Study on the Deployment of C-ITS in Europe: input data overview – cost data

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1 Introduction

Three main data inputs are required to carry out the cost-benefit assessment (CBA) of the various C-ITS deployment scenarios developed in conjunction with the C-ITS Platform Working Group 1 (WG1), namely:

- C-ITS service and infrastructure uptake and penetration rates:
  - Vehicle penetration/uptake rates allow an estimation to the total number of vehicles within the vehicle fleet for each vehicle category (or amongst new vehicles) equipped with the technologies required to support C-ITS services.
  - Separate penetration rates are also necessary to represent the extent of different road types equipped with C-ITS supporting infrastructure, allowing them to offer Vehicle-to-Infrastructure (V2I) services.
  - Uptake and penetration rates were determined for the baseline and each scenario based on consultation with WG1 members. The full list of uptake/penetration assumptions are summarised in a separate Excel spreadsheet circulated alongside this document.
- C-ITS service impact data:
  - These are the impacts of C-ITS services on individual vehicles when installed across different vehicle and road types.
  - Impacts can be in terms of fuel consumption, CO_2 emissions, polluting emissions, or accident rates.
  - Individual impacts are combined with C-ITS deployment scenario service bundle uptake and penetration rates in the ASTRA/TRUST modelling environments to estimate the total EU-level impact of services for each deployment scenario.
  - The EU-level impacts can be converted to monetary benefits through using typical values for the external cost of transport from the Handbook on External Costs of Transport (Ricardo Energy & Environment et al., 2014).
  - The full list of impacts assumptions are summarised in a separate Word document circulated alongside this document.
- C-ITS supporting technology and service costs:
  - Cost data makes up the final main input element for the CBA, allowing the uptake and penetration rates for different services to be translated into costs, in order to compare them directly to the estimated benefits from the various EU-level impacts calculated from the modelling.

The focus of this document is on summarising the C-ITS cost data assumptions used in the CBA.

1.1 Introduction to C-ITS sub-systems

In order to fully understand the costs associated with the deployment of C-ITS services, it is necessary to consider the cost of the hardware/devices and associated software and services used to facilitate those C-ITS services. These devices can be broadly categorised into four types[1]:

1. **Central ITS sub-systems**, which may be part of a centralised traffic management system. One such sub-system is able to manage C-ITS services for an entire city, or road operator, or national highway system etc. Deployment of other ITS sub-systems, such as C-ITS infrastructure/roadside units will require a central system for management purposes.
2. **Personal ITS sub-systems** such as mobile phones, tablets, personal navigation satnav-type devices, and other hand-held devices not attached to the vehicle's information bus – these can enable V2I communications along suitably equipped roads/regions, or in the future, may be able to support V2V communications if equipped to use the correct communications protocols.

[1] ERTICO, "Communication Technologies for future C-ITS service scenarios" (2015)

Note that in this study, it is assumed that personal ITS sub-systems are only able to offer V2I services.

3. **Vehicle ITS sub-system**, which are either fitted by the vehicle manufacturer or retrofitted to the vehicle, and are attached to the vehicle communication buses – these can enable both V2V communications and V2I along suitably equipped roads/regions. *Note that retrofitted vehicle ITS sub-systems are outside the scope of this study*.
4. **Roadside ITS sub-systems** such as beacons on gantries, poles, smart traffic lights, etc. which allow V2I communications along specific stretches of roads.

To reflect the distinction between these ITS sub-system, this document is therefore divided into four key sections as follows:

- Section 1: this section provides an introduction to the data collection task, summarises the key objectives and assumptions, and lists the main data sources.
- Section 2: this section itemises our cost assumptions for Central ITS sub-systems.
- Section 3: this section itemises our cost assumptions for Personal ITS sub-systems.
- Section 4: this section itemises our cost assumptions for Vehicle ITS sub-systems.
- Section 5: this section itemises our cost assumptions for Roadside ITS sub-systems.

In addition Section 6 includes a full list of data sources used in the cost data collection.

1.2 Cost data overview

1.2.1 Cost items collected

For each of the C-ITS sub-systems listed in Section 1.1, data related to the following parameters was collected:

1. Upfront costs, i.e. one-off costs incurred at the point of installation/commissioning.
2. Ongoing costs, i.e. the recurring costs associated with operating each sub-system.
3. Equipment lifetime, to establish whether it was necessary to account for replacement costs within the lifetime of the CBA modelling (2015 to 2030).
4. The cost owner, to enable an estimation of the impact of different cost items on the various key stakeholders in the deployment of C-ITS services.

1.2.2 Technology learning rates

The majority of the systems deployed to support the rollout of C-ITS services are currently at a relatively early stage of maturity and costs are likely to improve through time. To account for this, a learning rate of 10% is applied to all up-front costs for personal, in-vehicle and roadside ITS sub-systems. That is, for every doubling in installed volume, up-front costs reduce by 10%.

1.3 Sources of information

1.3.1 Literature

The cost data collection exercise built on our extensive literature review of over 100 documents from Task 1, which covered various aspects of C-ITS services and related technologies. Within this long list, a number of key sources for the cost data collection task were identified, as listed below:

- 004 – COMeSafety, BMW: D2.3 Cost Benefits Analysis & Business Model Elements for Deployment
- 011 – CVIS costs, benefits and business models
- 017 – eIMPACT Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe. Deliverable D4. Impact assessment of Intelligent Vehicle Safety Systems.

- 026 – NHTSA, US DoT: Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application
- 040 – COBRA, TNO: Deliverable 2 Methodology framework, Update
- 044 – CODIA
- 046 – SAFESPOT SP6 – BLADE – Business models, Legal Aspects, and Deployment
- 113 - EasyWay Business case and benefit-cost assessment of EasyWay priority cooperative services
- 114 – US DoT: National Connected Vehicle Field Infrastructure Footprint Analysis Final Report

1.3.2 Expert input

In addition to the desk-based data collection, the draft outputs of the cost data collection were discussed during the WG1 meeting held in Brussels on the 1st October 2015. This resulted in a number of revisions to the costs used in the CBA, which are also included in this document.

Finally, where data was inconsistent between studies or where gaps remained from the literature review, a number of industry experts (mainly from within WG1) were contacted either unilaterally or in groups as part of Task 8 (cross cutting stakeholder engagement task). Ricardo Energy & Environment invited industry experts to:

- Comment on the cost data collected
- Suggest further sources of information
- Provide cost data where sufficient evidence was not available in the literature

In particular, a teleconference was held on 12th October 2015 to discuss roadside ITS sub-system costs. Following the teleconference, Ricardo Energy & Environment issued a revised list of infrastructure costs to all attendees, as summarised in this document.

1.3.3 Base year

Given the varying base years for cost data originating from different data sources, all pre-2015 costs have been inflated to 2015 levels using the Eurostat Harmonised indices of consumer prices (HICP) (European Commission, 2015).

2 Central ITS sub-systems

Central ITS sub-systems are likely to be integrated into existing traffic management centres (TMCs). One such sub-system is likely to have the ability to manage an entire city, road operator, national highway system etc. A central ITS sub-system is necessary so that roadside sub-systems are connected to a central system, where data can be analysed and used to enable effective traffic management and the deployment of V2I services.

In this cost-benefit analysis central ITS sub-system costs are considered on a Member State level; costs have been calculated per Member State, depending on the level of infrastructure penetration.

2.1 Business model

It is assumed that roadside ITS sub-systems will be integrated into existing traffic management centres and that additional TMCs will not need to be built to support the management of C-ITS services. Consequently, the costs described in this section only refer to the cost of additional equipment/services required to connect the roadside units to TMCs, back office integration costs, etc. It is assumed that these costs are borne by the highways agencies/urban transport authorities in each Member State.

In addition to the TMC integration costs, it is assumed that software applications are required to deliver the C-ITS services to various personal or in-vehicle ITS sub-systems. These must additionally be developed in each Member State and it is assumed that these costs are borne by the transport/highways agencies in each Member State.

2.2 Summary of inputs to the cost-benefit analysis

A summary of the key cost assumptions used in the CBA is given in Table 3-1. Sections 2.3-2.5 discuss these aspects in more detail.

Table 2-1. Breakdown of costs for central ITS sub-systems (front runner country)

	Cost item	Input	Year	Cost owner
Upfront costs	Integration of roadside units into TMC. Interface to urban standards/protocols	€1.5 million	2015	Highways Agency
	Integration of roadside units into TMC. Interface to inter-urban standards/protocols	€1.5 million	2015	Highways Agency
	Interface from roadside unit to local traffic controller (urban)	€1 million	2015	Highways Agency
	Interface from roadside unit to local traffic controller (inter-urban)	€1 million	2015	Highways Agency
Ongoing costs (per year)	Back office operations and maintenance (urban)	€250,000	2015	Highways Agency
	Back office operations and maintenance (inter-urban)	€250,000	2015	Highways Agency
	Application development costs (urban)	€300,000	2014	Highways Agency
	Application development costs (inter-urban)	€300,000	2014	Highways Agency

2.3 Upfront costs

It is assumed that each roadside unit will be connected to a TMC. Based on conversations with industry experts, it is assumed that each EU Member State operates with different road traffic standards/protocols. Two major upfront cost items are relevant to deploying central ITS sub-systems in each Member State:

- A **cost for developing a TMC interface** for each Member State. Based on discussions with industry experts, development of a TMC interface is likely to cost between €1 million - €2 million. An average cost per interface of **€1.5 million** has been used in this CBA. Previous studies (EasyWay and COBRA) have suggested a cost of €500 per roadside ITS station to cover integration costs with TMCs. Based on this figure an average cost of €850,000 per TMC per country was calculated[2]. This compares well with the €1.5 million cost estimation used in this study, considering that previous studies have assumed an ITS sub-system range of 300-500m.
- An **interface to local traffic controllers** (e.g. traffic lights) for roadside ITS sub-systems. Based on discussions with industry experts, a cost of **€1 million** per interface has been assumed.

Furthermore, each Member State is likely to have different urban traffic standards and inter-urban traffic standards. The total cost for integration of C-ITS services is therefore estimated at **€2.5 million** each for urban and inter-urban areas respectively within each Member State.

These costs are triggered only once roadside ITS sub-system penetration reaches 10% across urban and inter-urban areas respectively.

2.4 Ongoing costs

Two principal ongoing costs are assumed to be incurred, as follows:

- The cost for **maintaining the TMC back-office and local controller interfaces**, estimated at 10% of capital costs based on the COBRA study (TNO, 2013), or **€250,000** per year for urban and inter-urban areas respectively.
- A cost for **developing and maintaining software applications** to deploy services to personal and in-vehicle ITS subs-systems, estimated at **€300,000** per year. The development, maintenance and improvement of C-ITS mobile applications has been estimated to require between 1-5 FTEs (full time equivalents) and will be paid for by highways agencies via an annual service fee to app developers. Three FTEs are estimated to cost €300,000 per year, based on the COMeSafety2 cost-benefit analysis (BMW, 2014). As for the other central ITS sub-system costs, separate applications will be required for urban traffic standards and inter-urban traffic standards in each Member State, so this cost is assumed to apply to both urban and inter-urban areas.

The total ongoing cost per Member State is therefore **€550,000** per year, with this cost being triggered for urban and inter-urban areas when each reaches 10% total ITS sub-system penetration.

2.5 Lifetime

The lifetime of the TMC integration is assumed to exceed the lifetime of the modelling (which runs to 2030) and therefore is not considered relevant for this section.

[2] Assuming a roadside ITS sub-system range of 1km and the number of roadside units deployed in the baseline scenario

3 Personal ITS sub-systems

Personal ITS sub-systems such as mobile phones, tablets, satnav-type personal navigation devices (PNDs), and other handheld devices not attached to the vehicle's information bus can enable V2I communications along suitably equipped roads. In the future, these devices may also enable V2V communications if equipped to use the correct communications protocols.

The objective of this cost-benefit analysis is to assess the costs and benefits of five realistic C-ITS deployment scenarios during the years 2015-2030 and to compare these to the baseline. To ensure a robust methodology, information for the modelling was drawn from current market trends, data on comparable existing technologies and knowledge of potential business models. Based on our analysis for the baseline scenario and discussions with key stakeholders, it is expected that C-ITS services on personal ITS sub-systems are initially likely to be provided by two major types of devices: **mobile phones**, and **personal navigation devices** (PNDs) such as TomTom or Garmin Satnav devices. These two categories of personal ITS sub-systems were therefore selected for modelling in this study and are described in more detail in the sections below.

In the future it is possible that many types of handheld devices will have the potential to support C-ITS services, however during the timeframe considered for this cost-benefit analysis these are likely to account for only a small percentage of personal ITS sub-systems. Furthermore, no cost or performance data exists for these unknown future devices on which to base modelling inputs and they are therefore not modelled in this study.

In the time period considered for the modelling it is likely that personal ITS sub-systems will only support V2I communication, as these devices will not be connected to vehicle information buses. The provision of V2V functionality through personal ITS sub-systems is therefore not considered in the scope of this study.

It is assumed that personal ITS sub-systems are only available in the aftermarket, to any vehicles that are not already equipped with in-vehicle C-ITS sub-systems. Costs are assumed to be consistent across all vehicle categories.

3.1 Mobile phones

3.1.1 Business model

As with any emerging technology, C-ITS services could be offered via a number of different business models. The method selected is likely to depend on the interaction between key stakeholders in the field and may ultimately vary by Member State, Highways Agency and technology/software provider.

Three options that have been suggested for smartphones are as follows:

- **Subscription based model**: In a subscription based business model, end-users would not be charged to download the application but would pay an annual subscription fee for use of the service. The subscription fee would be used to cover software development costs and enable the end-user to receive updates to the application during the subscription period. Any cellular data usage associated with using the application would be covered by the end-user.
- **App store/online marketplace based model**: On the other hand, in an app store based business model, there would be a one-off fee to download the application, with no additional subscription fees. In this case, the one-off fee would be set at a level sufficient to cover the software development and update costs. Any cellular data usage associated with using the application would be covered by the end-user.
- **Free model:** Alternatively, C-ITS services may be provided for free to smartphone users, for example by national highways agencies. In this business model, an independent app developer is paid by a highways agency/urban transport authority to develop and maintain an application required to enable C-ITS services on the relevant road network. In this business model, cellular data usage will be covered by the end-user, however there will be no upfront fee to download the app and no subscription fees to access the service. The highways agency/transport authority may choose to recoup some of its costs through e.g. allowing advertising within the app.

Based on discussions with WG1 members and current European pilot projects (such as NordicWay), the most likely business model to be offered for C-ITS services is deemed to be the 'free' model described above. It has been therefore been decided to model only the 'free' business model in the cost-benefit analysis.

3.1.2 Summary of inputs to the cost-benefit analysis

A summary of the key assumptions and inputs to the cost-benefit analysis for mobile phones is shown in Box 1 below. A full breakdown of costs is given in Table 3-1. Sections 3.1.1 - 3.1.5 discuss these aspects in more detail.

Box 1. Summary of key assumptions and inputs to the cost-benefit analysis for mobile phones

Key assumptions:

- Personal ITS sub-systems are only available via the aftermarket to existing vehicles that are not already equipped with in-vehicle ITS sub-systems
- Costs are assumed to be consistent across all vehicle categories
- Mobile phones will only provide V2I services, via the cellular network
- Mobile phones are already owned by the user – i.e. no up-front purchase costs are incurred
- C-ITS services will be available to the end-user via a free model. Highways agencies will pay software developers an ongoing fee to maintain applications.

Table 3-1. Breakdown of costs for mobile phones

	Cost item	Input	Year	Cost owner
Upfront costs	Equipment	€0	2015	End-user
	Mobile phone app cost	€0	2015	End-user
Ongoing costs (per year)	Data	€2.57	2012	End-user

3.1.3 Upfront costs

In the cost-benefit analysis for this project, there are no upfront costs. It is assumed that mobile phones are already owned by the user and that C-ITS services will be developed and provided for free by highways agencies, as described above. This approach is currently being followed by the NordicWay pilot project, which is aiming to deploy cellular based C-ITS services. To cover the cost of application development and maintenance, an ongoing cost has been included for urban and inter-urban standards in each Member State, as discussed in Section 2.

3.1.4 Ongoing costs

As discussed above, no annual subscription fees are included for use of the C-ITS mobile phone application, as all services are assumed to be provided for free by national Highways Agencies/urban transport authorities.

Use of C-ITS applications in mobile phones will require the user to transmit and receive additional data via the cellular network. To cover this additional data usage, a cost of **€2.57 per user per year** has been estimated. This is based on estimates of data volumes required to offer C-ITS services (and a price of $4.00/GB) cited in a US DoT NHTSA report on C-ITS applications (NHTSA, 2014).

3.1.5 Lifetime

Given the assumptions that C-ITS applications are offered free to the user and that mobile phones are already owner by the end-user, lifetimes are not relevant to mobile phones for the cost-benefit analysis.

3.2 Personal navigation devices (PNDs)

3.2.1 Business model

As for smartphones, a variety of business models are feasible for PNDs. Similarly to smartphones, subscription or app store based models are possible for PNDs, where users purchase the device and pay an annual subscription fee or one-off cost for access to C-ITS services. Previous EU cost-benefit analyses in this area have opted to follow a subscription based model (for example, the COBRA study (TNO, 2013)), however a survey of the satnav market today reveals a third, more likely approach.

Although there are differences depending on device and manufacturer, at least one major manufacturer offers premium products with features such as lifetime map updates and lifetime live traffic updates, with all cellular data usage and SIM card costs included in the purchase price of the PND (TomTom, 2015). This choice of business model offers a simple and attractive way for users to readily access these services 'straight out of the box'.

Based on discussions with WG1 and an assessment of the PND market today, it has been assumed that this relatively simple approach is adopted by manufacturers offering C-ITS services alongside PNDs in the cost-benefit analysis for this study.

3.2.2 Summary of inputs to the cost-benefit analysis

A summary of the key assumptions and inputs to the cost-benefit analysis for PNDs is shown in Box 2 below. A full breakdown of costs is given in Table 3-2. Sections 3.2.3 - 3.2.5 discuss these aspects in more detail.

Box 2. Summary of key assumptions and inputs to the cost-benefit analysis for PNDs

Key assumptions:

- PND lifetime: 10 years
- PNDs will only provide V2I services, via the cellular network
- PNDs will be purchased by the end-user to access C-ITS services – the cost accounted for in the CBA is the price differential between a non-cellular-connected PND and one that has a cellular connection and includes lifetime data
- C-ITS applications and cellular data will be included in the purchase price of the PND

Table 3-2. Breakdown of costs for PNDs

	Cost item	Input	Year	Cost owner
Upfront costs	Equipment	€123.64	2015	End-user
	PND app cost	€0.00	2015	End-user
	App/software development	€0.00	2015	Equipment provider
Ongoing costs (per year)	Data	€0.00	2015	End-user
	Subscription	€0.00	2015	End-user
	App development (updates)	€0.00	2015	Equipment provider

3.2.3 Upfront costs

In the cost-benefit analysis for this project, an upfront cost of **€123.64** per PND was used, based on the market research described below. This is the current average price differential between a satnav with no inbuilt cellular connectivity or live traffic updates, and a comparable cellular-connected satnav with lifetime free live traffic updates included the purchase price (Table 3-3).

It is assumed that all data and application costs for the lifetime of the device are included in this €123.64 upfront differential cost and that end-users will pay this premium over and above the price of a standard non-cellular-connected PND, specifically to gain access to C-ITS services.

To our knowledge, only one manufacturer in the UK (TomTom) currently delivers live traffic updates directly to PNDs via the cellular network[3], which is similar to some of the V2I functionality envisaged for the deployment scenarios in this study. To enable this, TomTom and Vodafone have signed a partnership that allows compatible TomTom devices to directly receive information via the cellular network. These PNDs contain a SIM card and all data required for this service is currently included in the initial purchase cost.

Price information was collected from a variety of retailers in the UK to estimate the cost of lifetime data and built-in cellular communications. Table 3-3 compares the TomTom Start 50 (which has no live traffic features) and the TomTom GO 5000 (which contains built in cellular connectivity). The TomTom GO 50 can provide a similar service to the TomTom GO 5000, using a smartphone's data connection; it is shown in Table 3-3 purely for information. Subtracting the average price at release of the TomTom GO 5000 from the TomTom Start 50 provides an estimate for the cost of on-board equipment/software required to offer cellular connectivity, in addition to the lifetime data usage in accessing these services. This differential equates to approximately £90 (€123.64[4]).

Table 3-3. Comparison of different PNDs showing costs and key features

	TomTom Start 50	TomTom GO 50	TomTom GO 5000
Geographic coverage	Full Europe	Full Europe	Full Europe
Lifetime map updates	Yes	Yes	Yes
Fuel efficient routing	Yes	No	Yes
Screen size	5"	5"	5"
Traffic (via cellular network)	**No traffic**	**Smartphone enabled**	**Built-in**
Voice recognition	No	Yes	Yes
Current cost range	£119.99 - £139.99	£129.99 - £139.99	£179.99 - £229.99

Sources: Price information was collected from a variety of retailers in the UK. ***At release, price difference between TomTom Start 50 and TomTom GO 5000 was £90*** (Trusted Reviews, 2014; Trusted Reviews, 2013)***.***

3.2.4 Ongoing costs

As highlighted in the above section, a business model for PNDs has been assumed whereby cellular data costs and C-ITS application costs are included in the purchase price of a PND. Therefore, there are no ongoing costs for the end-user as all C-ITS service costs are included in the purchase price.

3.2.5 Lifetime

A lifetime of 10 years is assumed for PNDs in this study, based on the COBRA cost-benefit analysis (TNO, 2013). A replacement cost is therefore applied in the cost-benefit analysis for any devices that are older than 10 years (note this will only occur towards the end of the modelling period (which ends in 2030), given that deployments only begin in 2018 in the scenarios.

[3] Without the need for a connection to a smartphone. Many PNDs currently available can be connected to the user's smartphone and use this data connection to access real-time traffic information.
[4] GBP/EUR Exchange rate of 1.3738 (Jan 2015 – October 2015 period average) Source: www.oanda.com/currency/historical-rates/

4 Vehicle ITS sub-system

In-vehicle ITS sub-systems can be either fitted by the vehicle manufacturer or retrofitted to the vehicle, and are attached to the vehicle communication buses. These can enable both V2V communications and V2I along suitably equipped roads. Retrofitted vehicle ITS sub-systems are outside the scope of this study, so this chapter only details costs for systems installed in new vehicles. It is assumed that costs are consistent across all vehicle categories.

In the cost-benefit analysis for this project vehicles are divided into two different categories: those capable of delivering only ITS-G5 based services, and those capable of delivering both ITS-G5 based services and cellular based services – the latter being relevant only in the 'high' scenario sensitivity, whereby V2I services are exclusively offered via cellular networks.

4.1 Vehicles with ITS-G5 only

4.1.1 Business model

A simple business model is adopted in the cost-benefit analysis, whereby costs are only included for the additional equipment/software required to deliver C-ITS services in new vehicles. Additional up-front equipment, integration, installation and software development costs are included at cost price (i.e. OEM costs), whilst a number of additional ongoing costs are incurred by both the OEM and end-user.

No additional subscription or up-front costs are included to access the C-ITS services other than the technology/software that enables them. This is consistent with our assumptions around central and personal ITS sub-systems, whereby it is assumed that C-ITS applications and services are offered free to the end-user, provided they have the equipment required to deliver them.

Clearly a number of the costs assumed to be incurred by the OEMs will eventually be passed on to the consumer through applying a mark-up (for example the NHTSA study assumes a 51% mark-up between OEM cost and consumer price on all vehicle components) (NHTSA, 2014). Whilst this mark-up has not been explicitly modelled in the cost-benefit analysis, it is taken account of in the CBA write-up.

4.1.2 Summary of inputs to the cost-benefit analysis

A summary of the key assumptions and inputs to the cost-benefit analysis for vehicles with only ITS-G5 communication is shown in Box 3 below. A full breakdown of costs is given in

Table 4-1. Sections 4.1.1-4.1.5 discuss these aspects in more detail.

Box 3. Summary of key assumptions and inputs to the cost-benefit analysis for vehicles with ITS-G5 only

Key assumptions:

- In-vehicle ITS sub-systems are only available to new vehicles coming off the production line
- Costs are assumed to be consistent across all vehicle categories
- Only costs associated with the equipment/software required to deliver C-ITS services to vehicles are included, as well as associated integration, testing, software development and ongoing costs
- Costs are assumed to be incurred by the vehicle OEM, except for ongoing maintenance and secure communications costs
- Two DSRC antennae and transmitter/receivers are assumed necessary, one to send and receive basic safety messages, the other for the security aspects of V2V communication

Table 4-1. Breakdown of costs for vehicles with only ITS-G5

	Cost item	Input	Year	Cost owner
Upfront costs	DSRC transmitter/receiver (for 2)	€101.17	2012	OEMs
	DSRC antenna (for 2)	€7.78	2012	OEMs
	Electronic Control Unit	€35.02	2012	OEMs
	Wiring	€7.00	2012	OEMs
	Installation	€5.35	2012	OEMs
	Development & integration	€15.09	2015	OEMs
	Vehicle software development	€1.51	2015	OEMs
Ongoing costs (per year)	Maintenance	€7.55	2015	End-user
	Secure communications	€2.44	2012	End-user
	Vehicle software (updates	€3.02	2015	OEMs

4.1.3 Upfront costs

For the cost-benefit analysis, a total upfront cost per vehicle (to the OEM) of **€172.92** was calculated. This is made up of in-vehicle equipment costs (€150.97), installation (labour) costs (€5.35), C-ITS integration/development/testing costs (€15.09), and software development costs (€1.51).

4.1.3.1 Equipment and installation costs

To enable C-ITS services based on ITS-G5 communication, a number of in-vehicle components are required, including: two DSRC transmitter/receivers, two DSRC antennas, an electronic control unit and additional wiring. In contrast to the NHTSA study, a cost for an in-vehicle screen has not been included; instead, it is assumed that all vehicles equipped with C-ITS services already have some form of display where C-ITS notifications could be presented.

Two DSRC antennas and transmitter/receivers are assumed to be necessary – one will be used to send and receive basic safety messages, whereas the other will be required for the security aspects of V2V communication, such as receiving certificates and certificate revocation lists (NHTSA, 2014).

The equipment costs used in this study are derived from the U.S. DoT NHTSA Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application report (NHTSA, 2014), where they are presented as a Day 1 cost per component to the OEM in 2012 dollars. These figures were converted to 2012 Euros to give the values listed in

Table 4-1.

Installing the additional equipment in vehicles also has implications in terms of labour costs. The cost to install the components listed above is estimated to be $6.88, in 2012 US dollars (NHTSA, 2014). This is equal to €5.35 (2012 Euros)[5].

The costs in the NHTSA study for ITS-G5 equipment are broadly comparable with EU studies such as CODIA (€150 in 2020, €120 in 2030) and COBRA (€100 - €250, depending on complexity of system and level of driver assistance). The COMeSafety2 (€30-€50 depending on volume, for an ITS-G5 unit integrated in existing telematics control units) and EasyWay studies (€50 in a 100% penetration

[5] USD/EUR Exchange rate of 0.7781 (January 2012 – December 2012 period average) Source: www.oanda.com/currency/historical-rates/

scenario) suggest slightly lower costs, however it is not clear whether these include two DSRC antennas and two DSRC transmitter/receivers as suggested by the NHTSA study.

4.1.3.2 Integration of C-ITS technology, development and testing costs

The cost of integrating new C-ITS services into passenger cars is estimated to cost **€15.09** per vehicle. This covers activities such as linking the equipment required to receive and process the signals for C-ITS services to the rest of the vehicle's safety and other systems, and carrying out all safety and functionality testing required for certification. It is assumed that:

- Based on discussions within WG1, the total cost of integrating the equipment required to deliver C-ITS services would be approximately €5 million per vehicle model.
- Integration and testing would need to be carried out separately for each of a manufacturer's vehicle models, with no savings from deploying the service across multiple models.
- On average, each manufacturer sells 12 models of passenger car in Europe[6], based on an analysis of the top 7 manufacturers operating in Europe (ranked by annual sales).
- Each model has a 5 year refresh cycle, which is consistent with the uptake rates used for new vehicles in the cost-benefit analysis
- The average number of vehicles sold per model by each manufacturer over the 5 year model lifecycle is c. 350,000[7].
- The resultant cost per vehicle sold is €5,000,000/350,000 = c. €15 up-front costs

4.1.3.3 Software development and integration costs

Software development costs have been estimated to be **€1.51** per vehicle, based on a 5 year model refresh cycle. This covers the cost of developing the software to support a range of C-ITS services, i.e. the software to process the incoming/outbound signals and to decide what to do with them, before sending further signals to the vehicle's CAM bus to request responses from various vehicle systems (e.g. displays, avoidance manoeuvres, etc.).

The assumptions used here are as follows:

- The initial software development costs would be approximately €1 million per model, based on a team of ten engineers working for a year to develop the software (BMW, 2014).
- Software could be shared to some extent across different vehicle models, due to there being significant overlap between the software deployed to different vehicle models from the same OEM. However, the differing complexity of different categories of vehicles (e.g. A-category versus E-category) would mean that individual vehicle models would still incur approximately 50% of the total development costs described above.
- This cost can be approximated as detailed below, however for the cost benefit analysis, this was calculated on a per manufacturer basis for the 7 manufacturers with the largest market share in Europe, to give an average cost of €1.51.
    - The average number of vehicles sold per model by each manufacturer over the 5 year model lifecycle is c. 350,000.
    - The resultant cost per vehicle sold is €1,000,000 x 50% / 350,000 = c. €1.40 up-front costs
- This software would need to be maintained by a team of 3-5 individuals full-time – as discussed in the ongoing costs section.

4.1.4 Ongoing costs

Ongoing costs total **€13.01** per vehicle and are composed of maintenance, secure communications and OEM maintenance of in-vehicle software:

- The additional equipment installed to support C-ITS services in new vehicles is likely to lead to incremental maintenance costs above those that would normally be incurred. A maintenance

[6] Based on an analysis of passenger car product ranges of the 7 manufacturers with the largest market share in Europe, in 2015 (SOURCE: ACEA).
[7] Based on an analysis of passenger car product ranges of the 7 manufacturers with the largest market share in Europe, in 2015 (SOURCE: ACEA).

cost equal to 5% of the capital cost of C-ITS equipment per year is assumed in this study – equivalent to **€7.55** per vehicle per year. It is assumed that this cost is borne by the vehicle end-user.

- A secure communications management system is necessary for vehicles to provide and receive secure and trusted communications. The cost of secure communications was estimated in the NHTSA report to be $3.14 (2012 dollars) per vehicle, which is equivalent to **€2.44** (2012 Euros)[8]. It is assumed that this cost is borne by the vehicle end-user.
- The cost of maintaining in-vehicle software after release, to provide updates where necessary throughout a model's typical lifecycle was estimated to be **€3.02** per vehicle per year. This cost can be approximated as detailed below, however for the cost benefit analysis, this was calculated on a per manufacturer basis for the 7 manufacturers with the largest market share in Europe:
    - This has been estimated to require 3-5 full time staff members (at €100k per year) for each vehicle model,
    - 50% of these costs are shared between models, as per the up-front vehicle software development costs.
    - The average number of vehicles sold per model by each manufacturer is c. 70,000 per year.
    - This translates to an annual cost of €400,000 x 50% / 70,000 = c. €2.85 per vehicle. It is assumed that this cost is borne by OEMs, alongside the up-front integration and software development costs.

A number of studies point to the potential effect of C-ITS services on insurance costs (particularly for safety-focused C-ITS services), however due to the lack of data available to support this assertion, these benefits were not included in the analysis.

4.1.5 Lifetime

The lifetime of all new vehicles has been estimated to be 12 years, based on the EasyWay and COBRA studies (EasyWay Cooperative Systems Task Force, 2012; TNO, 2013). Given that the lifetime of the modelling is limited to 2030, with initial deployments starting 2018, it is not necessary to consider replacements within this study.

4.2 Vehicles with ITS-G5 and cellular

As discussed above, this additional cost category is only relevant to the 'high' scenario sensitivity, whereby all V2I services are assumed to be delivered via cellular networks. In this case, a car must be equipped with both ITS-G5 (for V2V services) and cellular (for V2I services) capability.

4.2.1 Business model

The business model assumed for the cellular-based in-vehicle ITS sub-systems is much the same as that for ITS-G5 only-based ITS sub-systems. The only discerning factor is that the end-user would incur an additional data charge associated with the in vehicle ITS sub-system's use of the cellular network for V2I services.

4.2.2 Summary of inputs to the cost-benefit analysis

A summary of the key assumptions and inputs to the cost-benefit analysis for vehicles with ITS-G5 and cellular communication is shown in Box 4 below. A full breakdown of costs given in Table 4-2. Sections 4.2.1-4.2.5 discuss these aspects in more detail.

Box 4. Summary of key assumptions and inputs to the cost-benefit analysis for vehicles with ITS-G5 and cellular

Key assumptions:

- In-vehicle ITS sub-systems are only available to new vehicles coming off the production line

[8] USD/EUR Exchange rate of 0.7781 (January 2012 – December 2012 period average) Source: www.oanda.com/currency/historical-rates/

- Costs are assumed to be consistent across all vehicle categories
- Costs associated with the equipment/software required to deliver C-ITS services to vehicles are included, as well as associated integration, testing, software development and ongoing costs
- Additional cellular data costs are incurred in order to access V2I services
- Costs are assumed to be incurred by the vehicle OEM, except for ongoing maintenance, secure communications and data costs
- Two DSRC antennae and transmitter/receivers are assumed necessary, one to send and receive basic safety messages, the other for the security aspects of V2V communication

Table 4-2. Breakdown of costs for vehicles with ITS-G5 and cellular

	Cost item	Input	Year	Cost owner
Upfront costs	DSRC transmitter/receiver	€101.17	2012	OEMs
	DSRC antenna	€7.78	2012	OEMs
	Electronic Control Unit	€35.02	2012	OEMs
	Wiring	€7.00	2012	OEMs
	Cellular on-board equipment	€7.78	2012	OEMs
	Installation	€5.35	2012	OEMs
	Development & integration	€15.09	2015	OEMs
	Vehicle software development	€1.51	2015	OEMs
Ongoing costs (per year)	Maintenance	€7.55	2013	End-user
	Secure communications	€2.44	2012	End-user
	Vehicle software (updates)	€3.02	2015	OEMs
	Cellular data	€2.57	2012	End-user

4.2.3 Upfront costs

A total upfront cost per vehicle (to the OEM) of **€180.70** was calculated. This is made up of the same components as vehicles with only ITS-G5, however an additional €7.78 (2012 Euros)[9] has been added to cover all onboard cellular equipment (NHTSA, 2014).

4.2.4 Ongoing costs

Ongoing costs total **€15.97** per year, per vehicle. This is made up of the same components as vehicles with only ITS-G5, however an additional cellular data cost (to access V2I services via the cellular networks) is included. The data cost is based on estimates of data volumes required to offer C-ITS services (and a price of $4.00/GB) cited in a US DoT NHTSA report on C-ITS applications (NHTSA, 2014) The data cost for vehicles is assumed to be the same as for mobile phones (€2.57 per year).

[9] $10 (2012 USD). USD/EUR Exchange rate of 0.7781 (January 2012 – December 2012 period average) Source: www.oanda.com/currency/historical-rates/

4.2.5 Lifetime

As for vehicles with only ITS-G5 technology, the lifetime of all new vehicles has been estimated to be 12 years, based on the EasyWay and COBRA studies (EasyWay Cooperative Systems Task Force, 2012; TNO, 2013).

5 Roadside ITS sub-systems

Roadside ITS sub-systems such as beacons on gantries, poles etc., allow V2I communications along specific stretches of roads. For the purposes of the cost-benefit analysis, roadside ITS sub-systems for ITS-G5 communication are divided into the following two categories:

- **Upgrades to existing roadside infrastructure/roadside units** to enable the delivery of C-ITS systems via ITS-G5. These are relevant in urban areas only, where it is assumed that roadside ITS sub-systems are provided through upgrading existing traffic light systems.
- **Installation of new roadside units** to provide additional ITS-G5 coverage. These are relevant to inter-urban areas, where it is assumed that the required infrastructure is not already in place and that roadside ITS sub-systems must be installed from scratch.

Note that costs for new roadside ITS sub-systems are only relevant in the 'low' and 'central' scenario sensitivities, whilst in the 'high' sensitivity all inter-urban access to V2I services occurs via the cellular networks.

5.1 Upgrades to existing roadside ITS sub-systems

5.1.1 Business model

It is assumed that the cost of deploying, running and maintaining upgraded roadside ITS sub-systems is assigned to relevant urban transport authorities. Upgrades occur to existing signalised traffic junctions at a rate determined by the various deployment scenarios. It is assumed that one upgraded system is required per urban signalised junction.

All costs associated with integrating roadside ITS sub-systems into central traffic management centres (TMCs) and with local traffic controllers, are dealt with separately in the central ITS sub-system category. The costs associated with providing software and applications allowing end-users to access the V2I services that roadside ITS sub-systems facilitate are discussed in the central, personal and in-vehicle ITS sub-system categories.

5.1.2 Summary of inputs to the cost-benefit analysis

A summary of the key assumptions and inputs to the cost-benefit analysis for existing roadside infrastructure is shown in Box 5 below. A full breakdown of costs is given in Table 5-1. Sections 5.1.1-5.1.5 discuss these aspects in more detail.

Box 5. Summary of key assumptions and inputs to the cost-benefit analysis for upgrades to existing roadside infrastructure

Key assumptions:

- Upgraded roadside ITS sub-systems only relevant to urban areas, with a growing percentage of all signalised junctions equipped in the scenarios – this is the case across all sensitivities
- One upgraded system is required per upgraded urban signalised junction
- Upgraded roadside ITS sub-systems have an additional power consumption of 15 – 20 W
- Central ITS sub-system integration costs and software application development costs accounted for separately in Section 2.
- Upgraded roadside ITS sub-system lifetime: 10 years

Table 5-1. Breakdown of costs for upgraded roadside units

	Cost item	Input	Year	Cost owner
Upfront costs	Equipment/hardware	€3,000.00	2015	Highways Agency
	Installation/mounting	€1,500.00	2015	Highways Agency

	Cost item	Input	Year	Cost owner
Ongoing costs (per year)	Regular maintenance	€150.00	2015	Highways Agency
	Power consumption	€18.40	2014	Highways Agency
	Data	€200.00	2013	Highways Agency
	Secure communications	€37.68	2014	Highways Agency

5.1.3 Upfront costs

The total upfront cost for upgrading an existing roadside unit to be capable of delivering C-ITS functionality has been estimated to be **€4,500** based on a literature review and discussions with industry experts during a teleconference held with relevant WG1 members on 12th October 2015. This is composed of:

- An equipment/hardware cost, estimated to be €2,500 to €3,500 for a device such as a plug-in unit, situated on top of an existing pole/gantry and capable of 802.11p wireless communication. This unit includes a box (~2kg), omnidirectional antenna, processor and security chip. An equipment cost of **€3,000** has been assumed, which is in the middle of the suggested cost range.
- Installation and mounting costs will vary depending on the complexity of installation. A simple installation may cost €500, whereas a more complex installation would be in the region of €2,500. An average value of **€1,500** has been assumed.

5.1.4 Ongoing costs

The annual ongoing cost per roadside unit used in this study is €406.08, which is broken down as follows:

- Regular maintenance is assumed to be 5% of the capital cost per year, which equates to **€150 per year**. Several studies have cited this percentage for maintenance, such as the COBRA study and US focussed NHTSA US DoT Connected Vehicle Field Infrastructure Footprint Analysis (TNO, 2013; NHTSA, 2014). Regular maintenance will include activities such as realigning the antennas, rebooting hardware, checking system operational status and other routine checks (NHTSA, 2014).
- Power consumption: WG1 members advised that power consumption required for C-ITS functionality would be in the range of 15 – 20 W for an upgraded roadside unit. Using the second half of 2014 EU industrial average electricity price of €0.12 per kWh leads to a cost of **€18.40 per year** per roadside unit (Eurostat, 2015).
- Data costs, which were based on the COBRA study and were calculated to be **€200 per year**, per upgraded roadside unit (TNO, 2013).
- Secure communications: An extensive study was carried out by the US DoT to assess the costs of secure communications. It assumes that a security credentials management system will need to be developed and implemented (most likely by a private company) and suggests an annual cost of $50 per roadside unit to keep security credentials up to date (NHTSA, 2014). This is equivalent to **€37.68 per year**[10].

5.1.5 Lifetime

A lifetime of 10 years has been assumed for roadside ITS sub-systems. This is in keeping with the EasyWay and COBRA studies (EasyWay Cooperative Systems Task Force, 2012; TNO, 2013). When roadside units reach the end of their lifetime, it is assumed that they are replaced for the purposes of the cost-benefit analysis.

[10] USD/EUR Exchange rate of 0.7781 (January 2012 – December 2012 period average) Source: www.oanda.com/currency/historical-rates/

5.2 New roadside ITS sub-systems

5.2.1 Business model

It is assumed that the cost of deploying, running and maintaining new roadside ITS sub-systems is assigned to relevant highways agencies. Deployments are made to stretches of different road types at a rate determined by the various deployment scenarios, with one new roadside unit required per 1km of inter-urban road. This distance is greater than that stated in the COBRA and EasyWay studies (TNO, 2013; EasyWay Cooperative Systems Task Force, 2012) but was agreed with industry experts (during a teleconference held with relevant WG1 members on 12th October 2015) as a more appropriate figure to use given recent technological advances[11].

All costs associated with integrating roadside ITS sub-systems into central traffic management centres (TMCs) and with local traffic controllers, or for providing software and applications allowing end-users to access the V2I services that they facilitate, are dealt with separately in the central, personal and in-vehicle ITS sub-system categories.

5.2.2 Summary of inputs to the cost-benefit analysis

A summary of the key assumptions and inputs to the cost-benefit analysis for new roadside infrastructure is shown in Box 6 below. A full breakdown of costs is given in Table 5-2. Sections 5.2.1-5.2.55.2.1 discuss these aspects in more detail.

Box 6. Summary of key assumptions and inputs to the cost-benefit analysis for new roadside infrastructure

Key assumptions:

- New roadside ITS sub-systems only relevant to inter-urban areas, with a growing percentage of different road types equipped in the scenarios. This is not the case in the 'high' sensitivity, where no inter-urban roadside infrastructure is required due to the near-ubiquitous coverage provided by cellular networks – which are assumed to provide all V2I services in the 'high' sensitivity
- One new system is required per 1km of road equipped
- New roadside ITS sub-systems have an additional power consumption of 30 – 50 W
- Central ITS sub-system integration costs and software application development costs accounted for separately in Section 2.
- New roadside ITS sub-system lifetime: 10 years

Table 5-2. Breakdown of costs for new roadside units

	Cost item	Input	Year	Cost owner
Upfront costs	Equipment/hardware	€6,000.00	2015	Highways Agency
	Installation/mounting	€7,500.00	2015	Highways Agency
Ongoing costs (per year)	Regular maintenance	€300.00	2015	Highways Agency
	Power consumption	€42.05	2014	Highways Agency
	Data	€200.00	2013	Highways Agency
	Secure communications	€37.68	2014	Highways Agency

[11] COBRA assumes one roadside ITS sub-system every 300m and states "the upper bound on range is normally quoted as 1000m based on the latency requirements, but 300m allows a higher bit rate and a more reliable connection to be achieved, and this is the range often quoted"

5.2.3 Upfront costs

The total upfront cost to install a new roadside unit to be capable of delivering C-ITS functionality has been estimated to be **€13,500** based on a literature review and discussions with industry experts during a teleconference held with relevant WG1 members on 12th October 2015. This is composed of:

- An equipment/hardware cost: Installation of new base units in areas without previous roadside infrastructure is expected to be more costly than upgrading existing roadside units. The equipment cost for a new roadside ITS sub-system with traffic monitoring sensors is estimated to cost **€6,000**, as reported in the EasyWay, COBRA studies (EasyWay Cooperative Systems Task Force, 2012; TNO, 2013). This cost was broadly in the range suggested by industry experts and other EU studies such as SAFESPOT ((BASt et al., 2010).
- Installation and mounting costs, which will vary depending on the complexity of installation. Research shows that a number of activities are typically required for RSU installation and that costs will be highly site (and possibly Member State) dependent. A report issued by the US DoT (NHTSA, 2014) suggests that in addition to equipment and installation costs, the following activities must be considered:
  - Radio survey per site – to determine optimum placement of the ITS-G5 radio and antenna for maximum coverage
  - Map / GID generation – to accurately map the road layout, especially at intersections
  - Planning – estimated to be 5% of total cost
  - Design – costs related to installation of RSUs in each location
  - System integration and licence – administration costs associated with the new RSU
  - Traffic control – during installation of the unit, including any safety signage

  Industry experts suggest that a simple installation including the above may cost €3,000, whereas a more complex installation would be in the region of €12,000. An average value of **€7,500** has been assumed. For reference, an installation cost of €10,000 was assumed in the EasyWay project (EasyWay Cooperative Systems Task Force, 2012).

5.2.4 Ongoing costs

The annual ongoing cost per roadside unit used in this study is **€579.73**, which is broken down into:

- Regular maintenance is assumed to be 5% of the capital cost per year, which equates to **€300 per year**. Several studies have cited this percentage for maintenance, such as the COBRA study and US focussed NHTSA US DoT Connected Vehicle Field Infrastructure Footprint Analysis (TNO, 2013; NHTSA, 2014). Regular maintenance will include activities such as realigning the antennas, rebooting hardware, checking system operational status and other routine checks (NHTSA, 2014).
- Power consumption: WG1 members advised that power consumption required for new roadside ITS sub-systems would be in the range of 30 – 50 W. Using a power consumption of 40 W and the second half of 2014 EU industrial average electricity price of €0.12 per kWh, leads to an annual cost of **€42.05 per year** per roadside unit (Eurostat, 2015).
- Data costs, which were based on the COBRA study and were calculated to be **€200 per year**, per new roadside ITS sub-system (TNO, 2013).
  - Secure communications: An extensive study was carried out by the US DoT to assess the cost of secure communications. It assumes that a security credentials management system will need to be developed and implemented (most likely by a private company) and suggests an annual cost of $50 per roadside unit to keep security credentials up to date (NHTSA, 2014). This is equivalent to **€37.68 per year**[12].

5.2.5 Lifetime

A lifetime of 10 years has been assumed for roadside ITS sub-systems. This is in keeping with the EasyWay and COBRA studies (EasyWay Cooperative Systems Task Force, 2012; TNO, 2013). When

[12] USD/EUR Exchange rate of 0.7781 (January 2012 – December 2012 period average) Source: www.oanda.com/currency/historical-rates/

roadside units reach the end of their lifetime, it is assumed that they are replaced for the purposes of the cost-benefit analysis.

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