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Estimating Costs and Benefits of C-ITS Deployment in Austria, England and the Netherlands using the COBRA+ Tool

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Abstract

Cooperative systems which rely on vehicle-to-infrastructure communications are designed to tackle important road transport issues, such as safety and pollution. Since the associated monetary commitment is substantial, a clear understanding of the appropriate business models and likely costs, impacts and benefits is necessary before investment decisions can be made. A tool for estimating the costs and benefits, from both business and the societal point of view, was developed in the COBRA+ project, to assist National Road Authorities (NRA) during their decision processes. This paper illustrates the application of the tool to use cases in Austria, England and the Netherlands. The study identifies some of the key aspects to focus on in order to achieve a beneficial balance between costs and positive impacts. Findings reveal that the costs are likely to be higher than the monetised benefits over the time period investigated (to 2030). The financial role of the NRA (or their Road Operator) is particularly influential for the business case.

Keywords: Cooperative Intelligent Transport Systems, C-ITS, cost-benefit analysis, local dynamic event warnings, in-vehicle signage services, communications, business models

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1. Introduction

Cooperative Intelligent Transport Systems, or C-ITS, communicate and share information and data dynamically between vehicles or between vehicles and transport infrastructure. C-ITS can provide advice, warnings or take actions to improve safety, sustainability, efficiency and comfort, thus contributing to a road authority's objectives. In order to maximise the benefits of C-ITS for their networks and users, road authorities need to be able to answer several questions. Which C-ITS services will be most beneficial in meeting these objectives? What is the most suitable role for a road authority in the service delivery chain? What is the most appropriate investment in infrastructure at the roadside and back office in order to stimulate and support the development and roll-out of C-ITS services? Can conventional traffic management and traffic information be phased out as C-ITS services become more widespread? ANACONDA, a project in the Conference of European Directors of Roads (CEDR) 2014 Mobility and ITS programme, was carried out to provide support for national road authorities in answering such questions and making decisions on investment in C-ITS.

The "Assessment of user needs for adapting COBRA including online database" (ANACONDA) project built on the results of the previous COBRA project, which was carried out by the same consortium under a previous CEDR programme. The new COBRA+ tool developed in ANACONDA is a spreadsheet-based tool that enables national road authorities to compare the costs and monetised benefits of C-ITS in various contexts to support investment decisions under different deployment scenarios. COBRA+ is based on the best available evidence on the costs, benefits and impacts of C-ITS and takes account of recent and expected developments in communications technology and in-vehicle devices. It supports decision-making in the short and medium term (2 – 7 years), but estimates costs, benefits and impacts up to 2030. In this 2 – 7 year time horizon, it is expected that the options for communications will be cellular (3G and 4G) or a combination of ITS-G5 using dedicated wireless infrastructure and cellular known as 'hybrid' (C-ITS Platform, 2016). Users may select from a range of parameters to define deployment scenarios for investigation with the tool, including the services considered, the business model for delivering them and the rates of deployment of equipment in vehicles and infrastructure for further details of the tool see Ognissanto et al., 2017.

The ANACONDA project used the COBRA+ tool to investigate the implications and impacts of a range of use cases on safety, efficiency, the environment and costs and benefits for national road authorities. On the basis of this analysis, it identified key actions for road authorities in the short to medium term as they prepare for deployment of C-ITS. The project also identified legal barriers and enablers to deploying the services, and recommended actions for European road authorities within this time frame to address issues associated with liability, privacy and data accessibility.

This paper uses a series of use case analyses to demonstrate the application of the tool and draw conclusions for C-ITS deployment in European road authorities in the short to medium term. Section 2 presents the methodology and the various parameters that can be used to develop scenarios for investigation in the COBRA+ tool. Section 3 then summarises the results of use case analysis on the national road authority networks in Austria, England and the Netherlands where C-ITS deployment is planned. These provide comparisons of the impacts of the two communications options, two bundles of services and different business models. Finally, Section 4 draws conclusions on the basis of these results.

2. Methodology

Costs and monetised benefits associated with the implementation of C-ITS services in different deployment scenarios are estimated using the COBRA+ tool. Costs include the infrastructure, its maintenance, running the service, the users' devices, plus the development costs if desired. The benefits are related to improved road safety (that is, prevented fatalities, serious/slight injuries and damage costs of accidents resulting in injuries), saved travel time and fuel, and reduction in CO_2 emissions. The tool also offers the possibility of including in the benefits the savings derived from the phasing-out of legacy systems. The scenarios can be modelled in the tool through the selection of the following parameters:

- The country – five countries are currently available; examples from Austria, England and the Netherlands are presented in this paper.
- Road network – for each country it is possible to select the strategic national road network or a specific corridor (see Section 3 for a description). Motorways and rural roads are included in the model; urban roads are not.
- The C-ITS service or bundle (see Section 3.1 for more details).

- The communication platform – two options are available, the existing 3G/4G cellular network or a hybrid system that is a combination of ITS-G5 communications (which relies on a dedicated Wi-Fi infrastructure), and the cellular network when ITS-G5 is not accessible (see Section 3.2).
- The penetration rate of on-board factory fitted in-vehicle devices – it is likely that the proportion of new vehicles already equipped each year will increase with time; in the tool it is possible to select one of three different rates of growth.
- The penetration rate of aftermarket (fixed or portable) users' devices– it is assumed that after an initial increase of the number of aftermarket devices, a decrease will follow, due to the growth in availability of built-in equipment. Three trends are available for selection in the tool.
- The business model – this refers to the roles fulfilled by the Road Operator (RO) and other parties in the implementation and delivery of services; hence, the choice of business model determines the costs incurred by the RO (see Section 3.3 for details).
- Parameters characterising the deployment of the ITS-G5 infrastructure – these define the time frame, the rate of deployment and the percentage of beacons installed on existing poles or gantries.

The tool builds scenarios based on a series of assumptions, which in turn are based on data acquired through a literature review and stakeholder consultations (details are reported in Nitsche et al. (2017)). The parameters defined from these sources are:

- Country specific data, for both the strategic national road network and a specific corridor – these concern the standard infrastructure already in place for delivering services such as Dynamic Route Information Panels (DRIPs), the level of cellular network coverage and projections of the fleet composition as well as the main issues related to it, such as: road casualties, fuel consumption and the resulting carbon dioxide emissions (CO_2). The associated costs are also forecast, including monetary estimates of the time spent travelling for work, business or other purposes.
- Technology and service costs – these cover capital and operating expenditure on infrastructure (including the replacement at the end of life) and the expenditure associated with users' devices and service subscriptions.
- Estimates of impact factors for various C-ITS services and bundles (see Section 3.1) on motorways and other roads; the model takes also into account the different efficiencies of the communication systems used to deliver the services and possible overlaps with legacy systems, in which case reduced benefits are assumed to be achieved.

3. Investigation of key factors affecting benefits, costs and investment decisions

Three implementation choices, which play a significant role in the delivery and outcomes of C-ITS concern the communication platform, the specific bundle of services, and the business model. The impact of these parameters has been studied and the results are presented in the following sections.

The final year in the model is set to 2030. Calculations have been performed for the national road networks and specific corridors, more precisely:

- Austria – ASFINAG (Austria's national motorway and expressway operator) network formed by approximately 2,200 km; a 171 km motorway corridor (A1 from Vienna West to Linz, exit Ansfelden).
- England – more than 9,700 km (28% of which is motorway) of Strategic Road Network managed by Highways England; a 130 km corridor (32% of which is motorway) on the A2/M2 between London and the ferry port of Dover.
- The Netherlands – more than 7,600 km of the RWS (Rijkswaterstaat, the national roads operator) network (85% of which is motorway); and a 316 km motorway corridor on the route from Rotterdam, Breda, Tilburg, Eindhoven to Venlo (A16 – A58 – A2 – A67).

The three use cases are based on different national characteristics and assumptions about levels of deployment. In Austria, the mileage-based toll for vehicles over 3.5 tons is collected by a free-flow system realized by gantries placed above the lanes, using transceivers mounted on the gantries to communicate with on-board units installed on the windscreen of passing trucks. Those gantries are further equipped with ITS infrastructure such as Variable Message Signs, cameras and other traffic sensors. ASFINAG intends to use the gantries for the installation of ITS-G5 beacons for C-ITS services. Austria is a partner in the Cooperative ITS Corridor project to create harmonised and standardised cooperative ITS applications jointly with partners in Germany and the Netherlands. The English strategic road network has around 4,000 monitoring sites, 300 Variable Message Sign sites and 1,400 safety signs. It represents 2% of the total length of the national road network, but carries about one-third of the total motor vehicle traffic (DfT, 2014) and two-thirds of all heavy goods traffic, with serious consequences for the environment and for the time users spend travelling. Casualty rates are lower compared to other roads in England (ORR, 2017), but the objective is obviously to reduce them further. The Dutch road network is well covered by roadside equipment with more than 17,000 variable message signs and over 24,000 detectors, such as induction loops, cameras, weather sensors and radars. It has a good record in terms of safety; it is heavily utilized and peak hours are affected by traffic congestion.

3.1. Choice of C-ITS service bundle

Six C-ITS services grouped into two bundles have been considered for the analysis:

Bundle 1 – Local dynamic event warnings:

- Hazard Warning – the service provides information about critical conditions ahead including warning signs for dynamic events, such as slippery road, the presence of obstacles (debris, animal, people, etc.) and weather issues.
- Road Works Warning (short distance) – drivers are made aware of road works ahead. It can include additional information, such as the number of closed lanes, speed restrictions, etc.
- Traffic Jam Ahead Warning – drivers are warned about the location of congestion ahead in order to prevent rear-end collisions.
- Shockwave damping – advisory speeds are calculated based on real-time traffic data and transmitted to vehicles in order to prevent shockwaves and dissipate queues more quickly.

Bundle 2 – In-vehicle signage:

- In-Vehicle Signage (excluding speed limits) – information from relevant road signs, both static (e.g. prohibitions, right of way, upcoming junctions, etc.) and dynamic (e.g. lane configuration), are communicated to drivers.
- In-Vehicle Signage Speed Limits – both static and dynamic speed limits are continuously displayed to drivers.

The impact of the services within the same bundle could overlap; this has been taken into account in the estimation of the overall impacts factors of the bundles in order to avoid overestimation of benefits. Table 1 shows the factors used for Bundle 1 and Bundle 2 (for details see Nitsche et al. (2017)). Both bundles improve road safety; Bundle 1 in particular is far more effective than Bundle 2 on Motorways, while Bundle 2 is slightly more effective on other roads. Bundle 2 is also estimated to have an impact on time spent travelling, fuel consumption and, therefore, CO_2 emissions, but this is not the case for Bundle 1 in terms of direct impacts.

Table 1. Impact factors estimated for Bundle 1 and Bundle 2

	Bundle 1 – Local dynamic event warnings		Bundle 2 – In-vehicle signage	
Impact indicator	On Motorways	On other roads	On Motorways	On other roads
Fatalities	-13.0%	-5.3%	-6.1%	-16.6%
Non-fatal injuries	-10.3%	-5.4%	-3.0%	-8.4%
Accidents resulting in injuries	-8.1%	-4.3%	-2.4%	-6.6%
Time spent travelling	0.0%	0.0%	8.0%	0.0%
Petrol and diesel consumption	0.0%	0.0%	-2.3%	-3.5%
CO_2 emission	0.0%	0.0%	-2.3%	-3.5%

Table 2 shows the breakdown of the societal benefits for the strategic National Road Network estimated using the tool in the three countries from 2019 to 2030. Benefits for traffic efficiency and environment appear for Bundle 2 only, as explained above. The safety results are different in each of the three countries, due to the existing and forecast fatalities and injuries as well as the existing legacy systems on the network:

- In the Netherlands the number of injuries and accidents involving an injury is more effectively reduced by Bundle 1, but the number of fatalities is reduced slightly more by Bundle 2.
- In England, Bundle 2 is estimated to prevent more road casualties than Bundle 1.
- In Austria, Bundle 1 is estimated to prevent more road casualties than Bundle 2.

The chart in Fig. 1 shows as an example the results of the Cost Benefit Analysis for the two bundles in the English strategic road network context. Costs associated with implementing the service are the same for the two bundles and mainly consist of the capital and operating expenditure (CAPEX/OPEX) for the users' devices ('In-vehicle costs' in Fig. 1). In addition to these, Bundle 2 also has costs ('Un-intended impacts' in the chart in Fig. 1) resulting from the increased journey time on motorways (expressed by the 8% impact factor in Table 1). The higher the percentage of busy motorways in the network, the larger this contribution is to the overall costs. However, to take into account that preventing speeding has intrinsically positive impacts on safety and traffic flow, an additional field has been added to benefits. This has been designated 'Improved speed limit compliance' and its monetary value has been fixed in order to equal the costs due to longer journeys. As described above, Bundle 1 only provides safety benefits, while Bundle 2 also results in fuel and CO_2 emissions savings.

Table 2. Comparison of the societal benefits for Bundle 1 and Bundle 2 (National Road Network use cases*)

		Reductions in the time period 2019-2030					
			Road Safety		Traffic Efficiency	Environment	
Country	C-ITS bundle	Number of fatalities	Number of (serious/ slight) injuries	Number of accidents involving an injury	Time spent travelling (millions of hours)	Petrol and diesel (millions litres)	CO_2 emissions (millions tons)
Austria	Bundle 1 – Local dynamic event warnings	-29	-1,479	-775	0	0	0
	Bundle 2 – In-vehicle signage	-17	-550	-288	249	-439	-1
England	Bundle 1 – Local dynamic event warnings	-66	-5,547	-2,795	0	0	0
	Bundle 2 – In-vehicle signage	-154	-6,527	-3,383	539	-3,191	-7
The Netherlands	Bundle 1 – Local dynamic event warnings	-39	-661	-429	0	0	0
	Bundle 2 – In-vehicle signage	-42	-366	-232	430	-1,014	-2

* Other inputs include: cellular platform, medium in-vehicle devices penetration rate, CAPEX/OPEX and development costs included

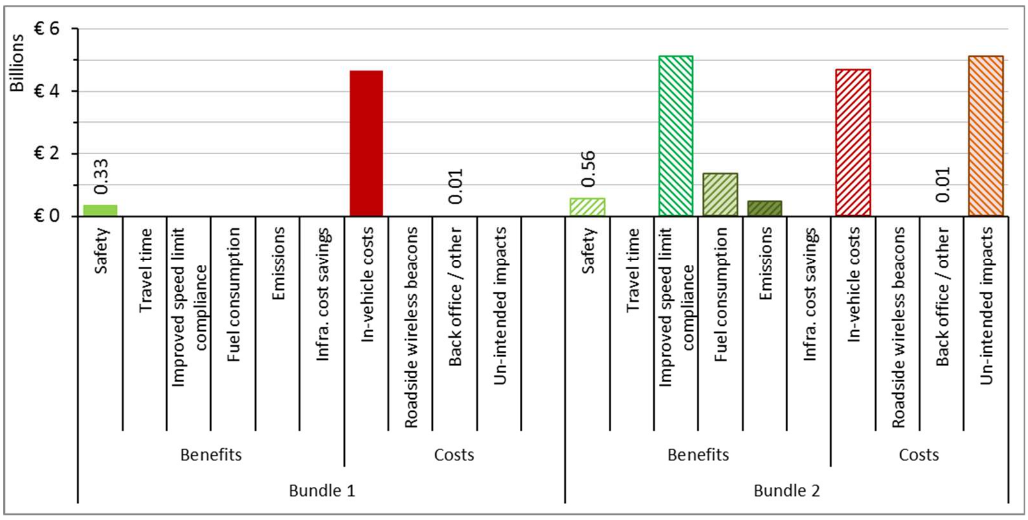

Fig. 1 Costs (red columns) and benefits (green columns) for Bundle 1 (solid-fill columns) and Bundle 2 (striped-fill columns) in the English strategic road network scenario (€, discounted)

A comparison of the overall 'value' of the two bundles in terms of Benefit Cost Ratio (cumulative benefits divided by cumulative costs) is shown in Table 3, looking at both the strategic national road network and the selected corridor in the three countries. The ratio of benefits over costs is higher for Bundle 2; this is to say that, since all the other parameters have been kept constant, that the overall benefits for society achieved by implementing Bundle 2 are higher than those realised by implementing Bundle 1 in all the scenarios analysed.

Table 3. BCR comparison between Bundle 1 and Bundle 2 for six use cases*

	Bundle 1 – Local dynamic event warnings		Bundle 2 – In-vehicle signage	
	National Road Network	Corridor	National Road Network	Corridor
Austria	0.28	0.06	0.98	0.32
England	0.07	0.03	0.76	0.53
The Netherlands	0.09	0.00	0.94	0.25

* Other inputs: same as for Table 2

From a monetary point of view, we can infer that Bundle 2 is more advantageous; to what extent will then depend on the specific characteristics of the road network and on the communication platform used. From a societal point of view the most suitable bundle is a less straight forward choice in some contexts. On the one hand selecting Bundle 1 over Bundle 2 helps to reduce road casualties more effectively (as for The Netherlands and Austria use cases), but on the other, this would mean that additional societal benefits, such as reduced CO_2 emissions and fuel consumption (and consequently benefits for climate, air quality and public health) would not be realised. The Bundles can be seen as which services will be deployed first. It is not so much as Bundle 1 vs Bundle 2, but which one will be deployed first, to be followed by the other Bundle(s).

3.2. Cellular vs Hybrid Communication

For implementing C-ITS, it is a fundamental decision which communication platform to build upon. The de facto standard for vehicular communication is the WiFi-based IEEE 802.11p (IEEE, 2007), which is also known as WAVE (Wireless Access in Vehicular Environments). The standard in the licensed ITS band of 5.9 GHz was developed to provide the minimum set of specifications required to ensure interoperability between wireless devices in environments that might rapidly change and where delivery must be completed in a very short time period. Examples of applications for WAVE are forward collision warning, lane change warning or traffic signal timing information (Ibanez et al., 2011). An adaptation of the IEEE 802.11p to the European spectrum is the ETSI ITS-G5 standard, tailored to the requirements of C-ITS applications such as in-vehicle signage, collision risk warning or road hazard signalling.

An alternative for vehicular communication is the use of the cellular 3G or 4G network. While IEEE 802.11p is designed to operate in a range of up to a few hundred meters, 4G or LTE (Long Term Evolution) can cover areas of 100 km. That is why it is applied to other vehicular fields such as information systems about road or traffic conditions or probe vehicle data collection. Performance studies have shown that 4G meets most of the application requirements in terms of reliability, scalability, and mobility support, but has high delays in the presence of higher cellular network load (Abid et al., 2012; Mir and Filali, 2014). Therefore, a hybrid approach is mostly preferable, with some C-ITS services implemented by the cellular network platform and some by the WiFi platform. To assist national road authorities in choosing the most beneficial platform for C-ITS deployment in their country, ANACONDA investigated the differences in costs and benefits between the cellular and hybrid option. In particular, this was done for England and the Netherlands, the results of which are presented in the following paragraphs.

In the case for the Netherlands, the C-ITS services investigated for implementation are Bundle 1 (local dynamic event warnings) and Bundle 2 (in-vehicle signage), as mentioned in the previous section. Table 4 gives a comparison of the BCR between hybrid and cellular. The BCRs are given within a certain range, because parameters such as in-vehicle equipment penetration rate were varied within this scenario. It can be seen that, holding all other parameters fixed, the hybrid deployment results in a slightly higher BCR than the cellular deployment in all cases. Several factors and assumptions contribute to this outcome. For example, the cellular implementation of local dynamic event warnings is assumed to have 80% of the effectiveness of the hybrid implementation due to ITS-G5's lower latency and higher reliability. There is no difference in the effectiveness assumed between the two implementations for the in-vehicle signage bundle.

Table 4: Range of Benefit Cost Ratio (BCR) for the Netherlands, comparing cellular and hybrid communication

C-ITS service bundle	Network	Cellular	Hybrid
Local dynamic event warnings	Corridor (316 km)	0.00-0.01	0.01
	Full Road Network (7600 km)	0.11-0.12	0.13
In-Vehicle Signage	Corridor (316 km)	0.27-0.29	0.31
	Full Road Network (7600 km)	1.01-1.03	1.04-1.05

Both the Dutch corridor and the full road network are already well-equipped with existing roadside traffic management systems. This leads to a large overlap with the new C-ITS bundles deployed, resulting in a reduced impact of the deployed in-vehicle systems in addition to the existing roadside systems. The corridor also has a much lower level of societal problems, meaning the safety and other issues are significantly lower for this small part of the overall Rijkswaterstaat network. This means that the total improvement is limited in absolute terms, and thus that the monetarised benefits that can be achieved are limited. Thus, the benefits generated on the corridor will always be lower than on the full network, because the corridor is a subset of the full network. The corridor is seen as the first step in deployment of C-ITS on the full road network. Finally, note that for the hybrid scenarios, the corridor equipment rate of ITS-G5 is 25%, compared to the level of 10% on the full network in 2027. The 25% equipment rate on the corridor was chosen to be a realistic estimate, consistent with current investment plans. Relatively speaking, more costs are incurred per kilometre for ITS-G5 deployment on the corridor than for the full network.

Turning now to another country, the English motorway operator Highways England is interested in investigating scenarios related to deployment of in-vehicle signage (Bundle 2) on the A2/M2 corridor under a public business model, in which the RO sponsors hybrid in-vehicle devices to stimulate the take up of services.

As presented in Table 5, the comparison between communication platforms in England also reveals that the BCR is slightly higher for hybrid implementations. Total costs are more than the double the benefits for the cellular scenario (by a factor of 2.2); the proportion is lower for the hybrid scenario (1.9). The overall difference in the cumulative societal benefits is about €0.9 billion in favour of the hybrid scenario, mainly due to the higher reduction estimated for injuries and travel time.

Table 5: Analysis results for the UK corridor, comparing cellular and hybrid communication, with 20% infrastructure equipped for ITS-G5 and high in-vehicle penetration rate

Results	**Cellular**	**Hybrid**
BCR 2030	0.47	0.54
Total costs (billions Euros)	8.9	9.6
Total societal benefits (billions Euros)	4.2	5.1
Impact on number of fatalities	-6	-8
Impact on number of injuries	-294	-426
Impact on travel time (Mio. hours)	-31	-45
Impact on CO2 emissions (Mio. tonnes)	-0.4	-0.5
Impact on fuel consumption (Mio. litres)	-162	-238

In summary, the analyses of the scenarios for both England and the Netherlands found that the BCR for the hybrid communication platform is higher than that of the cellular platform, keeping all other parameters in the scenario the same. Note that the hybrid scenarios may underestimate its potential effectiveness. It is likely that the impacts of the hybrid implementation, which uses ITS-G5 communication when available, will deliver significantly higher safety benefits than cellular implementations of the same service due to higher reliability and lower latency. At this moment, little to no data directly comparing the effectiveness of the cellular vs hybrid communication are available. The COBRA+ Tool contains an assumption that ITS-G5 is slightly more effective than the cellular implementation for two services in the local dynamic event warning bundle, resulting in an overall reduced impact of this bundle. Additionally, the hybrid implementation has the cellular service available outside the ITS-G5 locations. This means that the hybrid-equipped vehicles always have access to either ITS-G5 (with a higher effectiveness) or cellular implementations of the bundle. On the other hand, the costs of the ITS-G5 units need to be incurred.

Furthermore, the hybrid implementation does not take into account the safety and traffic throughout benefits of vehicle-to-vehicle safety services such as the Day 1 services emergency electronic brake light, emergency vehicle approaching, slow or stationary vehicle(s), traffic jam ahead warning (C-ITS Platform Final Report, 2016) as well as cooperative adaptive cruise control, which would most likely increase the benefits and thus the BCRs for the hybrid implementations shown in Table 4. Finally, given the focus of the study on the decision-making for the near future (2-7 years), 5G cellular was not considered due to the uncertainties in the required technology developments and standardisation for mobility applications.

3.3. Choice of Business Model

The Phase 2 C-ITS Platform Working Group Horizontal Issues established a consensus definition for a business model in the C-ITS context: **A Business Model describes the way in which organizations produce and deliver value to their customers/consumers.**

For three use cases, this section illustrates the effect of the choice of business model by the RO in the COBRA+ Tool on the share of costs borne by the RO as well as the payback year as a result of that choice. Given a chosen deployment scenario and the choice of a business model, the COBRA+ Tool allows the RO to determine the costs and benefits for itself, given its position on the role the RO will play in covering costs. Note that the results are not comparable between the use cases, due to country-specific characteristics such as the size of the vehicle fleet, level of deployment and the presence of legacy roadside systems such as Dynamic Route Information Panels.

The COBRA+ Tool offers three strategic options for the business model, reflecting the roles that the RO chooses to fulfil:

- Public: the RO takes the responsibility for providing the content and the service. In the hybrid model, the ITS-G5 roadside infrastructure is purchased, installed and operated and maintained by the RO.
- Mixed and Private: the RO reduces the number of roles it fulfils in the “mixed” and “private” models. The RO reduces its role in the extent of service provision and its role in the ITS-G5 infrastructure (in the hybrid scenario), with the “private” model reflecting a greater “hands-off” approach by the RO than the “mixed” model. In the private scenario, the RO outsources installation and operation and maintenance of the ITS-G5 infrastructure to third parties.

These models reflect the RO standpoints in CEDR.

The choice of communication platform determines the types of costs that need to be incurred in the scenario. The options are cellular communication (3G or 4G) or via hybrid communication. The Hybrid communication allows communication via cellular or Wi-Fi-p, depending on availability of the channel, the service, etc.

Use Case England focussed on the connected vehicle corridor on the A2/M2 between London and the ferry port of Dover. The business models examined are public models for both the cellular and hybrid platform choices, while varying whether the RO (variant ‘a’) or the driver pays (variant ‘b’) for the service. In all of the hybrid scenarios analysed, the RO sponsors the in-vehicle device (which means the RO incurs extra costs) in order to stimulate deployment.

Table 6 summarises the percentage of the costs borne by the NRA in the Use Case England. The difference between the business models of type ‘a’ and ‘b’ is considerable; in particular, for the cellular scenarios, where the business models differ in whether for running the service the RO has expenditure (1a) or revenue (1b). For the hybrid scenarios, the income arising from the user paying for the service helps to offset the expenditure on the deployment and maintenance of the ITS-G5 infrastructure. The business models in which the driver pays for the service result in a lower percentage of costs for the RO compared to the situation in which the RO pays for the service. For the hybrid scenarios, the percentage of costs for the RO are significantly higher than in the respective cellular scenarios. Finally, only in the cellular scenario in which the driver pays for the service is the Payback Year for the RO before 2030 (it is 2016).

Table 6. Percentage of costs borne by RO, Use Case England / Corridor

	Cellular		Hybrid	
	Public, RO pays for service (1a)	Public, Driver pays for service (1b)	Public, RO pays for service (7a)	Public, Driver pays for service (7b)
Range of percentage of costs borne by RO	0.12-0.18%	0%*	53-55%	4.8-9.9%
Payback year	Not before 2030	2016	Not before 2030	Not before 2030

* For these scenarios, the actual percentage results to be negative (-46%, -43% and -38% for the low, medium and high in-vehicle penetration, respectively) indicating that benefits are accrued by RO

Use Case Austria focussed on a certain section of the ECo-AT corridor, namely the A1 motorway from Vienna West to Linz (exit Ansfelden). The scenarios analysed the hybrid communication platform only, with the private RO (ASFINAG) taking full responsibility for the infrastructure investment, installation, operation and maintenance as well as service provision. Thus, the private RO chose the so-called “public” option in which the driver pays for the service. The RO does not subsidise the cost of the in-vehicle device. The scenarios examined both the local dynamic event warning and the In-Vehicle Signage bundles.

Table 7 summarises all calculated benefit-cost ratios in 2030 (cumulative benefits divided by cumulative costs) for the given combinations of parameters. Local dynamic event warnings result in higher Benefit-Cost Ratios (from 2.02 to 2.10) than in-vehicle signage (from 1.24 to 1.25). The calculated payback year is 2019 for all combinations. Both the Benefit-Cost Ratios and the payback years are quite positive, with the payback year of 2019 for these scenarios.

Table 7. Percentage of costs borne by RO, Use Case Austria / Corridor

	Hybrid		
	Benefit-Cost Ratio	Public, Driver pays for service (4b)	Payback year
Local dynamic event warning	2.02-2.10	0.23-0.25%	2019
In-vehicle signage	1.24-1.25	0.029-0.032%	2019

Use Case the Netherlands focussed on deployment at two levels, both the C-ITS Corridor (A16, A58, A2, A67) and on the full Rijkswaterstaat road network in the Netherlands. Both cellular and hybrid scenarios were investigated. Rijkswaterstaat is investigating Public-Private-Partnership business models, in which the driver pays for the services. The analyses show the results of the “mixed” and “private” business models. In total, almost 600 scenarios were examined using the COBRA+ Tool.

Table 8 summarizes the percentage of costs and the payback year for the RO, making use of infrastructure savings.

Table 8. Percentage of costs borne by RO, Use Case the Netherlands

		Cellular				Hybrid			
	Network	Mixed, Driver pays for service (2b)		Private, Driver pays for service (3b)		Mixed, Driver pays for service (5b)		Private, Driver pays for service (6b)	
		% Costs for RO	Payback Year	% Costs for RO	Payback Year	% Costs for RO	Payback Year	% Costs for RO	Payback Year
Local dynamic event warnings	Corridor	0.9-1.2%	Not before 2030	0.3-0.5%	Not before 2030	~1.5%	Not before 2030	<0.5%	Not before 2030
	Full Network	~1%	Not before 2030	~0.5%	Not before 2030	2-3%	Not before 2030	1-2%	Not before 2030
In-vehicle signage	Corridor	0.7-0.9%	Not before 2030	~0.3%	Not before 2030	0.8-1%	Not before 2030	~0.4%	Not before 2030
	Full Network	<0.3%	Not before 2030	~0.1%	Not before 2030	0.3-0.4%	Not before 2030	~0.2%	Not before 2030

* Excluding capital costs of in-vehicle equipment

The percentage of the costs borne by the RO in the scenarios examined under the business models investigated are all under 3%. The remaining costs are borne by the stakeholders providing the content and service, the maintenance and operation of the infrastructure etc., dependent on the choice of business model. Logically, the mixed model has a higher percentage of the costs for the RO than the private model. The difference between the two models is that, in the mixed model, the RO is responsible for the content of the services, and, in the case of the hybrid implementation, covers both the equipment and installation of the ITS-G5 roadside stations. In the private model, the RO is not responsible for service content and, in the case of the hybrid implementation, covers only the equipment costs of the ITS-G5 stations but not its installation. Note that the total costs exclude the capital costs of the in-vehicle equipment. The payback year for the RO in all scenarios is after 2030.

The insight provided by the COBRA+ Tool gives ROs understanding of the feasibility of the chosen business model. The feasibility will depend on the budget of each RO and the ability to develop win-win situations for cooperation with the other required stakeholders in the deployment and business model. The payback year and the percentage of costs borne by the RO vary from case to case. It is not possible to compare one country to the other, even if ROs choose the same business model in different countries, as the country-specific data will determine the benefits (which will differ) and thus the BCR and the payback year for the country.

4. Conclusions

This paper presented the COBRA+ Tool, a decision support tool for ROs to investigate the benefits and costs of deploying C-ITS infrastructure on their networks. Many factors have an impact on the benefits and costs by country. The costs can exceed the benefits in the timeframe analysed. Nevertheless, through a careful analysis of numerous parameters, and weighted selection of the goals, it is possible to identify those options which best suit the purposes, minimising the expenditure or even accruing profit in some circumstances.

Further developments of the model are desired. During the project, CEDR members had expressed interest in both extending the model to include urban areas as well as to add the data for other countries to allow other CEDR members to carry out analyses.

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