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C-ITS (Cooperative Intelligent Transport Systems) deployment in Europe - challenges and key findings

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Abstract
The domain C-ITS (Cooperative Intelligent Transport Systems) has seen development in Europe for more than a decade. It is the ambition of the European Commission and the EU Member States to establish large-scale deployment of sustainable services all road categories (including urban roads with inherent complex situations) with the support of authorities (at different levels), and ensure interoperability, security, and seamless availability of high-quality services for end-users (across different transport modes, environments and countries), with successful business models. This paper provides an overview of the history and the state of the art of C-ITS, analyses the challenges, defines C-ITS services, requirements and use cases, proposes generic a pan-European C-ITS architecture, investigates the next steps for C-ITS deployment, and discuss next steps for the C-ITS deployment.

Keywords: C-ITS services, use cases, deployment

Introduction

Development and deployment of C-ITS (Cooperative Intelligent Transport Systems) take place with the aim to improve safety, traffic efficiency, energy efficiency and comfort. C-ITS are based on ICT (Information and Communication Technologies), such as sensor technology, telecommunications, information processing and control technology. Various technologies can be combined in different ways to create stand-alone in-vehicle systems and cooperative systems (V2X).

Recently, the European Commission (EC) has extended the context of C-ITS to cooperative, connected and automated mobility. In October 2017 a survey of C-ITS services was conducted by C-MobILE (Accelerating C-ITS Mobility Innovation and depLoyment in Europe) (C-MobILE Consortium, 2017). Stakeholders from authorities, industry and academia completed the survey. In addition, consolidated technical and non-technical requirements of C-ITS services and use cases were defined, and the architecture for C-ITS implementation in cities will be further developed.

The next section provides a brief overview of the key activities related to C-ITS development and deployment in Europe. Furthermore, it presents the most recent results with respect to the elaboration of C-ITS services, use cases and requirements. Per service operational guidelines for C-ITS deployment in cities with respect to traffic management are also provided. Challenges and strategies for large-scale C-ITS deployment are discussed. Further innovation actions for C-ITS deployment are proposed. Finally conclusions are drawn.

An overview of C-ITS development and deployment in Europe

C-ITS has been developed more than one decade. In 2005 the EC, under the FP6-IST funding scheme, launched three IPs (Integrated Projects) targeting cooperative systems: SAFESPOT (Co-operative

Systems for Road Safety "Smart Vehicles on Smart Roads"; focusing on the in-vehicle side and traffic safety) [SAFESPOT Consortium, 2005], CVIS (Cooperative Vehicle Infrastructure Systems; focusing on the infrastructure side and traffic efficiency) [CVIS Consortium, 2005], and COOPERS (CO-OPerative SystEms for Intelligent Road Safety; focussing on the domain of the road operator) [COOPERS Consortium, 2005]. In 2009 the EU-funded project FREILOT (Urban Freight Energy Efficiency Pilot, 01-04-2009 to 30-09-2012) [FREILOT Consortium, 2009] was launched, which aimed to develop C-ITS services for freight transport. DRIVE C2X (01-01-2011 to 31-07-2014) [DRIVE C2X Consortium, 2011] substantially contributed to the development and evaluation of C2X-communication technologies for accelerating cooperative mobility in Europe.

In early 2014, the European Commission launched a C-ITS Deployment Platform, to take a more prominent role in the deployment of connected driving. After Phase I (2014-2016) [C-ITS Platform, 2016], the resulting shared vision on the interoperable deployment of C-ITS towards cooperative, connected and automated mobility in the European Union (EU) was further developed in Phase II (2016-2017) [C-ITS Platform, 2017]. The perspective of the C-ITS Platform is that ICT infrastructure-based cooperative, connected and automated transport is an option for enhancing traffic safety, traffic efficiency and energy efficiency, and for reducing fuel consumption. C-ITS services, determined in Phase I, are presented in Table 1. In Phase II, the definition of the services was elaborated in more detail (see Table 2).

Table 1 - C-ITS services in Phase I of the C-ITS Platform [C-ITS Platform, 2016]

List of Day 1 services	**List of Day 1'5 services**
Hazardous location notifications: Slow or stationary vehicle(s) & Traffic ahead warning Road works warning Weather conditions Emergency brake light Emergency vehicle approaching Other hazardous notifications *Signage applications:* In-vehicle signage In-vehicle speed limits Signal violation / Intersection Safety Traffic signal priority request by designated vehicles Green Light Optimal Speed Advisory (GLOSA) Probe vehicle data Shockwave Damping	Information on fuelling & charging stations for alternative fuel vehicles Vulnerable Road user protection On street parking management & information Off street parking information Park & Ride information Connected & Cooperative navigation into and out of the city (1st and last mile, parking, route advice, coordinated traffic lights) Traffic information & Smart routing

Table 2 - Additional C-ITS services in Phase II of the C-ITS Platform [C-ITS Platform, 2017]

Additional services	**Examples**
New additional urban specific services	Access Zone Mgt. (restricted lanes, zones, tunnels/bridges, mgt. freight loading/unloading areas) V2I Public Transport Vehicle Approaching V2V
Extended functionality of original list of D1/1.5 services	Access mgt. of speed - subset: in-vehicle signage V2I On/off-street parking mgt. - subset: on/off-street parking information V2I Temporary traffic light prior. for designated vehicles - subset of traffic light prior. of designated vehicles V2I Collaborative perception of VRUs - subset: VRU road user protection V2V Collaborative Traffic Mgt. - subset: connected, cooperative navigation into and out of the city V2I
Additional user groups of existing C-ITS D1/1.5 services	GLOSA (Green Light Optimized Speed Advisory) for cyclists V2I

In 2016, a series of C-ITS deployment projects were co-funded by the EC, e.g. CITRUS (C-ITS for Trucks), SolC-ITS (SOLRED C-ITS Monitoring Network), InterCor (Interoperable Corridors), C-The Difference, and SCOOP@F. In the same year, Member States and the EC launched the C-Roads Platform to link C-ITS deployment activities, to jointly develop and share technical specifications, and to verify interoperability through cross-site testing.

In June 2017, the C-MobILE (Accelerating C-ITS Mobility Innovation and depLoyment in Europe) project (2017-2020) was launched under Horizon2020 [C-MobILE Consortium, 2017]. It aims to stimulate large-scale, secure and interoperable C-ITS deployments across Europe, and focuses on the deployment of C-ITS services for mobility challenges including mixed traffic situations in urban areas.

C-ITS services, use cases and requirements

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Twenty C-ITS services were defined, based on the implementation interest of nine European cities: Helmond (NL), Eindhoven (NL), Copenhagen (DK), Barcelona (ES), Bilbao (ES), Vigo (ES), Newcastle (UK), Bordeaux (FR), and Thessaloniki (GR). For each C-ITS service, one or more use cases were defined (See Appendix I). Relevant technical and non-technical requirements were investigated, based on related C-ITS projects and initiatives, and incorporating as well knowledge of partners from authorities, industry and academia, who have been working in the C-ITS domain more than one decade. The scheme of the requirements of C-ITS services is illustrated in Figure 1.

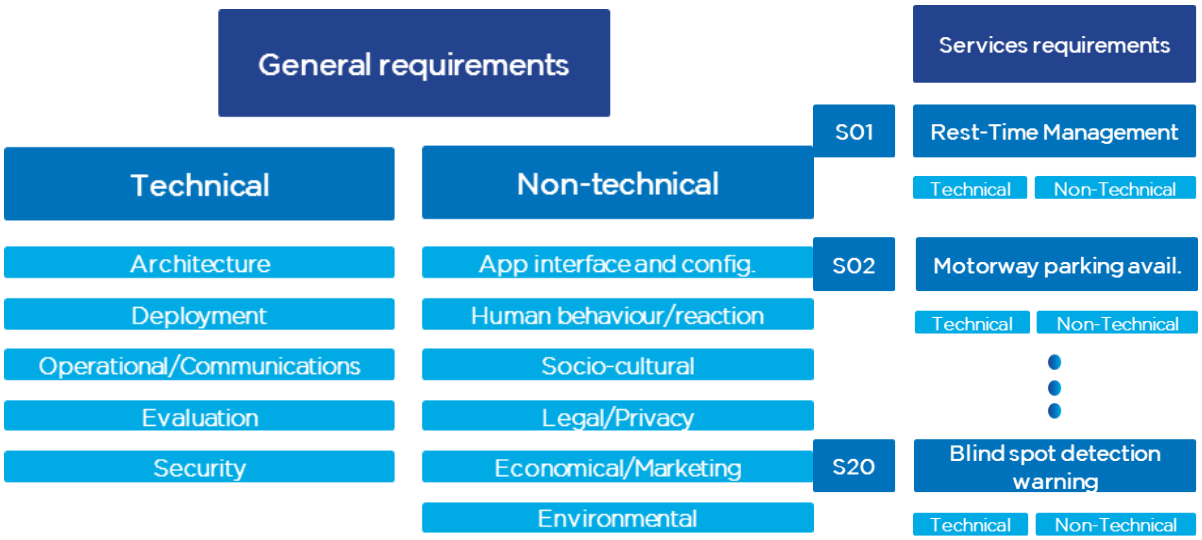

Figure 1 - Scheme of the requirements of C-ITS services [Castells, J., et al, 2017]

Operational guidelines for traffic management

The impact of C-ITS services on a road network can be significant, but is difficult to estimate due to the novelty of the concept. One of the key influencing factors for the impact is the penetration rate of C-ITS equipped vehicles and their compliance rate where applicable. This section will give a qualitative analysis of the services considered in Figure 1 that can help a traffic manager to decide whether to invest in a certain service, but also if operational actions may be required from a traffic management perspective.

Table 3 - C-ITS services in Phase I of the C-ITS Platform [C-ITS Platform, 2016]

Service	Usage	Description
Green priority	Managed	This service grants priority to certain road users and has a negative effect on other road users. Especially when close to saturation, this service should be turned off, as it will even decrease performance for prioritized vehicles when a traffic jam forms. A side effect can be that other traffic with the same route can join a platoon with the prioritized vehicle, however, if this is the goal, a traditional ITS green wave or route priority will be more effective. Simple policy rules can manage this service automatically when defined.
Green light optimal speed	Always on	This service reduces emissions of traffic. When a traffic jam an advice is not possible when queue length is taken into account and no intervention is required.
Cooperative pedestrian light	Managed	Effectively pedestrians get priority, which may not be desired close to saturation. Again simple policy rules are recommended for managing this service.
Emergency vehicle w.	Always on	Accidents can be prevented with this service and there would never be a negative effect.
Pedestrian w.	Always on	Accidents can be prevented with this service and there would never be a negative effect.
Road hazard w.	Intervention	It is possible some events are not automatically uploaded in the system and it could be useful to have an option to add them manually.
Traffic jam w.	Always on	Accidents can be prevented with this service and there would never be a negative effect.
Road works w.	Intervention	It is possible some events are not automatically uploaded in the system and it could be useful to have an option to add them manually.
Signal violation w.	Always on	Accidents can be prevented with this service and there would never be a negative effect.
In-vehicle signage	Always on	Information is provided that can also be viewed by looking at the conventional signs.
In-vehicle dynamic speed limit	Always on	This service has to be used in combination with a traditional ITS service, otherwise non-equipped vehicles will not comply. Management should be done using the conventional service, while the C-ITS counterpart informs road users on an extra channel.
Flexible infrastructure	Always on	Similar to dynamic speed limit. Compliance depends on non-equipped vehicles as well, the service can only follow the conventional ITS service.
Motorway/Urban parking availability	Always on	While it is possible to intervene in parking availability, end-users will quickly loose trust in the system if it is abused for trying to control behaviour. The main goal should be to prevent extra exposure due to searching for a parking space.
Rest time management	Intervention	A traffic manager can use special incentives to convince drivers to take their resting break earlier in order to reduce the traffic flow when a traffic jam is forming. It is, however, questionable how many vehicles can be reached in the first place and convinced in the second place. For the latter it is likely that monetary rewards are required to do this.
Mode & Trip advice	Intervention	In its basic version this is a purely informative service that should give a fair representation of the travel options in order to keep users trust. However, like for rest time management, it can be possible to introduce special incentives to attain a modal shift for special events.
Probe vehicle data	Always on	This services gives information for the traffic manager and does not influence traffic flow directly.
Emergency brake light	Always on	Accidents can be prevented with this service and there would never be a negative effect.
Slow or stationary vehicle	Always on	Accidents can be prevented with this service and there would never be a negative effect.
Cooperative cruise control	Always on	This is a vehicle centric service and cannot be switched off by the traffic manager.
Blind spot/VRU warning	Always on	Accidents can be prevented with this service and there would never be a negative effect.

Table 3 describes the operational guidelines and distinguishes three different types of operations. The first is "always on", this type of service will always have a beneficial effect on a selection of road users and no effect on other road users. The second type is "intervention", which means a traffic manager can intervene and manually add information that is not yet automatically retrieved through existing interfaces. However, ideally all information should be retrieved by the system to reduce workload of the operational traffic managers. The last type is "managed", this type requires a clear policy on how to use the service for example with a traffic management scenario or with a traffic manager adjusting the configuration in real-time.

Survey on C-ITS services

To gain more insight into the requirements and expectations of various stakeholders in this domain, a C-ITS Survey was conducted based on the defined services and use-cases (available at: http://c-mobile.bpmresearch.net). The C-ITS Survey included two main parts: (1) questions for determining the stakeholder profile of the respondents, (2) questions on reviewing a set of five to seven C-ITS services relevant to the stakeholder profile that the participant selected.

There were four major stakeholder profiles among which the participants were expected to choose based on the profile they would like to represent. These were: Drivers, Vulnerable Road Users – VRUs (e.g. pedestrians and cyclists), Public Authorities (cities, municipalities, traffic managers, road operators), and Service Providers (private industry consisting of C-ITS technology, service, or solution providers).

In total, 99 respondents participated in the survey. Majority of these respondents were experts in the C-ITS domain in different cities all around Europe, regardless of the profile they selected to provide their responses (e.g., an expert in a C-ITS architecture topic selecting the "driver" or "cyclist" profile and reviewing the services accordingly). The distribution among these 99 respondents with respect to these 4 profiles were well-balanced. The respondents provided 494 C-ITS service reviews for 20 services, averaging around 25 reviews per C-ITS service.

In the second part of the survey, we asked respondents to review a set of C-ITS services from a set of viewpoints. The first viewpoint represented their opinions on the societal value of the services. Table 4 presents the descriptions of four different types of societal value dimensions.

Table 4 - Societal value areas and descriptions

Dimension	Description
Road Safety	Increasing individual safety for all road users by informing or warning these users, or directly interacting with the vehicle.
Traffic Efficiency	Improving mobility by reducing delay and travel time. This is achieved by increasing the efficiency of the traffic flow, and preventing or reducing traffic jams by informing, advising, instructing individual road users, either directly or indirectly via applications.
Comfort	Increasing the comfort of individual road users. This can be achieved in various ways, e.g. by providing up-to-date information on traffic or route (as in navigation), or by providing priority to certain parties in the traffic.
Environmental Protection	Reducing the negative effects of traffic flow (CO2 emission, noise, air pollutant emissions, etc.) through improved (fuel) efficiency.

We asked respondents to indicate -for each service- the extent to which the service's influences these societal value dimensions. Respondents provided their answers on a 5-point Likert Scale with items ranging from Strongly Disagree to Strongly Agree. The results are presented in Figure 2.

The survey participants considered all services to significantly contribute at least to one of the societal value dimensions, which provided sufficient justifications for the implementation of all services that we have selected. In the overall, the services are considered to improve the safety dimension the most,

and the services that involve warnings (e.g., road hazard warning, road works warning, signal violation warning, motorcycle approaching indication/ warning) are regarded as the key means to improve traffic safety. However, some services that contribute mostly to the efficiency, such as green priority, flexible-infrastructure, in-vehicle signage, are deemed to have the most significant contributions when all dimensions are considered together.

Figure 2 - Responses regarding the societal value of C-ITS services

The second viewpoint with respect to which participants reviewed the services, involved the business aspect. We asked respondents to give their opinions (using a 5-point Likert scale) on the business value and usefulness of the services they review, as well as their willingness to pay for these services. These aspects are known to influence end-user's intention to use the service, and service providers' willingness to invest for its implementation and deployment. The results are summarized in Figure 3.

Accordingly, all services in our list were considered to be useful, with road works warning, in-vehicle signage, and motorcycle approaching indication leading in the list. When their business value is considered, some services were deemed to suffer from the lack of clear business value. Emergency vehicle warning, and emergency brake light are two services where respondents saw difficulties with respect to return on investment and profitability. While all services in our set were considered to have positive contributions to the society and deemed useful in the overall, the participants were very clear in their opinion on their willingness to pay for these services. Respondents were willing to pay to none of these services.

These results show a clear need to have well-thought and well-structured business models for these services in order to go beyond pilot implementations and provide self-sustaining large-scale service implementations.

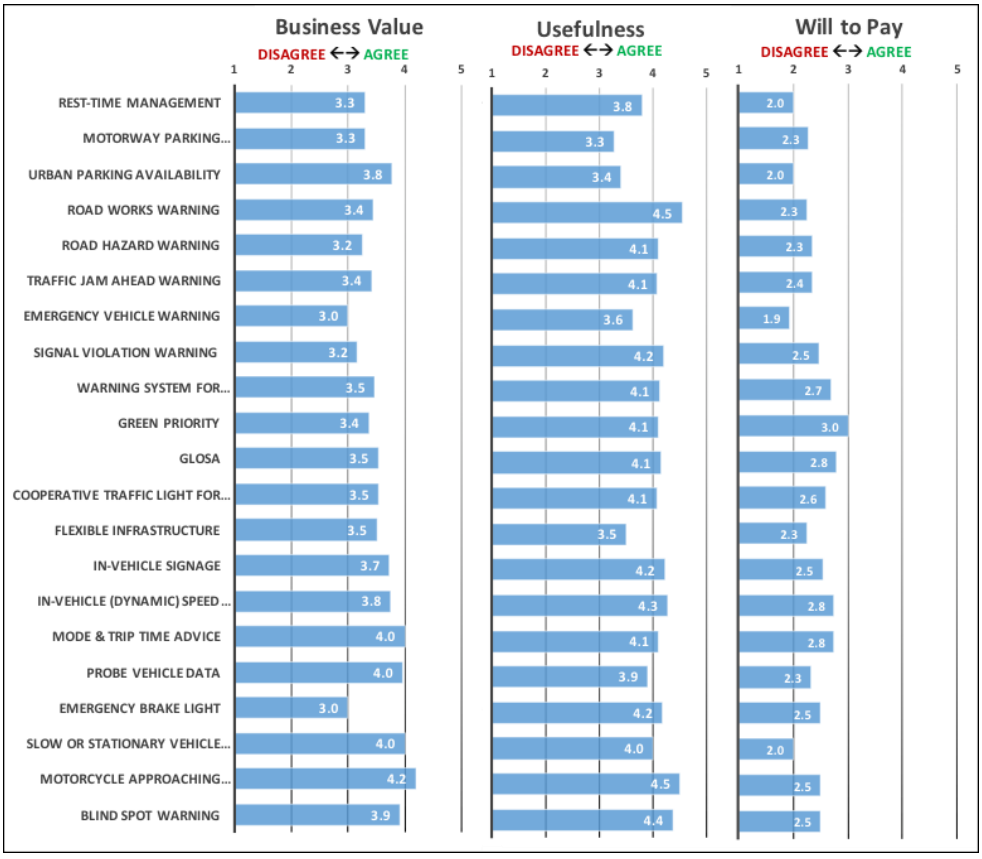

Figure 3 - Responses regarding the other types of value of C-ITS services

Challenges and innovation actions for C-ITS deployment

The European Commission has the ambition to further enhance road safety, traffic efficiency and energy efficiency of road transport, and to significantly reduce negative environmental impact of road transport. One of the approaches for this is (Cooperative) ITS. The main challenges are the following:

1) How to extend the capabilities of existing products and services in the C-ITS marketplace and develop new ones that are useful for the end-users?
2) What are appropriate (short-term, mid-term and long-term) business models for the C-ITS domain (if at all feasible)?
3) Which policies (at European, national, regional and local levels) are needed for stimulating C-ITS deployment, in addition to the current ones. How to best join efforts?
4) How to significantly improve relevant operational and decision-making processes for all stakeholders (authorities, industry and end-users).

To address these challenges, and therefore, in order to enable large-scale and interoperable C-ITS deployments across Europe, the following strategies need to be adopted. Firstly, products and services should be highly reliable and robust. The bundling of C-ITS applications and the provision of the necessary means for further development of innovative products and services will pave the way to automated road transport. Secondly, collaborative business models are expected to be developed and accepted by the actors; if no feasible business model would be identified and implemented, the authorities at different levels have to (co-)invest for achieving sustainable road transport. Thirdly, consistency of European policy and strong cooperation between authorities are needed for the large-scale deployment of C-ITS, and for the wide-spread adoption of best practices of C-ITS applications by various cities, regions and countries. Last, but not least, active involvement of stakeholders from

public and private sectors is essential. To create viable and functioning partnerships is a must for establishing large-scale deployment of sustainable services in complex urban areas. Further innovation actions are as follows:

1) Substantial enhancement of the reliability and robustness of C-ITS products and services.
2) Development of a C-ITS framework with major stakeholders, especially also including viable business models for enabling solutions in different cities.
3) Assessment, including the use of CBA (Cost-Benefit Analysis), of the cumulative benefits of C-ITS applications and integration of multiple transport modes.
4) Enabling secure and interoperable C-ITS deployment in complex urban environments, across countries, and involving large groups of end users.
5) Validation of operational procedures for large-scale deployment of sustainable C-ITS services in Europe.
6) Provision of testing approaches to evaluate the impact of C-ITS architectures and services.

Conclusion

Interoperable and secure C-ITS (Cooperative Intelligent Transport Systems) applications will make road transport safer, more efficient and more environment-friendly. A comprehensive approach has been selected to investigate C-ITS deployment possibilities. The results of the survey show the importance and potential of the C-ITS services. However, the willingness-to-pay is very low, which indicates the importance of building business cases for sustainable large-scale implementations of these services. Guidelines for C-ITS deployment (per service) in cities with respect to traffic management are proposed at an operational level. Challenges, such as products and services, business development and exploitation, policy, and processes, were analysed. Clear strategies were determined to deploy sustainable services, which can be supported by local authorities, and to ensure interoperability and seamless availability of high-quality services for end users from a perspective of successful business.

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Appendices

Appendix I Main C-ITS services and use cases

#	Service	Use Cases
1	Rest-Time management	UC1.1 - Rest time indication
2	Motorway parking availability	UC2.1- Information on parking lots location, availability and services via internet UC2.2- Information on parking lots location, availability and services via I2V UC2.3- Information about a truck parking space released by a user UC2.4- Reservation of a truck parking space released by a user UC2.5- Guide the truck in the port (terminal or truck parking)
3	Urban parking availability	UC3.1- Information about a truck parking space released by a user UC3.2- Reservation of a truck parking space released by a user
4	Road works warning	UC4.1- Road works warning for 4 situations
5	Road hazard warning (incl. jams)	UC5.1- Hazardous location notification UC5.2- Traffic condition warning, including: UC5.3- Weather condition warning
6	Emergency Veh Warning	UC6.1- Emergency Vehicle Warning for 3 situations
7	Signal Violation Warning	UC7.1- Red light violation warning
8	Warning sys for pedestrian	UC8.1- Safe Travelling Experience by Warning Signage
9	Green priority	UC9.1- Green Priority for Designated Vehicles
10	GLOSA	UC10.1 - Optimized Driving Experience with GLOSA
11	Cooperative traffic light for pedestrian	UC11.1- Cooperative Traffic Light for Designated VRUs UC11.2- Cooperative Traffic Light based on VRU detection
12	Flexible infrastructure (peak-hour lane)	UC12.1- Flexible infrastructure as in-vehicle signage
13	In-vehicle signage (e.g. Dynamic speed limit)	UC13.1- In-Vehicle Signage, dynamic traffic signs UC13.2- In-Vehicle Signage, static traffic signs
14	Mode & trip time advice	UC14.1- Mode and Trip Time Advice for Event Visitors UC14.2- Mode and Trip Time advice for Drivers
15	Probe Vehicle Data	UC15.1- Basic probe vehicle data UC15.2- Extended probe vehicle data
16	Emergency Brake Light	UC16.1- Emergency electronic brake lights
17	Cooperative (Adaptive) Cruise Control	UC17.1 - CACC passenger vehicles approaching urban environment UC17.2 - CACC passenger vehicles approaching semi-urban environment UC17.3 - Truck Platooning UC17.4 - Cooperative Adaptive Cruise Control
18	Slow/Stationary Vehicle Warning	UC18.1 - Slow or stationary vehicle warning
19	Motorcycle approaching indication (incl. other VRUs)	UC19.1 - The approaching two-wheeler warning (V2V) UC19.2 - The approaching two-wheeler warning (V2V and V2I)
20	Blind spot detection / warning (VRUs)	UC20.1 - Digital Road Safety Mirror

Appendix II An overview of bundles proposed by the European Commission

Service bundle	**C-ITS Services**	
Bundle 1 Day 1, V2V, ITS-G5	• Emergency brake light • Emergency vehicle approaching	• Slow or stationary vehicle(s) Traffic jam ahead warning • Hazardous location notification
Bundle 2 Day 1, V2I, mainly applicable to motorways	• In-vehicle signage • In-vehicle speed limits • Probe vehicle data	• Shockwave damping • Road works warning • Weather conditions
Bundle 3 Day 1, V2I, mainly applicable to urban areas	• Green Light Optimal Speed Advisory (GLOSA) / Time To Green (TTG)	• Signal violation/Intersection safety • Traffic signal priority request by designated vehicles
Bundle 4 Day 1.5, V2I, Parking Information	• Off street parking info • On street parking management/information	• Park & Ride information • Information on AFV fuelling & charging stations
Bundle 5 Day 1.5, V2I, Traffic and other information	• Traffic information and smart routing	
Bundle 6 Day 1.5, Freight specific services	• Loading zone management • Zone access control management	
Bundle 7 Day 1.5, V2X (mainly urban areas), ITS-G5	• VRUs protection (pedestrians and cyclists)	
Bundle 8 Day 1.5, V2V, likely to be ITS-G5	• Cooperative collision risk warning • Motorcycle approaching indication	
Bundle 9 Day 1.5, V2I	• Wrong way driving	