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. This document has been prepared to provide background information about VC to WP.29 participants.

Achieving VC capabilities can benefit from collaboration between policymakers, industry stakeholders, and researchers to deploy and protect relevant communications technologies.

At its 188th session in November 2022, WP.29 requested the Informal Working Group (IWG) on Intelligent Transport Systems (ITS) to perform preparatory activities and to explore the potential role of WP.29 related to VC (see: ECE/TRANS/WP.29/1168 para 19). This document is the outcome of those preparatory activities. The purpose of this document is to identify potential activities for further consideration at WP.29.

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I. VC Definitions

In this document, the wording:

‘Transmitted material’ includes data, commands, and other information.

‘Built-in system’ refers to components built into the vehicle. Built-in system does not include communications devices brought into the vehicle.

‘VC’ is communications from and to built-in systems and from and to mobile communications devices connected to built-in systems.

> Note: Communications by mobile communications devices that are not a built-in systems are not included in VC, even if the built-in system serves as the communications 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.

‘Road transport infrastructure components’ include roadside units, electronic signs, traffic control and management systems, and other road transport infrastructure.

‘Surroundings’ is drivers/vehicle owners outside their vehicle, household elements, other vehicles, VRUs, road transport infrastructure components, service providers, cloud-based operations, etc.

‘Multihop’ is a subtype of mesh network communications technology with the built-in systems passing on information knowing their geographic location and that are able to direct their passing on of transmitted material to be in the desired direction of the message originator.

‘ADS’ is an Automated Driving System as designated in SAE J3016.

‘DCAS’ is a Driver Control Assistance System as define in WP.29 Reg 171.

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 components 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 communications components 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 transmitted material exchange over tens to hundreds of metres or as an in-vehicle wireless communications link between an in-vehicle internet router and vehicle occupants' communications devices, often referred to as a Wi-Fi hotspot.

d. Direct short-range communications between vehicles (V2V) and between vehicles and road transport infrastructure components (V2I), or between vehicles and VRUs (V2VRU, sometimes V2P), 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 the 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 support built-in systems and vehicle occupants to receive transmitted material from their surroundings.

VC can support built-in systems to provide their surroundings with transmitted material including:

- State of the vehicle, such as:
  - Vehicle location, speed, heading, and trajectory.
  - Vehicle acceleration and braking.
  - Vehicle signalling (audio and visual).
  - Use of vehicle features, such as 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 built-in systems to provide real-time notifications and warnings to vehicle occupants about possible 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 built-in systems 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 can support 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 possible collisions by receiving real-time information about other road users' location, speed, heading, and trajectory. 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, such as intersections with obscuring items, where visual recognition by in-vehicle sensors (e.g., radar, camera, lidar) is compromised or not possible.

   VC can also report various types of possible 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. 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 transmitted material to vehicles by capabilities such as a collective perception service by:

- Roadside sensors detecting the presence of a VRU and sending the detection (including position and movement) to vehicles and VRUs to make them aware (Collective perception).
- Vehicle sensors detecting the presence of a VRU and sending the detection (including position and movement) to other vehicles and VRUs to make them aware (Collective perception).

VC can support communications devices in the possession of VRU provide transmitted material to built-in systems about the VRU. Vehicles equipped with VRU detection systems can share the information that they identify with surrounding vehicles and road transport infrastructure components. This transmitted material can then be used to implement VRU protection strategies.

This transmitted material – 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 transmitted material 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 vehicle-to-vehicle Multihop 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 transmitted material can help identification of areas for targeted maintenance and repair of road transport infrastructure components.

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

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

d. *Optimised traffic signal management*: VC can support vehicles to provide information about their activities to traffic management systems. With this information, traffic signal controllers can adjust their signal timing. In the future, VC might support replacing inductive-loop detectors as well as support red-light violation prevention, reducing crashes and improving safety. Also, see the *Safety information for vehicle occupants* use case above.

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

f. *Real-time traffic information:* VC can support built-in systems and drivers to receive information on road network status. VC can also support built-in systems sending information to the road transport infrastructure components about situations that the vehicle encounters.

g. *Traffic management for major events*: VC can support the road transport infrastructure components to provide information about road closures, detours, and other route changes during special traffic situations, such as events, parades, protests, and VIP travel. This transmitted material can help drivers and vehicles with ADS features plan their routes and avoid congested areas.

3. *Advanced Vehicle Capabilities*

a. *ADS support:* VC can support the deployment and improved performance of ADS. VC transmitted material received as additional input might be used to improve ADS features' performance within their Operational Design Domain (ODD) and even extend their ODD. This supplementary transmitted material, 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 features with crucial, real-time information, including:

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

   Similarly, DCAS features might benefit.

   Also, see the *Road works* and *Traffic management for major events* use cases above.

b. *Automated Vehicle Marshalling (AVM)*: VC can support services such as remote and Automated Valet Parking (AVP).

c. *Lane manoeuvres*: VC can support ADS features (and possibly DCAS features) 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, heading, and trajectory, ensuring earlier awareness of these emergency vehicles and facilitating safe interaction with them. Emergency vehicles might send instructions to ADS vehicles without a fallback user.

e. *Cooperative manoeuvre coordination*: VC can support collaboration between vehicles to improve safety and efficiency. Such collaboration includes platooning and intersection movement coordination includes for vehicles with ADS features (and possibly DCAS features). Also, see the *Collision warning and avoidance* and *Lane manoeuvres* use cases above.

f. *Remote interaction*: VC can support 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 without a fallback user, etc.

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

g. *Remote driving*: VC can support a human outside a vehicle to control the vehicle. This control can be for 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 communications-equipped home and destination items, 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 transmitted material from the grid to control EV charging times and support bidirectional electricity flows, enabling EVs to power the grid or the user's home. Such activities can 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 built-in 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 software maintenance*: VC can support updating in-vehicle software, firmware, map data, etc.

c. *Vehicle diagnostic and maintenance information*: VC can support accessing real-time information on the health and performance of in-vehicle components, and transmitting the status of in-vehicle components to vehicle owners, vehicle manufacturers, and independent repairers.

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

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

6. Support for Authorities

a. *Investigation and information collection*: VC can support 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 support legal authorities to track a stolen vehicle. VC can also allow the vehicle owner, and in some cases, the vehicle's insurance companies to track a stolen vehicle. As a condition for insuring some vehicles, insurance companies require that the vehicle can be tracked by a third-party service provider.

7. *Fleet and Logistics*

a. *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.

b. *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.

c. *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 considerations and challenges faced when using VC. These considerations and challenges, including possible countermeasures, vary across uses/applications, countries, and regions. Taking into account the considerations and challenges in the development of VC applications might translate into specific requirements. 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 might attempt to exploit vulnerabilities in communications protocols and compromise the integrity of transmitted material exchanged between vehicles and external systems.

   Possible countermeasures include: Many vehicle manufacturers have implemented systems to secure vehicles and their information (e.g., following ISO 21434 in conforming to UN R 155), often named CyberSecurity Management System (CSMS).

   Similarly, many road transport infrastructure operators have implemented systems to secure their components and information (e.g., following ISO 27001), often named Information Security Management System (ISMS).

b. *Privacy*: Information exchange among vehicles and road transport infrastructure components can raise privacy issues, especially with regard to the Personally Identifiable Information (PII) of vehicle occupants and other road users.

   Possible countermeasures include: Authentication to access vehicle information, including anonymisation and pseudonymisations of the information, are mitigations to reduce the risks involved. In certain cases, access and processing of PII is allowed (1) with a vehicle occupant´s consent, (2) when necessary to protect vital interests of a vehicle occupant or another person, (3) based on public interest or (4) in compliance with legal obligations.

c. *Information overload for human drivers*: The amount of information provided to drivers might increase with VC. Safety-related messages such as warnings and cautions might be difficult for some drivers to recognise when surrounded by other information.

   Possible countermeasures include: The design of the in-vehicle Human Machine Interface (HMI) for such messages can take account the driver workload and follow industry HMI guidelines.

d. *Vehicle service lives, backward compatibility, and future proofing*: Communications technology and their ecosystems can evolve much faster than vehicles are scrapped. Lack of continuity of communications services for the service life of vehicles can be an issue.

   Possible countermeasures include: Development of in-vehicle communications components can take into account the long service lives of vehicles or take into account the short lifecycle of the communication technologies. A core issue lies in balancing backward compatibility with future proofing to ensure that safety-related VC capabilities are maintained.

e. *Communications interference*: VC can be disrupted by interference, either within the same frequency range (in-band) and from outside that frequency range (out-of-band).

Such interference can disrupt or limit information exchange between vehicles, road transport infrastructure components, and the communications infrastructure.

Possible countermeasures include: Techniques such as power control, spectrum transmission template, receiving filters, and other comprehensive technical means can be used. International regulations on radio spectrum and its use, which come from the UN agency ITU-R and are supplemented with regional and national regulations, can reduce interferences to an acceptable level when followed by communications devices.

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

   Possible countermeasures include: Applications and the related communications systems can be designed resiliently to handle potential issues. In addition, relevant service organisations can patrol regularly to ensure that the infrastructure is well maintained.

g. *Damage to in-vehicle communications components*: Physical damage to in-vehicle communications components, such as antennas and other in-vehicle communications equipment, might compromise functions reliant on information exchange.

   Possible countermeasures include: Notifications about such issues can be provided to the vehicle occupants, fleet managers, and vehicle manufacturers. Failsafe or fail-operational designs are possible. Physical designs can provide fall back or make repair easy.

h. *Latency*: Communications are subject to delays due to network 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 components (radio base stations, gateway, etc.), which can cause some delay, and satellite communication transmission paths are relatively longer and lead to intrinsic delays.

   Possible countermeasures include: VC applications can be designed so that the delays for the chosen communication methods match the latency requirements for the application. Factors such as the maximum number of communications participants at any time, the coverage of the chosen methods, and the supported vehicle speed can be considered. VC applications can be designed to request a minimum quality of service.

i. *Limited Coverage*: Communications infrastructure can have areas of limited or no signal (dead spots). Such limits might disrupt information transmission.

   Possible countermeasures include: Applications using VC can be designed to expect dead spots and areas of poor coverage. Information on VC coverage can be sent from in-vehicle VC applications and added to maps sent to vehicles. Alternative communications approaches, such as vehicle-to-vehicle Multihop or (possibly LEO) satellite, might provide an alternative for safety-related VC, even if the communications speed and bandwidth is lower.

j. *Service Outages*: Communications infrastructure can experience service outages due to technical failures (e.g., power cuts), tropospheric interference, maintenance activities, etc.

Outages can range from short to lengthy in disaster situations. Also, see the *Damage to communications infrastructure* consideration above.

Possible countermeasures include: VC applications can be designed to be resilient to interruptions by communications infrastructure outages, both local and wide area. Temporary VC infrastructure can be provided by communications operators and authorities in disaster situation. Alternative communications approaches, such as vehicle-to-vehicle Multihop or (possibly LEO) satellite, might be an alternative for safety-related VC, even if the communications speed and bandwidth is lower.

k. *Jurisdiction differences*: Different jurisdiction can have different (incompatible) communications infrastructure and/or communications regulations.

   Possible countermeasures include: Table-driven implementations can handle variations. Flexible structures are possible such as cellular eSIM.

l. *Protection and harmonization of automotive safety-related radio spectrum*: Some radio spectrum has been allocated, and additional spectrum might be allocated, for safety-related VC. There are inconsistencies in the frequency bands used for VC between regions and countries. There is a risk of safety-related radio spectrum being used for other purposes due to demand for radio spectrum from other stakeholders.

   Possible countermeasures include: The preservation or allocation of adequate, protected radio spectrum for safety-related VC might become a priority for communications regulators. Prompt commercial use of radio spectrum allocated for safety-related VC will help.

m. *Market Penetration*: Some VC applications require a substantial number of communications devices be deployed to function effectively.

   Possible countermeasures include: Authorities can encourage deployment, possibly with incentives. VC technologies can first expand using pre-existing, widely deployed communications infrastructure while bundling it with other VC technologies requiring a longer time to be effective due to the penetration constraint. If there is a substantial safety benefit from VC deployment for a specific use, regulation might be appropriate.

n. *VRU detection*: The communications devices used by VRUs often have limited positional accuracy. In addition, such communications devices might also have issues with reliability, availability of information (independent of whether a communications device is charged or switched on), etc.

   Possible countermeasures include: In-vehicle components for VRU protection can treat VC from VRU communications devices as supplementary information to the vehicle's sensors.

o. *Aftermarket equipment*: Aftermarket equipment with communications capabilities might have inferior capabilities to the VC capabilities of built-in systems.

   Possible countermeasures include: Detecting that the VC is coming from aftermarket equipment and taking possible lower reliability into account. In-vehicle components can treat VC from aftermarket devices as supplementary information to the vehicle's sensors.

p. *Interoperability*: It is complex for vehicles and road transport infrastructure components to seamlessly exchange information in support of common services, such as collision avoidance and cooperative adaptive cruise control.

Possible countermeasures include: A unified approach can be created that ensures that vehicles from different manufacturers and that road transport infrastructure components from different road operators or different service providers communicate effectively. Some applications using VC can use multiple communications technologies with different service levels according to availability and needs.

q. *Harmonised services*: Triggering conditions and minimum Key Performance Indicators (KPI) for senders and receivers of VC are varied and complex.

Possible countermeasures include: Harmonised structurers can achieve effective communications-based services using recognised standards and practices. Industry organisations might create recommended KPIs for different parts of VC. Different service levels might be appropriate for different applications using VC. The service levels required might vary between communications device type.

r. *Compliance assessment*: Minimum performance of services using VC and the communicated information are expected.

Possible countermeasures include: Achieve the required quality and accuracy and timeliness of transmitted material as well as the appropriate level of security for the communications services offered and material transmitted using recognised standards and practices.

s. *Costs vs. benefits*: Communications infrastructure, road transport infrastructure communications components, information exchange, maintenance, and in-vehicle communications components as well as licenses and fees for some communications technologies might be expensive, depending on the benefits achieved by the applications using VC.

Possible countermeasures include: Costs can be handled as a policy issue when benefits accrue to society and not the vehicle manufacturer.

t. *National and regional requirements*: VC is subject to regulations, rules, and practices that vary among regions and jurisdictions.

Possible countermeasures include: Creating international regulations and using table-driven implementations that handle the variations.