Paper ID EU-TP1815

Pan-European deployment of C-ITS: the way forward

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Abstract
Development and deployment of Cooperative Intelligent Transport Systems (C-ITS) take place with the aim to improve safety, traffic efficiency, energy efficiency and comfort. The ambition of the European Commission and the EU Member States at this stage is to initiate and establish large-scale deployment of sustainable services on all road categories with the support of authorities at different levels, and to ensure interoperability, security, and seamless availability of high-quality services for end-users. This paper explores operational procedures for large-scale C-ITS deployment in Europe, and targets two groups of authorities, road operators and municipality members, as well as technical developers for the implementation of C-ITS services. The paper also, based on the most recent results, provides guidelines with technical details of the C-ITS services, such as Day-1 and Day-1.5 services, as defined by the EU C-ITS Platform for properly implementing pan-European interoperable C-ITS services.

Keywords: C-ITS, deployment, operational procedure, guidelines

Introduction

Cooperative Intelligent Transport Systems (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). C-ITS has seen development in Europe for more than a decade. In addition to technical development of communication technologies, evaluation of V2X for accelerating cooperative mobility in Europe has been carried out.

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 can significantly contribute to enhancing traffic safety, traffic efficiency and energy efficiency, and to reducing fuel consumption [Lu (Ed.), 2016; 2019].

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. Figure 1 illustrates the C-ITS strategy for the European Union (EU) Member States, and a roadmap for C-ITS deployment in 2019-2045 for paving the way toward connected, cooperative and automated mobility. This is very ambitious and challenging, from various perspectives (technical, social and political).

The paper contributes to the first step of large-scale C-ITS deployment in Europe. The next section introduces C-ITS services and requirements for pan-European implementation. Next, operational procedures for C-ITS deployment are proposed, followed by a section on guidelines. Then an example is provided explaining how the guidelines shall be used. Finally, conclusions are drawn.

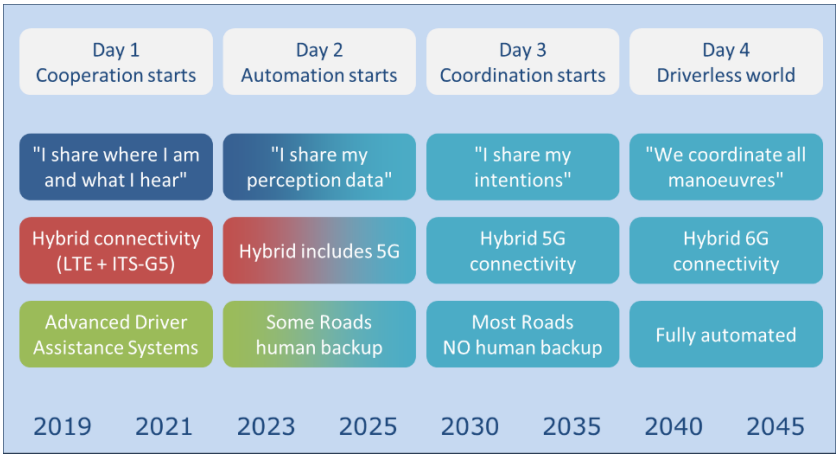

Figure 1 - C-ITS strategy of European Union [EC, 2017]

C-ITS services and requirements for deployment

C-ITS services are summarised in Table 1 and 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 Mgmt. (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

C-ITS development and deployment in Europe is unbalanced. Some cities have invested in ICT infrastructure during the past decades, and are therefore able to implement C-ITS services. Examples are Helmond (The Netherlands), Copenhagen (Denmark), Bordeaux (France) and New Castle (UK). However, most cities do not have any experience with C-ITS, and even insufficient knowledge. C-ITS technologies are feasible, but not off the shelf. For different services the requirements for implementation will be different. For authorities this complicates decisions to enable C-ITS services for road safety, traffic efficiency (therefore, air quality improvement), and energy efficiency.

Operational procedures for C-ITS deployment

This section presents a generic approach for the introduction of C-ITS services in cities. The approach is made operational in a structured procedure of four consecutive phases: Preparation, Planning, Execution and Operation. An overview of the approach and details per phase are provided in Figure 2.

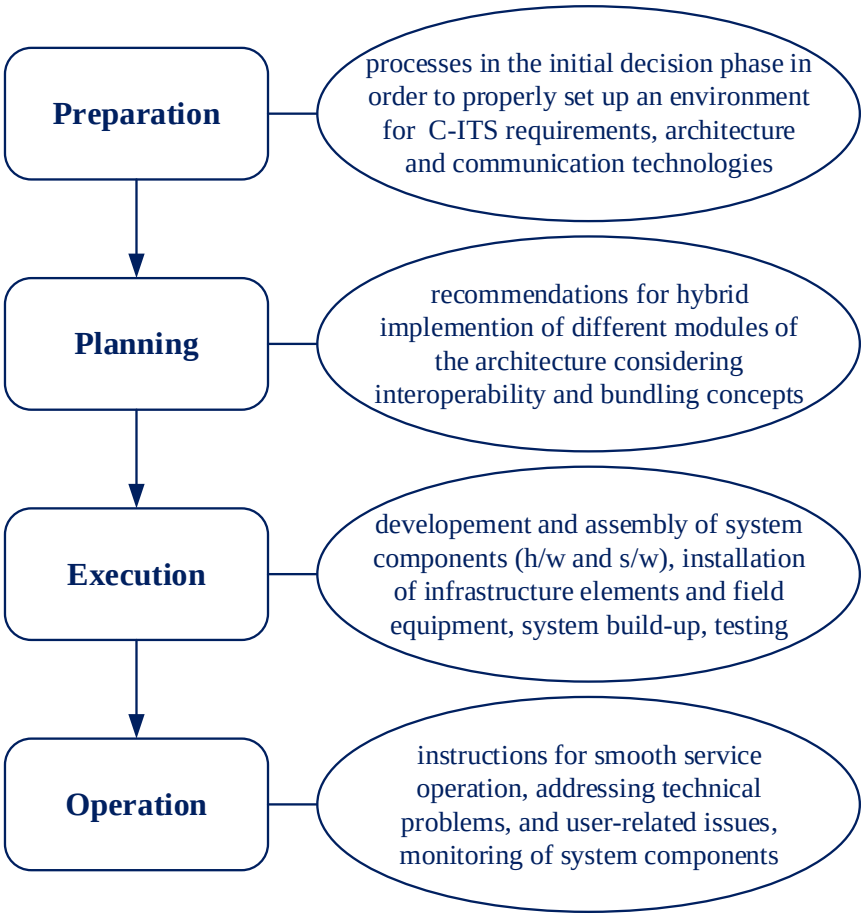

Figure 2 - Procedure for the introduction of C-ITS services in cities

Guidelines for C-ITS deployment

C-Mobile has developed detailed guidelines for cities to implement C-ITS services. The guidelines target two different audience groups: 1) road operators and municipality members (authorities); and 2) technical developers for the implementation of C-ITS services.

Tables 3-7 describes the operational guidelines and distinguishes different phases of the C-ITS implementation.

Table 3 - C-ITS implementation guidelines - general issues [Castells, et al., 2018]

No.	General issues
G0	A "city" is defined as all those partners belonging to the decision making and road management activities for an urban geographical area
G1	A city shall carefully design the activities and timeline involved in the preparation, implementation, deployment and operation and maintenance phases.
G2	A city shall identify which technical stakeholders are relevant for the C-ITS deployment and prepare tenders for covering the activities out of its scope
G3	A city shall define its own business model in order to compensate economically, socially, environmentally and/or with safety on roads, the expenses derived from the C-ITS deployment.
G4	It is always recommended that experienced stakeholders take specific roles for the reinforcement of availability, integrity, upgrade capacity and quick response.

Table 4 - C-ITS implementation guidelines - preparation phase [Castells, et al., 2018]

	Preparation phase
G5	Cities should define a technical plan for their C-ITS services, which includes identification of achievable technical target, determination of the communication technology, identification of the local C-ITS architecture and identification of the best deployment locations
G6	The requirements elicitation process shall comprise technical and non-technical aspects, in order to cover the entire spectrum of a complex C-ITS deployment
G7	A city shall involve almost all of the partners in the requirements elicitation process to address the different scopes and needs, including end-users
G8	There shall be a process of identifying the C-ITS services to be deployed, including the type (V2V, V2I and V2N) which will lead to particular requirements for each service
G9	The requirements shall be revised during the different phases of the deployment in order to properly check if the initial requirements are fulfilled
G10	Cities main transport objectives are optimal traffic flow, zero road fatalities, emissions reduction, congestion reduction and social inclusiveness, for which the C-ITS deployment shall contribute
G11	Cities should always target a hybrid implementation for their C-ITS services as a future-proof, flexible plan as long as the economic and technical requirements (infrastructure availability, latency requirements) make it feasible and appropriate
G12	The local C-ITS architecture shall be particularly designed taking into account the communication technology used, the C-ITS services to be deployed and the data sources available for them
G13	With an efficient architecture, the ITS-G5 and the cellular-based approaches share the same Central System. This provides flexibility and adaptability
G14	A smart dissemination should be offered by the Communication Provider for enhancing the management of the services and provide hybrid compatibility
G15	For a full integration of the C-ITS services into society, all kinds of users should be targeted, such as pedestrians and Vulnerable Road Users (VRUs), including riders and disabled people
G16	Active detection of VRUs should use the same devices for the notifications to the users when possible (not controlled by the city and very dependent on the scenario the users are located)
G17	Passive detection of VRUs is costly for the city but independent of the communication technology used by the users. It is geographically limited but usually more accurate
G18	Roadside equipment installation shall be carefully chosen in order to avoid malfunctioning, bad services experience and reduced impact of the C-ITS services
G19	The equipment shall be installed where a minimum of information is available, as well as quite close between them in order to properly cover extended areas completely
G20	The antennas should point into the upstream of the vehicles in order to increase the likelihood of a successful communication
G21	Cities and Service Providers shall be aware that they are receiving ‘personal data’ from users and they have to comply with GDPR
G22	Cities should explicitly be able to demonstrate users’ consent in terms of processing their personal data.
G23	Cities and Service Providers should take the role of data controllers since they are the entities in charge of the processing and storage of the personal data for the C-ITS services
G24	Cities can allow an external organisation to carry out the processing of the data that they control, but do not lose the control of data since they instruct the purpose to that company to process data
G25	Cities need to assign a Data Protection Officer since they process and monitor regular and systemic data from users on a large scale.

Table 5 - C-ITS implementation guidelines - implementation phase [Castells, et al., 2018]

	Planning phase
G26	The role of the Service Provider is usually being responsible of the provisioning and the software implementation for the different components of the architecture
G27	Every EU deployment city/region shall target pan-European interoperability. The European Commission is making standarisation efforts for the harmonisation of C-ITS deployments
G28	Cities developing C-ITS services shall abide by specified communication standards or definitions for those interoperability interfaces and features
G29	In order to form part of the EC PKI, a RootCA shall be available to provide certificates to the actors of the C-ITS operation. Either the RootCA shall be implemented or used from others' solutions
G30	The TMS are usually connected with the Roadside Systems and the Data Providers with "local" interfaces. These interfaces can remain unchanged for the C-ITS services.
G31	A TMS shall either make a decision or adapt and forward the information gathered from Roadside Systems and Data and Service Providers, depending on the services and the city needs and requirements
G32	The Bundling concept targets a better TMS coordination with some C-ITS services at the same time depending on the current needs, which increases the impact of the services and higher likelihood of success
G33	The TMS shall build a control strategy with the aim of determining which strategy apply in each situation, which are "inform traffic about the situation", "enlarge the outflow", "reduce the inflow" and "reroute traffic". Each C-ITS service can be used in some of these strategies
G34	The Roadside Systems, Traffic Management System, the Data Providers and end-user devices are the possible data sources for the C-ITS services. They shall transmit, either direct or indirectly, the information to the Service Provider
G35	One of the most recommended protocols to transmit information to the Service Provider is using a REST interface with a PUSH strategy when the information is available in the data sources
G36	The output of the Service Provider shall be standard C-ITS messages, which are generated based on the information received from the different data sources
G37	The Service Provider shall generate and encode the C-ITS messages using ASN.1. This means that all entities able to generate and manage C-ITS messages shall implement an ASN.1 encoder/decoder
G38	The Service Provider shall sign all C-ITS messages for dissemination except for ITS-G5 since the RSU is obliged to sign them too, which would lead to a double security header/signature
G39	The Service Provider shall either implement or use a dissemination method, which is key for ensure interoperability
G40	The Service Provider shall be capable of calculating situations/risks for each of the service, in order to properly react to the information received
G41	Road layout information shall be managed by the Service Provider in order to increase the accuracy and impact of the services
G42	The local Service Provider shall be the first contact point for the client devices (PID, RSU). It shall implement the interfaces to provide connectivity details based on the location of the devices
G43	The Service Provider shall implement the capabilities needed for enabling the interoperability, which may require the implementation of standardised interfaces and data formats, depending on the interoperability approach
G44	The Communication Provider, usually manages by the SP, shall implement a GeoMessaging approach for an efficient hybrid dissemination of the data
G45	Most of the ITS systems (RS) already deployed in a city can be useful for the C-ITS services as well, with little or no adaptation needed
G46	The data acquired from the RS shall be real-time and accurate data for most of the services
G47	The standards implemented by default in ITS-G5 equipment are not enough for covering the different city needs. Some extra implementation is needed mostly in the application layer, for the interaction with the Service Provider through the Communication Provider
G48	Knowing the CAN bus architecture of a vehicle and having access to it is not a trivial fact and may cause delays in the implementations and deployments. Ensuring the access to the data beforehand will avoid unexpected issues
G49	Having a GNSS receiver with an integrated Inertial Measurement Unit (IMU) may help to improve the robustness of the information. Moreover, some of the CAN bus data may also be provided, thus avoiding potential CAN access issues
G50	The On Board Units (OBU) shall be properly connected with an HMI system to show information to the drivers/end-users.
G51	Any implementation in the OBUs cannot add high latency to any of the steps for transmission/

	reception of information
G52	The PIDs shall implement most of the same standards as the RSU/OBUs but taking into account the different communication protocol and the battery consumption
G53	The PIDs shall implement a registration process for getting connectivity details with the proper server, as well as authentication services to use and actions (publish/subscribe) permitted
G54	PIDs shall collect its location information for sending it to the Back Office in the format required (usually standard CAM messages) or being able to transform it to properly realize the current location
G55	Keep HMI as simple as possible, providing reliable information taking into account traffic conditions and local regulations (e.g. for GLOSA: avoid not applicable/feasible recommendations when traffic jams are present on traffic conditioning vs TTG/TTR prohibition)
G56	When implementing bundling in a city both end-user and operator-manager points of view shall be taken into account. These must be integrated into a comprehensive plan that ensures the viability of the implementation
G57	The C-ITS services selection should be based on city/region policy objectives. The most important traffic problems shall be identified and TM strategies shall be created
G58	A city shall identify beforehand the type and number of users of the C-ITS services to be deployed in order to measure the needs of the implementation and ensure a successful operation
G59	In order to ensure the positive impact of the C-ITS services to be deployed, the most critical and relevant parts of the network shall be carefully identified
G60	The involved components shall use a Public Key Infrastructure to be able to trust each other and also other PKI's entities from other regions thanks to a Trust List Manager (TLM) developed by the EC
G61	This PKI infrastructure is intended for all types of devices, including ITS-G5 and cellular-based devices. These devices shall manage special ETSI certificates
G62	CAM and DENM messages are considered personal data and they are sent. The proposed implementation for cellular comm. does not imply sending the location outside the vehicles/VRUs, and the information is always signed so only those authorized entities can receive it
G63	The Data Controller shall be in charge of ensuring that no personal data is processed and disclosed within its systems
G64	There are 5 principles for the data processing from the GDPR to follow; purpose limitation, data minimization, accuracy, storage limitation and integrity and confidentiality

Table 6 - C-ITS implementation guidelines - deployment phase [Castells, et al., 2018]

	Execution phase
G65	The most recommended height for the RSU installation is 4 meters, based on the common installation location of the OBUs in regular cars.
G66	The position within the intersection must be as centred as possible in order to provide good coverage for all intersection approaches
G67	The installation must be done by authorised and qualified personnel and must follow the appropriate safety measures.

Table 7 - C-ITS implementation guidelines - operation phase [Castells, et al., 2018]

	Operation phase
G68	The TMS and the Service Provider are the main actors involved in the operation of the C-ITS services. This includes the management of the services, actuation plans for dealing with end-users and the maintenance of the equipment
G69	During operation, incidences or errors such as broken devices, corrupt data, equipment malfunction etc. may occur. Methods of pre-empting and mitigating incidences or errors must be developed, as well as methods for detecting and correcting them
G70	Each Service Provider and/or Road Operator should operate a so called Pilot Operation and Maintenance Server (POMS) platform, which also helps to monitor the RSUs deployed
G71	It is appropriate to make current and future drivers aware of these technological developments by reaching them through the most appropriate means, be it awareness campaigns or driver training
G72	The Traffic Management System (TMS) shall be capable of monitoring the entire network constantly and choosing the best C-ITS strategies against the different traffic problems. The service provider shall control the available C-ITS services and manage them following the TMS indications
G73	The development of new systems will be needed to operationally execute the bundling concept. Hence, the existing infrastructure will need to be adapted and new components will have to be integrated.

An example for C-ITS bundling implementation

Within C-MobILE , a bundling concept was developed: "Bundling is the provision of several C-ITS services as one combined service. The C-Mobile service bundles will be developed and provided in the form of open, modular and extendable wrap applications, which (by having the ability to interface with all single services) will bring together the complete suite of C-ITS services under one common user environment, with rich user experience features. The bundles will be able to operate either in an automated mode, by providing context-, location- and user-preferences based information and guidance to the end user as well as in a user-selected mode, where the end user selects the specific service or services relevant and useful for him/her. The bundled C-ITS services logic will rely upon intelligence that will feature both end user as well as policy related parameters, in order to ensure to the highest degree possible that the envisioned innovative C-ITS services cover in an optimal way the multi-parameter needs." [Mitsakis, et al. 2018]

The bundling concept is essential from a traffic management perspective, ensuring a seamless service to end-users, enabling integration of existing applications through a multi-variant optimisation of properties of the individual applications, and securing policy goals like accessibility, environment and liveability by optimizing traffic flow. Hence, from a traffic management perspective bundling is a coordinated operation of multiple (C)-ITS services for traffic management purposes. To ensure a coordinated operation C-MobILE adapted the Dutch Dynamic Traffic Management (DTM) "control strategy" [CROW, 2017]. This control strategy consists of a step-by-step approach for selecting and activating so-called strategies when trying to solve or mitigate a throughput problem with pre-defined policy objectives, which are used to define the importance and function of roads as well as quantitative thresholds for nodes, links, segments and route parts. For each of the four strategies (C)-ITS services have been identified, which contribute to the strategy. [Castells, et al, 2018]. Figures 3 and 4 provide a detailed example.

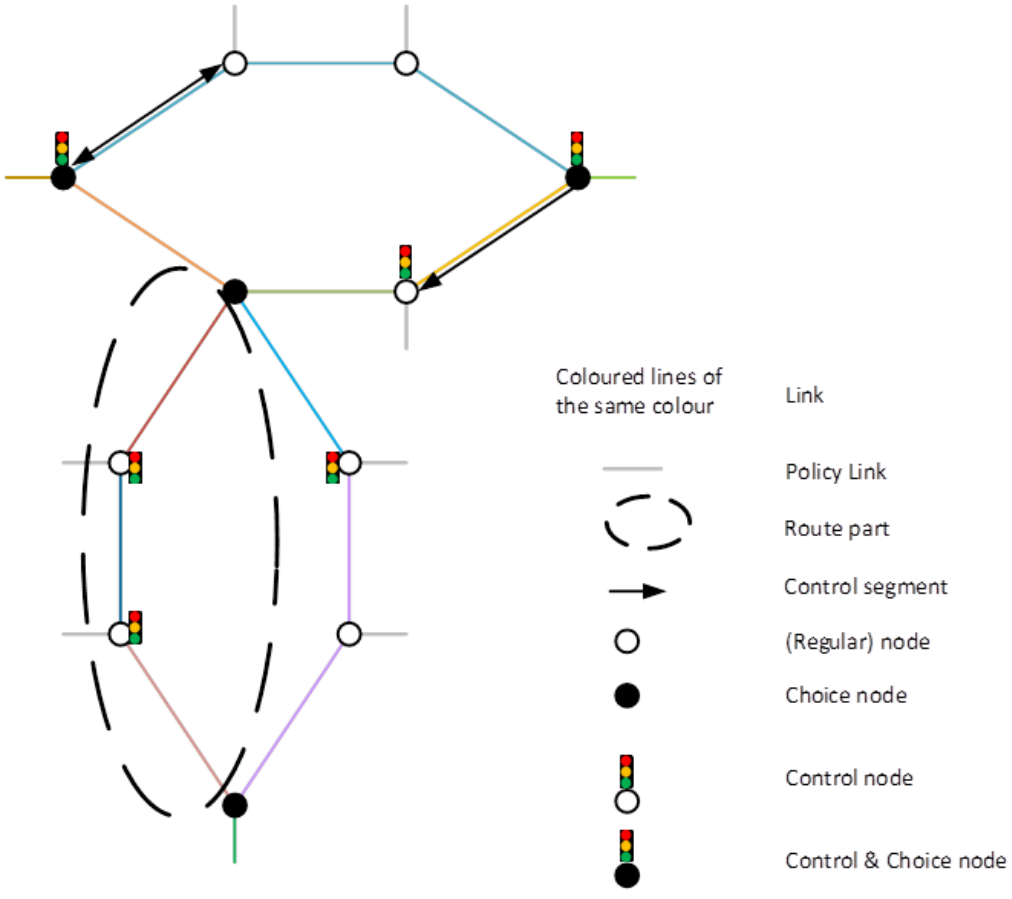

Figure 3 - Road network with choice nodes, control nodes, control segments [Mitsakis, et al. 2018]

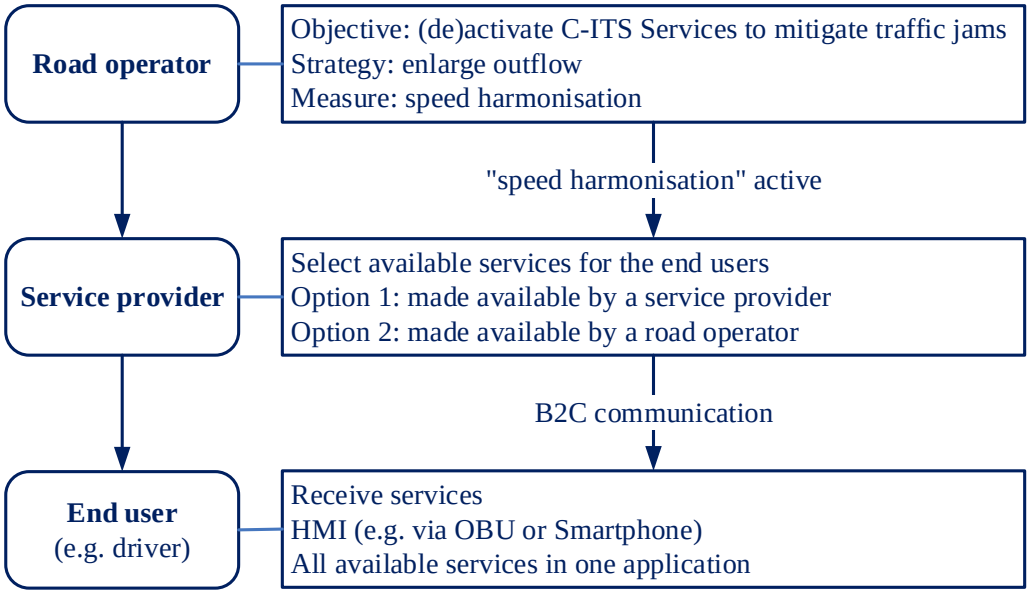

Figure 4 - Operational process for activating mobility services (adapted after [Mitsakis, et al. 2018]

Conclusion

The paper presents recently developed operational procedures and guidelines for cities to implement C-ITS services, or to extend or extend their already existing C-ITS services. A thorough discussion is provided of the different steps that have been identified most adequate to properly cover the multiple activities required for a complete C-ITS deployment, including interoperability at European level. The guidelines are supported by more extensive additional content, which details the different phases to cover, providing support information for the process of requirements elicitation and the identification of deployment locations, advices for the implementation of the different components, and even advices on how to deal with the end-users once the C-ITS services have become operative. Standards and existing regulations, such as the new privacy regulation (GDPR) and the PKI infrastructure for security, are well addressed. Special attention is given to interoperability, and important technical aspects during the implementation phase are well covered.

The guidelines for operational procedures are useful for cities and technical stakeholders to expand their C-ITS knowledge with content directly delivered from experts in C-ITS. The deployment of C-ITS services will help authorities to facilitate connected, cooperative and automated road transport within a European framework.

Acknowledgments

The paper presents some results of the EU-funded project C-MobILE (Accelerating C-ITS Mobility Innovation and depLoyment in Europe). C-MobILE has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 723311. The authors especially thank the C-MobILE consortium partners for their kind support.

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