Costs and benefits of bundled C-ITS services. The C-MobILE approach.

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***Abstract*:** The project C-MobILE (Accelerating C-ITS Mobility Innovation and depLoyment in Europe), funded under the H2020 programme, aims to create a fully safe and efficient road transport system, without casualties and serious injuries on European roads, in particular in complex urban areas. C-MobILE clusters C-ITS (Cooperative Intelligent Transport Systems) services into four thematic application bundles according to their relevance, which will be demonstrated at eight pilot sites. The C-ITS 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. Applications are combined into the following four bundles: urban efficiency, infrastructure-to-vehicle safety, traffic efficiency and vehicle-to-vehicle safety. The bundles offer end-users and road operators an optimized benefit from their set of applications, given their perspective, objectives and traffic situation. Bundling of applications is expected to generate benefits extending far into the future. The present paper presents costs and benefits of bundled C-ITS services, which is crucial and sets the basis for the quantification of the magnitude of their economic impact in the Intelligent Transport Systems sector. The economic impacts relate to changes in: transport user benefits (consumer's surplus), system operating costs and revenues (producer surplus), cost of externalities (environmental costs, accidents, etc.), and investments costs.

Keywords: Cooperative Intelligent Transport Systems, urban areas, bundles, costs, benefits.

1. INTRODUCTION

Advancements in communications technologies are spurring a revolution within the transportation network. Short-range dedicated radio and mobile phone technology allow drivers, pedestrians, transit passengers, freight operators, and transportation management personnel to communicate with each other within a connected transportation network, forming the Cooperative Intelligent Transport Systems (C-ITS) concept. The C-ITS concept refers to the capability of the various elements of the modern surface transportation system (e.g. personal, transit, and freight vehicles, pedestrians, bicyclists, roadside infrastructure, transportation management centres) to communicate, via Vehicle-to-Infrastructure (V2I) or Vehicle-to-Vehicle (V2V) communications, with each other on a rapid and continuous basis, while no personally identifiable information is shared between the vehicles. This communication can occur via several mechanisms, such as dedicated short-range communications (DSRC), allowing rapid communications between elements of a C-ITS network, and cellular phone technology, anticipated also to facilitate the use of many C-ITS services [1].

During the last years a large number of projects demonstrating C-ITS implementation have taken place in Europe under various funding schemes. The ongoing project C-MobILE (Accelerating C-ITS Mobility Innovation and depLoyment in Europe), funded under the H2020 programme (The EU Framework Programme for Research and Innovation), is the most current one and aims to establish a fully safe and efficient road transport system on European roads. Over a 42-month timeframe, C-MobILE will deploy services for specific mobility challenges in different settings / environments and for a range of use cases having a strong uptake potential, such as Vulnerable Road Users (VRU) safety at intersections, traffic light operation, eco-driving, traffic routing, goods delivery and parking. C-MobILE will focus as well on easing the decision process of local authorities to invest in C-ITS, creating awareness of C-ITS solutions in real-life situations, reducing complexity for development and making C-ITS accessible for the general public to develop front-end services to enable low-cost and wide-scale deployment on smartphone and other commodity devices. A total of eight C-ITS equipped cities / regions (Barcelona, Bilbao, Bordeaux, Copenhagen, Newcastle, North Brabant, Thessaloniki and Vigo) are involved in C-MobILE, which aspires to elevate the existing research pilot sites to large-scale deployment locations of sustainable services thanks to the support of local authorities and operators. Within the project framework two major objectives are pursued: a common approach, ensuring interoperability and seamless availability of services towards acceptable cost for end-users and a positive business case for all parties in the supply chain, and the delivery of comprehensive (ex-ante and ex-post demonstration) cost-benefit analyses, business models and understanding of end-user needs related to service availability and uptake that are vital for large-scale deployments and real market roll-out [2].

The overall concept of C-MobILE relies on the demonstration of C-ITS solutions at large-scale in urban and extra-urban environments, by providing bundled C-ITS services, deployed to address a particular scenario or need. The definition of bundles refers to an open, modular and extendable wrap application that brings together a complete suite of C-ITS services under one common user environment, able to operate either in an automated mode or in a user-selected mode, with the ultimate goal of covering multi-parameter needs, as well as easing the widespread introduction of C-ITS. The bundling concept aims to ensure a seamless service to end-users and to enable integration of existing applications through a multi-variant optimisation of properties of the individual applications. The bundled C-ITS services logic relies 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. For each application, the required stakeholders, estimated implementation complexity, maturity level, user groups, and potential benefits (e.g. for traffic efficiency and safety) will be assessed and analysed in detail, so as to ensure that all needs and requirements will be captured and accounted for. Based on this assessment, applications are combined into the following four bundles, sorted by core themes: urban efficiency, infrastructure-to-vehicle safety, traffic efficiency, and vehicle-to-vehicle safety [2].

Table 1: Overview of bundles and applications in C-MobILE.

Bundle 1: urban efficiency	Bundle 2: infrastructure-to-vehicle safety	Bundle 3: traffic efficiency	Bundle 4: vehicle-to-vehicle safety
Rest time management	Road work warning	Green priority	Emergency Brake Light
Motorway parking availability	Road hazard warning (incl. traffic jams)	Green light optimal speed advisory (GLOSA) / "Dynamic eco-driving"	Cooperative (Adaptive) cruise control (Urban ACC)
Urban Parking availability	Emergency Vehicle Warning	Cooperative traffic light for pedestrian	Slow or Stationary Vehicle Warning
	Signal Violation Warning	Flexible infrastructure (HOV, peak-hour lanes)	Motorcycle approaching indication (including other VRUs)
	Warning system for pedestrian (not limited to crossings)	In-vehicle signage (e.g. Dynamic speed limit)	Blind spot detection / warning (VRUs)
		Mode & trip time advice (e.g. by incentives)	
		Probe Vehicle Data	

The deployment of these bundles is accompanied by a series of various costs and benefits, estimated to affect the whole transport system, from individual end-users to road traffic operators. The deployment of the bundled C-ITS services entails sizable costs for equipping the roadways and vehicles, and for operating and maintaining the system over a long time horizon. Each bundle, with regard to its goals, proposed functionalities and technical requirements of the services included, is estimated to provide specific benefits, covering major benefit categories, such as safety, mobility, operations optimization and environmental sustainability [3]. The methodology followed in this paper includes the identification of the costs and benefits of C-ITS services, derived from an extended literature review, and then an attempt to match these findings to the aforementioned bundled C-ITS services.

2. COSTS

Costs of C-ITS deployment could be comprised of two types of costs. First, C-ITS deployment requires non-recurring costs: the upfront, initial costs required to deploy the infrastructure, which appear only once in the lifetime of the system. Second, C-ITS deployment requires also recurring costs: the costs required to operate and maintain the infrastructure [4].

2.1. Non-recurring costs

2.1.1. Infrastructure deployment costs

Infrastructure deployment costs include the costs for planning, acquiring and installing the C-ITS equipment. National and local agencies need to evaluate the costs for planning and design, which include mapping intersections and deciding where to deploy the required C-ITS equipment based on traffic and safety analyses [4]. Planning and design cost elements are usually comprised of [5]:

- A radio survey, which is the cost of identifying radio interference and determining the optimal location for a DSRC radio (or multiple radios) and an antenna at a specific location to maximize coverage.
- A map / GID generation, which includes the cost for highly accurate mapping of an intersection. This can be done either through as-built plans, accurate satellite (or other overhead) images or a survey crew.
- The planning cost, which includes the costs of developing a general regional plan for deploying a C-ITS environment throughout an entire region. This includes the analysis of where to deploy DSRC radios in a region based on traffic and safety analysis.
- The design cost, which includes all of the design costs associated with deploying the DSRC infrastructure at a specific location.
- The construction inspection, which includes the cost of overseeing construction, reviewing contractor submittals for radios and other hardware to be deployed. This cost also includes testing at the site to ensure full functionality.
- The system integration and license, which includes the costs associated with licenses for the radios, the cost to set the radios up within the overall system (e.g. IP addresses) and the costs to add a site to a central system.
- The traffic control, including the cost for basic traffic control during deployment of a DSRC radio unit. This could include signage specific to a region for advance warning of road construction or the traffic control necessary in case the traffic signal needs to be turned off during installation of the DSRC radio equipment.

The costs for acquiring and installing the C-ITS equipment constitute the investment costs of a C-ITS infrastructure deployment. This cost category generally includes several elements such as [5]:

- Roadside communications equipment (for DSRC or other wireless services) together with enclosures, mountings, power, and network backhaul.
- Traffic signal controller interfaces for applications that require signal phase and timing (SPaT) data.
- Systems and processes required to support management of security credentials and ensure a trusted network.

- Mapping services that provide highly detailed roadway geometries, signage, and asset locations for the various C-ITS applications.
- Positioning services for resolving vehicle locations to high accuracy and precision.
- Data servers for collecting and processing data provided by vehicles and for distributing information, advisories, and alerts to users.

Regarding the case of V2V deployment, the investment costs are given by the sum of the component costs for the in-vehicle systems, comprising of the on-board equipment (OBE) costs of the system (i.e., the components that need to be installed on a vehicle to support the V2V services operating in the system). Such components typically amount to a communication tool (including antenna and cables) and a display. Further, the V2V system needs a dual frequency GPS, digital maps including intersections, a warning module and a long-range radar at the front end. Component costs depend on penetration rate, because market penetration is interrelated to production output [6].

The main installation cost is labor, but there are also some costs for materials used in the installation of the vehicle equipment (e.g., minor attachments such as brackets or plastic tie downs to secure wires). Estimates for installation costs can be separated into "Material Costs" (for the minor attachments), "Labor Costs" and "Variable Burden" (i.e., other costs that are not direct labor or direct material used in the part, but are costs that vary with the level of production, such as set-up costs, in-bound freight, perishable production tools, and electricity).While the supplier costs and the installation costs are both costs that are incurred in order to install the components necessary to support V2V services, many vehicles are already being equipped with GPS units. For those vehicles, the GPS component of the V2V system is not a cost that is attributable to the V2V system [7].

In case of V2I deployment, the investment costs are the sum of costs for equipping the vehicles and the infrastructure. The V2I in-vehicle system uses the same basic equipment as the V2V in-vehicle system. In addition to the in-vehicle system, the V2I system needs components for the infrastructure equipment. Besides closed-circuit television (CCTV) video cameras, which are assumed to be standard equipment in 2020 roadside units and dedicated antenna systems, automatic ice detection systems, laser scanners, and digital maps including intersections could be considered. The equipment of infrastructure (e.g. roadside ITS sub-systems, such as beacons on gantries, poles, smart traffic lights) represents typically a major cost block of the total V2I system because the infrastructure must be equipped irrespective of the number of equipped vehicles. It is however questionable whether an entire road network would have to be equipped, considering that the accident risk on roads is not uniform. Risk mapping provides the key to come up with working hypotheses about the relation between infrastructure equipment and coverage of accidents [6].

Installation costs arise as well from backhaul connectivity, which establishes connectivity for communication between roadside units and back offices or traffic management centers (TMCs). These costs are likely to be implemented differently across a region, hence resulting to the variability of the estimated backhaul costs per area. Areas where current capacity is sufficient, require minimal backhaul investment. Costs are limited to design and integration with existing backhaul infrastructure, while additional costs for hardware are minimal. Where existing capacity is insufficient to handle the anticipated bandwidth requirements for V2V and V2I communications, new or upgraded backhaul infrastructure is required. The costs for these areas are dependent upon the specific architecture and design of the local agency and can range from low capital cost options with ongoing operational expenses, to higher cost options, such as the deployment of new fiber optic communications [7].

Considering the concept of bundled C-ITS services, if a component is needed by two or more services, the services can share access to this component, so that the component is needed only once. This results in bundle costs which are lower than the sum of costs needed for systems with accordant stand-alone services. The synergies help the bundle to achieve a higher profitability [8].

2.2. Recurring costs

2.2.1. Operational and maintenance costs

There are several types of recurring costs associated with V2V and V2I deployments, including equipment maintenance and replacement, security, and personnel costs. This type of costs arises from operating and maintaining the C-ITS network, in order to ensure that the deployment remains functional over time. Field infrastructure operations costs, associated with operation of the equipment, include standard considerations for power and communication, as well as the additional cost to existing Operations Centers for additional hardware and personnel to monitor system performance. Regular maintenance costs are expected to include such items as realigning the antennas, rebooting hardware, checking the system to confirm operation status and other typical checks. As with most technologies, there is also the possibility of an annual license or maintenance fee for a device for support from the manufacturer. This fee is intended to cover the costs of developing and distributing firmware updates that improve functionality and security of the device [5].

The C-ITS infrastructure will need to be replaced as it reaches the end of its lifecycle. DSRC radios are estimated to last anywhere from one year to ten or more years before needing replacement. Cisco routers and switches, based on industry experience, have an expected lifespan of seven to eight years. Traffic signal controllers, if undisturbed, often remain operational for ten to twenty years or longer. Stakeholders typically estimate that the hardware deployed for C-ITS services has a life-span of ten years. The operational lifespan of the RSUs is not, however, solely a function of the hardware. It is expected that the RSU software will be updated on a regular basis to assure that the devices have the latest security and application updates [5]. Security costs are also a recurring cost and include the costs of keeping the security credentials of the Security Credential Management System (SCMS) up to date and the costs to manage the security system. In addition, states and localities may also need to hire new personnel or train existing staff to operate these systems. Personnel costs depend on the size of the deployment, as smaller deployments may not need dedicated personnel to complete maintenance, while large deployments may require staff dedicated to system monitoring on site or on call [4].

3. BENEFITS

C-ITS deployment can provide wide benefits for users and society. A need for the identification and monetization of benefits is essential. Monetized benefits can be divided into two categories: 1) direct monetary benefits, where the implementation of a bundle of C-ITS services leads to a direct saving to the road authority, and 2) societal benefits, where the C-ITS services provide a monetisable benefit to society as a whole, increasing the total social welfare [9].

3.1. Direct monetary benefits

From a road authority's perspective, the most important potential benefits of bundled C-ITS services can be defined as [10]:

- Reducing incidents and accidents and their network impacts.
- Asset condition monitoring (e.g. road surface friction, potholes).
- Reducing cost of traffic data collection.
- Road capacity optimization.

- Better information to drivers.
- Improved coverage / penetration of both information services on the road network and sensor data from the road network.
- Potential to reduce or remove infrastructure.

3.2. Societal benefits

3.2.1. Safety benefits

One of the most anticipated societal benefits of C-ITS services is the improvement of roadway safety conditions. C-ITS technology promises to exhibit profound effects on driver, passenger, and pedestrian safety. The innovative communications technology to be utilized by the C-ITS services will provide drivers and vulnerable road users (VRUs) with advance warnings of various situations, allowing time for reaction and avoidance [1]. The C-ITS services are expected to offer some of the most promising opportunities for avoiding accidents, fatalities, severe and slight injuries [6].

3.2.2. Mobility benefits

Bundled C-ITS services have the potential to increase mobility, by enabling traffic data collection and mobility information provision within the urban environment. This way traffic management centers can proceed in the optimization of traffic flows, at and between intersections and roundabouts, taking into account all modes of mobility (e.g. vehicles, public transport, emergency vehicles, bicyclists and pedestrians). Transportation system managers will have the ability to identify and address congestion in real-time, ensuring travel time savings, as well as reduction of vehicle-hours. C-ITS services provide also the opportunity to promote selected modes of mobility with respect to the size of cities. Public transport (bus and tram) can be fostered using C-ITS services in all vehicles and related traffic lights, e.g. for prioritization of public transport modes, as well as collecting passenger and other data. Emergency vehicles such as police cars, fire brigades and ambulances can use C-ITS services as well in order to warn other traffic participants and / or to request prioritization at traffic lights [11].

3.2.3. Environmental benefits

C-ITS services are expected to contribute to reducing negative environmental externalities of transport. C-ITS services offer a high potential for avoiding high traffic density by improving the processes, safety and efficiency of all modes of transportation. Such services allow foresighted driving, passing traffic lights in adaptive “green waves”, smoothing traffic flows and reducing efforts for finding a parking place. Cooperative feedback to drivers and adaptive techniques in traffic control provides smoothest circulation, lesser delays and stops, diversion of traffic flows in response to automatically detected incidents and timely notifications to drivers, both on V2V and V2I communications capabilities, contributing this way to energy and fuel savings, as well as to emissions and noise reduction. Fuel consumption reductions constitute a major environmental benefit and they can be directly estimated as limiting GHG emissions. GHG emissions reduction includes also direct air-quality improvement in highly dense city centres, by proportionally reducing most toxic concentrations of NOx, SOx and PM2.5 concentrations [11].

3.2.4. Economic benefits

One of the economic benefits, arising from improved traffic flows, is expected to be the reduction of needed expenditure in road infrastructure expansion and maintenance. Coordinated deployment of C-ITS services is expected to reduce as well redundancy and increase roll-out speed and network effects. The deployment of new

C-ITS services can create new jobs and business opportunities and common specifications can broaden the C-ITS market and make it more accessible. The deployment of C-ITS is expected to have positive impacts on international competitiveness, research and innovation and the Digital Single Market, in particular as it is a stepping stone towards cooperative, connected and automated mobility [11].

Table 2: Overview of costs and benefits of bundled C-ITS services.

	Bundle 1: urban efficiency	Bundle 2: infrastructure-to-vehicle safety	Bundle 3: traffic efficiency	Bundle 4: vehicle-to-vehicle safety
Costs				
Non-recurring costs				
Infrastructure deployment	×	×	×	×
Recurring costs				
Operation	×	×	×	×
Maintenance	×	×	×	×
Benefits				
Direct monetized benefits				
Cost savings for road authorities	×	×	×	×
Societal benefits				
Safety				
Improvement of roadway safety conditions		×		×
Accidents reduction		×		×
Fatalities reduction		×		×
Severe and slight injuries reduction		×		×
Mobility				
Traffic flows optimization	×		×	
Congestion reduction	×		×	
Travel time savings	×		×	
Vehicle-hours reduction	×		×	
Prioritization of selected transport modes	×		×	
Environment				
Fuel consumption reduction	×		×	
GHG emissions reduction	×		×	
Economy				
Reduction of infrastructure expansion and maintenance	×	×	×	×
Increase of roll-out speed and network effects	×	×	×	×
Generation of new jobs	×	×	×	×
Generation of new business opportunities	×	×	×	×
International competitiveness	×	×	×	×
Advance in research and innovation	×	×	×	×
Digital Single Market accessibility	×	×	×	×

4. CONCLUSIONS

In this present paper the costs and benefits of bundled C-ITS services are presented. An extensive description of the concept of bundled C-ITS services, within the framework of the C-MobILE project, is initially described. Subsequently, the various types of costs and benefits, arising from bundled C-ITS services, are thoroughly presented too. Regarding the costs of bundled C-ITS services deployment, two major categories can be defined: 1) non-recurring costs, which are associated with the infrastructure deployment, and 2) recurring costs, which are associated with the operation and maintenance of the infrastructure. As far as the benefits from the deployment of bundled C-ITS services are concerned, the two main identifiable categories are: 1) direct monetized benefits, and 2) societal benefits. Societal benefits include many aspects of the C-ITS transport network, having an impact on the social welfare, such as safety, mobility, environment and economy. Overall, it is demonstrated that despite the costs accompanied with the deployment of bundled C-ITS services, the implementation of such technologies can provide efficient solutions, able to increase road safety, mitigate traffic congestion and ameliorate its negative environmental impacts, as well as to promote economic growth. A Cost-Benefit Analysis (CBA) of the bundled C-ITS services, to be performed for the C-MobILE project, constitutes a valuable procedure for the assessment of the enhanced effects of this innovative technology in monetary terms.

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