5GAA Automotive Association

White Paper

C-V2X Use Cases
Methodology, Examples and Service Level Requirements

Contents

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Executive summary

5G Automotive Association (5GAA) have defined a methodology to describe Use Cases(UC), UC descriptions have been done by numerous constellations during the last decades, different in every region, using different terminology and different ways to describe, etc, This have made it difficult to communicate in one 'language'.

To overcome this, 5GAA as a leading global organisation with worldwide representation from almost all sectors of the industry have set a common language in this area in a way that is also suitable for Automakers (also known as OEMs) and their interest.
This is also proposed since 5GAA works on new, innovative use cases that includes complex interaction between vehicles and between vehicles and infrastructure in relation to self-driving (autonomous) vehicles, so it is a good time for a new fresh (re)start of this area.

5GAA have also aligned the UC groupings and characterization of UCs to make it easier see where a UC have a benefit and to identify potential stakeholders, the following UC grouping are used, Safety, Vehicle Operations Management, Convenience, Autonomous driving, Platooning, Traffic Efficiency and Environmental friendliness, Society and Community (These groupings are further described in the white paper).

5GAA have also introduced the concept of Service Level Requirements (SLR) to provide requirements for the UCs. (This is further described in the white paper.)

This white paper describes the 5GAA methodology used to create solution agnostic UC descriptions in order to facilitate the selection of the most suitable technology to realize a UCs. The white paper uses a few UCs to illustrate the methodology, note that the described UCs are just some examples and do not reflect any 5GAA prioritization of UCs.

1.0 Introduction

5G Automotive Association (5GAA) bringing together automotive and telecommunications industries with the goal is to accelerate the global deployment of Cellular Vehicle-To-Everything (C-V2X), as a first step towards a fully integrated intelligent transport system with 5G. In order to achieve this goal 5GAA has organized its work along five complementing work streams or work groups covering the following areas:

1. Use cases
2. Solutions and architecture
3. Testing, pilots, interoperability
4. Spectrum, regulatory and standards
5. Business and go to market strategies

Arguably the first step in understanding the value 5GAA brings to the communities is to clearly define the use cases. As defined, the use case can be viewed as a "description of set of sequences of actions that a system performs that yield an observable result of value to an actor". We point out that while the use cases that are defined by 5GAA represent the interaction between actors they can also be viewed as problem statements from their communications viewpoint. In addition to use case description the work in Work Group 1 covers development of detailed application requirements referred to as Service Level Requirements. Together with use case description this information is subsequently used by other 5GAA Work Groups to develop solutions, create test procedures and demos and pilots, evaluate spectrum needs and co-operate with standards development organizations and finally create the business case and path for deployment.

This white paper describes 5GAA's approach in defining use cases and associated Service Level Requirements. In Section 2 we describe our methodology and present the format used to record use cases. Section 3 gives a quick summary of use cases covered by this white paper providing enough information to follow the service level requirements presented in Section 4. Detailed description of each use case can be found in the Appendix A. We conclude the white paper with a summary in Section 5 and briefly present the planned future work.

2.0 5GAA WG1 Scope and Methodology

The main goals of 5GAA WG1 include the definition of solution agnostic automotive use cases for C-V2X and the derivation of service level requirements from the use cases.

2.1 Definitions and Templates

For description of C-V2X use cases, WG1 firstly analyzed the relationship between road environments, use cases and use cases scenarios by introducing a hierarchical classification:

- **Road environments**: are the typical places where vehicle traffic and C-V2X use cases occur, such as intersections, urban and rural streets, high speed roads (Autobahn), parking lots, etc. Each use case should be mapped to at least one road environment, while the latter can be associated to one or more use cases. In combination, multiple use cases form the communication performance requirements in an environment.
- **Use Cases**: are the high level procedures of executing an application in a particular situation with a specific purpose. A use case may entail a number of specific scenarios, where different requirements may apply.
- **User Stories**: Given a high level use case description as described above, different specific use case scenarios can be derived for different situations that may imply in different specific requirements. For example, one use case may have a variation for driver assistance and another variant for fully automated driving.

Based on the above definitions a 3-level hierarchy has been defined, where in the highest level we have the road environment, in the middle level the use cases and in the lowest level the use cases scenarios.

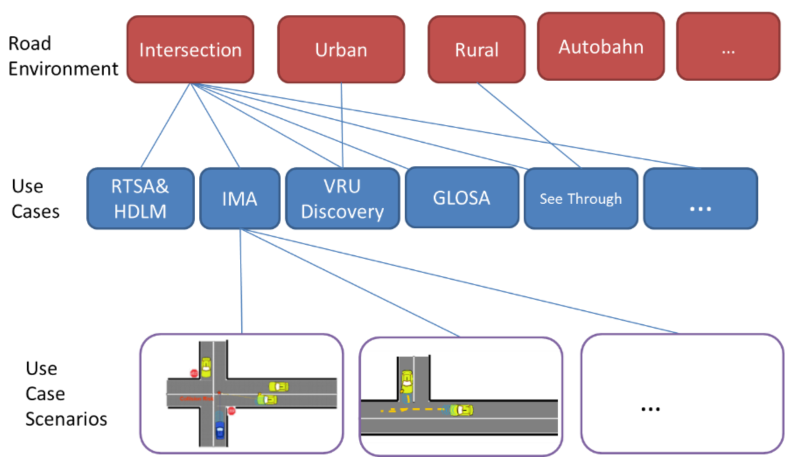

Figure 1 Definition of the hierarchy between road environment, use cases and use cases scenarios

The hierarchy and the relation between the different levels is exemplified in Figure 1 and it is observed that:

- Every use case is connected to at least one road environment and at least one use case scenario
- Every road environment may serve a framework to many use cases
- Use case scenarios are specific variations of one use case; Solution-agnostic, our assumptions.

The C-V2X use cases are described using a template applicable to a wide range of use cases that allows a more detailed description of C-V2X use cases to support the derivation of the service-level requirements. The template is presented in Annex A.2 with the corresponding explanation of the different fields.

The objective of the template is to remain as abstract as possible relative to the specific implementation and architecture of the overlaying cellular system but define specific roles for the different actors, the applicable road environment and the specific use case scenario/user story. The UC descriptions are written from the vehicle perspective and strive to be solution agnostic and applicable to both driven and autonomous vehicles. The realization of UCs do not preclude applications performing various tasks supporting the UCs, such as collecting information, analysing etc. Furthermore, radio symbols in figures indicate a connected vehicle. It is also assumed that messages are exchanged in a secure way between authenticated parties.

5GAA WG1 has defined service level requirements that describe C-V2X use case requirements in a technology and implementation agnostic way. The list of considered service level requirements is provided below:

Definitions of C-V2X Service-level Requirements

Service level Requirement	Definition
Range	Expected distance from Host Vehicle (HV) to scenario application zone
Information requested/generated	Quality of information / Information needs of the end-user (e.g., a driver, a passenger, robot in the car or remote, application program running in an ECU, etc…). In this description the end result of the information delivery is important while the actual transfer is not a concern.
Service Level Latency	Measurements of time from the occurrence of the event in scenario application zone to the beginning of the resulting actuation. Depending on implementation, this includes one or more of following: o processing of the event into information by the information generator, o communication of the information to end-user, o processing of the information by the end-user and o time to actuation driven by the result of processing of the information.
Service Level Reliability	Based on an agreed QoS framework, the guaranteed and expected performance to start/initialize, perform and finalize (end-to-end) applications within use cases. Different agreed and provided QoS levels will result in different performances within the applications. Known or expected changes in service level reliability before starting an application or during operation should be announced timely to the relevant applications and entities involved.
Velocity	Describes the maximum absolute speed of a vehicle at which a defined QoS can be achieved (in km/h). Note: Describes the extent of mobility and the average speed of the vehicle involved in the use case. Note that there may be a need to capture the peak expected speed. This definition may also be required to be split to describe the type of mobility from the speed. For instance, nomadic is a type of mobility.

Vehicle Density	Expected number of vehicles per a given area (per km2) during the execution of the use case. Note: that this provides an indication that multiple vehicles within the same area run the same (and potentially additional) use case(s) in parallel.
Positioning	Positioning Accuracy / Position Accuracy / Location accuracy, at the time when position information is delivered to end-user (HV), between the actual position and the position information: a) Location type: absolute / geographical or relative or N/A, b) KPI: accuracy level. Note: The confidence interval of position information is provided in units of sigma e.g., 1-sigma (1σ), 2-sigma (2σ), 3-sigma (3σ).
Interoperability/ Regulatory/ Standardization Required	Yes / No, to indicate the need for inter-OEM interoperability, e.g., in case of cooperative safety use cases.

2.2 Use Case Grouping

Taking into consideration that a number of new, innovative use cases have emerged during the last years and many more will come in the following years, 5GAA has identified the following groups of use cases:

1. Safety
2. Vehicle Operations Management
3. Convenience
4. Autonomous driving
5. Platooning
6. Traffic Efficiency and Environmental friendliness
7. Society and Community

C-V2X use cases grouping helps to easier identify which stakeholder would benefit from a C-V2X use case. It should be noted that a use case may belong to more than one of the proposed groups. A short description of the identified groups is provided below.

Safety: This group includes use cases that provide enhanced safety for vehicle and driver. Examples of use cases include Emergency Braking, Intersection Mgmt. Assist, Collision warning or Lane change. These use cases would in many apply equally to autonomous vehicles or to provide assistance to drivers, with some notable exceptions such as See-Trough, camera assistance with are intended for human drivers. It is expected that many of these use cases would need to be defined into a standard and regulated mode to ensure consistent operation and functioning between different OEMs.

Vehicle Operations Management: This group includes use cases that provide operational and management value to the vehicle manufacturer. Use cases in this group would include sensors monitoring, software updates, remote support, etc. From a business and monetization modelling point of view, these are use cases that could be provided by vehicle manufacturers (OEMs) to improve efficiency of vehicle maintenance and vehicle monitoring. Some use cases such as remote support would be attractive to vehicle owners/drivers, transport/delivery companies. These use case are likely not requiring standardization, as each OEM could be developing them in their own proprietary mode. (Potentially a group of OEMs could agree on a proprietary standard and implementation to save development cost for certain UCs)

Convenience: This group includes use cases that provide value and convenience to the driver. Examples for this group can include Infotainment, assisted and cooperative navigation, and autonomous smart parking. These are use cases which may not be mandated from a safety program point of view, but that provide significant value to the driver or passengers in the vehicles. From a business modelling point of view, these are use cases that would be attractive to vehicle drivers or passengers.

Autonomous Driving: This use case group address use cases that are relevant for Autonomous/self-driving vehicles (Society of Automotive Engineers (SAE) level 4 and 5), examples in this group are control if autonomous driving is allowed or not, Tele-operation (potentially with Augmented Reality support for a remote driver), handling of dynamic maps (update/download), some of the Safety UCs that require cooperative interaction between vehicles to be efficient and safe. These use cases are from a business modelling point of view attractive of value to vehicle owners/drivers, transport/delivery companies.

Platooning: This use case group address use cases that are relevant for platooning, examples in this group are platoon management, e.g., collect and establish a platoon, determine position in platoon, dissolve a platoon, manage distance within platoon, leave a platoon, control of platoon in steady state, request passing through a platoon. These use cases are of interest to transport companies and potentially by road operators/road traffic authorities since road infrastructure could be used more efficiently. Potentially also for society as it could provide environmental benefits such as reduced emissions. These use cases are from a business modelling point of view attractive to vehicle owners/drivers, transport/delivery companies.

Traffic Efficiency and Environmental friendliness: This group includes use cases that provide enhanced value to infrastructure or city providers, where the vehicles will be operating. As examples for this use case group, Green Light Optimal Speed Advisory (GLOSA), traffic jam information, Routing advise e.g., Smart routing. These use cases are from a business modelling point of view attractive of value to vehicle owners/drivers, transport/delivery companies, potentially subsidized by public means since it could provide environmental benefits.

Society and Community: This group includes use cases that are of value and interest to the society and public, e.g., Vulnerable Road User (VRU) protection, public services, such as ambulance, police, fire brigades, Emergency answering points, governments, road authorities, examples in this group are Emergency vehicle approaching, traffic light priority, patient monitoring, crash report. These use cases are from a business modelling point of view attractive to the public/private sector.

3.0 C-V2X Use Case Examples

This section contains a short description of example use case descriptions developed by 5GAA WG1. Each use case can be composed of multiple use case scenarios, wherein use case scenarios can differ in terms of road configuration, actors involved, service flows, etc. A more detailed description of the use cases is provided in Annex A.2.

Cross-Traffic Left-Turn Assist (Safety, Autonomous Driving): Assist Host Vehicle (HV) attempting to turn left across traffic approaching from the opposite direction.

Intersection Movement Assist (Safety, Autonomous Driving): Stationary HV proceeds straight from stop at an intersection. HV is alerted if it is unsafe to proceed through the intersection (i.e., alerts for approaching cross-traffic from the left or the right side, incoming traffic intending to turn left).

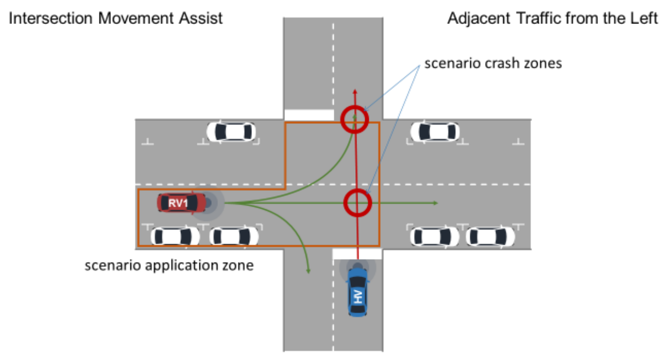

Figure 2 Intersection Movement Assist – Adjacent Traffic from the left

Emergency Break Warning (Safety, Autonomous Driving): Alert HV that a lead Remote Vehicle (RV) is undergoing an emergency braking event.

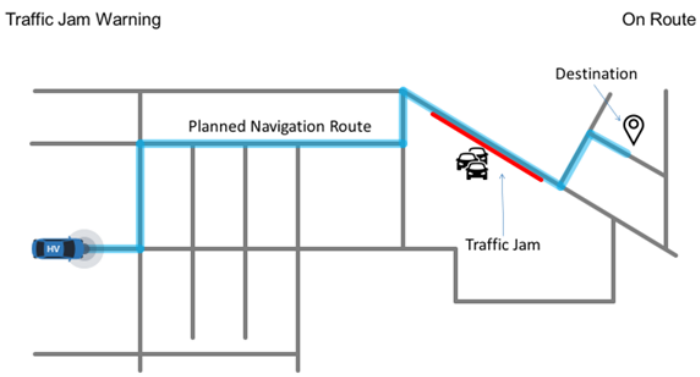

Figure 3 Traffic Jam Warning – On Route

Traffic Jam Warning (Convenience): Warn HV of an approaching traffic jam on the road or notify HV of a traffic jam on the navigation route.

Software Update (Vehicle Operations Management): Vehicle manufacturer updates electronic control module software for targeted vehicles.

Remote Vehicle Health Monitoring (Vehicle Operations Management): Owners, fleet operators and authorized vehicle service providers monitor the health of HV and are alerted when maintenance or service is required.

Hazardous Location Warning (Safety, Autonomous Driving): Warn the HV of a hazardous location and provide additional information to safely navigate around the hazard.

Speed Harmonization (Traffic Efficiency and Environmental friendliness, Autonomous Driving): Notify HV of recommended speed to be applied at certain location to optimize traffic flow, minimize emissions and to ensure a smooth and safe ride.

High Definition Sensor Sharing (Autonomous Driving): Vehicle uses its own sensors (e.g., HD camera, lidar), and sensor information from other vehicles, to perceive its environment (e.g., come up with 3D model of world around it) and safely performs an automated driving lane change.

See-Through for Pass Maneuver (Safety): Driver of Host Vehicle that signals an intention to pass a Remote Vehicle (RV) using the oncoming traffic lane is provided a video stream showing the view in front of the RV.

Lane Change Warning (Safety): HV signals an intention to change lane and an alert is received by neighboring vehicles in case of a lack of space, risk of collision or his maneuver is not permitted on the current road segment.

Vulnerable Road User (Society and Community, Safety): Alert HV of approaching VRU in the road or crossing an intersection and warn of any risk of collision

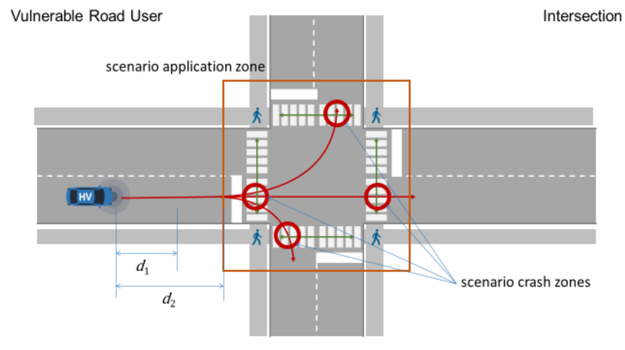

Figure 4 Vulnerable Road User - Intersection

4.0 Service-level Requirements of Example C-V2X Use Cases

This section provides the service level requirements of the example C-V2X use cases developed by 5GAA WG1. For some of the use cases different user stories have been presented with different service level requirements.

4.1 Cross-Traffic Left-Turn Assist

User Story	Detailed description and specifics
User Story #1	Automated vehicles exchange awareness messages (e.g., CAM, BSM). No information about future trajectories is exchanged. Instead, a risk for collision is calculated based on the data collected in the past and present and a warning is displayed to the driver, consecutively.
User Story #2	In this user story, higher automation levels are considered. Autonomous cars exchange planned, future trajectories with each other. Based on those, more accurate estimation regarding possible collisions are possible.

User Story #1
(all scenarios, no matter which direction traffic is coming from)

Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	350	Maximum communication range assumed, this allows for ~ 5 s to react (at the max speed mentioned within the velocity section).
Information requested/generated	Quality of information / Information needs	300 bytes per message	LTA in user story one is based on normal awareness messages (e.g., CAM, BSM) exchange.
Service Level Latency	[ms]	100	Normal awareness messages (e.g., CAM, BSM) latency.
Service Level Reliability	%	90	For single awareness messages (e.g., CAM, BSM) without retransmission, this reliability is enough to ensure the ETSI requirement of <5% probability of two consecutive awareness message (e.g., CAM, BSM) transmission failing.
Velocity	[m/s]	33.3	Most critical situations are to be expected at rural intersections. Here, the RV could be driving with up to 120 km/h, and the HV that wants to turn is on the way of slowing down, possibly also from 120 km/h. Therefore, maximum speeds of 120 km/h seem to be a reasonable value.
Vehicle Density	[vehicle/km^2]	1500	This use case is expected to mostly happen not in very dense metropolis areas, since sight at intersections is mostly good, speeds are limited around 50 km/h, and traffic lights can be expected at most intersections.
Positioning	[m]	1.5 (3σ)	The most probable scenario for the use case is envisioned in rural intersections that are hard to see and where higher speeds of the participating cars are expected.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	In order to perform lane-accurate positioning, a positioning accuracy of around 1m should be provided.

User Story #2 (all scenarios, no matter which direction traffic is coming from)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background

Range	[m]	350	Maximum communication range assumed, this allows for ~ 5 s to react (at the max speed mentioned within the velocity section).
Information requested/generated	Quality of information / Information needs	Approx. 1000 bytes per message	Intended trajectories have to be sent by the RVs, since they determine whether or not a collision is imminent or not. In order to do so, some more payload than with normal CAMs should be used.
Service Level Latency	[ms]	10	LTA is a rather critical use case. Depending on the implementation, warning messages might be issued only shortly before actual turning is said to happen. Therefore, this short of a latency seems reasonable.
Service Level Reliability	%	99.9	A service level reliability this high should be enough to allow perceived zero-error appearance of the cross-traffic left-turn assist. False positives are more problematic than false negatives.
Velocity	[m/s]	33.3	Most critical situations are to be expected at rural intersections. Here, the RV could be driving with up to 120 km/h, and the HV that wants to turn is on the way of slowing down, possibly also from 120 km/h. Therefore, maximum speeds of 120 km/h seem to be a reasonable value.
Vehicle Density	[vehicle/km^2]	1500	This use case is expected to mostly happen not in very dense metropolis areas, since sight at intersections is mostly good, speeds are limited around 50 km/h, and traffic lights can be expected at most intersections.
Positioning	[m]	1.5 (3σ)	In order to perform lane-accurate positioning, a positioning accuracy of around 1m should be provided.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between different OEMs is needed. It should be regulated that every vehicle has to make its presence known periodically (as a broadcast). Standardization is required in the sense that the format for trajectories should be common to all so that they can be understood by all.

4.2 Intersection Movement Assist

User Story	Detailed description and specifics

User Story #1	Two vehicles are approaching an intersection (as described in main event flow). The vehicles determine the risk for a collision based on the vehicles' estimated trajectories.

User Story #1 (all scenarios, no matter which direction traffic is coming from)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Min 100	Braking distance at 0.4g from 100km/h, e.g., at an intersection on a rural road.
Information requested/generated	Quality of information / Information needs	awareness messages (e.g., CAM, BSM) (around 300 bytes)	Calculate trajectories based on exchanged data in awareness messages (e.g., CAM, BSM). Changes in kinematics of involved vehicles might require this information to be updated (or shared periodically) within the boundaries given by the Service Level Latency.
Service Level Latency	[ms]	100	Not highly time critical, but should stay below 100ms to be effective / comparable to other ADAS.
Service Level Reliability	%	High / 99.99	Needs to reliably allow for trajectory calculation to avoid collisions.
Velocity	[m/s]	33.3	Assuming speeds up to 120 km/h.
Vehicle Density	[vehicle/km^2]	12000	Max assumed density in urban situation.
Positioning	[m]	1.5 (3σ)	Required for accurate trajectory calculation and collision risk estimation in relation to vehicle size.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

4.3 Emergency Brake Warning

User Story	Detailed description and specifics
User Story #1	HV is moving at very high speed different from RV in a highly congested traffic scenario illustrated in Annex A.2. HV is driven by human driver. RV applies brake in order to make an emergency stop. HV is at distance D behind the RV and the HV driver does not see RV applying brake or is distracted. Wet road conditions assumed.

User Story #2	HV is at least Level 2 automation. HV is moving at very high speed different from RV in a highly congested traffic scenario illustrated in Annex A.2. HV is driven by human driver or robot. RV applies breaks in order to make an emergency stop. Wet road conditions assumed.

User Story #1			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	360	Under the assumptions of Vrv=25 m/s, Vhv=50 m/s and a=0.4g this is the minimum distance (400 ms margin or 20 meters) at which HV needs to be warned to avoid collision.
Information requested/generated	Quality of information / Information needs	awareness messages (e.g., CAM, BSM) (between 200-400 bytes)	The message should be delivered to HV. It contains the information about the hard braking event at RV. It contains other information regarding RV such as location, velocity, acceleration, etc.
Service Level Latency	[ms]	120	Ideally, the information about the Hard Braking event should be conveyed as soon as possible. Examining current radar and camera vision sensors the detection times are 100-300 ms which makes V2X latency within the same budget. Additionally, for the reliability that we are requesting this latency seems reasonable. For example, the latency of 100 ms causes the HV to travel additional 5 meters before final stop at 50 m/s initial velocity, however, this additional distance is budgeted in the range estimate. This includes handling, access, and OTA latency.
Service Level Reliability	%	99.99	The Hard Braking event message needs to be delivered to the HV with high reliability.
Velocity	[m/s]	69.4	250km/h, as assumed maximum speed
Vehicle Density	[vehicle/km^2]	12000	Assume maximum density.
Positioning	[m]	1.5 (3σ)	HV needs to know whether the hard braking vehicle in the front is in the same lane.

Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability needs to be in place for HV to receive a message from RV.

User Story #2			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	290	Under the assumptions of Vrv=25 m/s, Vhv=50 m/s, 0.5 second reaction time and a=0.4g (and 300 ms margin or 15 meters) this is the minimum distance at which the Level 3 system needs to be warned to avoid collision.
Information requested/generated	Quality of information / Information needs	awareness messages (e.g., CAM, BSM) (between 200-400 bytes)	The message should be delivered to HV. It contains the information about the hard braking event at RV. It contains other information regarding RV such as location, velocity, acceleration, etc.
Service Level Latency	[ms]	120	Reasonable latency in the context of the other existing sensor systems as well as taking into account the high reliability needed.
Service Level Reliability	%	99.99	The Hard Braking event message needs to be delivered to the HV with high reliability.
Velocity	[m/s]	69.4	250km/h, as assumed maximum speed.
Vehicle Density	[vehicle/km^2]	12000	Assume maximum density.
Positioning	[m]	1.5 (3σ)	HV needs to know whether the hard braking vehicle in the front is in the same lane.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability needs to be in place for HV to receive a message from RV.

4.4 Traffic Jam Warning

User Story #1 Urban Scenario on Road Warning

Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	1000	Warn early enough to safely brake when approaching the traffic jam. Calculation based on the duration of a traffic jam and the possibility for it to still exist when a vehicle driving on its way with an average speed is reaching the jam (duration 2 h, speed 50 km/h).
Information requested/generated	Quality of information / Information needs	Uplink awareness messages (e.g., CAM, BSM, DENM)	Get Traffic jam information from awareness messages ((e.g., CAM, BSM, DENM) or from other (backend) services. Size usually around 300bytes
Service Level Latency	[ms]	2000	Traffic jams are normally not happening within a very short time period. If communication range is big enough e.g., on a highway 2 seconds driving with 150 km/s means 80 meters. Jam should be visible if you are as close as 80 meters in urban environment (50 km/h) 2 seconds means 26 meters which should be close enough to see the jam
Service Level Reliability	%	Medium / 50	Normally a traffic jam contains several cars. Assuming an equipment rate of 20% and an average of at least 10 cars per jam means that there are at least 2 cars which send the message in parallel.
Velocity	[m/s]	19.4	Assuming typical maximum allowed speeds and some safety (70 km/h).
Vehicle Density	[vehicle/km^2]	12000	Max assumed density in urban situation.
Positioning	[m]	20 (1σ)	As there is the assumption that the jam is not something very spontaneously and as the warning is meant for areas higher than LoS the given values seem reasonable.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

User Story #2 Rural Scenario on Road Warning

Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	1000	Warn early enough to safely brake when approaching the traffic jam. Calculation based on the duration of a traffic jam and the possibility for it to still exist when a vehicle driving on its way with an average speed is reaching the jam (duration 2 h, speed 50 km/h, 100 km/h 150 km/h)
Information requested/generated	Quality of information / Information needs	Uplink awareness messages (e.g., CAM, BSM, DENM)	Get Traffic jam information from awareness messages ((e.g., CAM, BSM, DENM) or from other (backend) services. Size usually around 300bytes
Service Level Latency	[ms]	2000	Traffic jams are normally not happening within a very short time period. If communication range is big enough e.g., on a highway 2 seconds driving with 150 km/s means 80 meters. Jam should be visible if you are as close as 80 meters in urban environment (50 km/h) 2 seconds means 26 meters which should be close enough to see the jam.
Service Level Reliability	%	Medium / 50	Normally a traffic jam contains several cars. Assuming an equipment rate of 20% and an average of at least 10 cars per jam means that there are at least 2 cars which send the message in parallel.
Velocity	[m/s]	33.3	Assuming typical maximum allowed speeds and some safety (120 km/h).
Vehicle Density	[vehicle/km^2]	9000	Max assumed density in rural situation.
Positioning	[m]	20 (1σ)	As there is the assumption that the jam is not something very spontaneously and as the warning is meant for areas higher than LoS the given values seem reasonable.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

User Story #3 Highway Scenario on Road Warning

Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	1000	Warn early enough to safely brake when approaching the traffic jam. Calculation based on the duration of a traffic jam and the possibility for it to still exist when a vehicle driving on its way with an average speed is reaching the jam (duration 2 h, speed 50 km/h, 100 km/h 150 km/h)
Information requested/generated	Quality of information / Information needs	Uplink awareness messages (e.g., CAM, BSM, DENM)	Get Traffic jam information from awareness messages ((e.g., CAM, BSM, DENM) or from other (backend) services. Size usually around 300bytes.
Service Level Latency	[ms]	2000	Traffic jams are normally not happening within a very short time period. If communication range is big enough e.g., on a highway 2 seconds driving with 150 km/s means 80 meters. Jam should be visible if you are as close as 80 meters in urban environment (50 km/h) 2 seconds means 26 meters which should be close enough to see the jam
Service Level Reliability	%	Medium / 50	Normally a traffic jam contains several cars. Assuming an equipment rate of 20% and an average of at least 10 cars per jam means that there are at least 2 cars which send the message in parallel.
Velocity	[m/s]	69.4	Assuming typical maximum allowed speeds and some safety (250 km/h).
Vehicle Density	[vehicle/km^2]	4500	Max assumed density in highway situation.
Positioning	[m]	2 (1σ)	As there is the assumption that the jam is not something very spontaneously and as the warning is meant for areas higher than LoS the given values seem reasonable.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

User Story #4 Urban Scenario on Route Information

Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	100000	Warn early enough to safely brake when approaching the traffic jam. Calculation based on the duration of a traffic jam and the possibility for it to still exist when a vehicle driving on its way with an average speed is reaching the jam (duration 2 h, speed 50 km/h).
Information requested/generated	Quality of information / Information needs	Uplink awareness messages (e.g., CAM, BSM, DENM)	Get Traffic jam information from awareness messages ((e.g., CAM, BSM, DENM) or from other (backend) services. Size usually around 300bytes.
Service Level Latency	[ms]	Minutes	Traffic jams are normally not happening within a very short time period. If communication range is big enough e.g., on a highway 2 seconds driving with 150 km/s means 80 meters. Jam should be visible if you are as close as 80 meters in urban environment (50 km/h) 2 seconds means 26 meters which should be close enough to see the jam.
Service Level Reliability	%	Medium / 50	Normally a traffic jam contains several cars. Assuming an equipment rate of 20% and an average of at least 10 cars per jam means that there are at least 2 cars which send the message in parallel.
Velocity	[m/s]	19.44	Assuming typical maximum allowed speeds and some safety (70 km/h).
Vehicle Density	[vehicle/km^2]	12000	Max assumed density in urban situation.
Positioning	[m]	20 (1σ)	As there is the assumption that the jam is not something very spontaneously and as the warning is meant for areas higher than LoS the given values seem reasonable.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

User Story #5 Rural Scenario on Route Information

Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	200000	Warn early enough to safely brake when approaching the traffic jam. Calculation based on the duration of a traffic jam and the possibility for it to still exist when a vehicle driving on its way with an average speed is reaching the jam (duration 2 h, speed 50 km/h, 100 km/h 150 km/h).
Information requested/generated	Quality of information / Information needs	Uplink awareness messages (e.g., CAM, BSM, DENM)	Get Traffic jam information from awareness messages ((e.g., CAM, BSM, DENM) or from other (backend) services. Size usually around 300bytes.
Service Level Latency	[ms]	Minutes	Traffic jams are normally not happening within a very short time period. If communication range is big enough e.g., on a highway 2 seconds driving with 150 km/s means 80 meters. Jam should be visible if you are as close as 80 meters in urban environment (50 km/h) 2 seconds means 26 meters which should be close enough to see the jam.
Service Level Reliability	%	Medium / 50	Normally a traffic jam contains several cars. Assuming an equipment rate of 20% and an average of at least 10 cars per jam means that there are at least 2 cars which send the message in parallel.
Velocity	[m/s]	33.3	Assuming typical maximum allowed speeds and some safety (120 km/h).
Vehicle Density	[vehicle/km^2]	9000	Max assumed density in rural situation.
Positioning	[m]	20 (1σ)	As there is the assumption that the jam is not something very spontaneously and as the warning is meant for areas higher than LoS the given values seem reasonable.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

User Story #6 Highway Scenario on Route Information

Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	300000	Warn early enough to safely brake when approaching the traffic jam. Calculation based on the duration of a traffic jam and the possibility for it to still exist when a vehicle driving on its way with an average speed is reaching the jam (duration 2 h, speed 50 km/h, 100 km/h 150 km/h).
Information requested/generated	Quality of information / Information needs	Uplink awareness messages (e.g., CAM, BSM, DENM)	Get Traffic jam information from awareness messages ((e.g., CAM, BSM, DENM) or from other (backend) services. Size usually around 300bytes.
Service Level Latency	[ms]	Minutes	Traffic jams are normally not happening within a very short time period. If communication range is big enough e.g., on a highway 2 seconds driving with 150 km/s means 80 meters. Jam should be visible if you are as close as 80 meters in urban environment (50 km/h) 2 seconds means 26 meters which should be close enough to see the jam.
Service Level Reliability	%	Medium / 50	Normally a traffic jam contains several cars. Assuming an equipment rate of 20% and an average of at least 10 cars per jam means that there are at least 2 cars which send the message in parallel.
Velocity	[m/s]	69.4	Assuming typical maximum allowed speeds and some safety (250 km/h).
Vehicle Density	[vehicle/km^2]	4500	Max assumed density in highway situation.
Positioning	[m]	20 (1σ)	As there is the assumption that the jam is not something very spontaneously and as the warning is meant for areas higher than LoS the given values seem reasonable.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

4.5 Software Update

User Story	Detailed description and specifics
Software Update (Conventional-Routine)	The "normal" case requiring a software update in a conventional (non-autonomous) vehicle. Software download and software installation are separate. The software is downloaded securely and reliably, as coverage and bandwidth are available. Its transmission must not adversely affect any safety-critical or user experience-critical functions. The driver is asked for consent to install the software when appropriate. Software installation is a separate process that occurs when safe and convenient. It may also vary depending on the vehicle manufacturer, model, and specific ECUs. For example, a non-critical system might be updated any time but a safety-critical system might only be updated when the vehicle is securely parked and will not be used for an extended period.

Software Update (Conventional-Routine)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Within network service provider coverage	In principle, the user story is applicable in the network service provider coverage area.
Information requested/generated	Quality of information / Information needs	1.5GB within 168 hours.	This is a current-day example of a major OEM update image that would be manually updated and installed today. Normally the process of downloading the software update occurs in the background and should defer to more latency-sensitive applications.
Service Level Latency	[ms]	Not applicable	Software updates themselves are not latency-sensitive.
Service Level Reliability	%	99	Software updates should successfully transfer reliably but this can occur over an extended period as above. Exceptions would be when a vehicle is persistently out-of-range (for example, in long-term underground parking), or only sporadically within range (such as a farmer who only occasionally drives into town), in which case priority may be given for a more rapid download when they are in range.
Velocity	[m/s]	up to 19.4 (70 km/h)	This is a typical city speed, where it will be helpful to collect software updates over time. Note that a consistent download rate is not required, since the

			download may collect parts of the software image as available and pause and continue downloading as needed.
Vehicle Density	[vehicle/km^2]	1500 vehicles/km^2 < 15 vehicles/km^2 typically need a specific update at a time.	For instance, assuming an overall vehicle density of 1500 vehicles/km^2, but only a fraction of these would require a specific software update due to differing vehicle manufacturers, vehicle platforms, on-board equipment, and other factors. We expect that <1% of vehicles would need a specific software update at any given time.
Positioning	[m]	30 (1σ)	It is typically enough for the network service provider to identify in which street/road and approximate position inside this street/road. More precision could be helpful to validate that a vehicle is safely parked before an update installation begins, or whether it is within range of other communications mechanisms (e.g., home Wi-Fi).
Interoperability/ Regulatory/ Standardization Required	[yes/no]	No / Yes / No	We expect individual vehicle manufacturers and 3rd party SW Update system developers will specify their own software updates and this will not be interoperable across manufacturers. There may be regulatory requirements, and for conventional vehicles we rely on current expectations for updates, which typically require service by dealerships and may take months to schedule and implement. Standardization could be helpful but is not required, given the proprietary nature of updates and specific architectural needs from different vehicle manufacturers.

User Story	Detailed description and specifics
Software Update (Autonomous-Routine)	The “normal” case requiring a software update in an autonomous (self-driving) vehicle. The controlling party is asked for consent to install the software, potentially specifying preconditions (e.g., no passengers aboard, during off-peak hours, during next refueling / recharging, etc).

	The software is downloaded securely and reliably, as coverage and bandwidth are available. Its transmission must not adversely affect any safety-critical or user experience-critical functions. Software installation is a separate process that occurs when safe and the controlling party conditions are met.

Software Update (Autonomous-Routine)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Within network service provider coverage	In principle, the user story is applicable in the network service provider coverage area.
Information requested/generated	Quality of information / Information needs	3GB within 24 hours	This is a conservative estimate of a current self-driving stack based on publicly-available information. Normally the process of downloading the software update occurs in the background and should defer to more latency-sensitive applications.
Service Level Latency	[ms]	Not applicable	Software updates themselves are not latency-sensitive.
Service Level Reliability	%	99	Software updates should successfully transfer reliably but this can occur over an extended period as above. Exceptions would be when a vehicle is persistently out-of-range (for example, in long-term underground parking), or only sporadically within range (such as a farmer who only occasionally drives into town), in which case priority may be given for a more rapid download when they are in range.
Velocity	[m/s]	19.4 (70 km/h)	This is a typical city speed, where it will be helpful to collect software updates over time. Note that a consistent download rate is not required, since the download may collect parts of the software image as available and pause and continue downloading as needed.
Vehicle Density	[vehicle/km^2]	1500 vehicles/km^2 < 15 vehicles/km^2 typically need a specific update at a time.	For instance, assuming an overall vehicle density of 1500 vehicles/km^2, but only a fraction of these would require a specific software update due to differing vehicle manufacturers, vehicle platforms, on-board equipment, and other factors. We expect that <1% of vehicles would need a specific software update at any given time.
Positioning	[m]	30 (1σ)	It is typically enough for the network service provider to identify in which street/road and approximate position inside this street/road.

			More precision could be helpful to validate that a vehicle is safely parked before an update installation begins, or whether it is within range of other communications mechanisms (e.g., home Wi-Fi).
Interoperability/ Regulatory/ Standardization Required	[yes/no]	No / Yes / No	We expect individual vehicle manufacturers and 3rd party SW Update system developers will specify their own software updates and this will not be interoperable across manufacturers. There may be regulatory requirements, and for conventional vehicles we rely on current expectations for updates, which typically require service by dealerships and may take months to schedule and implement. However, the expectations for self-driving vehicles and corresponding regulations will require much greater urgency and may even include temporarily removing an affected vehicle from normal driving operations. Once the vehicle is parked, the urgency to apply the software update depends on commercial concerns such as the cost of vehicle downtime in an autonomous fleet. Standardization could be helpful but is not required, given the proprietary nature of updates and specific architectural needs from different vehicle manufacturers.

User Story	Detailed description and specifics
Software Update (Autonomous-Urgent)	Urgent need for critical software update in an autonomous (self-driving) vehicle. In this case, the first priority may be to order the vehicle to safely exit the roadway and park. The controlling party is informed of a critical need for an update and agrees to the vehicle state requirements to perform the download and update (e.g., in route or stopped, passengers onboard or empty, etc.). With controlling party's consent regarding the conditions, the vehicle update is performed, which may require steps to stop in a safe location and inform passengers on board. Once the controlling party agrees to the conditions, the updates are downloaded to target vehicles, while necessary requirements for update installation (like safely parking) are addressed in parallel. If passengers are aboard, the controlling party (e.g., fleet operator) or vehicle informs passengers of the situation and attends to their comfort and safety. For example, another vehicle may be dispatched to carry the passengers to their destinations. Assuming no passengers are aboard OR the download and installation can be completed with high confidence quickly (within minutes), the software download and installation proceed as in the routine case, but with a higher delivery priority (i.e. streaming or other content downloads take lower priority). In cases of longer update installation durations, passengers may be transferred to another vehicle and the download will occur as if routine while the vehicle is parked. However, the high cost of an expensive autonomous vehicle sitting idle while another is needed to deal with passengers, or any time the update can be accomplished more quickly than the

	arrival of a replacement vehicle, make the "update while you wait" scenario more compelling.

Software Update (Autonomous-Urgent)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Within network service provider coverage	In principle, the use case is applicable in the network service provider coverage area.
Information requested/generated	Quality of information / Information needs	3GB within 2 hours.	This is a conservative estimate for a current self-driving stack based on publicly-available information. Normally the process of downloading the software update occurs in the background and should defer to more latency-sensitive applications.
Service Level Latency	[ms]	10 minutes to deliver "critical update required" message	The most stringent requirement is to deliver the "critical update required" message, especially in the case of an autonomous vehicle. But even this is in the range of minutes. Software updates themselves are not latency-sensitive.
Service Level Reliability	%	99	Software updates should successfully transfer reliably but this can occur over an extended period as above. Exceptions would be when a vehicle is persistently out-of-range (for example, in long-term underground parking), or only sporadically within range (such as a farmer who only occasionally drives into town), in which case priority may be given for a more rapid download when they are in range.
Velocity	[m/s]	69.4 (250 km/h)	This is an allowed speed in some motorways and at least the "critical update required" message should be deliverable at any speed the vehicle is likely to travel. Ideally the download itself can be completed at this speed. Once the vehicle is parked and secured, installation can be completed over a longer period.
Vehicle Density	[vehicle/km^2]	1500 vehicles/km^2	For instance, assuming an overall vehicle density of 1500 vehicles/km^2, but only a fraction of these would require a specific software update due to differing

		< 15 vehicles/km^2 typically need a specific update at a time.	vehicle manufacturers, vehicle platforms, on-board equipment, and other factors. We expect that <1% of vehicles would need a specific software update at any given time.
Positioning	[m]	30 (1σ)	It is typically enough for the network service provider to identify in which street/road and approximate position inside this street/road. More precision could be helpful to validate that a vehicle is safely parked before an update installation begins or whether it is within range of other communications mechanisms (e.g., home Wi-Fi).
Interoperability/ Regulatory/ Standardization Required	[yes/no]	No / Yes / No	We expect individual vehicle manufacturers and 3rd party SW Update system developers will specify their own software updates and this will not be interoperable across manufacturers. There may be regulatory requirements, and for conventional vehicles we rely on current expectations for updates, which typically require service by dealerships and may take months to schedule and implement. However, the expectations for self-driving vehicles and corresponding regulations will require much greater urgency and may even include temporarily removing an affected vehicle from normal driving operations. Once the vehicle is parked, the urgency to apply the software update depends on commercial concerns such as the cost of vehicle downtime in an autonomous fleet. Standardization could be helpful but is not required, given the proprietary nature of updates and specific architectural needs from different vehicle manufacturers.

User Story	Detailed description and specifics
Software Update	Software update delivery outside network service provider coverage. A vehicle is outside of V2I/V2N coverage and enters the C-V2X range of another vehicle with the appropriate software update available.

(Without Infrastructure)	For example, two or more similar vehicles from the same managed fleet arrive in close proximity to transfer cargo, refuel / recharge, or for the explicit purpose of receiving an update or other maintenance. • Assumes a site outside network service or roadside infrastructure coverage where at least two vehicles come into close proximity of each other. • At least one vehicle (the "serving vehicle") holds the appropriate software update and can serve as a secure download server to the target vehicle(s). • Before the software transfer is initiated, the system in the serving vehicle identifies the target vehicle(s) and the need for software updates. This process may be done through a bulletin published by the serving vehicle which identifies vehicles needing specific updates. • The driver (human or robot) is informed that a critical update is in progress and that the vehicle should not be powered down or driven until update completion. • The download must happen over a short period while the vehicles are in close proximity of each other.

Software Update (Without Infrastructure)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	< 100m between vehicles	This user story assumes the vehicles are in close proximity.
Information requested/generated	Quality of information / Information needs	1.5GB	This is a current-day example of a major OEM update image that would be manually updated and installed today.
Service Level Latency	[ms]	30 seconds	The goal is to deliver updates vehicle-to-vehicle and minimize disruption to their regular activity.
Service Level Reliability	%	99	Software updates should successfully transfer completely and reliably 99% of the time in the time desired above.
Velocity	[m/s]	0	We assume the vehicles will be parked in close proximity for this transfer.
Vehicle Density	[vehicle/km^2]	1500 vehicles/km^2 Minimum of 2 vehicles involved (server and target)	For instance, assuming an overall vehicle density of 1500 vehicles/km^2, but this is a Vehicle-to-Vehicle application for a "peer to peer" transfer. Scenarios where one server delivers updates to multiple targets at a time are also desirable.
Positioning	[m]	50 (1σ)	Vehicles need to be in close proximity, and are expected to identify each other directly.

Interoperability/ Regulatory/ Standardization Required	[yes/no]	No / Yes / No	We expect individual vehicle manufacturers and 3rd party SW Update system developers will specify their own software updates and this will not be interoperable across manufacturers. There may be regulatory requirements, and for conventional vehicles we rely on current expectations for updates, which typically require service by dealerships and may take months to schedule and implement. Standardization could be helpful but is not required, given the proprietary nature of updates and specific architectural needs from different vehicle manufacturers.

User Story	Detailed description and specifics
Software Update (Vehicle to Workshop)	Software update delivery in a specific context, such as a dealership, workshop, or fleet parking facility. A vehicle enters an area where “private” C-V2X capability / RSU can quickly deliver a software update directly to the vehicle. For example, a vehicle enters a workshop for a brief service such as changing tires or replacing fluids, and relevant software updates are available. The software is delivered quickly via a direct C-V2X connection while other services are performed. This reduces total downtime and provides updates in a safe situation where technicians are available in case of anomaly, taking advantage of close range and unlicensed spectrum. • Assumes a controlled environment such as a dealership / workshop, fueling / charging station, or fleet parking facility. • The download must be completed quickly with the car stationary, with systems powered on to handle the transfer and installation. • The driver (human or robot) and technician (if applicable) are informed that a critical update is in progress and that the vehicle should not be powered down or driven until update completion. • Before the software transfer is initiated, the secure local RSU identifies the target vehicle(s) and the need for software updates. This process may be done through a bulletin published by the RSU which identifies vehicles needing specific updates.

Software Update (Vehicle to Workshop)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	< 100m between	Scenario is within a specific location and context as described.

		vehicle and RSU	
Information requested/generated	Quality of information / Information needs	32GB	This is a current-day example of a major OEM update package that today would be manually updated and installed.
Service Level Latency	[ms]	15 minutes	The goal is to deliver updates while other minor services such as tire changes are performed.
Service Level Reliability	%	99.9	Software updates should successfully transfer reliably and within the desired timeframe.
Velocity	[m/s]	0	We assume the vehicles will be parked during the download.
Vehicle Density	[vehicle/km^2]	1500 vehicles/km^2 Up to 100 vehicles updated simultaneously	For instance, assuming an overall vehicle density of 1500 vehicles/km^2, but a maximum of 100 vehicles to be updated at any one time within the facility.
Positioning	[m]	50 (1σ)	Vehicles need to be in close proximity to the private C-V2X RSU.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	No / Yes / No	We expect individual vehicle manufacturers and 3rd party SW Update system developers will specify their own software updates and this will not be interoperable across manufacturers. There may be regulatory requirements, and for conventional vehicles we rely on current expectations for updates, which typically require service by dealerships and may take months to schedule and implement. Standardization could be helpful but is not required, given the proprietary nature of updates and specific architectural needs from different vehicle manufacturers.

4.6 Remote Vehicle Health Monitoring

User Story	Detailed description and specifics
User Story #1	A vehicle is travelling on a highway and is losing air pressure in one or more of its tires. A road or fleet operator needs to be made aware of the situation.

User Story #1			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	There is no concrete upper limit to the desired range. The vehicle needs to convey the message to the road operator of fleet manager cloud which in most cases is physically far away from the vehicle.
Information requested/generated	Quality of information / Information needs	< 1KB	The information must be timely and accurate. Since the information is safety related, it must be accurate.
Service Level Latency	[ms]	< 30 sec	Latency is not a critical factor.
Service Level Reliability	%	99.99	It is critical that the information be sent and received successfully.
Velocity	[m/s]	69.4	Health monitoring related events and messages should be able to be sent successfully at maximum highway driving speeds (250 km/h).
Vehicle Density	[vehicle/km^2]	12000	A vehicle that is on the verge of becoming stranded due to a degrading condition should be able to successfully send the information in a traffic congested environment.
Positioning	[m]	1.5 m (3σ)	Since this information may be used to dispatch assistance, the location of the vehicle must be known within a lane width and within the vehicle's length. 1.5 meters is the typical accuracy required to locate a vehicle within a lane.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Information should be standardized to enable road operators to identify vehicles that are at risk of becoming stranded and dispatch an appropriate level of assistance.

4.7 Hazardous Location Warning

User Story	Detailed description and specifics
HV only supported by RVs	A Remote Vehicle (RV) is driving on the road and approaches a dangerous area which is detected by using RV's sensors. The HV might drive behind the RV in the same direction, or in front of the RV in the opposite direction, so towards the area where the RV has

	detected the dangerous situation. RVs detecting such dangerous situations will broadcast information about those with other vehicles, e.g., the HV. The HV or HV driver can assume appropriate actions after having received the awareness information.
HV receives information from a backend/cloud	This use case mainly refers to a Real Time HD Map update service. The HV is receiving information that is relevant for the road/route ahead from a backend, containing information that might allow the HV to adjust its route accordingly. The traffic management mentioned in 'Other Actors' roles' could play a role here.

User Story #1 (HV only supported by RVs)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	300 – physical limit	Communication is only done by vehicles in the vicinity of the HV. It is limited to the range of physical transmission.
Information requested/generated	Quality of information / Information needs	300 bytes	Normal size of awareness messages (e.g., CAM, BSM) should be enough, maybe containing fields indicating common types of critical situations that lie ahead. Transmission of detailed object information is not needed. Standard transmission rate of 10 Hz should be enough.
Service Level Latency	[ms]	100	Driving with 120 km/h, 300 m (minimum communication range) will take just short of 10 s, so 100 ms for the car to react should be enough.
Service Level Reliability	%	99	The HV could aggregate warnings from several RVs, each individual RVs reliability thus does not have to be too high.
Velocity	[m/s]	69.4	250 km/h – Max speed on highways, also realistic for relative speeds of HV and RV driving in different directions.
Vehicle Density	[vehicle/km^2]	12000 (urban) 9000 (rural) 4500 (highway)	Maximum assumption on vehicle density.
Positioning	[m]	1.5 (3σ)	Typical positioning accuracy to confirm traffic lane.

		5 (1σ)	For non-lane-specific information, less accurate localization is acceptable.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Inter-OEM-operability must be assured.

User Story #2 (HV receives information from a backend/cloud)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	~ 30 000	Situations are relevant along a navigation route or along a road if a navigation route is not known. Depends on the needs for efficient re-routing.
Information requested/generated	Quality of information / Information needs	300 – 1000 bytes	From the backend, the HV will receive information (events, or vector data), not raw data. Some details are needed, but still no need for detailed object descriptions or the like.
Service Level Latency	[ms]	1 – 2 s / 10 – 200 s	Information may need to be aggregated from multiple RVs before a situation is identified.1-2 s for safety-related information concerning the vicinity of the HV; 10 – 200 s for general information about route obstructions or the like further ahead, in order to make timely rerouting possible.
Service Level Reliability	%	99 Low	For safety-related information, timely and reliable communication is decisive. In the backend, data of several vehicles is aggregated, so the single vehicle’s data has to be moderately reliable. For rerouting information, this should be enough.
Velocity	[m/s]	69.4	250 km/h – Max speed on highways
Vehicle Density	[vehicle/km^2]	12000 (urban) 9000 (rural) 4500 (highway)	Maximum assumption on vehicle density.
Positioning	[m]	1.5 (3σ) 5 (1σ)	Typical positioning accuracy to confirm traffic lane. For non-lane-specific information, less accurate localization is acceptable.

Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Inter-vendor-operability must be assured.

4.8 Speed Harmonization

User Story #1 (In user story#1, we assume human driver drives HV which would then result in taking human reaction time into account for SLR calculation.)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	123/59/26	This value is calculated as concatenation of braking distance of HV and d_{RVf}. d_{RVf}. It can be derived from the typical braking distance formula with velocity of stationary vehicles (i.e. RV). Braking distance formula = (Human reaction time)*velocity + velocity^2/(2μg). where μ represents the coefficient of friction and g represents gravitational acceleration. In order to acquire sample values, we used the following assumptions. μ = 0.8 g = 9.8 [m/s^2] Human Reaction Time = 1.0 [s]
Information requested/generated	Quality of information / Information needs	Information about RV(s) speed/position Information to HV about recommended speed (Maximum 300 bytes for payload size)	Information may be processed locally by HV to determine harmonized speed (if only dependent on RV(s) speed/position). Information may be processed by external entity that determines recommended speed to advise HV about. Assuming 300bytes is enough to carry speed and location information.
Service Level Latency	[ms]	2500/1800 /1400	Latency should be low enough to allow a smooth adjustment, collisions could be prevented by on-board

			sensors or other means. Exact value can be derived from d_{RVf} divided by speed gap between HV and RV.
Service Level Reliability	%	80	This should be relatively lower than the value for other safety critical use cases.
Velocity	[m/s]	Highway: 69.4 Rural: 33.3 Urban: 19.4	Assuming typical maximum allowed speeds and some safety margin.
Vehicle Density	[vehicle/km^2]	12000	Max assumed density in urban situation.
Positioning	[m]	1.5 (3σ)	Same as other scenario which requires lane level positioning accuracy, assuming different speed limit is applicable per lane.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

User Story #2 (In user story#2, we assume HV is highly automated, therefore human reaction time does not have to be considered at all.)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	59/23/8	This value is calculated as concatenation of braking distance of HV and d_{RVf}. d_{RVf} can be derived by typical braking distance formula with velocity of stationary vehicle(i.e. RV). Braking distance formula = (Human reaction time)*velocity + velocity^2/(2μg) where μ represents coefficient of friction and g does gravitational acceleration. In order to acquire sample values, we used following. μ = 0.8 g = 9.8 [m/s^2] Human Reaction Time = 0 [s]
Information requested/generated	Quality of information /	Information about RV(s)	Information may be processed locally by HV to determine harmonized speed (if only dependent on RV(s) speed/position).

	Information needs	speed/position Information to HV about recommended speed (Maximum 300 bytes for payload size)	Information may be processed by external entity that determines recommended speed to advise HV about. Assuming 300bytes is enough to carry speed and location information.
Service Level Latency	[ms]	1500/800/400	Latency should be low enough to allow a smooth adjustment, collisions could be prevented by on-board sensors or other means. . The exact value can be derived from d_{RVf} divided by the speed gap between HV and RV.
Service Level Reliability	%	80	This should be relatively lower than the value for other safety critical use cases.
Velocity	[m/s]	Highway: 69.4 Rural: 33.3 Urban: 19.4	Assuming typical maximum allowed speeds and some safety margin.
Vehicle Density	[vehicle/km^2]	12000	Max assumed density in urban situation.
Positioning	[m]	1.5 (3σ)	Same as other scenarios which require lane level positioning accuracy, assuming different speed limits are applicable per lane.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization.

4.9 High Definition Sensor Sharing

User Story #1			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Min. 80	40m is approximately 2s driving time at 160km/h, which should provide enough time for sensor sharing negotiation.

Information requested/generated	Quality of information / Information needs	numerical	Processed and unprocessed data may be exchanged Near zero error rate tolerance (after error correction) on transmission link is required. Max 1000 bytes packet size (processed data). Larger for un-processed data.
Service Level Latency	[ms]	10	Lowest possible latency is needed to reduce reaction times of HV and RV. 10ms is considered realistically achievable in 3GPP Rel-16.
Service Level Reliability	%	99.9	Very high, the reliability here should be sufficient to guarantee QoS (whole system).
Velocity	[m/s]	69.4	Max highway speed assumed to be 250km/h.
Vehicle Density	[vehicle/km^2]	12000	Max assumed density in urban situation
Positioning	[m]	0.1 (3σ)	Relative between two vehicles. High accuracy is required to avoid collision.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between manufacturers' implementations to be guaranteed by standardization. Processed sensor data shall be understandable between different manufactures' implementations.

4.10 See-Through for Pass Maneuver

User Story #1			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	100	As the two vehicles concerned in the exchange of visual information are driving in the same lane, the communication range is: from 50 to 100 meters, considering a legal headway of 2 seconds.
Information requested/generated	Quality of information / Information needs	15 Mbps	Video Streaming. 15 Mbps are needed to transmit a progressive high definition video signal with resolution 1280x720, frame rate 30 Hz, colour depth 8 bit, 24 bit resolution, subsampling 4:2:2 and a typical compression of 1:30 (e.g., with H.264).

Service Level Latency	[ms]	50	The latency requirement for a video frame depends on the vehicle speed and heading as well as pitch angle changes. Latency of 50 ms should be kept, lower values would increase the experience of this function. Additional delays would lead to additional buffering in the rear vehicle. 50ms is the considered e2e communication layer latency, without including application layer processing times e.g., coding, de-coding. Additional Latency requirements • The duration of service discovery phase should be in maximum 500ms (i.e. time duration for HV to identify if RV supports the see-through service).Service Discovery includes the communication establishment phase (i.e., receive resources) as well as the discovery request and discovery response messages that HV and RV send, respectively. • The see-through establishment phase (i.e., a) HV asks for see-through and b) RV provides the first video frame) should complete in maximum within 500ms. Service Discovery and see-through establishment within 1000ms will help the driver of the HV to activate the requested see-through service quickly and take a fast decision whether to proceed within the overtake action. This also affects the engagement of the driver with the see-through application • The see-through release phase should be complete in maximum within 500ms.
Service Level Reliability	%	99	Reliability 99% at the communication layer of for video frames is needed to avoid massive artefacts that may lead to degradation of video quality for assisted driving. The video will be used to distinguish objects, front vehicles etc in order to support driver's decision to realize an overtake or not.
Velocity	[m/s]	33.3 (120 km/h)	This is the maximum speed limit for non-urban streets (i.e. not highways).120 km/h is the maximum speed of the HV and RV.

			Note: The transmitter of the video and the vehicle receiving the information will be more or less at the same speed 0 to 30 km/h (relative velocity).
Vehicle Density	[vehicle/km^2]	9000	This type of service is most probable to be used in rural road environments. 2 vehicles are involved in this use cases.
Positioning	[m]	1.5 (3σ)	A positioning accuracy to know HV's and RV's location (including direction) and lane.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability is needed between the vehicles that participate in the see-through service. Regulatory oversight for safety-related issues is needed. Standardization on the application layer (message set and flow control).

4.11 Lane Change Warning

User Story #1 (Lane change warning – lagging vehicle{:RV1_v>HV_v}, High Way)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	83	The range is derived from the different between HV (100kmh) and RV1 (120kmh) speeds.
Information requested/generated	Quality of information / Information needs	Approx. 300 bytes per message / high QoS	Speed, Global Navigation Satellite System (GNSS) location, past trajectory, turn sign ON and side, like awareness frame messaging (e.g., BSM).
Service Level Latency	[ms]	400	Depend on the number of repetitions and message cadence.
Service Level Reliability	%	99.9	A service level reliability this high should be enough to allow perceived zero-error appearance of the lane change. False positives are more problematic than false negatives.
Velocity	[m/s]	HV (28) RV1 (33)	Varies between rural, urban and highway. But more important for this UC is the speed different between the HV and RV

Vehicle Density	[vehicle/km^2]	4500	Maximum considered density for a highway road environment.
Positioning	[m]	1.5 (3σ)	In order to perform lane-accurate positioning, a positioning accuracy of around 1.5m should be provided.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between different OEMs is needed. It should be regulated that every vehicle has to make its presence known periodically (as a broadcast). Standardization is required in the sense that the format for trajectories should be common to all so that they can be understood by all.

User Story #2 (Lane change warning –leading vehicle {: HV_v>RV2_v}, Urban)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	28	The range is derived from the different between the HV and RV speeds.
Information requested/generated	Quality of information / Information needs	Approx. 300 bytes per message / high QoS	Speed, GNSS location, past trajectory, turn sign ON and side, like awareness frame messaging (e.g., BSM).
Service Level Latency	[ms]	400	Depend on the number of repetitions and message cadence.
Service Level Reliability	%	99.9	A service level reliability this high should be enough to allow perceived zero-error appearance of the lane change. False positives are more problematic than false negatives.
Velocity	[m/s]	RV2 (11) HV (14)	Varies between rural, urban and highway. But more important for this UC is the speed different between the HV and RV.
Vehicle Density	[vehicle/km^2]	12000	Maximum considered density for an urban road environment.
Positioning	[m]	1.5 (3σ)	In order to perform lane-accurate positioning, a positioning accuracy of around 1.5m should be provided.

Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between different OEMs is needed. It should be regulated that every vehicle has to make its presence known periodically (as a broadcast). Standardization is required in the sense that the format for trajectories should be common to all so that they can be understood by all.

User Story #3 (Lane change warning –Not Permitted {: T_Maneuver>T_safe}, Rural)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	51	The range is derived from the different between the HV and RV speeds,
Information requested/generated	Quality of information / Information needs	Approx. 300 bytes per message / high QoS	Speed, GNSS location, past trajectory, turn sign ON and side, like awareness frame messaging (e.g., BSM).
Service Level Latency	[ms]	400	Depend on the number of repetitions and message cadence.
Service Level Reliability	%	99.9	A service level reliability this high should be enough to allow perceived zero-error appearance of the lane change. False positives are more problematic than false negatives.
Velocity	[m/s]	HV (23)	Varies between rural, urban and highway. But more important for this UC is the speed different between the HV and RV.
Vehicle Density	[vehicle/km^2]	9000	Maximum considered density for a rural road environment.
Positioning	[m]	1.5 (3σ)	In order to perform lane-accurate positioning, a positioning accuracy of around 1.5m should be provided.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	Interoperability between different OEMs is needed. It should be regulated that every vehicle has to make its presence known periodically (as a broadcast). Standardization is required in the sense that the format for trajectories should be common to all so that they can be understood by all.

4.12 Vulnerable Road User

User Story	Detailed description and specifics

Awareness of the presence of VRUs near potentially dangerous situations	This VRU user story describes a scenario in which a presence warning at crossings and spots without line-of-sight (LOS), e.g., automatic detection of pedestrians waiting and/or crossing from infrastructure is intended. VRUs are watched via infrastructure support as surveillance cameras / wireless detection mechanisms and/or are equipped with mobile VRU devices (UE). Awareness notifications are shared with drivers e.g., via roadside units / monitoring system attached to a 3GPP system (e.g., potentially using MEC) sending messages to drivers or drivers C-ITS systems monitor actively VRUs that are equipped with a device.
	
	The User Story involves one or multiple vehicles and it assumes V2I and/or V2P connectivity.
	
	In this user story a vehicle has entered an area in which VRUs are present.
	
	- The area could be crossings (incl. cross-walks, zebra crossings) and spots without line-of-sight (LOS)
	- VRUs are watched via infrastructure support as surveillance cameras / wireless detection mechanisms and/or are equipped with mobile VRU devices (UE).
	- Awareness notifications are shared with driver’s e.g.,
	    o via roadside units or
	    o via monitoring systems attached to a 3GPP system (extension of user story e.g., potentially using MEC) sending messages to drivers or vehicle’s C-ITS systems monitor actively VRUs that are equipped with a device.

Collision risk warning	This VRU user story describes a scenario in which a collision prevention at crossings and spots without LOS, e.g., automatic detection of pedestrians waiting and/or crossing from infrastructure is intended.
	
	In this VRU user story the accuracy, performance and functionality of VRU devices incl. UEs is sufficient for collision risk detection, and vehicles share the information collected by sensors with each other.
	
	Vehicles have entered an area in which VRUs are present.
	
	- The area could be crossings (incl. cross-walks, zebra crossings) and spots without line-of-sight (LOS)
	- VRUs are watched via infrastructure support as surveillance cameras / wireless detection mechanisms and/or are equipped with mobile VRU devices (UE).
	- VRUs are watched via information collected by vehicles sensors and relevant information is shared with other vehicles and/or road site units.
	- Warning notifications are shared with driver’s e.g.,
	    o via roadside units or
	    o via monitoring systems attached to a 3GPP system (e.g., potentially using MEC) sending messages to drivers
	    o other vehicle’s C-ITS system based on sensor data
	    o vehicle’s C-ITS systems monitoring actively VRUs that are equipped with a device.

	- Cooperative actions and maneuvers are enabled via cooperative message exchange in a bi-directional manner.

User Story #1 (Awareness of the presence of VRUs near potentially dangerous situations)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Min. 80 a) Urban 150 b) Rural 300	1. For long distances we expect local sensors of the vehicle (electronic horizon) to be able to resolve VRU protection scenarios. 2. We do not foresee that a full stop will be feasible in most VRU protection scenarios. It is rather to trigger an obstacle avoidance maneuver. Therefore, 40m are roughly 2s driving time when driving with 80km/h should provide enough time to trigger an appropriate event.
Information requested/generated	Quality of information / Information needs	Surveillance: medium quality Safety: very high	Surveillance: The data rate depends strongly on the capabilities of the different C-ITS systems to process received RAW data and generate information data. To allow all "sensor detected" data being shared we recommended initially a higher data rate. The end goal is to communicate only information/processed data. Safety: Vehicle needs information on the precise location of the VRUs in its vicinity and its own position in the near future.
Service Level Latency	[ms]	100 Recommended communication latency: 20	This is the maximum latency tolerable for allowing for a reaction due moving VRUs very near the road. 20 ms for VRU communication latency are comparable to that of cooperative maneuvers and sensor sharing because we see that the VRU situations will occur much more unexpected and in close proximity to the vehicle. Thus, longer communication latencies would be adversarial to the intended purpose. Example for justification: For a 50 km/hr drive in dense urban environments (80m communication radius), the total time budget until a potential complete stop has to be initiated is approximately 3.96 sec.
Service Level Reliability	%	99.9	High, the reliability here should be sufficient to guarantee QoS. 99.9% should be sufficient, since additional vehicle sensors are in place that can help to avoid collisions.

Velocity	[m/s]	Urban: 19.4 Rural: 33.3	In urban areas, considering 70 km/h max speed. In rural areas, considering 120 km/h max speed.
Vehicle Density	[vehicle/km^2]	Concerned VRUs: ~300 total Present VRUs per km^2: ~10000 Vehicles: 1500	Figures given only for urban areas, since we consider this one as the more critical case with regards to vehicle number/density. Concerned VRUs are the ones near streets, not counting workers in offices or the like. However, for total network load, etc., all VRUs in the given area have to be considered, that is as many as the network can support.
Positioning	[m]	1m (3σ)	In order to correct positioning based on GNSS (e.g., GPS, Galileo), this accuracy should be enhanced via the 3GPP System. The 3GPP System shall provide a positioning accuracy of 1 – 2 m, e.g., considering support of GNSS, highly accurately positioned RSU and CV2X UEs.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	In order to make it possible to share information and data on VRUs between vehicles, inter-OEM-operability should be guaranteed. Interoperability of UEs with RSUs, vehicles, and other local entities should be also guaranteed.

User Story #2 (Collision risk warning)			
Service level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Min. 80 a) Urban 150 b) Rural 300	1. Limited range for calculations = 80m, since this is the communication range in highly-dense metropolitan areas. 2. For longer-distances we expect other local sensors of the vehicle (electronic horizon) to be able to assist in VRU protection scenarios. 3. We do not foresee that a full stop will be feasible in most VRU protection scenarios. It is rather to trigger an obstacle avoidance maneuver. Therefore, 40m are roughly 2s driving time when driving with 80km/h should provide enough time to trigger an appropriate event.

Information requested/generated	Quality of information / Information needs	Surveillance: medium quality Safety: very high	Surveillance: The data rate depends strongly on the capabilities of the different C-ITS systems to process received RAW data and generate information data. To allow all “sensor detected” data being shared we recommended initially a higher data rate. Safety: Vehicle needs information on the precise location of the VRUs in its vicinity and its own position in the near future.
Service Level Latency	[ms]	100 Recommended communication latency: 20	This is the maximum latency tolerable for allowing for a reaction due moving VRUs very near the road. 20 ms for VRU communication latency are comparable to that of cooperative maneuvers and sensor sharing because we see that the VRU situations will occur much more unexpected and in close proximity to the vehicle. Thus, longer communication latencies would be adversarial to the intended purpose. Example for justification: For a 50 km/hr drive in dense urban environments (80m communication radius), the total time budget until a potential complete stop has to be initiated is approximately 3.96 sec.
Service Level Reliability	%	99.9	High, the reliability here should be sufficient to guarantee QoS. 99.9% should be sufficient, since additional vehicle sensors are in place that can help to avoid collisions.
Velocity	[m/s]	Urban: 19.4 Rural: 33.3	In urban areas, considering 70 km/h max speed. In rural areas, considering 120 km/h max speed.
Vehicle Density	[vehicle/km^2]	Concerned VRUs: ~300 total Present VRUs per km^2: ~10000 Vehicles: 1500	Figures given only for urban areas, since we consider this one as the more critical case with regards to vehicle number/density. Concerned VRUs are the ones near streets, not counting workers in offices or the like. However, for total network load, etc., all VRUs in the given area have to be considered.
Positioning	[m]	0.5m (3σ)	In order to correct positioning based on GNSS (e.g., GPS, Galileo), this accuracy should be enhanced via the 3GPP System.

			The 3GPP System shall provide a positioning accuracy of 0.5 m, e.g., considering support of GNSS, highly accurately positioned RSU and CV2X UEs.
Interoperability/ Regulatory/ Standardization Required	[yes/no]	Yes / Yes / Yes	In order to make it possible to share information and data on VRUs between vehicles, inter-OEM-operability should be guaranteed. Interoperability of UEs with RSUs, vehicles, and other local entities should be also guaranteed. Sharing information collected by sensor data form vehicles passing / approaching the area where VRUs are present references UC T-170339

5.0 Conclusions and Next Steps

This document presented an example set of C-V2X use case descriptions, the service level requirements and the corresponding framework developed in WG1 for the description of solution agnostic use cases and service level requirements.

5GAA WG1 continues to work on more advanced C-V2X use cases with complex interactions and more advanced protocols. These use cases have challenging requirements for future communication systems, such as 5G, and are applicable to both driven and autonomous vehicles, some examples are: “Group Start”, “Tele-Operated Driving”, “Tele-Operated Driving Support”, “Tele-operated Driving for Automated Parking”, “Obstructed View Assist”, “Cooperative Maneuver of Autonomous Vehicles for Emergency Situations”, “Continuous Traffic Flow via Green Lights Coordination”, “Remote Automated Driving Cancellation (RADC)”, “High definition map collecting & sharing”, “Automated Intersection crossing”, “Autonomous vehicles parking by automated Driving”, “In-Vehicle Entertainment (IVE) – High Definition Content Delivery, On-line Gaming and Virtual Reality”.

Annex <A>

A.1 Use Case Description Template

The following table presents the template for detailed description of C-V2X use cases with the corresponding explanation of the different fields.

Template for Use Case Descriptions

Fields	Description
Use Case Name	Name and abbreviation of the use case if existing
User Story/Use Case Scenario	Many user stories can be defined for a single use case. Additionally, different user stories could lead to the same requirements and the same system solution. It is not necessary and likely not practical to define all the user stories initially and it is expected that more user stories can be added later.
Category	Safety | Vehicle Operations Management | Convenience | Autonomous driving | Platooning | Traffic Efficiency and Environmental friendliness | Society and Community
Road Environment	Intersection | Urban | Rural | Highway | Other
Short Description	Short description of the use case
Actors	Drivers, vehicles, traffic lights, VRUs, Remote operators, Application Servers, …. including defining who the sending and receiving actor is (human, vehicle, or AV – automated vehicle, e.g., SAE Automation levels 1-5 that are considered for the specific use case and that may affect the performance requirements).
Vehicle Roles	Host Vehicle (HV) | Remote Vehicle (RV)
Road & Roadside Infrastructure Roles	Role of the road and traffic infrastructure (e.g., traffic signs, lights, ramps, etc.). Does not refer to the network infrastructure.
Other Actors' Roles	The Role of other actors that are involved in this use case (e.g., VRU)
Goal	Goal of the use case.
Needs	The needs to be fulfilled in order to enable the use case.
Constraints / Presumptions	Basic requirements that all actors need to adhere to.
Geographic Scope	Geographic areas where the use case is applicable.
Illustrations	Pictorial information exemplifying the use case and showing the role of the different actors.
Pre-Conditions	Necessary capability of the different actors to ensure the realization of the use case.
Main Event Flow	Flow of events from the moment the use cases is triggered to the moment the use case closes. Includes the trigger point to enter and to exit the use case (i.e., who and what).
Alternative Event Flow	Alternative flow of events in case a different possibility exists. Alternative Event Flows in this document are not intended as replacements for the Main Event Flow. They are intended to represent different possible flows.
Post-Conditions	Description of the output of flow clarifies which data is provided to the HV.

	• Note1: This data will trigger implementation specific actions in the HV • Note 2: This shall also be contained in the field information requirements
Information Requirements	High level description of information exchanged among involved actors (e.g., sensor data, kinematic data, …)

A.2 Detailed Description of Example C-V2X Use Cases

Cross-Traffic Left-Turn Assist

Use Case Name	**Cross-Traffic Left-Turn Assist**
User Story	Assist HV attempting to turn left across traffic approaching from the opposite, left, or right direction.
Category	Safety, Autonomous Driving
Road Environment	Intersections, mostly for rural and outer city intersections, big metropolitan intersections to a lesser extent.
Short Description	Alerts HV attempting to turn left across traffic of an RV approaching from the opposite direction in the lanes that HV needs to cross.
Actors	• Host Vehicle (HV) • Remote Vehicle 1 (RV1) • Remote Vehicle 2 (RV2) • Remote Vehicle 3 (RV3)
Vehicle Roles	• HV represents the vehicle stopped at intersection. • RV1 represents cross-traffic vehicle approaching from the right. • RV2 represents cross-traffic vehicle approaching from the left. • RV3 represents oncoming-traffic vehicle.
Roadside Infrastructure Roles	• Roads are defined by their lane designations and geometry. • Intersections are defined by their crossing designations and geometry. • Traffic lights and stop signs control right of way traffic flow through an intersection (if available). • Local Traffic laws and rules control right of way through 3-way stops, 4-way stops and unsigned intersections.
Other Actors' Roles	Not applicable
Goal	• Avoid a lateral collision between HV and RV1. • Avoid a lateral collision between HV and RV2. • Avoid an oncoming collision between HV and RV3.
Needs	• HV needs to know if there is a risk of collision with RV1 approaching from the right. • HV needs to know if there is a risk of collision with RV2 approaching from the left. • HV needs to know if there is a risk of collision with an oncoming RV3.
Constraints / Presumptions	• RV1's intended direction through the intersection is known or can be guessed based on past values. • RV2's intended direction through the intersection is known or can be guessed based on past values.

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- RV3's intended direction through the intersection is known or can be guessed based on past values.

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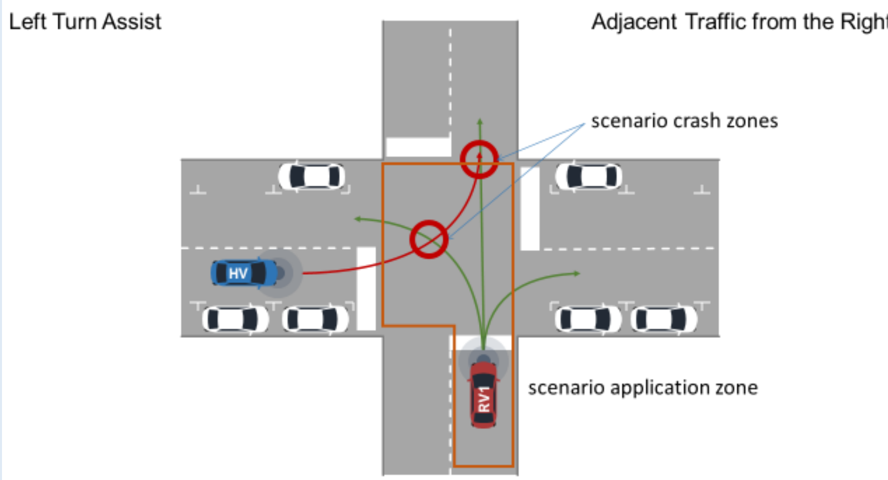
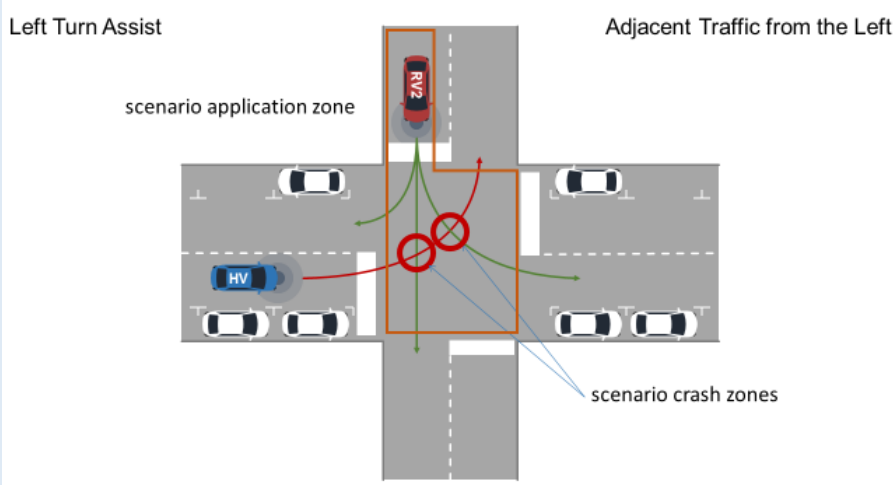
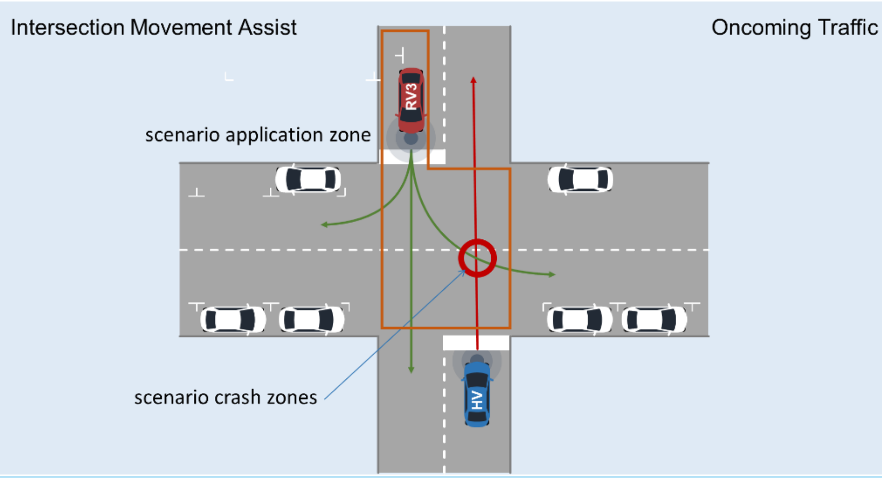
<tr><td>Geographic Scope</td><td>Global</td></tr>
<tr><td>Illustrations</td><td>







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<tr><td>Pre-Conditions</td><td>

- HV is stopped at or moving towards an intersection.
- HV signals its intention to turn left.
- The "Adjacent Traffic from the Right" scenario application zone is determined from:
  - HV's location

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	o lane designations and geometry o intersection geometry o posted speed limits o Road Conditions (if available) • The “Adjacent Traffic from the Left” scenario application zone is determined from: o HV’s location o lane designations and geometry o intersection geometry o posted speed limits o Road Conditions (if available) • The “Oncoming Traffic” scenario application zone is determined from: o HV’s location o lane designations and geometry o intersection geometry o posted speed limits o Road Conditions (if available)
Main Event Flow	• RV1 is in the “Adjacent Traffic from the Right” scenario application zone • If RV1 has the right of way; o RV1’s trajectory through the intersection is estimated using; ▪ RV1’s location and dynamics ▪ RV1’s turn signal state ▪ Lane designations and geometry ▪ Intersection geometry o HV’s trajectory through the intersection is estimated using; ▪ HV’s location ▪ HV’s estimated acceleration ▪ Lane designations and geometry ▪ Intersection geometry o If there is a risk of collision based on the estimated trajectories of HV and RV1 then; ▪ HV is warned of a risk of collision with RV1 approaching from the right. • Otherwise if HV has the right of way; o RV1’s stopping distance is estimated using; ▪ RV1’s location and dynamics ▪ Lane designations and geometry ▪ Intersection geometry ▪ Road Conditions (if available) o If there is a risk that RV1 cannot stop before the intersection; • HV is warned of a risk of collision with RV1 approaching from the right.
Alternative Event Flow	• RV2 is in the “Adjacent Traffic from the Left” scenario application zone • If RV2 has the right of way;

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RV2’s trajectory through the intersection is estimated using;

RV2’s location and dynamics
RV2’s turn signal state
Lane designations and geometry
Intersection geometry

HV’s trajectory through the intersection is estimated using;

HV’s location
HV’s estimated acceleration
Lane designations and geometry
Intersection geometry

If there is a risk of collision based on the estimated trajectories of HV and RV2 then;

HV is warned of a risk of collision with RV2 approaching from the left.

Otherwise if HV has the right of way;

RV2’s stopping distance is estimated using;

RV2’s location and dynamics
Lane designations and geometry
Intersection geometry
Road Conditions (if available)

If there is a risk that RV2 cannot stop before the intersection;

HV is warned of a risk of collision with RV2 approaching from the left.
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<tr>
<td>Post-Conditions</td>
<td>

RV3 is in the “Oncoming Traffic” scenario application zone
If RV3 has the right of way;

RV3’s trajectory through the intersection is estimated using;

RV3’s location and dynamics
RV3’s turn signal state
Lane designations and geometry
Intersection geometry

HV’s trajectory through the intersection is estimated using;

HV’s location
HV’s estimated acceleration
Lane designations and geometry
Intersection geometry

If there is a risk of collision based on the estimated trajectories of HV and RV3 then;

HV is warned of a risk of collision with oncoming RV3.

Otherwise if HV has the right of way;

RV3’s trajectory and stopping distance is estimated using;

RV3’s location and dynamics
RV3’s turn signal state
Lane designations and geometry
Intersection geometry
Road Conditions (if available)

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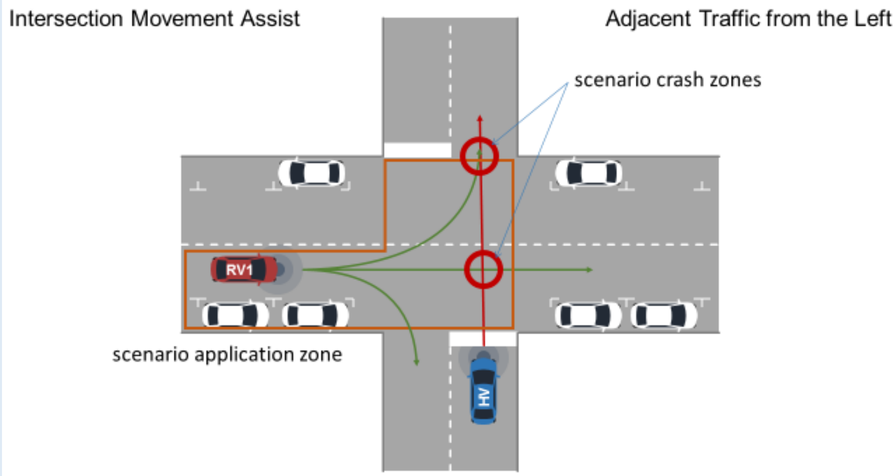
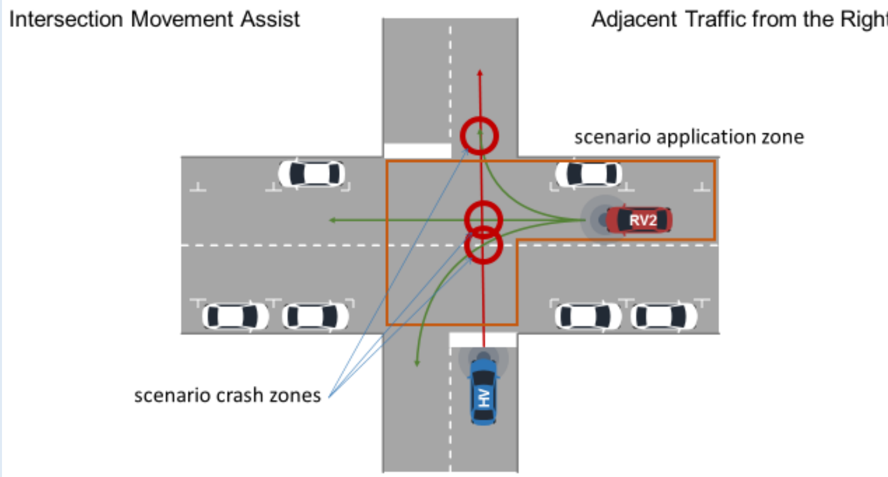
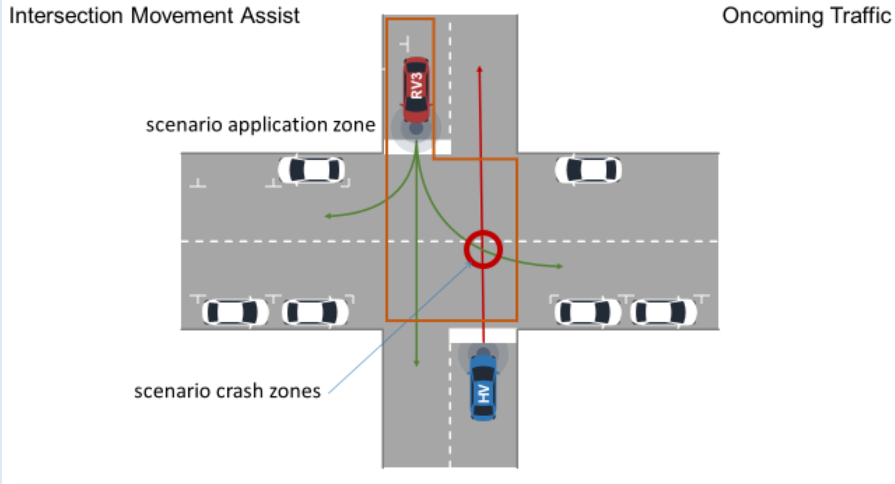
	○ If there is a risk that RV3 cannot stop before the intersection; • HV is warned of a risk of collision with oncoming RV3.
Information Requirements	• HV's location. • HV's turn signal state. • HV's estimated acceleration from stopped. • RV1's location and dynamics. • RV1's turn signal state. • RV2's location and dynamics. • RV2's turn signal state. • RV3's location and dynamics. • RV3's turn signal state. • Lane designations and geometry. • Intersection geometry. • Traffic stop signs. • Traffic light signal phase and timing. • Traffic rules and laws for 3-way stops, 4-way stops and unsigned intersections. • Current Road Conditions (if available)

Intersection Movement Assist

Use Case Name	**Intersection Movement Assist**
User story	Stationary HV proceeds straight from stop at an intersection. HV is alerted if it is unsafe to proceed through the intersection.
Category	Safety, Autonomous Driving
Road environment	Intersections
Short Description	Alerts HV that is stopped and intending to proceed straight through the intersection of: • approaching cross-traffic from the left • approaching cross-traffic from the right • oncoming traffic intending to turn left
Actors	• Host Vehicle (HV) • Remote Vehicle 1 (RV1) • Remote Vehicle 2 (RV2) • Remote Vehicle 3 (RV3)
Vehicle roles	• HV represents the vehicle stopped at intersection. • RV1 represents cross-traffic vehicle approaching from the left. • RV2 represents cross-traffic vehicle approaching from the right. • RV3 represents oncoming-traffic vehicle.
Road & Roadside infrastructure roles	• Roads are defined by their lane designations and geometry. • Intersections are defined by their crossing designations and geometry. • Traffic lights and stop signs control right of way traffic flow through an intersection (if available). • Local Traffic laws and rules control right of way through 3-way stops, 4-way stops and unsigned intersections.

Other Actors' roles	Not applicable
Goal	• Avoid a lateral collision between HV and RV1. • Avoid a lateral collision between HV and RV2. • Avoid an oncoming collision between HV and RV3.
Needs	• HV needs to know if there is a risk of collision with RV1 approaching from the left. • HV needs to know if there is a risk of collision with RV2 approaching from the right. • HV needs to know if there is a risk of collision with an oncoming RV3.
Constraints / Presumptions	• The acceleration of HV from stopped must be assumed. • RV1's intended direction through the intersection is known. • RV2's intended direction through the intersection is known. • RV3's intended direction through the intersection is known.
Geographic Scope	Global
Illustrations	

Pre-Conditions	• HV is stopped at an intersection.
	• The “Adjacent Traffic from the Left” scenario application zone is determined from:
	  ○ HV’s location
	  ○ lane designations and geometry
	  ○ intersection geometry
	  ○ posted speed limits
	  ○ Road Conditions (if available)
	• The “Adjacent Traffic from the Right” scenario application zone is determined from:
	  ○ HV’s location
	  ○ lane designations and geometry
	  ○ intersection geometry
	  ○ posted speed limits
	  ○ Road Conditions (if available)
	• The “Oncoming Traffic” scenario application zone is determined from:
	  ○ HV’s location
	  ○ lane designations and geometry
	  ○ intersection geometry
	  ○ posted speed limits
	  ○ Road Conditions (if available)

Main Event Flow	• RV1 is in the “Adjacent Traffic from the Left” scenario application zone
	• If RV1 has the right of way;
	  ○ RV1’s trajectory through the intersection is estimated using;
	    ▪ RV1’s location and dynamics
	    ▪ RV1’s turn signal state
	    ▪ Lane designations and geometry
	    ▪ Intersection geometry
	  ○ HV’s trajectory through the intersection is estimated using;
	    ▪ HV’s location
	    ▪ HV’s estimated acceleration
	    ▪ Lane designations and geometry

<table>
<tr><td></td><td>
Intersection geometry
If there is a risk of collision based on the estimated trajectories of HV and RV1 then;
HV is warned of a risk of collision with RV1 approaching from the left.
Otherwise if HV has the right of way;
RV1’s stopping distance is estimated using;
RV1’s location and dynamics
Lane designations and geometry
Intersection geometry
Road Conditions (if available)
If there is a risk that RV1 cannot stop before the intersection;
HV is warned of a risk of collision with RV1 approaching from the left.
</td></tr>
<tr><td>Alternative Event Flow</td><td>
RV2 is in the “Adjacent Traffic from the Right” scenario application zone
If RV2 has the right of way;
RV2’s trajectory through the intersection is estimated using;
RV2’s location and dynamics
RV2’s turn signal state
Lane designations and geometry
Intersection geometry
HV’s trajectory through the intersection is estimated using;
HV’s location
HV’s estimated acceleration
Lane designations and geometry
Intersection geometry
If there is a risk of collision based on the estimated trajectories of HV and RV2 then;
HV is warned of a risk of collision with RV2 approaching from the right.
Otherwise if HV has the right of way;
RV2’s stopping distance is estimated using;
RV2’s location and dynamics
Lane designations and geometry
Intersection geometry
Road Conditions (if available)
If there is a risk that RV2 cannot stop before the intersection;
HV is warned of a risk of collision with RV2 approaching from the right.
</td></tr>
<tr><td>Alternative Event Flow</td><td>
RV3 is in the “Oncoming Traffic” scenario application zone
If RV3 has the right of way;
RV3’s trajectory through the intersection is estimated using;
RV3’s location and dynamics
RV3’s turn signal state
</td></tr>
</table>

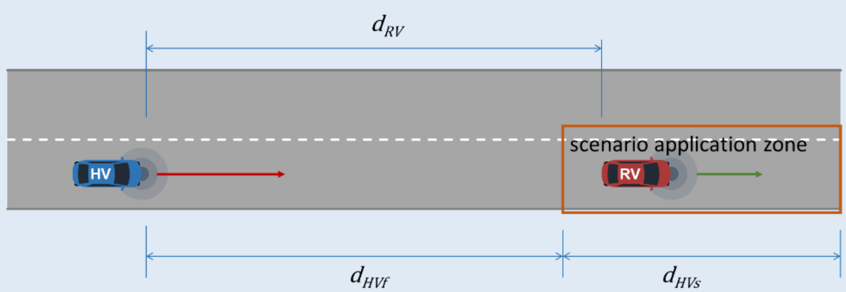
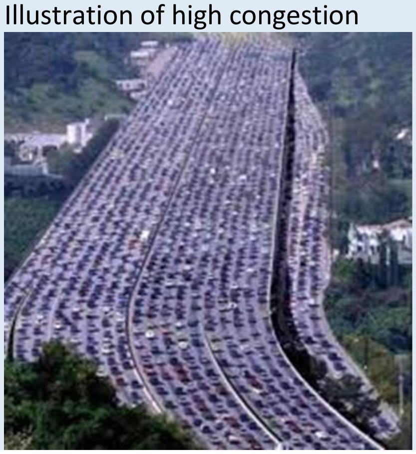
	▪ Lane designations and geometry ▪ Intersection geometry ○ HV's trajectory through the intersection is estimated using; ▪ HV's location ▪ HV's estimated acceleration ▪ Lane designations and geometry ▪ Intersection geometry ○ If there is a risk of collision based on the estimated trajectories of HV and RV3 then; ▪ HV is warned of a risk of collision with oncoming RV3. • Otherwise if HV has the right of way; ○ RV3's trajectory and stopping distance is estimated using; ▪ RV3's location and dynamics ▪ RV3's turn signal state ▪ Lane designations and geometry ▪ Intersection geometry ▪ Road Conditions (if available) ○ If there is a risk that RV3 cannot stop before the intersection; ▪ HV is warned of a risk of collision with oncoming RV3.
Post-Conditions	• HV is aware of a risk of collision with RV1 approaching from the left. • HV is aware of a risk of collision with RV2 approaching from the right. • HV is aware of a risk of collision with oncoming RV3.
Information Requirements	• HV's location. • HV's turn signal state. • HV's estimated acceleration from stopped. • RV1's location and dynamics. • RV1's turn signal state. • RV2's location and dynamics. • RV2's turn signal state. • RV3's location and dynamics. • RV3's turn signal state. • Lane designations and geometry. • Intersection geometry. • Traffic stop signs. • Traffic light signal phase and timing. • Traffic rules and laws for 3-way stops, 4-way stops and unsigned intersections. • Current Road Conditions (if available)

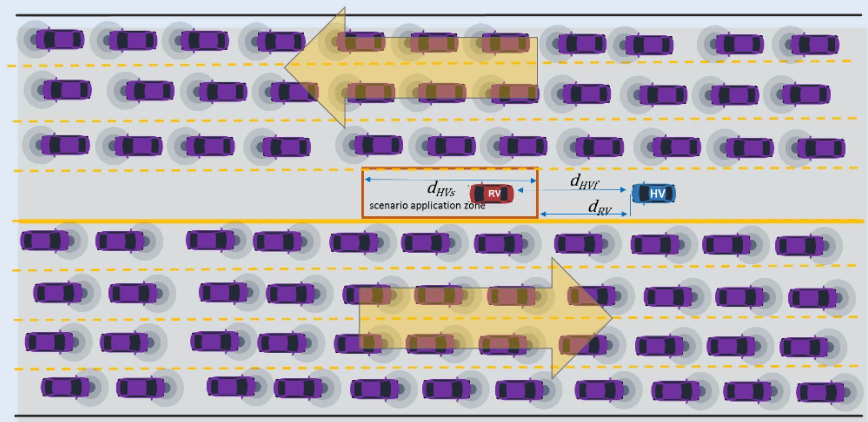
Emergency Break Warning

Use Case Name	**Emergency Break Warning**
User story	Alert HV that a lead RV is undergoing an emergency braking event.

Category	Safety, Autonomous Driving
Road environment	Urban, Rural, Highway
Short Description	Alert HV if a lead vehicle is braking.
Actors	• Host Vehicle (HV) • Remote Vehicle (RV)
Vehicle roles	• HV represents the vehicle approaching the lead vehicle from behind. • RV1 represents the lead vehicle that has applied its breaks.
Road & Roadside infrastructure roles	Not applicable
Other Actors' roles	Not applicable
Goal	• Avoid a rear end collision between HV and RV.
Needs	• HV needs to know if there is an emergency braking event in RV.

Constraints / Presumptions	• Assumptions will be required for the following information:
	  ○ HV's safe following distance.
	  ○ HV's safe stopping distance
	  ○ RV's safe stopping distance is same as HV's

Geographic Scope	Global
Illustrations	Emergency Break Warning – No Congestion  Illustration of high congestion  

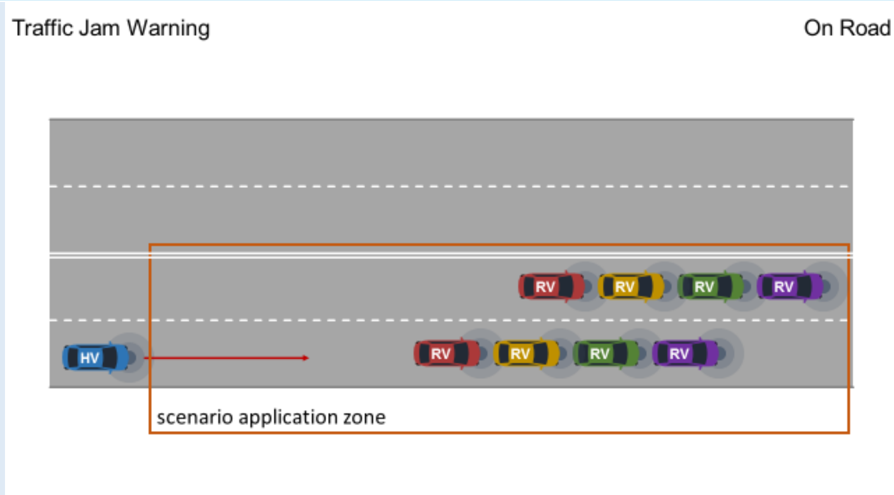
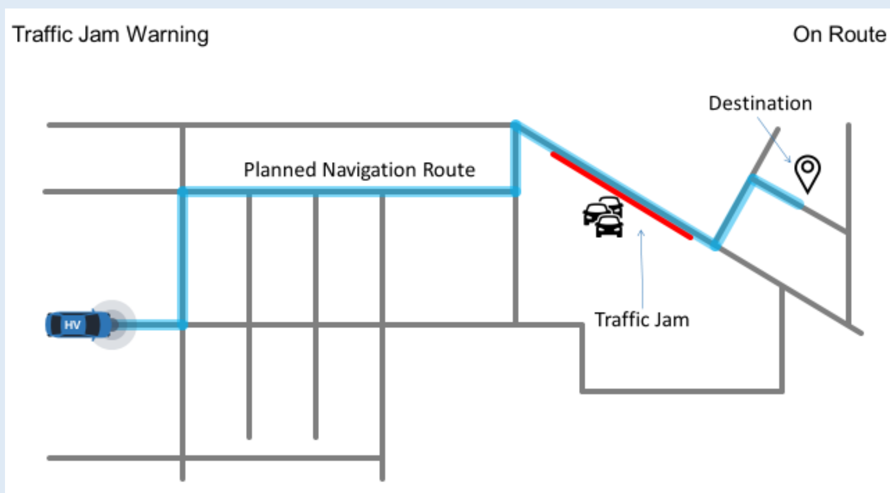
	Emergency Break Warning – Congestion  • d_{RV} = distance between HV and RV • d_{HVf} = safe following distance of HV • d_{HVs} = safe stopping distance of HV

Pre-Conditions	• HV is following RV
	• The “Emergency Break Warning” scenario application zone is determined from:
	  ○ HV’s location and dynamics
	  ○ HV’s safe following distance
	  ○ HV’s safe stopping distance
	  ○ Lane designations and geometry
	  ○ Road Conditions (if available)

Main Event Flow	• RV applies the breaks. • If RV is in “Emergency Break Warning” scenario application zone. a. HV is alerted of the braking event in a leading RV
Post-Conditions	• HV is aware of a braking event in a leading RV.
Information Requirements	• HV’s location and dynamics • HV’s safe following distance • HV’s safe stopping distance • RV’s location and dynamics • Lane designations and geometry • Current Road Conditions (if available)

Traffic Jam Warning

Use Case Name	**Traffic Jam Warning**
User Story	Alert HV of an approaching traffic jam.
Category	Convenience
Road Environment	Urban, Rural, Highway
Short Description	• Warn HV of an approaching traffic jam on the road. • Notify HV of a traffic jam on the navigation route.
Actors	• Host Vehicle (HV) • Remote Vehicle (RV)
Vehicle Roles	• HV represents vehicle approaching traffic jam. • RVs represent remote vehicles caught in traffic jam.

Road & Roadside Infrastructure Roles	• Roads are defined by their lane designations and geometry.
Other Actors' Roles	Not Applicable
Goal	• Alert HV of approaching traffic jam.
Needs	• HV need to be aware of approaching traffic jam and its geometry.
Constraints / Presumptions	
Geographic Scope	Global
Illustrations	 
Pre-Conditions	• HV is moving forward • Known traffic jam is defined by its location and geometry • The "On Road" scenario application zone is determined from: ○ HV's location and dynamics ○ HV's safe stopping distance ○ lane designations and geometry ○ road conditions (if available) • The "On Route" scenario application zone is determined from: ○ HV's location ○ HV's planned navigation route
Main Event Flow	• If the traffic jam's location is in the "On Road" scenario application zone;

	o Warn HV of the approaching traffic jam.
Alternate Event Flow	• If the traffic jam's location is in the "On Route" scenario application zone; o Notify HV of the traffic jam location and geometry.
Post-Conditions	• HV is aware of the approaching traffic jam on the road. • HV is aware of the traffic jam's location and geometry on the navigation route.
Information Requirements	• HV's location and dynamics • HV's safe stopping distance • HV's planned navigation route (if available) • Lane designations and geometry • Traffic jam's location and geometry.

Software Update

Use Case Name	**Software Update**
User story	Vehicle manufacturer updates electronic control module software for targeted vehicles.
Category	Vehicle Operations Management
Road environment	Intersection, Urban, Rural, Highway, Other
Short Description	• Vehicle Manufacturer or Controlling Authority publishes software updates for one or more electronic control units (ECUs) on targeted Host Vehicles (HVs).
Actors	• Host Vehicle (HV) • Vehicle Manufacturer • Controlling Authority (could be fleet operator, owner / user onboard, etc.) • Human Driver
Vehicle roles	• HV represents the targeted vehicle for an intended software update.
Roadside infrastructure roles	Not applicable
Other Actors' roles	• Vehicle Manufacturer publishes software updates • Vehicle Controlling Authority publishes software updates or approves installation of software update
Goal	Deliver software updates to targeted vehicles.
Needs	• Vehicle manufacturer needs to distribute software updates. • Vehicle manufacturer needs to notify HV in case of urgently-needed update • Vehicle manufacturer needs to ensure secure delivery of authentic software updates to HV • HV needs to download and install software updates • HV owner may need to accept or approve application of software updates • HV owner needs to accept or reject free optional software updates • HV owner needs to purchase or reject optional software updates with new features

Constraints / Presumptions	• Vehicle manufacturer targets an update for a list of vehicles • A software update may depend on minimum ECU hardware versions, other ECU software versions, or on a chain of previous software versions. • Scenarios may differ between conventional and autonomous cars • HV includes capabilities to download, store, manage, and install software. In many cases a device (or devices) may provide these capabilities for a group of ECUs, while other ECUs may provide these capabilities for themselves. • A coordinated software update may involve a group of ECUs • A software update may be routine (non-urgent) or urgent • A software update may be mandatory or optional • Software updates may vary in size, depending on target ECU(s). Sizes from less than 1MB to more than 32GB must be considered. • Software download must be secure, and the integrity of the downloaded update must be assured (e.g., image signing, etc.) • A software update might be rolled back • Where feasible, HVs will retain one previous software version to facilitate rollbacks. If this is not feasible, any single SW update package and process should include the capability to roll back the updates contained in that package in case the planned update cannot complete. • There might need to be multiple, staged updates to move the vehicle systems to the current, recommended or required versions. For example, the steps might include: ECU1 updated from v2.1 to v2.4, then updated from v2.4 to v3.1. ECU2 updated from v5.0 to v6.0 to v7.0 to v7.1. This can be done in one update sequence, but could increase update package size and would affect update timing. • It may be possible that intermediate update stages (e.g., ECU1 at v2.4 and ECU2 at v6.0) may not be considered compatible or safe, so the entire update sequence may need to be completed before the function or vehicle can be used. • Downloading software updates must not adversely affect the performance of safety features.
Geographic Scope	Global
Illustrations	Not applicable
Pre-Conditions	• Vehicle manufacturer or controlling authority publishes a software update for a target list of HVs
Main Event Flow	• Vehicle manufacturer or controlling authority posts a mandatory software update and notifies targeted HVs of the new software version on affected ECUs. • Update can be characterized as routine (non-urgent) or urgent and could target conventional (human-driven) or autonomous (self-driving) vehicles. • In case of “urgent” updates, an “Urgent Update Required” message is sent to the vehicle, and handled as in the user stories below.

	• HV receives notification and starts downloading the software update • HV may download segments of the software update at opportune moments that do not affect the performance of safety features or other driver-facing features such as voice calls or streaming content, or to accommodate changing network availability. • HV may pause and continue downloads as needed; it should not re-start a large download from the beginning and may receive parts of the download out of order. Thus the download is "reliable" even given any gaps in coverage or delays caused by higher-priority uses of available bandwidth, or switching between multiple communications mechanisms. • When HV completes downloading the posted software update a. HV should either retain a copy of the previously-installed version of software in case of an issue with the update that requires reverting to the previous version or have a mechanism to reverse the changes contained in the SW update package. b. HV receives approval from human driver (conventional, if required) or controlling authority (autonomous) to install the software update. Such a separate step after package download is not always mandatory. c. HV installs the downloaded software update at a safe, appropriate, driver-approved (where required) time. d. HV notifies vehicle manufacturer and controlling authority of update completion and an updated manifest of ECUs, installed software versions, retained rollback versions, any relevant download rate and installation statistics, etc. as appropriate for the SW update process.
Alternative Event Flow	• Vehicle manufacturer posts an optional software update and notifies targeted HVs of the new software version and features on affected ECUs • HV owner is notified of the optional software update, its new features and cost if applicable • If HV owner accepts or purchases the update; a. HV starts downloading the software update b. HV may download segments of the software update at opportune moments that do not affect the performance of safety features or other driver-facing features such as voice calls or streaming content. c. HV may pause and continue downloads as needed; it should not re-start a large download from the beginning and may receive parts of the download out of order. Thus the download is "reliable" even given any gaps in coverage or delays caused by higher-priority uses of available bandwidth, or switching between multiple communications mechanisms. d. When HV completes downloading the posted software update;

	i. HV should either retain a copy of the previously-installed version of software in case of an issue with the update that requires reverting to the previous version, or else have a mechanism to reverse the changes contained in the new SW update package. ii. HV installs the downloaded software update at a safe, appropriate, driver-approved (where required) time • HV notifies vehicle manufacturer and controlling party of update completion and an updated manifest of ECUs, installed software versions, retained rollback versions, any relevant download rate and installation statistics, etc. as appropriate for the SW update process.
Post-Conditions	• Mandatory software updates are deployed on target HVs. • Optional software updates are either rejected or deployed on target HVs
Information Requirements	• Urgency / Criticality of Update • HV's list of ECUs with current software versions • Vehicle Manufacturers latest software versions per ECU on each HV • Any dependencies between ECUs and software versions • HV's software update download progress • HV's software update installation progress

Remote Vehicle Health Monitoring

Use Case Name	**Remote Vehicle Health Monitoring**
User story	Owners, fleet operators and authorized vehicle service providers monitor the health of HV and are alerted when maintenance or service is required.
Category	Vehicle Operations Management
Road environment	Intersection, Urban, Rural, Highway, Other
Short Description	Owners, operators and vehicle service providers request a report of the HVs current health including: • On-board Diagnostic Trouble Codes • Predicted Maintenance (fluids, breaks, tires, battery, etc…)
Actors	• Host Vehicle (HV) • Vehicle Owner • Fleet Operator • Automotive Service Provider
Vehicle roles	• HV represents the vehicle that needs maintenance or service.
Roadside infrastructure roles	Not applicable
Application server roles	Not applicable

Other Actors' roles	Not applicable
Goal	• Provide owners, operators and vehicle service providers of HV health report on request. • Alert owners, operators and vehicle service providers of HV health issues requiring maintenance or service.

Needs	• Owners, operators and vehicle service providers need to know the health of the vehicle including:
	  ○ Required and estimated maintenance
	  ○ Detected problems that require service and the location of HV

Constraints / Presumptions	Not applicable
Geographic Scope	Global
Illustrations	Not applicable
Pre-Conditions	Not applicable
Main Event Flow	• HV owner, operator or vehicle service provider requests a health report • HV provides on-board diagnostic trouble codes • Required maintenance is determined based on component use and wear. • A health report is provide to the requester.
Alternate Event Flow	• HV detects a problem using on-board diagnostics • The HV owner, operator or vehicle service provider is notified of the detected on-board diagnostic trouble code.
Alternate Event Flow	• HV driver detects a problem that requires service. • The HV owner, operator or vehicle service provider is notified of the driver reported problem.
Alternate Event Flow	• A HV component requires maintenance based on determined use and ware. • The HV owner, operator or vehicle service provider is notified of the required maintenance.

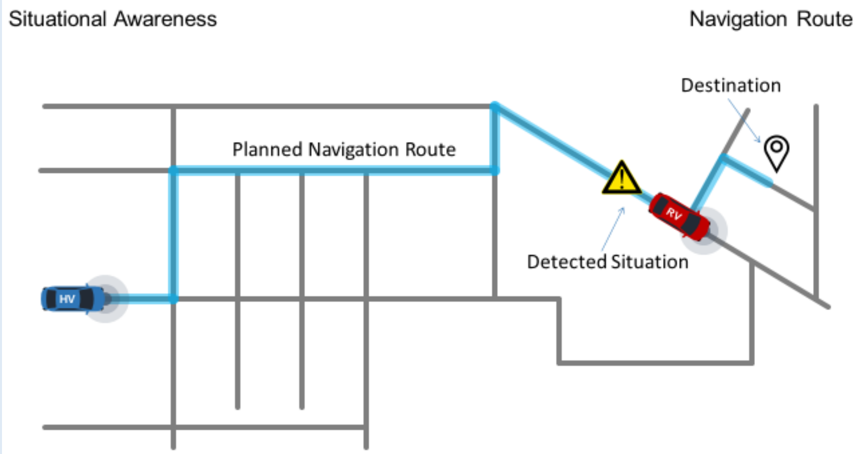
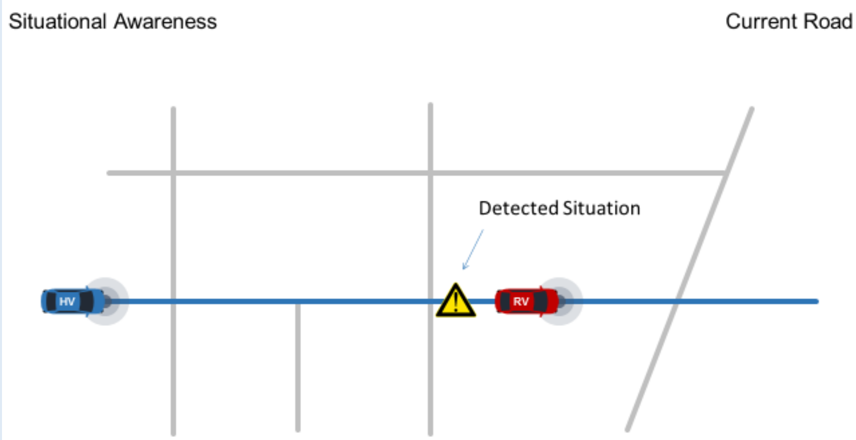
Post-Conditions	• Owners, operators and vehicle service providers are aware of the health of the vehicle including:
	  ○ Required and estimated maintenance
	  ○ Detected problems that require service and location of HV

Information Requirements	• HV health report
	  ○ On-board Diagnostic Trouble Codes
	  ○ Predicted Maintenance (fluids, breaks, tires, battery, etc…)
	  ○ Required Maintenance (fluids, breaks, tires, battery, etc…)
	• HV Location

Hazardous Location Warning

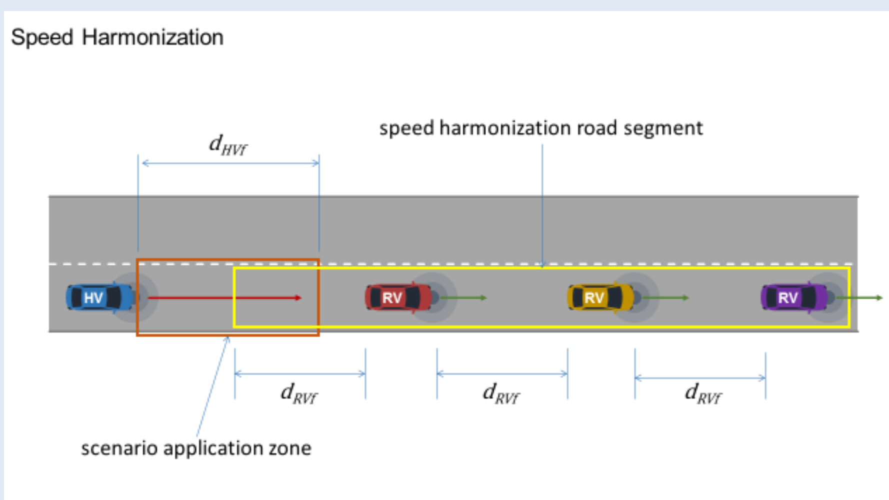
Use Case Name	**Hazardous Location Warning**

User Story/Use Case Scenario	An autonomous or semi-autonomous vehicle is driving on a road (route), heading towards a road segment, which presents unsafe and unknown conditions ahead. A host vehicle is made aware of situations detected and shared by remote vehicles. Situations may include such things as accidents, weather, traffic, construction.
Category	Safety, Autonomous Driving
Road Environment	Urban, Rural, Highway
Short Description	A host vehicle is made aware of accidents, traffic, adverse weather, road conditions, construction and other situations detected and shared by remote vehicles. The shared situations are relevant along the host vehicle's navigation route or current road of travel. Some examples include but are not limited to: • traffic congestion detected by slowly-moving RVs • adverse weather conditions detected by temperature changes and wiper activation • accidents detected by air bag deployment events • slippery road conditions detected by traction control events • disabled vehicles detected by hazard lamps or tire pressure
Actors	• Remote Vehicle (RV) • Host Vehicle (HV)
Vehicle Roles	• RV represents the vehicle detecting and sharing situational information. • HV represents the vehicle made aware of situational information.
Road & Roadside Infrastructure Roles	• Roads are defined by their lane designations and geometry.
Other Actors' Roles	Traffic Management: An entity that collects accidents, traffic, adverse weather, road conditions, construction and other situations and reports them to other vehicles. (For user story 2, not for 1)
Goal	Alert HV of a situation that lies ahead along its navigation route or current road segment.
Needs	• HV needs to be aware of a situation that lies ahead along its navigation route or road segment.
Constraints / Presumptions	The "Navigation Route" scenario includes all roads ahead along HV's known navigation route. The "Current Road" scenario includes the length of the road ahead that HV is currently travelling on.
Geographic Scope	Global

Illustrations	 
Pre-Conditions	• One or more RV's have detected conditions that constitute a situation that HV should be made aware of.
Main Event Flow	If the situation's location is on HV's navigation route: One or more RV's have reported conditions to the Traffic Management entity that constitute a situation that one or more HVs should be made aware of HV is made aware of the situation's nature and location. (cf. user story #2)
Alternate Event Flow	If the situation's location is ahead along HV's current road of travel: • One or more RV's detect a situation that one or more HVs should be made aware of • The RV(s) provide the notification to the HV(s) • HV is made aware of the situation's nature and location
Post-Conditions	• HV is made aware of a detected situation along its navigation route or current road ahead.
Information Requirements	• RV's location and dynamics • RV's wiper, lamps status • RV's outside temperature, barometric pressure • RV's hazard lamps, tire pressure

	• RV's ABS, Stability Control, Traction Control, Airbag events • Road Map • HV's Navigation Route • Road conditions • Construction Zone Map

Speed Harmonization

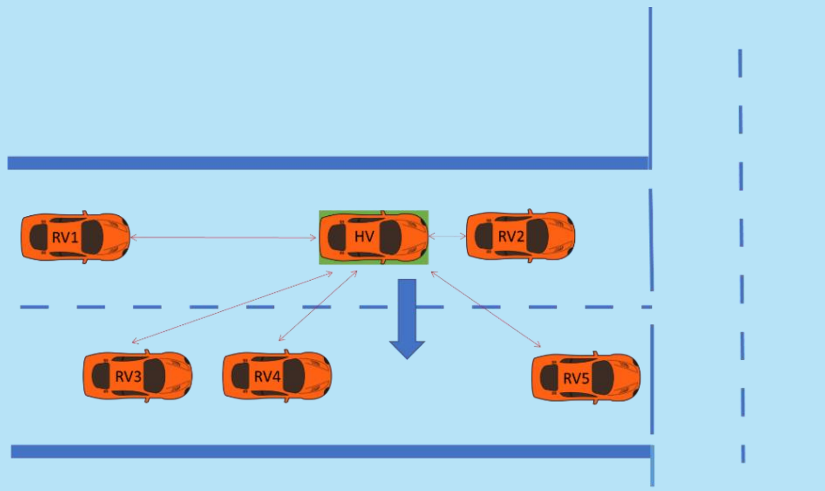
Use Case Name	Speed Harmonization
User Story	Notify HV of recommended speed to optimize traffic flow, minimize emissions and to ensure a smooth ride.
Category	Traffic Efficiency and Environmental friendliness, Autonomous Driving
Road Environment	Urban, Rural, Highway
Short Description	Notify HV of recommended speed based on traffic, road conditions and weather information.
Actors	• Host Vehicle (HV)
Vehicle Roles	• HV represents the vehicle receiving posted speed limits.
Road & Roadside Infrastructure Roles	• Roads are defined by their lane designations and geometry. • Posted Speed Limits are associated with road & lane segments.
Other Actors' Roles	Not Applicable
Goal	• Notify HV of the optimal speed to enable a comfortable ride and alleviate the need for frequent acceleration and deceleration. • Promote environmental friendly driving patterns. • Reduce risks of collisions due to stop and go traffic.
Needs	• HV needs to know the recommended speed to optimize traffic flow, minimize emissions and to ensure a smooth ride.
Constraints / Presumptions	• RVs on the harmonized road segment are aware of the recommended speed.
Geographic Scope	Global
Illustrations	 d_{HVf} = safe following distance of HV d_{RVf} = safe following distance of RV

Pre-Conditions	• HV is moving forward.
	• The scenario application zone is determined from:
	  ○ HV's location & dynamics
	  ○ HV's safe following distance
	  ○ lane designations and geometry
	  ○ posted speed limits
	• The speed harmonization road segment is determined from:
	  ○ RVs' location & dynamics
	  ○ RVs' safe following distance
	  ○ lane designations and geometry
	  ○ road conditions (if available)

Main Event Flow	• If the "speed harmonization road segment" is in the scenario application zone; ○ Notify HV of the recommended harmonized speed
Post-Conditions	• HV is aware of the recommended harmonized speed.
Information Requirements	• HV's location and dynamics. • HV's safe following distance • RVs' location & dynamics • RVs' safe following distance • Lane designations and geometry • Posted speed limit associated with lane or road segments. • Road conditions (if available)

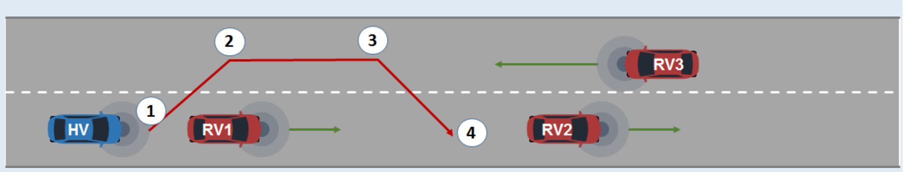
High Definition Sensor Sharing

Use Case Name	**High Definition Sensor Sharing**
User story/Use case scenario	The vehicle has automated driving mode and changes lanes.
Category	Autonomous Driving
Road environment	Suburban, Urban, Rural, Highway
Short Description	Vehicle uses its own sensors (e.g., HD camera, lidar), and sensor information from other vehicles, to perceive its environment (e.g., come up with 3D model of world around it) and safely performs an automated driving lane change.
Actors	• Host Vehicle • Remote Vehicles
Vehicle roles	• On-board sensors detect other vehicles and objects. • On board processors calculate relative distances and trajectories of other vehicles. • Processed and/or un-processed information is shared with other vehicles.
Roadside infrastructure roles	Not applicable
Other Actors' roles	None
Goal	Automated driving lane change safely performed.
Needs	• Capability of vehicle to calculate accurately, and in real time, its relative position with other vehicles, road markings and objects.

	• Capability of the vehicle to use its own sensor information and/or that of other vehicles, including those not in line of sight. • System must work during the day and the night, and in all weather conditions.
Constraints / Presumptions	Not all vehicles will be equipped.
Geographic Scope	Global
Illustrations	 HV = Host Vehicle RV = Remote Vehicle
Pre-Conditions	• Necessary software available in clients and applications. Communication means available. • The Host Vehicle has to understand the sensor data from the Remote Vehicles, in an agreed format.
Main Event Flow	• Host Vehicle captures 360 degree sensory information (e.g., other vehicles, road markings). • Host Vehicle calculates in real time its distance from other vehicles and objects, their relative positions and their trajectories. • Host Vehicle receives processed and/or un-processed information (e.g., video) from remote vehicles and uses that information to improve its perception of the surroundings and add certainty to its calculations. • Host Vehicle, taking into account information received from Remote Vehicles, calculates what the gap between Remote Vehicle 4 and Remote Vehicle 5 will be for the next n seconds. Host Vehicle knows from information received from Remote Vehicle 5 that a junction is near and therefore Remote Vehicle 5 is likely to slow down imminently. • Host Vehicle determines that it is safe to move from the left lane to the right lane. • Host Vehicle notifies remote vehicles of its intention. • Host Vehicle performs the manoeuvre, adjusting its speed to the optimum.
Alternative Event Flow	As above except in step 3 the HV requests sensor information from specific RVs.

Post-Conditions	The vehicle has moved from the left lane to the right lane.
Information Requirements	• Accurate dynamic relative position and planned trajectory • High Definition images. • LIDAR. • Dynamic 3D absolute position. • Accuracy of the data and liability for sharing. • Agreed formats of data for sharing.

See-Through for Pass Maneuver

Use Case Name	**See-Through for Pass Maneuver**
User story	Driver of Host Vehicle that signals an intention to pass a Remote Vehicle (RV) using the oncoming traffic lane is provided a video stream showing the view in front of the RV.
Category	Safety
Road environment	Rural (2-lane highways)
Short Description	• HV approaches from behind or follows RV1 with the intention to pass using the oncoming lane. • Video stream of the front view of RV1 is shown to the HV driver during the passing maneuver.
Actors	• Host Vehicle (HV) • Remote Vehicle 1 (RV1) • Remote Vehicle 2 (RV2) • Remote Vehicle 3 (RV3)
Vehicle roles	• HV represents the vehicle intending to pass RV1. • RV1 represents the vehicle being passed. • RV2 represents the vehicle in front of RV1. • RV3 represents the closest vehicle in the oncoming traffic lane.
Roadside infrastructure roles	• Roads must define their lanes and direction of traffic flow in each lane. • Road must indicate where passing is not permitted across traffic lanes.
Other Actors' roles	Not applicable
Goal	Provide HV driver a clear, reliable and real-time view of the road situation in front of the vehicle it is trying to pass and help avoid possible collision.
Needs	• Communication capabilities allowing real-time video transfer High-resolution display in HV
Constraints / Presumptions	• HV and RV meet basic communications capabilities and performance requirements described for sending and receiving messages. • HV and RV are equipped to send and receive messages as well as high-bandwidth real-time video content.
Geographic Scope	National
Illustrations	 • State 1 = HV starts receiving streaming video from RV1

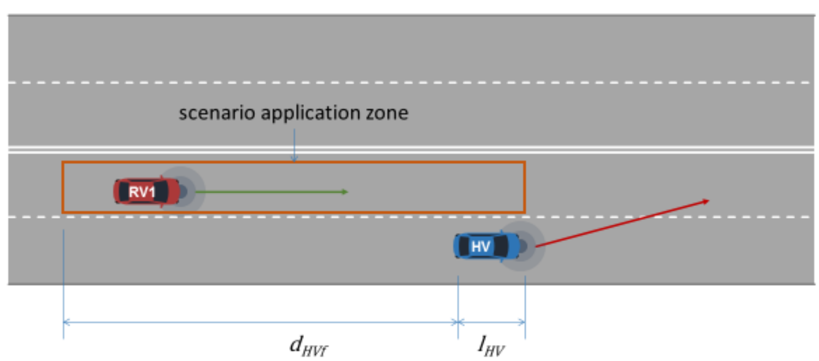
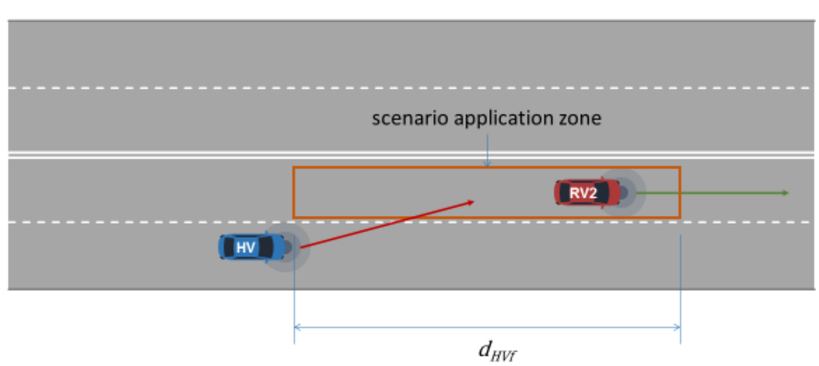
	• State 2 = HV has fully moved into the passing lane, continues receving video streaming from RV1 • State 3 = HV has reached the position in the passing lane when it is ready to start the maneuver to return to the starting lane • State 4 = HV completes the passing maneuver and can stop receiving the • streaming video from RV1
Pre-Conditions	• HV is approaching from behind or following RV1 • The HV and RV are in communication range. The RV is capable of collecting front facing visual information.
Main Event Flow	• The HV is approaching the RV from behind on the same lane. • HV is following RV on a two-way road and makes a decision to initiate a passing maneuver. • HV requests RV's visual information of its front view for the purpose of making a passing decision as well as additional information during the passing maneuver. • The RV provides visual information of its front view periodically or event-based. • The HV receives the visual information from the RV. • The HV driver is able to see the RV front facing.
Alternative Event Flow	Not applicable
Post-Conditions	Based upon the visual information from the RV, the HV driver is able to • make an informed decision to overtake the RV when there is no traffic coming in on the opposite direction • Complete a successful passing maneuver with the additional visual information from RV1.
Information Requirements	• Video streaming capability between vehicles as well as short message exchange capability.

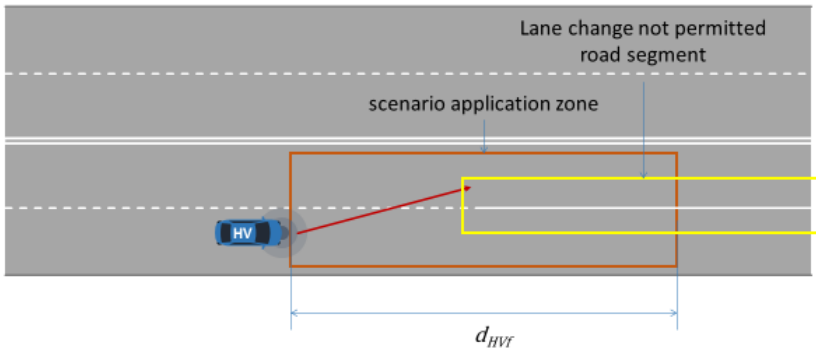
Lane Change Warning

Use Case Name	**Lane Change Warning**
User story	Host Vehicle (HV) signals an intention to change lanes.
Category	Safety, Autonomous Driving
Road environment	Urban, Rural, Highway
Short Description	• Alert HV intending to change lanes of a lack of space or risk of collision with a lagging RV1 approaching from behind in the target lane. • Alert HV intending to change lanes of a lack of space or risk of collision with a leading RV2 in the target lane. • Alert HV intending to change lanes that this maneuver is not permitted on the current road segment.
Actors	• Host Vehicle (HV) • Remote Vehicle 1 (RV1) • Remote Vehicle 2 (RV2)

Vehicle roles	• HV represents the vehicle intending to change lanes. • RV1 represents the lagging vehicle in the target lane. • RV2 represents the leading vehicle in the target lane.
Road & Roadside infrastructure roles	• Roads are defined by their lane designations and geometry. • Road segments indicate where changing lanes is not permitted.
Other Actors' roles	Not applicable
Goal	Avoid HV encroaching into RV2; avoid HV encroaching into RV1.
Needs	• HV needs to know if there is a lack of space or risk of collision with a lagging RV1 in the target lane. • HV needs to know if there is a lack of space or risk of collision with a leading RV2 in the target lane. • HV needs to know if a lane change is not permitted on the current road segment.

Constraints / Presumptions	• Assumptions will be required for the following information:
	  ○ HV's safe following distance
	  ○ RV1's safe following distance is the same as HV's.

Geographic Scope	Global
Illustrations	Lane Change Warning Lagging Vehicle  Lane Change Warning Leading Vehicle 

	Lane Change Warning Not Permitted  • d_{HVf} = safe following distance of HV • l_{HV} = lenght of HV

Pre-Conditions	• HV has signalled its intention to change lanes.
	• Known road segments define is passing is not permitted.
	• The “Lagging Vehicle” scenario application zone is determined from:
	  ○ HV’s location and dynamics
	  ○ HV’s length
	  ○ HV’s safe following distance
	  ○ lane designations and geometry
	  ○ road conditions (if available)
	• The “Leading Vehicle” scenario application zone is determined from:
	  ○ HV’s location and dynamics
	  ○ HV’s safe following distance
	  ○ lane designations and geometry
	  ○ road conditions (if available)

Main Event Flow	• If RV1 is in the “Lagging Vehicle” scenario application zone;
	  ○ If the trajectory of RV1 and HV cross;
	    ▪ Warn HV of the risk of collision with RV1
	  ○ Otherwise;
	    ▪ Alert HV of the lack of space to safely complete the manoeuvre.

Alternative Event Flow	• If RV2 is in the “Leading Vehicle” scenario application zone;
	  ○ If the trajectory of RV2 and HV cross;
	    ▪ Warn HV of the risk of collision with RV2
	  ○ Otherwise;
	    ▪ Alert HV of the lack of space to safely complete the manoeuvre.

Post-Conditions	• HV is aware of a lack of space or of a risk of collision with a lagging RV1 in the target lane. • HV is aware of a lack of space or of a risk of collision with a leading RV2 in the target lane. • HV is aware of whether a lane change is permitted or not on the current road segment.

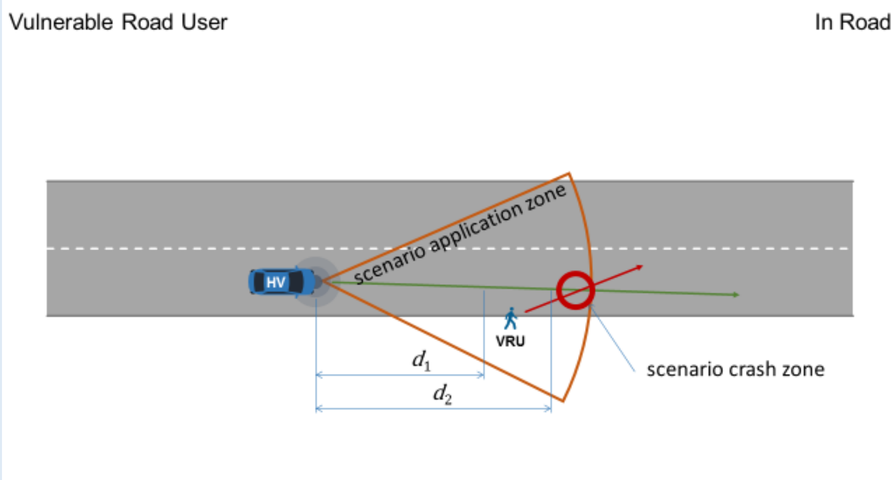
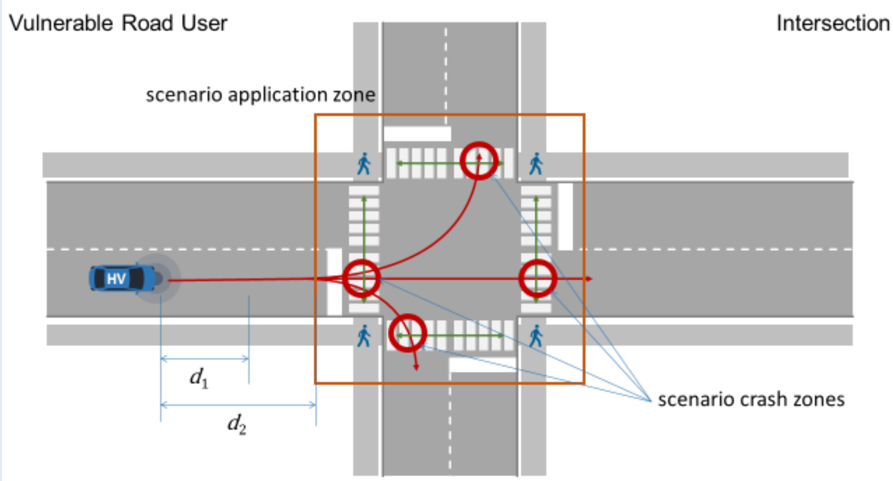
Information Requirements	• HV's location and dynamics • HV's length • HV's safe following distance • RV1's location and dynamics • RV2's location and dynamics • Lane designations and geometry • Road segment lane change rules • Road conditions (if available).

Vulnerable Road User

Use Case Name	**Vulnerable Road User**
User story	Alert HV of approaching VRU in the road or crossing an intersection and warn of any risk of collision.
Category	Society and Community, Safety
Road environment	Intersection, Urban, Rural, Highway, Other
Short Description	Alert HV of approaching VRU in the road or crossing an intersection and warn of any risk of collision.
Actors	• Vulnerable Road User (VRU) • Surveillance cameras at traffic lights/crossings
Vehicle roles	HV represents the vehicle moving forward Host Vehicle (HV) | Other Vehicles roles
Road & Roadside infrastructure roles	• Roads are defined by their lane designations and geometry. • Intersections are defined by their crossing designations and geometry. • Traffic lights and stop signs control right of way traffic flow through an intersection (if available). • Pedestrian crossings are defined by their designations and geometry.
Other Actors' roles	VRU represents a pedestrians, bike, eBike, motorbike, skateboard etc. … that is travelling along the road or intends to cross the road.
Goal	Avoid collision between HV and VRU.
Needs	• HV needs to be aware of VRU on the road and any risk of collision. • HV needs to be aware of VRU at an intersection and any risk of collision.

Constraints / Presumptions	• Assumptions will be required for the following information:
	    ○ HV's safe stopping distance
	    ○ VRU's trajectory is constant
	    ○ extent of scenario application zones

Geographic Scope	Global

Illustrations	  • d_1 = stopping distance of HV • d_2 = distance from HV to scenario crash zone

Pre-Conditions	• HV is moving forward.
	• Before establishment of LoS, if any
	• Known VRU is characterized (bike, pedestrian, motorcycle,…)
	• The “In Road” scenario application zone is determined from:
	    ○ HV’s location and dynamics
	    ○ HV’s safe stopping distance
	    ○ lane designations and geometry
	    ○ road conditions (if available)
	• The “Intersection” scenario application zone is determined from:
	    ○ HV’s location and dynamics
	    ○ HV’s safe stopping distance
	    ○ intersection geometry
	    ○ road conditions (if available)

Main Event Flow	• If VRU is in the “On Road” scenario application zone;
	    ○ If HV’s trajectory and VRU’s trajectory are on a collision course then
	        ▪ Warn HV of the risk of collision with the approaching VRU

	○ Otherwise ▪ Caution HV of the approaching VRU

Alternate Event Flow	• If VRU is in the “Intersection” scenario application zone;
	  ○ If HV’s trajectory and VRU’s trajectory are on a collision course then
	    ▪ Warn HV of the risk of collision with the approaching VRU
	  ○ Otherwise
	    ▪ Caution HV of the approaching VRU

Post-Conditions	• HV/Driver is aware of its approach towards the VRU and any risk of collision (Day 1-1.5) • HV is aware of its approach towards the VRU and takes the necessary safety measures to avoid or mitigate collision (Day 3)
Information Requirements	• HV’s location and dynamics. • HV’s safe stopping distance. • VRU’s location and dynamics. • VRU’s characterization (bike, pedestrian, motorcycle, …) • Lane designations and geometry. • Intersection geometry • Current Road Conditions (if available) • Other vehicle sensor data