside ITS, which tracks continuously the movement of the vehicle trajectories, will compute a potential risk for priority sign violation and potential collisions.

Additionally, the ICRW, of the vehicle which is about to violate the priority, or the roadside ITS may trigger a DENM transmission. It enables a receiving ITS-S to estimate the collision risk and accordingly triggers a warning to driver. In this case, this use case is linked with the crossing or merging collision risk warning use cases as described in clause 5.1.2.

Traffic light violation warning:

In this use case, a traffic light violation risk is detected against a vehicle approaching to an intersection equipped with traffic lights while the access is not allowed by the traffic light (e.g. traffic light is in red phase). In the example scenario as presented in Table 2, a vehicle is approaching to the intersection from east and driving straight to exit the intersection. It receives SPATEM/MAPEM message from road side ITS-S and is informed that the light is in red phase. The ICRW application computes the distance and time required to stop the vehicle and compares it with the remaining distance and time to the stop line and remaining red phase time. If a brake is required to stop the vehicle before the stop line during the red phase, a warning may be issued to the driver or an action is taken automatically by the in-vehicle system (e.g. automatic braking).

Optionally the ICRW of the roadside ITS-S, based on the knowledge of the of the intersection, the traffic light signage, the allowed maneuvers and the trajectories of the vehicles, is able to estimate a red light violation and potential collision risk in advance and to inform the violating vehicle.

Additionally, the ICRW, of the vehicle which is about to violate the traffic light, or the roadside ITS may trigger a DENM transmission. It enables a receiving ITS-S to estimate the collision risk and accordingly triggers a warning to driver. In this case, this use case is linked with the crossing or merging collision risk warning use cases as described in clause 5.1.2.

Turning regulation violation warning:

In this use case, a turning regulation risk is detected against a vehicle exiting an intersection from segment that is not allowed. In the example scenario as presented in Table 2, an vehicle is approaching from south, it receives an IVIM message from roadside ITS-S and is informed that turning to left is not allowed at the intersection. The ICRW application calculates the vehicle path prediction using in-vehicle data e.g. steering wheel angle, yaw rate, etc. and estimates whether a turning violation risk exists. If yes, the ICRW application may issue a warning to the driver, reminding him/her to take appropriate action to avoid the violation.

Optionally the ICRW of the roadside ITS, based on the knowledge of the of the intersection, the allowed maneuvers and the trajectories of the vehicles, is able to estimate a turning violation. After detection of the risk the roadside ITS shall inform the violating vehicle.

Additionally, the ICRW of the vehicle, which is about to violate the turning regulation, or the roadside ITS may trigger a DENM transmission. It enables a receiving ITS-S to estimate the collision risk and accordingly triggers a warning to driver. In this case, this use case is linked with the crossing or merging collision risk warning use cases as described in clause 5.1.2.

5.2 ICRW originating mode functionalities

5.2.1 CAM transmission

Vehicle ITS-S or road side ITS-S implementing the ICRW application shall be able to transmit CAMs. The triggering of CAM shall be as specified in ETSI EN 302 637-2 [1].

As additional feature, the CA basic service of a vehicle ITS-S may increase the CAM transmission rate when in the safety field as described in annex A. It is recommended to include this feature in new release of the CA basic service.

NOTE: Decentralized Congestion Control mechanism may be needed to manage the network load.

5.2.2 DENM transmission: signalling of a traffic sign violation risk

When a collision risk or violation risk is detected, the ICRW application should trigger DENM transmission to inform vehicle ITS-Ss approaching to or located in the intersection area.

The detection of traffic sign violation may be supported by the ICRW receiving mode functionalities, by processing received messages from other vehicle ITS-Ss and from road side ITS-S. This functionality is described in clause 5.3.1.

Alternatively, the traffic light violation or priority violation may be detected by other means e.g. camera system with image processing algorithm capable of detecting the traffic light violation, or with data from other sources e.g. digital map.

5.2.3 DENM transmission: signalling of an intersection collision risk

When an intersection collision risk is detected, the ICRW application may trigger DENM transmission to inform vehicle ITS-Ss approaching to or located in the intersection area.

The detection of intersection collision risk may be supported by the ICRW receiving mode functionalities, by processing received messages from other vehicle ITS-S and from road side ITS-S. This functionality is described in clause 5.3.1.

Alternatively, the collision risk may be detected by other means e.g. camera system with image processing algorithm capable of detecting the vehicles' movement.

5.2.4 Interaction with other ITS-S layers

ICRW application may interact with functionalities of other ITS-S layers for:

- Optionally, adjusting the CAM time interval if necessary.

NOTE 1: Mechanisms for CAM rate control by application are defined in annex A of the ETSI TS 101 539-3 [3].

- Controlling DENM transmission.
- Inhibiting or enabling the ITS-S pseudonym change.
- Optionally, providing requirements to Decentralized Congestion Control (DCC).
- Informs lower layers of the priority level, if necessary.

NOTE 2: The priority level is assigned by ICRW receiving mode, according to the criticality of the traffic situation perceived by the ITS-S. The priority level and traffic safety critical situation are defined in clause 5.3.1.

5.3 ICRW receiving mode functionalities

5.3.1 Detection of risk

5.3.1.1 Traffic sign violation risk detection

Detection by vehicle ITS-S: For the detection of a traffic light violation, the ICRW may use the SPATEM (Signal Phase and Timing) and MAPEM messages. SPATEM and MAPEM shall be as specified in ETSI TS 103 301 [4]. A SPATEM message contains information of the current and/or future phase and timing information of traffic lights, a MAPEM message contains information of the intersection topology (driving lanes, crosswalk lanes etc.) as well as connectivity between lanes to enter and exit the intersection. By processing received SPATEM and MAPEM messages of an intersection, a vehicle ITS-S is able to match the traffic phase and timing information with the position, speed of the vehicle in order to estimate whether a traffic light violation risk exists.

For the detection of a priority violation, the ICRW application may use "Infrastructure to Vehicle Information" IVIM message. IVIM shall be as specified in ETSI TS 103 301 [4]. An IVIM message contains information of a traffic signage (including priority signage) as well as the area information in which the traffic sign is relevant. By processing received IVIM of an intersection, a vehicle ITS-S is able to match the priority information with the position, speed of the vehicle in order to estimate whether a priority violation risk exists.

Optionally, the vehicle ITS-S may trigger a DENM transmission as described in clause 5.2.2.

Detection by roadside ITS-S: The roadside ITS-S monitors the trajectories, speed and heading of the approaching vehicles in the intersection and within the conflict area (e.g. based on received CAMs) in real time. Based on the knowledge of the detailed map of the intersection (lane based), the traffic signage, the allowed maneuvers, the current signal state of the traffic lights (for signalized intersections), and the trajectories of the vehicles the roadside ITS-S is able to estimate a potential traffic rules violation and collision risk in advance. The roadside ITS-S triggers a warning DENM right after first detection of potential signal violation to all traffic participants in the intersection.

Using additional sensor at roadside (e.g. radar, motion detectors, "angle of signal arrival a roadside", WEB-Cam) a fusion of different information sources is possible. This enables the roadside ITS-S to enhance the prediction of traffic participants breaking traffic rules and the estimation of potential risks.

5.3.1.2 Intersection collision risk detection

Detection by vehicle ITS-S: A vehicle ITS-S receives CAM/DENM from vehicles and SPATEM/MAPEM/IVIM from road side ITS-Ss within the intersection area. It processes the received messages and estimates if paths of any vehicles are crossing its own path. In addition, the vehicle ITS-S estimates if any collision risk exists for the crossing. If yes, the ICRW of the vehicle issues an warning to the driver. Optionally the vehicle ITS-S may trigger a DENM transmission to inform such collision risk to other vehicles, as described in clause 5.2.3.

Detection by roadside ITS-S: A roadside ITS monitors continuously the trajectories, speed and heading of the approaching vehicles in the intersection and especially within the conflict area (e.g. based on received CAMs) in real time. The roadside ITS has knowledge of the detailed map (lane topology) of the intersection, the traffic signage, the allowed maneuvers, the current signal state of the traffic lights (for signalized intersections), and the trajectories of the vehicles. Thus the ICRW application of the roadside ITS-S is able to estimate a potential violation of traffic rules and to estimate a collision risk in advance. The estimation is be based on processing the received CAMs and DENMs from the vehicles or other means like radars, cameras, etc.

Upon the estimation of an intersection collision risk, the roadside ITS may trigger an intersection collision risk DENM transmission, as described in clause 5.2.3.

5.3.2 Application priority management

The priority level of an ITS-S application denotes the application priority relative to other applications of the ITS-S. Based on the estimated traffic criticality, the ICRW may adjust accordingly its priority level.

Three levels of criticality and corresponding priority level shall be as defined in clause 5.3.1 of ETSI TS 101 539-3 [3]. This definition also applies to ICRW.

The priority level may be communicated to other layers to adjust the transmitting mode functionalities as defined in clause 5.2.4.

5.3.3 Issuing warning to vehicle driver

The purpose of the ICRW is to warn the vehicle driver about the risk of an imminent intersection collision and violation. The driver is alerted to take an immediate action, e.g. brake, to avoid the collision.

A driver assistance warning should be triggered before the predicted collision according to the estimated Time To Collision. This TTC may be calculated according to the following elements by processing vehicle data and received messages:

- The distance separating the potentially colliding vehicles or the distance between the vehicle and traffic light stop lane.
- The trajectory path of vehicles through the conflict zone of the intersection.
- The speed of vehicles.
- The vehicle type.
- The braking capabilities of vehicles.
- The estimated driver reaction time, which may take into account driver state/capabilities.
- Known driver's manoeuvring intentions, e.g. turning intention or straight driving of vehicles through the conflict area of the intersection.
- Known deteriorated weather conditions or road hazard situation which may reduce the visibility of the driver or the stability of the vehicle.
- Potential collision warning received from roadside ITS-S.

6 Application functional requirements

6.1 Introduction

The ICRW warning is issued in receiving ITS-S. However, the application relies on the performances of the originating ITS-S (vehicle and roadside) which transmit CAMs, DENMs and infrastructure messages.

The present clause provides functional requirements of ICRW (denoted as FRxx in the following clause).

6.2 Crossing collision risk detection requirements

FR1. ICRW application shall define triggering conditions for state machine switching. Examples of state machine transition conditions are given in annex B.

FR2. ICRW application shall implement appropriate functions to support the triggering of state transitions.

FR3. ICRW shall be able to evaluate the traffic safety criticality as defined in clause 5.3.1.

FR4. When a collision risk is detected, and the need of issuing a warning is established, the application priority level shall be set to "1" or higher.

FR5. When the application priority level is set to "1" or higher, application may request security to block the pseudonym change in order to avoid a temporary loss of the monitored vehicle.

FR6. For estimation of the intersection crossing risk, the ICRW shall obtain position, movement data of the vehicles.

FR7. For estimation of the intersection crossing risk, the application shall verify the potential crossing between the trajectory of vehicles. The Trajectory crossing of vehicles may require a certain level of positioning accuracy or map database.

FR8. The ICRW application shall analyse a risk of collision with other vehicles. This may be realized by estimating the TTC between itself and the other vehicles.

FR9. While monitoring the evolution of vehicles trajectory, the ICRW application may stop issuing the warning if the vehicles path does not cross with each other anymore. This may be detected by verifying the changing of vehicle trajectories.

FR10. The ICRW application shall analyse a risk of collision at the reception of collision risk warning DENM transmitted by other ITS-S.

6.3 Traffic sign violation detection requirements

FR11. For stop sign violation risk warning use case, the ICRW shall be able to detect stop sign violation risk of a vehicle. In one possible implementation, the stop sign violation may be detected by calculating the required stop distance of the vehicle being monitored and comparing with the remaining distance to the stop sign effective position.

FR12. For priority violation risk warning use case, the ICRW shall be able to detect priority violation risk of a vehicle. In one possible implementation, the priority violation may be detected by calculating the time required for the vehicle being monitored to enter the intersection and comparing with the time required for at least one vehicle to enter the intersection from the road segment having higher priority.

FR13. For turning regulation violation risk warning use case, the ICRW shall be able to detect turning violation risk of a vehicle. In one possible implementation, the turning violation may be detected by predicting the trajectory of the vehicle being monitored and comparing with access right information of the road segment targeted by the predicted trajectory.

FR14. For traffic light violation risk warning use case, the ICRW shall be able to detect traffic light violation risk of a vehicle. In one possible implementation, the traffic light violation may be detected by calculating the distance and time required for the vehicle being monitored to stop and comparing with stop effective position and traffic phase timing.

FR15. In order to detect the stop sign, priority sign or turning sign violation, the ICRW application obtains information of corresponding sign effective position and the traffic (road segment) that is impacted by the sign. The road sign data may be obtained by processing the received IVIM message or other means e.g. digital map as defined in MAPEM.

FR16. In order to detect the traffic light violation, the ICRW shall obtain information of current traffic light phase and timing and traffic/road segment to which each phase and timing information applies. In addition, the ICRW shall obtain information of intersection topology and geometry information.

FR17. In order to detect the traffic light violation, the ICRW shall obtain information of future traffic light phase and timing and traffic/road segment to which each phase and timing information applies. The traffic light phase and timing may be obtained by processing the received SPATEM/MAPEM message or other digital map.

FR18. In order to detect the violation, the ICRW shall obtain position and movement data of the vehicle being monitored.

FR19. For priority violation detection, the ICRW may obtain position and movement information of other vehicles.

FR20. In order to detect the violation, the ICRW may calculate the predicted path of the vehicle being monitored.

FR21. In order to detect the violation, the ICRW shall be able to check the relevance of the sign or traffic light information with regards to the vehicle being monitored.

FR22. In case violation is detected, the ICRW may further estimate the crossing risk with one or other vehicles in the intersection area. Functional requirements as defined in clause 6.2 shall apply.

FR23. In case violation is detected, the ICRW application shall raise its priority level to "2" or higher.

FR24. In case violation warning is issued, the ICRW may further trigger the collision risk detection between the violating vehicle with at least another vehicle.

FR25. The ICRW application may stop issuing the warning if the violation risk is eliminated.

FR26. The ICRW shall analyse the violation warning DENM warning message received from other ITS-S.

6.4 Warning triggering requirements

FR27. At detection of a risk, the ICRW shall be able to trigger a warning to the driver by e.g. interaction with in vehicle human machine interface (HMI).

FR28. At the reception of a ICRW DENM, the ICRW shall be able to trigger a warning to the driver by e.g. interaction with in vehicle human machine interface (HMI).

The warning triggering time may consider TTC. An example is described in annex C.

Recommendations on the warning presentation are provided in annex E.

6.5 DENM transmission requirements

FR29. At detection of a risk, the ICRW should trigger a DENM transmission by sending a request to the DEN basic service.

FR30. Upon detection of a risk for the first time, the ICRW shall trigger a new DENM generation as specified in ETSI EN 302 637-3 [2].

FR31. The ICRW shall request update DENM transmission as specified in ETSI EN 302 637-3 [2], as long as the detected risk persists.

FR32. The ICRW may not request cancellation or negation DENM transmission as specified in ETSI EN 302 637-3 [2].

FR33. The ICRW shall set the relevance area that covers the intersection area in which a risk is detected.

FR34. When the priority level to "1" or higher, the ICRW shall set the traffic class to the highest level.

FR35. The ICRW shall increase the information quality of DENM when the probability of collision risk increases.

FR36. The data to be provided from an ITS-S application to the DEN basic service is specified in ETSI EN 302 637-3 [2]. The data shall be set as specified in Table 3 for crossing collision warning use cases as defined in clause 5.1.2.

Table 3: Data elements values to be communicated to the DEN basic service by the ICRW application (crossing collision risk warning use cases)

Data element	Data setting rules	DENM Container	Mandatory (M) or Optional (O)
detectionTime	Shall be set to time at which the collision risk is detected	Management	M
eventPosition	Shall be set to position of detected collision risk	Management	M
validityDuration	Shall to set to default value 30 s	Management	
repetitionDuration	N/A		
Transmission interval	N/A		
Repetition interval	N/A		
relevantDistance	From the eventposition, shall cover the intersection area		
relevanceTrafficDirection	Shall be set to 0		
stationType	Shall be set to station type of transmitting ITS-S	Management	M
informationQuality	By default set to 0 unless specified elsewhere	Situation	
eventType	Shall be set to: Direct cause: 97 Sub cause: 2	Situation	
linkedCause	In case other events are detected	Situation	O
eventHistory	N/A		O
eventSpeed	Shall be set to speed of the vehicle at detectionTime, if collision risk is detected by a vehicle ITS-S	Location	O
eventPositionHeading	Shall be set to heading of the vehicle at detectionTime, if collision risk is detected by a vehicle ITS-S	Location	O
Traces	Shall include: PathHistory of vehicles prior to detectionTime The PathHistory shall be determined as described in ETSI EN 302 637-2 [1]	Location	M
roadType	Shall be set to roadType at eventPosition	Location	O
Destination area	Shall cover the intersection area		M
Traffic class	When application priority level is set to 1 or higher, it shall set to highest priority DENM value as specified in ETSI TS 102 636-4-2 [5]. Otherwise, it shall be set to DENM value as specified in ETSI TS 102 636-4-2 [5]		M

FR37. The data shall be set as specified in Table 4 for violation risk warning use cases as defined in clause 5.1.3.

Table 4: Data elements values to be communicated to the DEN basic service by the ICRW application (violation risk warning)

Data element	Data setting rules	DENM Container	Mandatory (M) or Optional (O)
detectionTime	Shall be set to time at which the violation risk is detected	Management	M
eventPosition	Shall be set to position of violating vehicle at detectionTime	Management	M
validityDuration	Should be set to default value of 5 s	Management	
repetitionDuration	N/A		
Transmission interval	N/A		
Repetition interval	N/A		
relevanceDistance	Shall be set to distance from eventPosition covering the intersection area	Management	M
relevanceTrafficDirection	Shall be set to 0 (all directions)	Management	O
stationType	Shall be set to station type of the violating vehicle	Management	M
informationQuality	By default set to 0 unless specified elsewhere		M
eventType	Shall be set to: • Direct cause: 98 • Sub cause: set according to detected violation type		M
linkedCause	If available		O
eventHistory	N/A		
eventSpeed	Shall be set to speed of the violating vehicle at detectionTime		M
eventPositionHeading	Shall be set to heading of the violating vehicle at detectionTime		M
Traces	Shall include the PathHistory of the violating vehicle prior to the detectionTime, PathHistory shall be determined as described in ETSI EN 302 637-2 [1]		M
roadType	Shall be set to roadType at eventPosition		O
Destination area	Shall cover the intersection area		M
Traffic class	When application priority level is set to 1 or higher, it shall set to higher priority DENM value as specified in ETSI TS 102 636-4-2 [5]. Otherwise, it shall be set to DENM value as specified in ETSI TS 102 636-4-2 [5]		M
eventPositionDescription	ID of ingress lane at which the violation risk is detected. It shall be as described in ETSI TS 103 301 [4]	Alacarte	O

6.6 Message processing requirements

FR38. Conforming ITS-S shall have the capability to decode and interpret the data elements of the received CAM, DENM, SPATEM, MAPEM, IVIM messages.

FR39. When detecting a signal violation at an intersection either through the analysis of received CAM and SPAT / stop sign messages or after the reception of "Signal Violation Warning" DENMs, a Vehicle ITS-S ICRW application should assess the risk of collision with the Vehicle which is violating the signal.

FR40. The ICRW application may stop TTC monitoring of another vehicle if this vehicle changes its itinerary, e.g. flashing lights activated or significant change in the curvature, yaw rate or steering wheel angle or path prediction, and therefore no crossing with monitoring vehicle's itinerary.

7 Application operational requirements

7.1 Introduction

The present clause provides operational requirements of ICRW (denoted as ORxx in the following clause).

7.2 Security and reliability requirements

The ICRW application design should consider the following failure situations in order to be fault tolerant:

- The issuing of a warning when no collision risk is detected (fail jabbering mode).
- The generation and transmission of DENM which does not correspond to collision risk.
- The interruption of processing the received messages (fail silent mode).
- The abnormal silence (fail silent mode) of the ICRW application not warning the driver of a detected collision risk.

The security functionalities have an impact on the overall system performance in terms of processing time, processing capacity, etc. Such impact may not be negligible for ICRW application operation, in which the Maximum Latency Time should be respected in order to provide warning to driver in time.

OR1. In between each pseudonym update, CAM and DENM generation shall use a common station ID.

OR2. In case of a detected abnormal behaviour of the LCRW application, the LCRW application shall not trigger any warning to user.

OR3. When the application priority level is set to 1 or higher, the traffic class of the DENM should be set to higher than CAM.

NOTE: In case of detected LCRW failure, an information may be presented to the driver.

7.3 System minimum performance requirements

7.3.1 Event position accuracy

OR4. The confidence level for the estimation of event position shall be at least 95 %.

OR5. The event position accuracy should be equal or better than two (2) meter. In case this accuracy requirement cannot be fulfilled, the event position accuracy shall enable receiving vehicle to position the event in the interaction lane.

7.3.2 Communication coverage

OR6. The required communication range shall be set to 300 meters in a line of sight situation and when the channel load is at relaxed state, in order to enable the detection of a vehicle on time even when it is running at high speed.

OR7. When the used G5A channels are not congested, the current transmit power level requirements measured at the antenna level shall be at least 18 dBm.

OR8. The required communication range may be reduced in certain situation e.g. if the traffic around is slow e.g. less than 50 km/h, or in channel congested situation.

7.3.3 System end to end latency time

OR9. Performance class A system as defined in clause 4 should be used for ICRW. In a critical safety situation, the latency time T4 - T6 of 80 ms as defined in clause 4 may be required.

7.3.4 Message processing

OR10. ITS-S shall be able to decode and interpret CAM/DENM/SPATEM/MAPEM/IVIM properly.

OR11. When the application priority level is set to 1 or higher (assist mode), the traffic class value for DENM shall be set to higher than CAM.

OR12. In case ICRW triggers a DENM transmission, the DENM shall be updated at 10 Hz, as long as the collision risk and violation risk persists.

OR13. A conforming ITS-S should be able to process at least 1 000 CAM and DENM per second. This corresponds realistically to the maximum of messages which can be transmitted in CCH of the G5 technology every second.

OR14. The traffic light controller or the supporting Road Side ITS-S shall have a communication range that is sufficient to ensure collision risk detection with a vehicle driving at its maximum design speed.

OR15. The infrastructure message SPATEM/MAPEM/IVIM messages frequency shall be at least 1 Hz.

OR16. The T2-T0 latency requirements for infrastructure message (SPATEM/MAPEM/IVIM) shall be less than 800 ms.

OR17. When the road side ITS-S detects the collision and violation risk and triggers a DENM transmission, the ICRW application shall set the traffic class higher than CAM.

Annex A (informative): CAMs interval adjustment based on critical safety situation

Multiple approaches are possible to adjust dynamically the CAMs interval:

1) Adjustment by the CA basic service based on the highly dynamic data evolutions of the originating vehicle ITS-S perception as specified in ETSI EN 302 637-2 [1].

2) Adjustment by the road safety applications of the ITS-S, based on the perception of the criticality of the traffic safety situation around the vehicle ITS-S.

The option 1 may not take into account some particular critical traffic safety situations. For example, when a vehicle is moving slowly (stopped) without significant dynamic evolutions, it will result in a decrease of CAMs interval to 1 Hz, even when a critical traffic safety situation is observed with at least one of its neighbour ITS-Ss driving at high speed. For such situation, CAMs transmitted by this slow moving vehicle may not be received by other ITS-Ss in time, in order to take necessary actions to avoid potential collision risk.

The alternative solution 2 may be used to cover the above mentioned situation, taking into account the overall traffic situation perceived by ITS-S. In this solution, the ITS-S safety application may detect a critical traffic safety situation (e.g. through the monitoring of TTC with its neighbours) and then may request an adjustment of the CAMs interval accordingly. For example, an ITS application may request that the CAMs interval remain at its lowest value (100 ms or lower) as long as the priority level is set to "1" or higher.

Annex B (informative): Application state machine

Figure B.1 shows the state machine for the ICRW application at vehicle ITS-S.

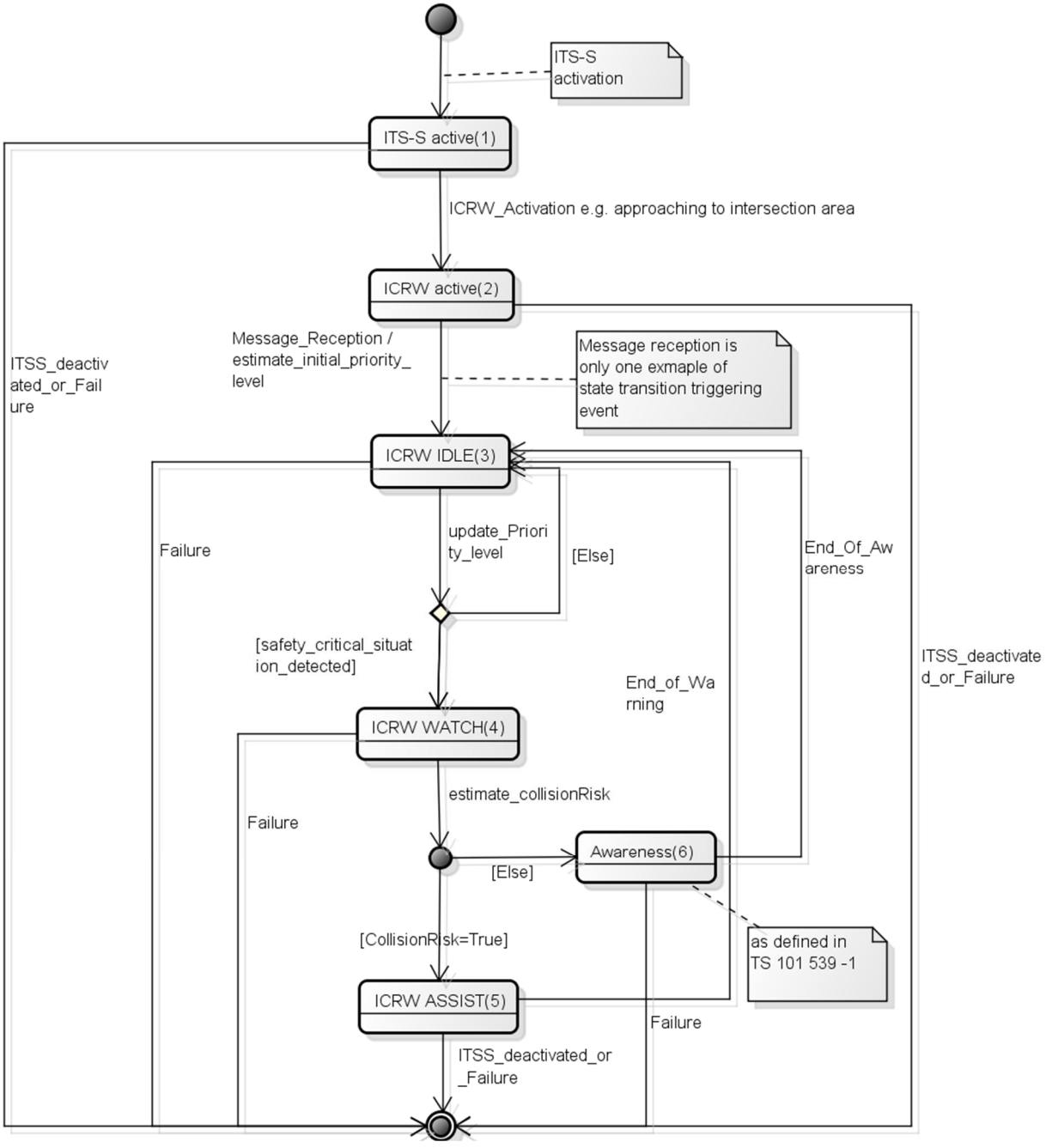


Figure B.1: Example of ICRW application state machine at ITS-S

In this implementation example of the ICRW application receiving mode functionalities, the following machine states are defined:

- ITS-S active(1): The ITS-S is activated.
- ICRW active(2): The ICRW application is activated. The application has finished the initialization phase. During this phase, all required functionalities of the application and facilities layer are activated, as well as their interfaces.

- ICRW IDLE(3): At the reception of the first CAM/DENM/SPATEM/MAPEM/IVIEM after the activation, the ICRW application start evaluating the traffic safety critical situation and set a priority level. This may be realized by monitoring the movements of the ego vehicle and compares it to the movement of neighbour vehicles. In this state, no collision risk is detected.

- ICRW WATCH(4): The ICRW application detects a critical traffic safety situation with a target vehicle. It is watching carefully the evolutions of the vehicles to estimate the TTC. In this state the application priority level is set to "1".

- ICRW ASSIST(5): The application is assisting the driver to avoid a collision. A warning is issued to driver. This state is triggered when a collision risk with another vehicle is confirmed. In this state, the application priority level is set to "1" until the critical safety situation has been eliminated. If appropriate driver action has not been taken, the application priority level may be set to "0" when TTC continues to decrease and the one vehicle enters the "pre-crash" phase with the other one.

State transitions are defined as follow:

- (Start-1): The ITS-S is activated.

- (1 - end): ITS-S is deactivated or failure of ITS-S.

- (1-2): ICRW is activated. ICRW application may be activated when the vehicle is approaching an intersection area.

- (2-1): ICRW is deactivated or fault condition. For example, the ICRW may be switched to ITS-S active sate when the vehicle has exited the intersection area without encountering any collision or violation risk.

- (2-end): ITS-S is deactivated or failure of ITS-S.

- (2-3): First CAM,DENM or infrastructure message (SPATEM, MAPEM, IVIEM) is received.

- (3-end): ICRW is deactivated or fault condition.

- (3-4): Safety critical traffic situation is detected. Accurate watch of vehicle trajectory is required. In this example, the safety critical traffic situation is determined using a safety shield concept. The safety shield concept is presented in the informative annex D.

- (3-end): ICRW is deactivated or fault condition.

- (4-5): Crossing collision risk or violation risk is detected.

- (4-6): Road hazard is relevant to the vehicle but no collision risk is detected, an information is provided to driver as defined in ETSI TS 101 539-1 [i.4].

- (5-3): End of warning.

- (6-3): End of awareness.

- (5-end): ICRW is deactivated or fault condition.

- (6-end): ICRW is deactivated or fault condition.

Annex C (informative): Safety Shield

The general principle of detecting and signalling a risk of collision to the driver of the vehicle can be derived from the "Safety Shield" concept as explained in Figure C.1.

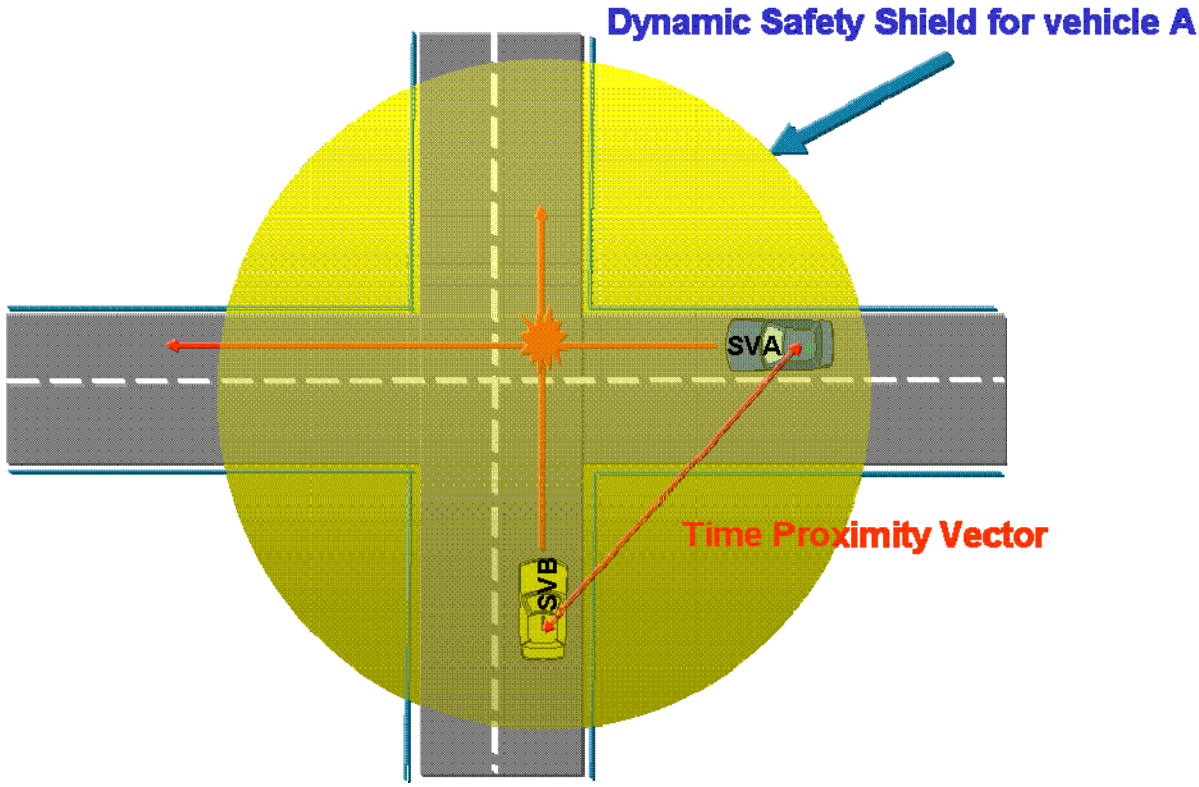


Figure C.1: Safety Shield concept at an intersection level

In this concept, when a vehicle detects another vehicle at a time distance of itself creating an obstacle potentially leading to a collision, it is considering that this vehicle is entering in its safety shield.

A safety shield is then a virtual dynamic area surrounding the subject vehicle. This area is dynamic given that the time separating two vehicles is a direct function of the relative velocities.

The minimum time required for the triggering of a driver warning is provided by the following equation:

$$TTCmin > MLT + MDRT + MAT + \varepsilon$$

In this equation, the MAT (Maximum Action Time) denotes the time required for vehicle to take required action for collision avoidance, such as time required for vehicle to stop. It is very related to the deceleration capabilities of the two vehicles but also to some other variables such as their masses and the driver braking behaviour. Consequently the evaluation of the MAT is completely under the responsibility of the OEM.

The MDRT (Maximum Driver Reaction Time) denotes the time required for human driver to be aware of, to interprete the HMI information and to act on vehicle system.

The MLT (Maximum Latency Time) denotes the time required by ICRW to process the received message, estimate collision risk and presents the risk warning to driver with HMI.

This TTCmin can directly allow the calculation of the time left before a possible collision (providing the limits of the safety shield) by adding to it some margin time (ε) taking into account the level of accuracy of the two vehicle positioning systems.

Consequently, when the ICRW application detects another vehicle entering in the safety shield of the vehicle according to its own evolution, it will be entering the "WATCH" state monitoring carefully the evolutions of the trajectories of both the subject and the target vehicles. When calculating that the TTCmin is reached, it will be entering the "ASSIST" state delivering the warning to the HMI support function.

Annex D (informative): Driver HMI considerations

A vehicle ITS Station detecting a risk of collision should warn the driver in time for being able to start the required action for avoiding the collision. The following possibilities may be considered:

- In case a warning is provided, a visual information may be provided.
- In complement, an audible signal or haptic information can be added at the discretion of OEMs.
- The signalling of a signal violation risk should be clearly distinguishable from an intersection collision risk warning.
- The audible warning tone should be selected such that it can be easily heard and discriminated from any other type of warning or driver information in the vehicle.
- In case of a ICRW defect, it should be signalled to the driver.
- The ICRW should stop immediately the warning if the collision or violation risk are eliminated, e.g. flashing lights activated or significant change in the curvature.

However, as several safety critical applications may be cohabitating in a given vehicle, it could be necessary to have included an arbitration function (in HMI support for example) selecting which warning to deliver to the driver in case of simultaneity of applications' requests. A driver warning can be delivered upon some strict conditions avoiding to distract not necessarily the driver. Conditions to be considered are:

- Distance separating the subject vehicle from the road hazard.
- Speed of the subject vehicle.
- Confidence level in the received information.
- Started drivers actions.
- Consistency of the simultaneous requests.
- Possibility to merge several requests into one consistence assistance advise.

Annex E (informative): Bibliography

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.

Standardisation mandate addressed to CEN, CENELEC and ETSI in the field of information and communication technologies to support the interoperability of co-operative systems for intelligent transport in the European Community.

History

Document history		
V1.1.1	June 2018	Publication