Vehicular Communications Definition, Types, Value, Uses, and Considerations
Prepared for the Task Force on Vehicular Communications (TF on VC)

This document provides an overview of Vehicular Communications (VC) including its definition, types, value, uses, and considerations. Achieving the potential benefits of VC requires a comprehensive approach involving collaboration between policymakers, industry stakeholders, and researchers to deploy and protect such communications capabilities.

I. Definitions

In this document, the wording:

'Information' is data, commands, and other information.

'VC' is communications from and to in-vehicle systems and from and to mobile communications devices connected to in-vehicle systems. Communications by mobile communications devices that are not connected to in-vehicle systems are not included in VC, even if the vehicle serves as the device's connection to a cellular network (e.g., by an in-vehicle Wi-Fi hotspot).

'Vehicle' refers to vehicles of categories M (passenger vehicles), N (goods vehicles), and T (agricultural and forestry tractors) within WP.29 regulations.

'VRU' is vulnerable road users including people (e.g. pedestrians) on an element of the road network as well as occupants and users of vehicles of WP.29 vehicle category L (motorcycles, tricycles, bicycles, scooters, and similar road transport equipment.)

'Road user' is vehicles and VRUs.

'Surroundings' is drivers/vehicle owners outside their vehicle, household elements, (other) vehicles, VRUs, road transport infrastructure components (roadside units, electronic signs, traffic control and management systems, and other road transport infrastructure), service providers, cloud-based operations, etc.

'Multi hop' is a subtype of mesh network communications technology with the in-vehicle devices that pass on information knowing their geographic location and that are able to direct their passing on of information to be in the desired direction of the message originator.

'ADS' is an Automated Driving System according to SAE J3016.

II. VC Types

This section provides general background about types of VC.

VC includes the following broad categories:

a. Wired and wireless.

b. One to one (unicast), one to a group (multicast), and one to many (broadcast).

c. Unidirectional and bidirectional.

Current wired communications devices in vehicles primarily are:

a. The On-Board Diagnostic (OBD) port.

b. Universal Serial Bus (USB) ports.

c. The Electrical Vehicle (EV) charging equipment.

While these devices often utilise wired connections, they might also use wireless communications approaches.

Individual vehicles usually have only a few wireless communications technologies. The wireless communications technologies, listed below in approximate range order, might appear in a vehicle now or in the future, include, but are not limited to:

a. Very-short range communications, such as access control technology using Radio-Frequency IDentification (RFID) and Near-Field Communications (NFC) for short-range identification data exchange in the range of centimetres.

b. Close-range communications, such as Bluetooth, Ultra-Wide-Band (UWB), and infrared for communications in the range of a few metres.

c. Radio Local Area Networks (LAN), such as wireless LAN (IEEE 802.11 family) for information exchange over tens to hundreds of metres or as an in-vehicle wireless communications link between an in-vehicle internet router and vehicle occupants' devices, often referred to as a Wi-Fi hotspot.

d. Direct short-range communications between vehicles (V2V) and between vehicles and road transport infrastructure (V2I), or between vehicles and VRUs (V2VRU), such as Cellular Vehicle-to-Everything (C-V2X) sidelink communications and IEEE 802.11p.

e. Cellular communications providing voice, text messages, and mobile internet access via International Mobile Telecommunications (IMT).

f. Radio, such as AM, FM, shortwave, and DAB+.

g. Satellite, such as Global Navigation Satellite Systems (GNSS), satellite radio, and satellite internet.

III. VC Value

VC has potential to:

- Improve road user safety.
- Reduce the environmental impact of road transport.
- Enhance the road transport efficiency.
- Improve the road transport experience.
- Improve driving experience and comfort.
- Reduce road transport costs.

VC can allow in-vehicle systems and vehicle occupants to receive information from their surroundings.

VC can allow in-vehicle systems to provide their surroundings with information including:

- State of the vehicle, such as:
    - Vehicle location, speed, and trajectory.
    - Vehicle acceleration and braking.
    - Vehicle signalling (audio and visual).
    - Use of vehicle features, such as Driver Control Assistance Systems (DCAS) and ADS.
- The state of driver engagement (including sudden health issues).
- Identified road conditions.
- Identified weather and environmental conditions.
- Identified other road users.

IV. VC Uses

This section provides general information on possible uses of VC, grouped according to the type of use case. Some elements appear in multiple use case descriptions below, as common terminology does not always have precise boundaries. Possible use cases include, but are not limited to:

1. Safety and Emergency

a. *Safety information for vehicle occupants*: VC can support in-vehicle systems to provide real-time notifications and warnings to vehicle occupants about potential hazards. These notifications and warnings are based on information collected from their surroundings.

   Notifications and warnings include information about wrong-way driving, traffic congestion, VRU presence, slippery roads, vehicles with excessive speed, and other road hazards.

b. *Safety information for road-transport operations:* VC can support vehicles to transmit real-time information to their surroundings, allowing road transport infrastructure operators to improve their traffic management operations. These real-time notifications and warnings can be used to improve service operators' information and overall traffic management, possibly leading to infrastructure improvements or can be used for notifications on Variable Message Signs (VMS).

c. *Emergency services:* VC can support first responders and emergency services to accelerate their response by providing real-time information about crashes, road hazards, and other incidents. Also, see the *Traffic signal priority* and *Emergency vehicle support* use cases below.

d. *Automated Emergency Call Systems (eCall/AECS)*: VC enables in-vehicle AECS that can automatically detect the occurrence of a crash to call emergency services and provide vital information, such as location, crash severity, number of occupants, and other vehicle information. This process can reduce emergency response times and improve the effectiveness of the emergency response. Also, see the *Emergency services* use case above.

e. *Collision warning and avoidance:* VC can support drivers and vehicles systems detect and avoid potential collisions by receiving real-time information about other road users' locations, speeds, and trajectories. This information can be used as additional input to in-vehicle safety systems complementing the in-vehicle sensors, enhancing collision prevention capabilities.

   VC, combined with good vehicle positioning, can improve both the vehicle's detection capability of the 360° surrounding conditions as well as improving the likelihood that the vehicle is detected by other vehicles. This capability is especially useful in supplementing recognition in challenging scenarios such as bad weather as well as identifying non-line-of-sight objects, where visual recognition by in-vehicle sensors (e.g. radar, camera, lidar) is compromised or not possible (V2V, V2I, and V2VRU).

   VC can also report various types of potential local hazards, allowing for a more comprehensive risk assessment. In addition, safety is improved when road transport infrastructure components identify road users not providing VC information and send the VC information to surrounding road users in real time (V2I). Also, see the *Safety information for vehicle occupants* use case above.

f. *VRU protection*: VRUs can be protected from vehicles and other VRUs through VC to avoid collisions. The detected presence of a VRU can be communicated as information to all vehicles, including by a collective perception service, including:

- Roadside sensors detect the presence of VRU and send the V2I detection (including position and movement) to road users to make them aware (Collective perception).
- Vehicle sensors detect the presence of VRU and send the V2V detection (including position and movement) to other vehicles and VRU to make them aware (Collective perception).
- Communications devices carried by VRUs. VRU send their presence (position and movement) to other vehicles and make them aware (V2VRU).

In addition, VC can support communications equipment in the possession of VRU alerting drivers and in-vehicle systems about their presence. Vehicles equipped with VRU detection systems can share the information that they identify with surrounding vehicles and road transport infrastructure components. This information can then be used to implement VRU protection strategies.

This information – if reliable, relevant, reasonably accurate, and real-time – can be used as additional input for collision-related and other safety systems. Safety is improved when road transport infrastructure components identify VRUs and send the information to surrounding road users in real time. See the *Collision warning and avoidance* use case above.

g. *Natural disaster and crisis management:* VC can support vehicles and their occupants to receive notifications and warnings about various disasters and crises, including tsunamis, typhoons, and wildfires as well as unrest, strikes, shootings, terrorist attacks, etc. VC can support evacuations, by enabling sharing information from authorities.

In situations where the primary communications infrastructure is disrupted, vehicle-to-vehicle communications might be able to relay information across the road network using a multi-hop approach or a (possibly LEO) satellite approach. Such approaches might allow for comprehensive notifications and warnings to reach vehicle occupants even in areas where there are communications infrastructure outages. Similarly, vehicles in areas where there are communications infrastructure outages can use such approaches to deliver information to road transport operators and authorities responsible for the disaster response and management.

h. *In-vehicle notifications and warnings*: VC can support vehicles to receive notifications and warnings from their surroundings of special situations ahead on the road. Such situations include road closures and rerouting, materials spills, and crashes. Also, see the *Safety information for vehicle occupants* use case above.

2. ***Traffic Management***

   a. *Road transport infrastructure management:* VC can support road transport operators to optimise traffic flow, reduce congestion, and improve overall road transport efficiency and safety. Vehicles can provide real-time information on their location, movement, intended manoeuvres (e.g., lane changes, upcoming turns), etc. In addition, vehicles can report local hazards, such as road surface issues and areas with frequent braking or electronic stability control activation. This information can help identification of areas for targeted maintenance and repair of the road transport infrastructure.

   b. *Road works:* VC can support road transport infrastructure to inform drivers and in-vehicle systems (including ADS-equipped vehicles) about road works, including detours, lane changes, revised speed limits, and potential delays. Real-time warnings can reduce crashes and improve safety for both vehicle occupants and road workers.

   c. *Optimised traffic signal systems:* VC can support vehicles to receive intersection Signal Phase and Timing (SPaT) information, along with intersection topology, from traffic signal controllers. With this information, in-vehicle systems can optimise vehicle speed for energy efficiency to achieve green-light-optimal speeds. Traffic signal controllers can provide red-light violation warning information to in-vehicle systems to allow passing the warning to both the violating driver as well as divers in other vehicles approaching the intersection.

      In addition, vehicles can provide information about their activities. With this information, traffic signal controllers can adjust their signal timing. In the future, VC could replace inductive-loop detectors and support red-light violation prevention, reducing crashes and improving safety. Also, see the *Safety information for vehicle occupants* use case above.

   d. *Traffic signal priority*: VC can support emergency vehicles (police vehicles, ambulances, fire vehicles, rescue vehicles, etc) and public transport vehicles to request priority at traffic signals, facilitating a swift change to green and/or extending the length of the green light.

   e. *Real-time traffic updates:* VC can support in-vehicle systems and drivers to receive information on road network status.

   f. *Event management*: VC can support the road transport infrastructure to provide information about road closures, detours, and other route changes during special traffic situations, such as events, parades, protests, and VIP travel. This information can help drivers and ADS-equipped vehicles plan their routes and avoid congested areas.

3. ADS Support

a. *ADS support:* VC can support the deployment and improved performance of ADS. By utilising information received as additional input, ADS features might improve their performance within their Operational Design Domain (ODD) and even extend their ODD. This supplementary information, complementary to the in-vehicle software's own sensor interpretations, might allow for earlier and smoother automated actions.

   Road transport infrastructure components can provide ADS-equipped vehicles with crucial, real-time updates, including:

   - Changed road conditions, such as special traffic situations, road works, and crash locations.
   - Information about challenging topological situations, such as tunnel entries, highway entries and exits, reversible lanes, roundabouts, and complex intersections.

   When approaching their ODD limits, ADS vehicles without a fallback user can indicate this condition, enabling remote human interaction or automated guidance from road transport infrastructure components.

   Also, see the *Road works* and *Event management* use cases above.

b. *Automated Vehicle Parking (AVP)*: VC can facilitate valet and remote parking.

c. *Merging*: VC facilitates ADS-equipped vehicles to safely and reliably complete challenging manoeuvres, such as lane changing and merging into crowded lanes.

d. *Emergency vehicle support*: VC can support emergency vehicles to transmit their location, speed, and trajectory, ensuring earlier awareness by ADS features of these emergency vehicles and facilitating safe interaction with them. Emergency vehicles might send instructions to ADS vehicles without a fallback user.

e. *Cooperative automated driving*: VC can support collaboration between vehicles to improve safety and efficiency. Such collaboration includes functionalities, such as platooning and coordinating intersection entry for ADS-equipped vehicles. Also, see the *Collision warning and avoidance* use case above.

f. *Remote interaction*: VC enables out-of-vehicle humans and equipment to interact with ADS vehicles without a fallback user. Such interaction can include remote supervision, sending instructions to the ADS vehicle, etc.

g. *Remote driving*: VC can enable a human outside a vehicle to control the vehicle. This control can be remotely driving an ADS vehicle without a fallback user that is exiting its ODD or has a failure. This control can also be remotely driving a non-ADS vehicle without or with vehicle occupants.

4. In-Vehicle Experience and Convenience

a. *Infotainment and convenience:* VC can enhance the in-vehicle experience for vehicle occupants by delivering multimedia content, internet access, and personalised services. This delivery includes providing real-time information, such as location of rest areas for people and vehicles; availability of overnight parking for lorries; status of facilities for campers; location, availability, and pricing of EV charge points and fuel stations; and availability of parking spaces. In addition, reservations can be made for parking, EV charging, and other services, such as dining and lodging.

b. *Remote activations*: VC can be used for remote initiation of vehicle actions, such as door locking and unlocking, accessing the temperature control, managing EV charging, and opening the trunk for delivery and pickup. In addition, VC can be used from the vehicle for controlling home and destination devices, such as home appliances and garage doors.

   VC can support services such as vehicle sharing, vehicle rental, and automated transport.

c. *EV Charging support:* VC can support using information from the grid to control EV charging times and facilitate bidirectional electricity flows, enabling EVs to power the grid or a user's home and devices. Such activities could play a role in supporting electrical energy storage and electric grid balancing.

d. *Payment services*: VC can be used for in-vehicle purchases, such as payments for tolls, road pricing, parking, fuelling, EV charging, and drive-thru purchases.

e. *Wide area information provision*: VC can be used in vehicles through FM, AM, shortwave, and DAB+ radio; terrestrial TV; satellite radio; etc. broadcasts to provide general information to vehicle occupants and in-vehicle systems. This includes the use of TMC coding using ALERT-C or TPEG over FM RDS and DAB+.

5. Vehicle Management and Maintenance

a. *Geofencing*: VC can notify vehicle owners and managers when a vehicle exceeds pre-set geographic limits and speed limits. VC can provide information relevant to vehicle operations within those limits, such as traffic rules.

b. *Vehicle maintenance*: VC can support many activities, including updating in-vehicle software, firmware, map data, etc.; accessing real-time information on the health and performance of in-vehicle components; and transmitting the maintenance status of in-vehicle components to vehicle owners, vehicle manufacturers, and independent repairers.

c. *ISMR:* VC can support vehicle manufacturers to provide In-Service Monitoring and Reporting (ISMR) to vehicle-regulatory authorities about their vehicles.

d. *Vehicle emissions information*: VC can support in-vehicle systems to report the actual vehicle emission amounts to authorities to allow evaluating the real-world emissions of vehicles.

6. Other Services

a. *Investigation and information collection*: VC can allow legal authorities to retrieve information from vehicles, including whether an ADS feature is active or was active at a specific time.

b. *Remote authority vehicle control*: VC can remotely slow, stop, and disable a vehicle with appropriate legal authorisation.

c. *Stolen vehicle tracking*: VC can allow legal authorities to track a stolen vehicle.

d. *Public transport*: VC can provide waiting passengers with information about public transport arrival times and service variations, as well as assist public transport fleet operations and management, including prioritisation of public vehicles at traffic signals. Also, see the *Traffic signal priority* use case above.

e. *Fleet management*: VC can support fleet operators to collect information from their managed vehicles and control their operations. Also, see the *Geofencing* use case above.

f. *Freight movement*: VC can support activities such as tracking freight movement, improving freight transport efficiency, and lorries transmitting weight and digital documentation to relevant authorities, such as traffic management centres and customs authorities.

V. VC Considerations and Challenges

Although there are many benefits from VC, it is important to be aware of the potential considerations and challenges faced when using VC. These considerations and challenges, including the required countermeasures, vary across uses/applications, countries, and regions. Developing VC applications requires considering several factors that might translate into specific requirements. Potential considerations and challenges include, but are not limited to:

a. *Cybersecurity*: Communications are sensitive to cybersecurity threats, including hacking attempts and unauthorised access. Malicious actors may attempt to exploit vulnerabilities in communications protocols and compromise the integrity of information exchanged between vehicles and external systems.

   Vehicle manufacturers have implemented systems to secure vehicles and their information, often named CyberSecurity Management System (CSMS). Similarly, road transport infrastructure operators have implemented systems to secure their components and information, often named Information Security Management System (ISMS).

b. *Privacy*: Information exchange among vehicles and road transport infrastructure components could raise privacy issues, especially with regard to the personally identifiable information (PII) of vehicle occupants. Authentication to access vehicle information, including anonymisation and pseudonymisations of the information, are mitigations to reduce the risks involved. In general, access and processing of personal information is allowed (1) with a vehicle occupant´s consent, (2) when necessary to protect vital interests of a vehicle occupant or another person, or (3) based on public interest or compliance with legal obligations.

c. *Communications interference*: VC could be disrupted by interference, either within the same frequency range (in-band) and from outside that frequency range (out-of-band). Such interference could disrupt or limit information exchange between vehicles, road transport infrastructure components, and the communications infrastructure. International regulations on radio spectrum, which come from the UN agency ITU-R and are supplemented with regional and national regulations, mitigate the risk of communications interference.

   The out-of-band interference of VC should be restricted to an acceptable level. Techniques such as power control, spectrum transmission template, receiving filters, and other comprehensive technical means can be used.

d. *Vehicle service lives, backward compatibility, and futureproofing*: Development of VC equipment should take into account the long service lives of vehicles.

   Communications technology and ecosystems can evolve much faster. Continuity of communications services should be maintained for the service life of the vehicle. The core issue lies in balancing backward compatibility with futureproofing to ensure that all safety-of-life VC capabilities are maintained.

e. *Damage to communications infrastructure*: Physical attacks, mishaps, and environmental effects might cause roadside units and base stations to malfunction, disrupting communications. Also, see the *Cybersecurity* consideration above.

f. *Damage to in-vehicle communications equipment*: Physical damage to in-vehicle communications equipment, such as antennas and other in-vehicle communications components, might compromise functions reliant on information exchange. Notifications about such issues can be provided to the vehicle occupants.

g. *Delays (latency)*: All communications are subject to delays due to equipment processing time, protocol setup time, radio-spectrum bandwidth limitations, transmission rate, transmission throughput, etc. In addition, delays can come from communications technology limitations. For example, cellular communication systems contain many network component (radio base stations, gateway, etc.), which can cause some delay, and satellite communication transmission path is very long and leads to some delay.

h. VC applications should be designed so that the delays for the chosen communication methods match the acceptable data-transmission delays for the application. This requires considering factors such as the maximum number of communications participants at any time, the coverage of the chosen methods, and the supported vehicle speed.

i. *Limited Coverage*: Communications infrastructure can have areas of limited or no signal (dead spots). Such limits might disrupt information transmission. Consideration should be given to cases of a vehicle moving to a different legal jurisdiction that might have a different (incompatible) communications infrastructure and/or communications regulations.

j. *Service Outages*: Communications infrastructure can experience service outages due to various reasons, such as technical failures (e.g., power cuts) and maintenance activities. VC applications need to be resilient to interruptions by communications infrastructure outages, both local and wide area.

k. *Protection of safety-related radio spectrum*: Some radio spectrum has been allocated, and will be allocated, for safety-related VC. There is a risk of safety-related radio spectrum being used for other purposes due to increasing demand for radio spectrum and capacity from all stakeholders. The preservation of adequate, protected radio spectrum for safety-related VC should be ensured.

l. *Market Penetration*. Some VC applications require a substantial number of devices be deployed to function effectively. This relies on policies and strategies decided in the market.

m. *VRU awareness:* The detection and integration of components of systems protecting VRUs should take into account the position accuracy, reliability, availability of information (independent of whether a communications device is charged or switched on), etc. The information received from communications should supplement the vehicle´s safety systems for protecting VRUs.

n. *Interoperability:* Vehicles and road transport infrastructure components should be able to seamlessly exchange information to support common services, such as collision avoidance and cooperative adaptive cruise control. A unified approach is required to ensure that vehicles from different manufacturers and road transport infrastructure from different road operators or different service providers communicate effectively.

o. *Harmonised services*: Triggering conditions and minimum Key Performance Indicators (KPI) for senders and receivers of VC should be harmonised to provide effective communications-based services.

p. *Compliance assessment:* The minimum performance of the harmonised services of communications systems and communicated information should be validated using recognised standard procedures. It is necessary to achieve the required quality and accuracy of data and timeliness of transmitted information as well as level of security for the communications services offered.

q. *Costs*: Communications infrastructure, road transport infrastructure communications components, and in-vehicle communications equipment as well as licenses for communications technologies might be expensive. How costs are handled can be policy issues.