WEATHERSAFE

SAFETY ENHANCEMENT UNDER ADVERSE WEATHER CONDITIONS THROUGH IMPROVED ADAS/AD ROBUSTNESS

Deliverable D3.3

Connectivity Analysis

Project Name	WeatherSafe	
Dissemination level	Consortium	
Written by	Valentina Ciarla	UTAC
Issue date	04/07/2025	
Reviewer	Aurelien Garcia / Yoan Audegond	
Keywords	Connectivity, Adverse Weather Conditions, Impact, ADAS	
Version	2.0	

EXECUTIVE SUMMARY

This deliverable, produced under the WeatherSafe project, explores the role of connectivity technologies in enhancing road safety during adverse weather conditions. As autonomous and semi-autonomous driving systems increasingly rely on sensor-based perception, their limitations under poor weather make it critical to explore complementary technologies. Connectivity—particularly V2X (Vehicle-to-Everything) communication—is identified as a promising solution to bridge these gaps.

The report first outlines the evolution and current landscape of vehicle communication technologies, including local in-vehicle networks (e.g., CAN, Ethernet) and external communication protocols (e.g., 4G/5G cellular, Bluetooth, Wi-Fi, IEEE 802.11p, PC5/C-V2X). Each is evaluated for its capabilities, bandwidth, latency, and role in enabling safety-critical and infotainment functions.

It then analyses the suitability of these technologies to enhance Advanced Driver Assistance Systems (ADAS) under adverse weather by leveraging the physical resilience of radio-based V2X communication. These technologies are less affected by weather phenomena that degrade optical sensors, making them valuable supplements for hazard prediction and prevention.

Two specific use cases—slippery road and fog detection—are used to demonstrate how V2X messages (e.g., DENM, CAM, CPM) can provide early warnings and improve driver response through hazard anticipation. These messages can be received via cellular cloud systems or direct communication, with validation mechanisms using onboard sensors and vehicle dynamics data.

The report also links these technological capabilities with regulatory frameworks, such as the Euro-NCAP 2026 protocols and Directive 2010/40/EU, which emphasize the importance of real-time hazard communication for safety scoring and compliance. Finally, the document positions connectivity not as a standalone solution but as a crucial "additional sensor" that strengthens the redundancy and reliability of modern vehicle safety systems.

REVISION HISTORY

Revision	Date	Description, updates and changes	Status
1.0	17/01/2025	First draft version, open for discussion	Draft
2.0	04/07/2025	Finalized version, ready for diffusion	Approved

ABBREVIATIONS

ADAS	**Advanced Driver Assistance Systems**
BLE	Bluetooth Low Energy
CAM	Cooperative Awareness Message
CAN	Controller Area Network
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
CV2X	Cellular Vehicle-to-Everything
DENM	Decentralized Environmental Notification Message
D2D	Device-to-Device
DSRC	Dedicated Short Range Communication
ECU	Electronic Control Unit
ETSI	European Telecommunications Standards Institute
EU	European Union
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HMI	Human-Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
ITS-G5	ITS standard based on IEEE 802.11p in Europe
LIN	Local Interconnect Network
LTE	Long-Term Evolution
NR-V2X	New Radio Vehicle-to-Everything
OTA	Over-The-Air (software update)
PC5	Proximity Communication interface for sidelink in C-V2X
ProSe	Proximity Services
QoS	Quality of Service
SECUR	Safety Enhancement through Connected Users on the Road (Consortium project)
SRTI	Safety-Related Traffic Information
RTTI	Real-Time Traffic Information
TSN	Time-Sensitive Networking
UTAC	Union Technique de l'Automobile du motocycle et du Cycle (Project lead partner)
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WLANp	Wireless LAN protocol (IEEE 802.11p-based)

TABLE OF CONTENTS

EXECUTIVE SUMMARY 2
REVISION HISTORY 3
ABBREVIATIONS 4
TABLE OF CONTENTS 5
1. INTRODUCTION 6
2. VEHICLE COMMUNICATION TECHNOLOGIES 6
3. SUITABILITY OF THE DIFFERENT TECHNOLOGIES FOR THE SELECTED USE CASES 11
4. CONCLUSION 19
ACKNOWLEDGEMENTS 20
RÉFÉRENCES 21
TABLE OF ILLUSTRATIONS 23

1. Introduction

As is necessary for human drivers, a vehicle with driving delegation must continuously monitor and react to the driving environment (Lindsey Research, 2020). On the monitoring side, the vehicle uses several integrated sensors to perceive its surroundings, which sensors include cameras, radar, LIDAR, and ultrasonic. These sensors operate in conjunction with a full 360 view of its surroundings. This can be obtained by perceiving the environment via high-definition map to provide certainty of the vehicle's position on the roadway. This perception also includes the identification of other vehicles and potential road hazards, all classified by vehicle's onboard processing, which can classify people, cars, various objects, and potentially hazardous situations.
The inconvenient of these sensors is that they have relatively poor prediction capabilities, but their usage is more adapted for a real time control. To overcome this problem, the global industry trend is to fusion these sensors with V2x (Vehicle to everything) information allowing to enhance safety and the best possible customer experience.
Goal of this deliverable is to introduce connectivity as this additional technology that might help to predict dangerous situations linked to bad weather conditions, where standard perception sensors or actuators might be at the limits of their capabilities.

2. Vehicle communication technologies

2.1 Local communication technologies

The world of automotive communication is in the middle of a thrilling transformation, spurred by a major overhaul in E/E (Electrical/Electronic) Architecture—the very structure of a vehicle's electronic and electrical systems.
Traditional protocols like **CAN** (**Controller Area Network**) and **LIN** (Local Interconnect Network), once the sturdy backbone of in-vehicle networks, are finding themselves stretched as modern cars evolve into sophisticated, data-hungry systems. This shift is part of a broader E/E Architecture Transformation—a transition from decentralized systems with scattered ECUs (Electronic Control Units) to more centralized or zonal architectures. This reimagined architecture is designed to handle the complexity of modern vehicles by consolidating computing power and optimizing network efficiency (Kulyk, 2024)
The rise of ADAS and autonomous driving has introduced an insatiable demand for bandwidth, real-time data flow, and seamless integration across a vehicle's ecosystem. Enter Automotive Ethernet: a protocol born from the world of IT but adapted to tackle the unique rigors of automotive environments. Offering unparalleled speed, scalability, and support for time-sensitive networking, Ethernet is poised to become the network backbone of the future, seamlessly linking everything from infotainment to high-definition sensor data, while aligning perfectly with the goals of E/E Architecture Transformation.
Yet, despite Ethernet's promise, CAN, **CAN FD** (**Flexible Data Rate**), and **FlexRay** continue to serve essential roles in specific areas, such as handling critical safety functions and simpler applications where reliability and simplicity reign. This coexistence is giving rise to a new hybrid model, where legacy protocols work alongside cutting-edge solutions.
As vehicles continue to evolve into connected, software-defined machines, they require a communication protocol that can handle massive data flows in real time. Enter Automotive **Ethernet** – a technology adapted from traditional Ethernet, specifically tailored to meet automotive needs with adaptations like Time-Sensitive Networking (TSN) for prioritizing critical data and standards such as 100BASE-T1 (100 Mbps) and 1000BASE-T1 (1 Gbps).

Automotive Ethernet's biggest advantages are :

- Bandwidth: with speeds reaching up to 10 Gbps in development, it can support everything from high-definition infotainment to data-intensive sensors like LiDAR and radar, critical for autonomous driving.
- Unified network architecture, that allows it to connect various vehicle systems of different nature and technology - infotainment, ADAS, V2X (vehicle-to-everything) - and more – over a single, scalable platform.

For automotive Ethernet to work in critical systems, it incorporates TSN standards, which enable deterministic, low-latency communication by prioritizing time-sensitive data.
In a future of autonomous vehicle equipped with multiple cameras, LiDAR sensors, radar, and an infotainment system streaming high-definition video to passengers, Ethernet's high bandwidth can handle all these data streams in real time, while TSN ensures that safety-critical data, like obstacle detection from LiDAR, takes precedence over infotainment.

2.2 V2X COMMUNICATION TECHNOLOGIES

As discussed in the previous chapter, Ethernet network is there to support real time data transmission inside the different ECU of the vehicle, but part of these data comes from the external environment that brings the new vehicles into the tele-communication world.
In this case, we talk about smart vehicles, that require the usage of existing external communications technologies adapted to the constraints of the automotive industry.
Among these technologies, we cans find 2 main families:

- **Long range Connectivity**, that enables data transmission over vast distances via the use of OEM's or shared (e.g. DataForRoadSafety) cloud servers to store and transmit data for telematics, over-the-air (OTA) updates and cloud services. For automotive applications, **cellular networks** are the most deployed.
- **Short range Connectivity**, that enables fast and efficient communication over limited distances, typically within a few meters to a few hundred meters. Among these technologies, we can find
    - **Bluetooth**, that is used for phone pairing, hands free calling and some vehicle diagnostic.
    - **Wi-Fi**, that provides in-car internet access for passengers and connects to external vehicle services.
    - **Broadcast technologies** that share dynamic information, that could improve road safety, in local around the vehicle.

All these technologies contribute to the V2X (Vehicle-to-Everything) services, that allow the communication between the vehicles, infrastructures and pedestrian for smart traffic management and overall road safety improvement.
Among V2X applications, we can find:

- V2V (Vehicle-to-Vehicle): cars share real-time road data to prevent collisions.
- V2I (Vehicle-to-Infrastructure): smart traffic lights and road sensors improve city traffic flow.
- V2P (Vehicle-to-Pedestrian): Alerts pedestrians and drivers about potential accidents.

A quick overview extracted from (UTAC, 2023) of all these technologies will be presented in the paragraphs below.

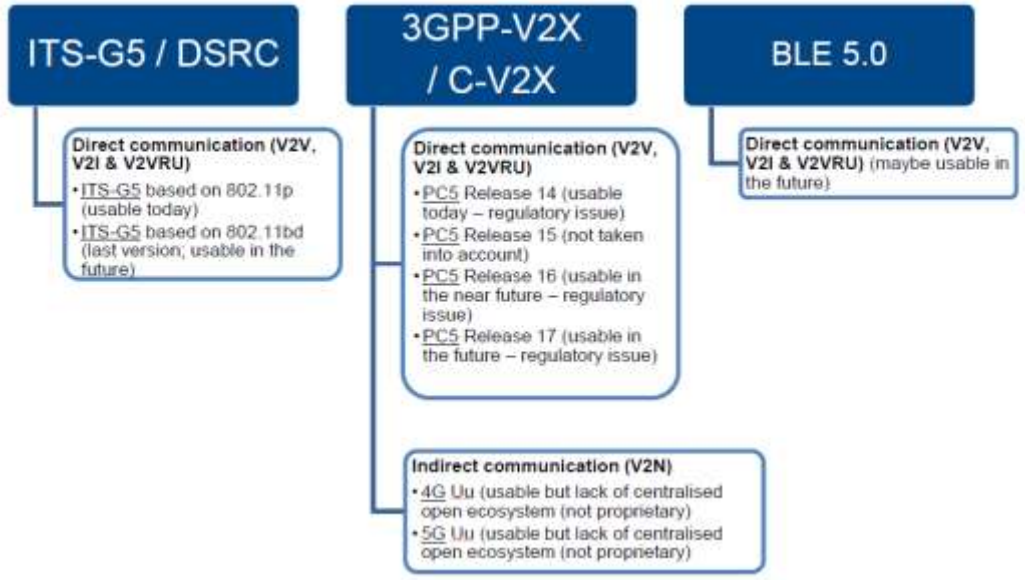


Figure 1- V2X Technologies used in automotive

2.2.1 CELLULAR GSM / 3G / 4G / 5G

The car phones were introduced in 1980s, primarily used by business professionals. They had limited coverage, poor security and expensive hardware.
Later on, in early 1990s the arrival of **GSM** (Global System for Mobile Communications) allowed a wider diffusion of sms-based telematics, basic GPS Navigation, that used the 2-G networks for data updates, and finally for emergency services. These lasts allowed cars to make a SOS call to reach the local garage or tire center or to facilitate the assistance intervention by sharing the exact position of the accident.
The speed up of the mobile data transmission via the 3G technology pushed some automakers to enable 3G-infortainement and telematics services in early 2000s. Main applications were mostly for infotainment for internet access and live weather/news updates.
The real revolution arrived with the **4G** | LTE technology (UTAC, 2022): the wider frequency band (from 800 MHw to 2.6 GHz) allowed the introduction of high-speed internet (up to 100 Mbps) for automotive applications. This has been possible thanks to a variable latency (from 30 ms up to 100 ms in case of bad conditions) and to the robustness of the network to the mobility, even if there can be some connection loss at high speeds. In most cases, a coupling with the GPS technology has been done to improve the positioning of the cars connected via the 4G.
Even if infotainment stays the most demanding automotive service, the 4G allowed the introduction of the cloud-based telematics: services like the Over The Air (OTA) software updates have been introduced to allow the car manufacturers to provide to the customer an off-line after-selling services by taking the control of the software installed on his car and updating it off-line. This technology has evident advantages in terms of cost (after-sale), time reduction and safety: the customer may have access to the last safety updates for the ECUs of his car without having to bring the car to the car dealer. 4G technology has also opened the road to the Vehicle-to-Network (V2N) communications: enabling cloud-based systems to improve vehicle performances by communicating of the local road characteristics.
Most recently, the **5G** cellular technology (UTAC, 2022)has been introduced also in the automotive market.

This technology enables the V2X communication services, thanks' to high-speed connectivity (up to 10 Gbps), low latency (<1 ms), massive device connectivity (up to many km) and robustness).
However, cellular based communication still present uncertainties concerning its mass deployment (5G network is only deployed in big urban areas) and congestion control mechanisms (in crowded neighbourhoods or cities, the network can be overloaded and thus increase communication latencies from few ms to hundreds ms).
The higher speed of the 5G network contributed also to:

- the improvement of already existing OTA update services,
- to process sensor data faster for better automation
- and to optimize fuel efficiency and emissions via the interaction with smart infrastructures.

2.2.2 Bluetooth Low Energy (BLE)

Bluetooth is a short-range wireless communication technology that enables devices to exchange data over radio waves (UTAC, 2022). It was developed as a low-power, cost-effective alternative to wired connections, and it has revolutionized mobile phones, automotive systems, smart devices, and Internet of Things (IoT) applications.
The frequency band is at 2,4 GHz (2400 MHz – 2483,5 MHz) with a data transfer up to 2 Mb/s. The communication distance is up to 400 m indoor and up to 50 m outdoor. Mobility is linked to radio range, while positioning has a precision between 2 and 5 m.
The short frequency band is not sufficient for the transmission of the V2X standardized messages due to these messages size, for this reason the usage of this technology is more linked to opportunistic services

- for driver's comfort
    - hands-free communication, infotainment (e.g. music streaming, voice control)
    - digital key or the keyless entry
- for vehicle diagnostics and performance tracking.

2.2.3 Wi-Fi standard : IEEE 802.11p and 3GPP standards : PC5 Sidelink

Direct communications has been developed and used in automotive to permit direct communication between one vehicle with another one without using a centralized server to host the conversation. We can find 2 kinds of technologies, having the same goal but with different standards and industries:

- **IEEE 802.11p (also called DSRC or ITS-G5)**, based on wireless communication module installed on the vehicle, making this last as a "moving data sender", that interacts with all data receivers that he encounters during his path;
- **C-V2X**, also known as **PC5**, is based on the cellular communication feature where two devices can communicate with each other without using a base station.
-

IEEE 802.11p wireless technology (UTAC, 2022) operates in the 5.9 GHz frequency band (Dedicated Short-Range Communications - DSRC) with a band of 10 MHz per channel and very low latency (< 2 ms for critical safety messages). This technology provides direct communication in V2V or V2I modes and does not need any cellular networks to be operationally, but the communication reposes on the other receivers (vehicles or infrastructures) that are close to sender.

The **PC5 (or CV2x)** interface (UTAC, 2022) and (UTAC, 2022) is a direct communication link standardized by 3GPP (3rd Generation Partnership Project) for Vehicle-to-Everything (V2X), Device-to-Device (D2D), and Public Safety applications. It allows devices to communicate via a cellular network in sidelink mode. It has low latency (~ 1 ms), operates on licensed and unlicensed spectrum on cellular (5.9 GHz ITS band or dedicated bands
As for the others communication technologies, there have been multiple releases during recent years, that are summarized in Table 2-1.
Starting from the Release 14 (UTAC, 2022), the PC5 communication protocol has started to play a huge role in V2X communications:

- V2V for alerts for lane changes, sudden braking and collision avoidance
- V2I (vehicle to infrastructure) as support for smart traffic lights and road hazard notification
- V2P (vehicle to pedestrian) to protect pedestrian and cyclists via smartphone alerts.

In terms of application, IEEE 802.11p standard is independent from telecom networks and allows a faster adoption (at least among vehicles equipped with the same technology), while PC5 technology is preferred in some case, because of the better scalability and future integration with 5G networks. Some hybrid solutions integrate both technologies for maximum efficiency.

3GPP Release	Year	Technology	PC5 Use Cases
12	2014	LTE D2D	➢ Introduced PC5 for Proximity Services (ProSe): public safety, first responders in disaster zones without network coverage
14	2017	LTE V2X	➢ Enhanced PC5 for Vehicle-to-Vehicle (V2V) and V2X applications.
16	2020	5G NR-V2X	➢ Upgraded PC5 for 5G-based V2X, improving reliability, range, and efficiency.
17+	2022 - present	Advanced 5G-V2X	➢ Adds enhanced side link for platooning, semi-autonomous driving, and smart transportation.

Table 2-1: Major releases of the PC5

All these features ensure

- fast data exchange for safety-critical applications (e.g., preventive collision avoidance),
- independency from network coverage (services are available almost everywhere as soon the sender and the receiver are close enough)
- and stable connections between vehicles and infrastructure (e.g. smart traffic lights)

On the other hands, the IEEE 802.11p technology

- struggles in high-density environment (e.g. urban areas) because of the limited scalability due to limited congestion control mechanism
- has a limited range (few hundreds meter) compared to the cellular networks that has potentially an infinite range
- Few vehicles are today equipped with direct communication technology antenna and chipset

3. Suitability of the different technologies for the selected use cases

The point in common of the sensor used for the perception (radar, camera or telecommunication) is electromagnetic spectrum. This last is comprised of all frequencies of electromagnetic radiation that propagate energy and travel through space in the form of waves (NASA, 2019):

- longer wavelengths with lower frequencies make up the radio spectrum.
- shorter wavelengths with higher frequencies make up the optical spectrum. The portion of the spectrum that we can see is called the visible spectrum.

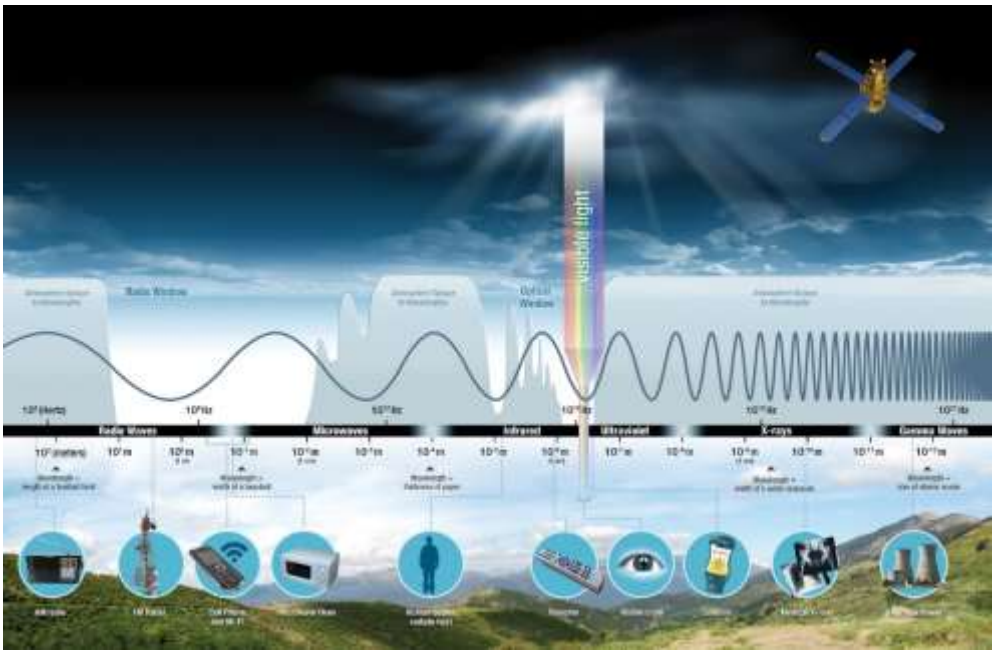


Figure 3-1 The Electromagnetic Spectrum (NASA, 2019)

Weather conditions have an impact on the absorption of the electromagnetic radiation, but it acts in a different way according to the frequency of the wave:

- it is crucial on infrared and ultraviolet waves, sent by radar and camera because it acts on the range of the visible
- while, it is almost negligible for radio waves used in connectivity technologies.

This physical consideration reassures to consider V2X communication technologies as an additional sensor to prevent accidentology in case of adverse weather conditions.

3.1 V2X MESSAGES

According to the definition of the Car-2-Car Communication Consortium (C2C-CC), V2X communication is divided into communication between (C-ITS, 2024)

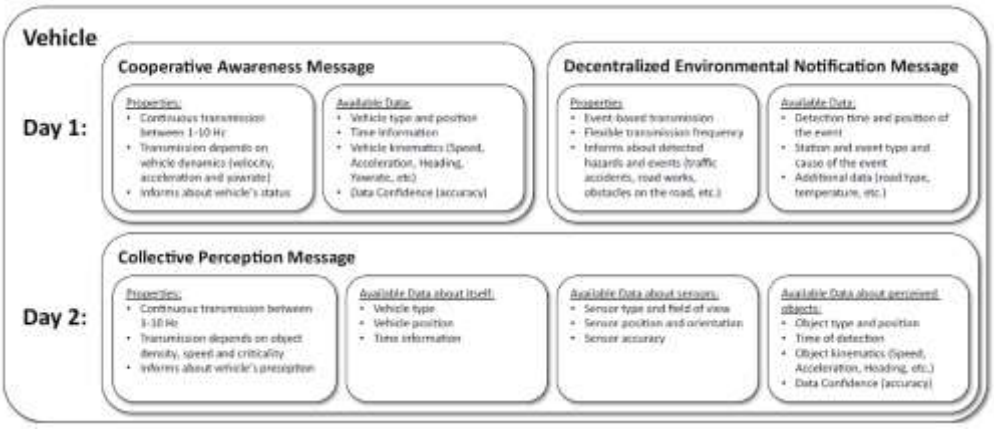
- vehicle and vehicle (V2V)
- vehicle and infrastructure (V2I)
- vehicle and people (V2P)

What makes this special is that all these entities communicate directly with each other (Bauder M. &.-G., 2024), (Festag, 2014) This means that information is sent directly to the environment at a dedicated frequency of approx. 5.9 GHz. Each vehicle, infrastructure, or person becomes an independent transmitter and receiver (C-ITS, 2024). The information is also only available within the transmitting range. Sending ranges of 800 m can be achieved with the aid of

WLANp, the current transmission standard at the physical layer, in line-of-sight situations without shadow effects from the surroundings (Bauder M. a.-G., 2022). Newer technologies can also have a transmission range of over 1000 m. Among current standardized messages, we divide (see Figure 3-2):

- **Day 1 messages**
  - **CAM** (Cooperative Awareness Message), that continuously sends vehicle-related actual information about its status at the frequency of 1 to 10 times per second. This includes the position and kinematics of the vehicle. They have been introduced and standardized via the ETSI EN 302 637-2 (ETSI, 2014).
  - **DENM** (Decentralized Environmental Notification Message), that is an event-message, based by the vehicles and is intended to warn other vehicles of danger spots or critical events. This includes, among other things, the warning of a traffic accident, roadblocks, or adverse weather conditions. Standardization has been done via the ETSI EN 302 637-3 (ETSI, 2019)

- **Day 2 messages**
  - In this case, vehicles will also be able to send information about their surroundings which will be realized by the Collective Perception Message (**CPM**). This message also contains self-related information, sensor information, and information like the CAM about the detected objects. CPM is also sent 1 to 10 times per second. Standardization has been done via the ETSI TS 103 324 (ETSI, 2023)



Currently, it is not easily possible to gain access to this data. Except for cellular network, which is internet based, otherwise no traces of it can be tracked. Due to the nature of direct communication, the data is therefore only available in the short term in the sending and

Figure 3-2 Properties and data of the messages of a V2X-capable vehicle today (Day 1) and in the future (Day 2) (Bauder M. &.-G., 2024)

receiving vehicle. In (Bauder M. a.-G., 2022), the concept of a forensic roadside unit was presented, which should receive and store the C2X data of the vehicles and all other entities, such as infrastructure, to make this data available to the expert in the event of an accident. Figure 3-3 shows an example of the scenario at an intersection.



Figure 3-3 3D visualization of an accident scene at an intersection shortly before an accident involving two cooperative vehicles.

Another open point linked to these messages are the accuracy and the resolution. In (Bauder M. a.-G., 2023) and in (Schweiger, 2024), both questions were systematically examined for the CAM and compared with the UNECE R160 specification of the EDR [12]. The accuracy was determined during various driving maneuvers (accelerated driving, constant driving, and cornering) (Schweiger, 2024). The expected temporal resolution (frequency) of the CAM depending on the environment (urban, rural, highway, and parking) was investigated in (Bauder M. a.-G., 2023).

3.2 FINAL USE CASES SELECTION AND DESCRIPTION

Results from the investigations in this domain are under development and for the moment they are not able to cover automotive safety standards and redundancy assessments. That's the main reason why the only known consumeristic application of the Connectivity in automotive are limited to the following use-cases:

1) **for driver's information**: the V2X system is able to transmit messages about the next **local hazard** that he may encounter on the current path (e.g. crash or construction zone present on the following x m) and then it's up to the driver to assess the safety criticism of the upcoming situation;

2) **for driver's comfort**: the V2X system is able to transmit messages about the next road characteristics (e.g. an intersection, a curb or a round-about known in the GPS map in next 200 m) and the vehicle can automatically adapt the vehicle current dynamics (speed, acceleration) to allow to pass the road event in a comfort way for the driver.

About the application to fulfill driver's information on local hasards, the new Euro-NCAP revisions for 2026 and 2029 aim to exploit this technology to enhance road safety. In particular, 2026 Safe Driving Vehicle Assistance protocols have been updated with compared to the 2024 one: it indicates that vehicles, able to send and receive local hazard information, are eligible to score the available points (Euro-NCAP, 2024).

Local hazard information contributing to the 2026 Euro-NCAP scores are the following:

- **Construction zones**
- **Items on road**
- **Stopped vehicle**
- **Broken down vehicle**
- **Post crash**
- **Poor weather**
- **Poor road**
- **Wrong way driver**
- **Amber + Blue lights**
- **Traffic jam**

Vehicles able to send and receive local hazard information are eligible to score the available points, described in (Euro-NCAP, 2024). Vehicles may communicate with a public cloud or via direct communication. Maximum points are achieved when both cloud and direct communication is possible.
"Receiving and informing" is understood as retrieving local hazard information into the vehicle and informing the driver about them in due time before reaching the event location. "Sending" understood as sharing local hazard information gathered by the vehicle within the DFRS cloud ecosystem or direct network.

The Directive 2010/40/EU specifications have been adopted in order to ensure compatibility, interoperability and continuity for the deployment and operational use of Intelligent Transport Systems (ITS) for the provision of EU-wide Safety Related Traffic Information (SRTI) and Real-Time Traffic Information (RTTI) services (EU, 2010).
For that purpose, Member States need to set up and manage their national access points (NAP), where the relevant data needs to be easily available for exchange and reuse.

According to this Directive, the events or conditions covered by the road safety-related minimum universal traffic information service shall consist of at least one of the following categories (EU, 2010):

- **temporary slippery road;**
- **animal, people, obstacles, debris on the road;**
- **unprotected accident area;**
- **short-term road works;**
- **reduced visibility;**
- **wrong-way driver;**
- **unmanaged blockage of a road;**
- **exceptional weather conditions**.

The information provided on one of each event shall include the following items:

- location of the event or the condition;
- the category of event with a short description (if appropriate);
- driving behavior advice (if applicable).

For the moment, this directive is mainly addressed to public and/or private road operators and/or service providers, that shall make these data available in the DATEX II (CEN/TS 161457) format or any fully compatible and interoperable with DATEX II machine-readable format through an access point.

3.2.1 EXAMPLES OF SPECIFIC POOR WEATHER CONDITIONS APPLICATION

As example of usage of the connectivity according to the Euro-NCAP and application of the Directive 2010/40/EU, let consider the 2 following examples of road hazard because of poor weather conditions (Car-2-Car, 2021):

- the slippery road
- fog

3.2.1.1 Slippery road prevention

As stated in previous paragraphs, the main goal of the connectivity is to establish standard messages that can be transmitted and the protocol requested by the EU Directive is the DATEX II. In case of slippery road, an event message DENM sent by the infrastructure allows to identify a specific zone with a risk.



Figure 3-4 Slippery road prevention

The following messages belong to the category "Temporary slippery road":

- Flooding
- Danger of aquaplaning

- Surface water hazard
- Slippery road
- Mud on road
- Loose chippings
- Oil on road
- Petrol on road
- Ice
- Black ice
- Snow drifts
- Icy patches



DATEX II (EN 16157-3)		TMC Events (EN ISO 14819-2)			TPEG2-TEC (ISO/TS 21219-15)				DENM (ETSI EN 302 637-3)		
DATEX Class	Type	Text (CEN-English)	Code		Cause Code	Sub Cause Code	Warning Level	Text	Cause Code	Sub Cause Code	Text
EnvironmentalObstruction	flooding	flooding. Danger	908		5	1	3	flooding	9	0	hazardous location - surface condition
WeatherRelatedRoadConditions	surfaceWater	danger of aquaplaning	1002		7		3	aquaplaning	7	0	aquaplaning
WeatherRelatedRoadConditions	surfaceWater	surface water hazard	1041		7		3	aquaplaning	7	0	aquaplaning
WeatherRelatedRoadConditions	slippery	slippery road (above Q hundred metres)	1003		6		3	slippery road	6	0	adverse weather condition - adhesion
NonWeatherRelatedRoad Conditions	mudOnRoad	mud on road. Danger	1055		6	3	3	mud on road	6	3	mud on road
NonWeatherRelatedRoad Conditions	looseChippings	loose chippings. Danger	1056		6	8	3	loose chippings	6	8	loose chippings
NonWeatherRelatedRoad Conditions	oilOnRoad	oil on road. Danger	1057		6	7	3	oil on road	6	7	oil on road
NonWeatherRelatedRoad Conditions	petrolOnRoad	petrol on road. Danger	1058		6	2	3	fuel on road	6	2	fuel on road
WeatherRelatedRoadConditions	ice	ice (above Q hundred metres)	1006		6	5	3	ice on road	6	5	ice on road
WeatherRelatedRoadConditions	blackIce	black ice (above Q hundred metres)	1038		6	6	3	black ice on road	6	6	black ice on road
WeatherRelatedRoadConditions	snowDrifts	snow drifts (above Q hundred metres)	1016		9	5	3	snow drifts	9	5	snow drifts
WeatherRelatedRoadConditions	icyPatches	icy patches (above Q hundred metres)	1047		6	5	3	ice on road	6	5	ice on road

Figure 3-5 Corresponding Message Subsets for the category "Temporary slippery road" (Car-2-Car, 2021)

The selection of the messages is based on the following rules:

- the significant message is "slippery road (above Q hundred meters)", which explains the effect of the category.
- The other messages are also selected, because they give drivers important information to adjust their driving behavior. For example, some of them can't be seen on first view (e.g. oil, petrol or black ice).
- Categories such as heavy snowfall or heavy rain are not relevant in this category, because they are part of category "exceptional weather conditions".

This message can be received by multiple communication channels:

- an upcoming vehicle via direct communication
- a smart infrastructure, provided by the road operator
- a back-end dynamic information, provided by the cluster of the specific car manufacturer.

If we consider that the message is received by an upcoming vehicle, one of the first to do is to confirm the confidence of the information. This can be done by coupling the Connectivity ot on board vehicle sensors like:

- on-board camera, that
  - may "see" the snow on the road
  - or recognize contextual panels presents in dangerous zones
- specific weather sensors, used to detect water on the windshield and to activate wipers
- temperature sensors, that may confirm the risk of ice or snow on the road if the measure a temperature lower than 0° C

- dynamic information from HD maps.

After that, the redundance on the confidence of the information can be done by monitoring on board vehicle data, like

- vehicle speed, if it is lower than the GPS speed it means that wheels are locked;
- vehicle deceleration: if the curbs does not decrease linearly, then the vehicle is over-braking
- Anti-Braking System activation: if it is activated by the braking system, it means that the vehicle is slipping.

The confirmation of the upcoming danger can be used

- by the system to inform the driver via a specific HMI and invite him to decrease the current speed, as requested by the Euro-NCAP
- but also to retransmit this message to others road operators (e.g. the car beyond) to allow to activate the same recognition strategy and support the anticipation of the braking and help to maintain the safety distance.

3.2.1.2 Fog prevention

Fog is part of local hazard because of reduced visibility, in addition to the following messages:

- visibility reduced
- smoke hazard
- dense fog
- patchy fog
- blowing snow
- serious fire

Fog is recommended as safety relevant if it presents a hazard to road user when the visibility could fall below e.g. 100 meters, exact value may be country specific.

DATEX II (EN 16157-3)

DATEX Class	Type
PoorEnvironmentConditions	visibilityReduced
PoorEnvironmentConditions	smokeHazard
PoorEnvironmentConditions	denseFog
PoorEnvironmentConditions	patchyFog
PoorEnvironmentConditions	blowingSnow
EnvironmentalObstruction	seriousFire
PoorEnvironmentConditions	fog

TMC Events (EN ISO 14819-2)

	Text (CEN-English)	Code
	visibility reduced (to Q)	1318
	smoke hazard (visibility reduced to Q)	1309
	dense fog (visibility reduced to Q)	1301
	patchy fog (visibility reduced to Q)	1307
	blowing snow (visibility reduced to Q)	1323
	serious fire	921
	dense fog (visibility reduced to Q)	1301

TPEG2-TEC (ISO/TS 21219-15)

Cause Code	Sub Cause Code	Warning Level	Text
18		3	visibility reduced
18	2	3	visibility reduced due to smoke
18	1	3	visibility reduced due to fog
18	1	3	visibility reduced due to fog
18	3	3	visibility reduced due to heavy snowfall
8	1	3	major fire
18	1	3	visibility reduced due to fog

DENM (ETSI EN 302 637-3)

Cause Code	Sub Cause Code	Text	Linked Cause
18	0	adverse weather condition - visibility	
18	2	visibility reduced due to smoke	
18	1	visibility reduced due to fog	
18	1	visibility reduced due to fog	
18	3	visibility reduced due to heavy snowfall	17 – 1 – strong winds
5	0	impassibility	18 – 2 – visibility reduced due to smoke
18	1	visibility reduced due to fog	

Figure 3-6 Corresponding Message Subsets for the category "Reduced visibility" (Car-2-Car, 2021)

As for the previous case, a DENM message can be sent by the road service operator, as we can in Figure 3-7.



Figure 3-7 Fog information sent by a French infrastructure operator

As in the example of the slippery road, this fog message can be received by

- an upcoming vehicle via direct communication,
- a smart infrastructure, provided by the road operator
- or as back-end dynamic information, provided by the cluster of the specific car manufacturer.

The confirmation of the confidence of the information can be obtained via a cross-check with on-board sensors to activate automatic beam light. The safety benefits for the driver is given via the reduced number of false positive on beam light activation.

4. Conclusion

This document is part of the WeatherSafe deliverables for the WP3 and aims to introduce the connectivity as an additional sensor, that may help to improve road safety in case of adverse weather conditions when the standard perceive sensors have a limited perception.
An introduction to the common telecommunication technologies used in automotive industry is done, by following the experience of the Consortium SECUR, leaded by the UTAC. Later on, a recall of the Euro-NCAP protocols and current legislation aiming to exploit these connectivity technologies to improve road safety is done.
Deliverable ends with the introduction of 2 examples of practical application of the connectivity to enhance road safety.

5. Acknowledgements

The AWC project consortium would like to acknowledge for their support and work all the Partners and Third Parties involved:



6. References

Bauder, M. &.-G. (2024, 09). Development of an Accident Reconstruction Method Using Cooperative Awareness Message Data. Récupéré sur https://www.researchgate.net/publication/384774753_Development_of_an_Accident_Reconstruction_Method_Using_Cooperative_Awareness_Message_Data

Bauder, M. a.-G. (2022). Does Vehicle-2-X Radio Transmission Technology Need to Be Considered within Accident Analysis in the Future? *Sensors, 22*, 9832. doi:10.3390/s22249832

Bauder, M. a.-G. (2022, 10). Opportunities and challenges of cooperative intelligent transportation systems on accident analysis.

Bauder, M. a.-G. (2023). Cooperative Awareness Messages' Generation Frequencies, Trigger Distributions, and Pseudonym Changes of First Commercially Deployed Vehicles in Real Operating Scenarios. *IEEE Access*, 69708-69719. doi:10.1109/ACCESS.2023.3292576

Car-2-Car. (2021). *Safety related message sets - Selection of DATEX II Situations, DENM and TPEG2-TEC Causes and TMC Events for EC high level Categories.* Récupéré sur https://www.car-2-car.org/fileadmin/documents/General_Documents/ITSTF20001_SafetyrelatedMessage-Sets-DATEXII_DENM_TPEG-TEC_TMC__v1.5_FINAL.pdf

C-ITS. (2024). *C-ITS: Cooperative Intelligent Transport Systems and Services.* Récupéré sur https://www.car-2-car.org/about-c-its/

ETSI. (2014). *Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2 Specification of Cooperative Awareness Basic Service.* Récupéré sur https://www.etsi.org/deliver/etsi_en/302600_302699/30263702/01.03.01_30/en_30263702v010301v.pdf

ETSI. (2019). *Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service.* Récupéré sur https://www.etsi.org/deliver/etsi_en/302600_302699/30263703/01.03.01_60/en_30263703v010301p.pdf

ETSI. (2023). *Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Collective Perception Service; Release 2.* Récupéré sur https://www.etsi.org/deliver/etsi_ts/103300_103399/103324/02.01.01_60/ts_103324v020101p.pdf

EU. (2010). *Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport Text with EEA relevance.* Récupéré sur https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0040

Euro-NCAP. (2024). *Safe Driving Vehicle Assistance Protocol - Implementation January 2026.* Récupéré sur https://www.euroncap.com/en/for-engineers/protocols/2026-protocols/

Festag, A. (2014). Cooperative intelligent transport systems standards in Europe. *Communications Magazine, IEEE, 52*, 166-172. doi:10.1109/MCOM.2014.6979970

Kulyk, A. (2024). *The Evolution of Automotive Networking: From CAN to Ethernet and Beyond.* LinkedIn . Récupéré sur https://www.linkedin.com/pulse/evolution-automotive-networking-from-can-ethernet-beyond-artem-kulyk-mzkcf/

Lindsey Research. (2020). *BMW Group Safety Assessment Report.* Hyde Park.

NASA. (2019). *Introduction to the Electromagnetic Spectrum.* Récupéré sur https://science.nasa.gov/ems/01_intro/

Schweiger, M. B.-G. (2024). Data accuracy in Vehicle-to-X cooperative awareness messages: An experimental study for the first commercial deployment of C-ITS in Europe. *Vehicular Communications, 47*, 100744. doi:https://doi.org/10.1016/j.vehcom.2024.100744

UTAC. (2022). *Technical document: 4G (Uu interface).* Récupéré sur https://www.utac.com/wp-content/uploads/2023/04/SECUR-WP2-D2.1-Technical-Document-Report-4G.pdf

UTAC. (2022). *Technical document: 5G (Uu interface).* Récupéré sur https://www.utac.com/wp-content/uploads/2023/04/SECUR-WP2-D2.1-Technical-Document-Report-5G.pdf

UTAC. (2022). *Technical document: Bluetooth Low Energy 5.0.* Récupéré sur https://www.utac.com/wp-content/uploads/2023/04/SECUR-WP2-D2.1-Technical-Document-Report-Bluetooth-Low-Energy-5.0.pdf

UTAC. (2022). *Technical document: ITS-G5 based on 802.11p.* Récupéré sur https://www.utac.com/wp-content/uploads/2023/04/SECUR-WP2-D2.1-Technical-Document-Report-ITSG5-based-on-802.11p.pdf

UTAC. (2022). *Technical document: PC5 based on 3GPP Release 14 (mode 4).* Récupéré sur https://www.utac.com/wp-content/uploads/2023/04/SECUR-WP2-D2.1-Technical-Document-Report-PC5-based-on-Release-14.pdf

UTAC. (2022). *Technical document: PC5 based on 3GPP Release 16 (mode 2).* Récupéré sur https://www.utac.com/wp-content/uploads/2023/04/SECUR-WP2-D2.1-Technical-Document-Report-PC5-based-on-Release-16.pdf

UTAC. (2023). *Safety Enhancement through Connected Users on the Road.* Récupéré sur https://www.utac.com/wp-content/uploads/2023/04/OASIM-Official-Project-Brochure.pdf

7. Table of illustrations

Figure 1- V2X Technologies used in automotive 8
Figure 3-1 The Electromagnetic Spectrum (NASA, 2019) 11
Figure 3-2 Properties and data of the messages of a V2X-capable vehicle today (Day 1) and in the future (Day 2) (Bauder M. &.-G., 2024) 12
Figure 3-3 3D visualization of an accident scene at an intersection shortly before an accident involving two cooperative vehicles. 13
Figure 3-4 Slippery road prevention 15
Figure 3-5 Corresponding Message Subsets for the category “Temporary slippery road" (Car-2-Car, 2021) 16
Figure 3-6 Corresponding Message Subsets for the category “Reduced visibility” (Car-2-Car, 2021) 17
Figure 3-7 Fog information sent by a French infrastructure operator 18