Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

ANACONDA

Report on use case results

Deliverable No 5.1

31 May 2017

Project Nr. 850708
Project acronym: ANACONDA
Project title:
Assessment of user Needs for Adapting COBRA including ONline DAtabase

Deliverable No 5.1 – Report on use case results

Revised due date of deliverable: 28.02.2016
Actual submission date: 28.02.2017
Resubmission with Austrian use case results: 04.04.2017
Resubmission with revisions: 31.05.2017

Start date of project: 01.09.2015 End date of project: 31.05.2017

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Version: 1.1 (31/05/2017)

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Revision and History Chart

Version	Date	Comment
0.1	2016.11.22	KM: create initial document structure
0.2	2017.01.14	KM Use Case Analysis for the Netherlands added
0.3	2017.02.17	FO: Use Case Analysis for the UK added
0.4	2017.02.20	KM: Executive Summary added. Conclusions revised.
0.5	2017.02.27	KM: Review feedback integrated
0.9	2017.04.01	PN: Added Austrian use case
1.0	2017.04.04	KM: Final integration of all three use cases
1.1	2017.05.18-31	KM, PN: Revision based on feedback ASFINAG

Executive summary

The “Assessment of user needs for adapting COBRA including online database” (ANACONDA) project builds on the results of the previous COBRA project and aims to position COBRA+ as a major tool for decision-making support for deployment of C-ITS for National Road Authorities (NRAs). The COBRA+ tool builds on the strengths of the original COBRA tool. COBRA is a decision support tool in the form of a spreadsheet that enables NRAs to compare the costs and monetised benefits of C-ITS in various contexts to support investment decisions under different deployment scenarios. The new COBRA+ tool was enhanced with new functionalities, greater geographic coverage and more flexibility.

The COBRA+ Tool supports decision-making for the short and medium term (2-7 years), while calculating the impacts to 2030. The short and medium term includes the possibility to deploy cellular 3G/4G and ITS G5 communication platforms, where the ITS G5 in-vehicle units are hybrid, enabling 3G/4G and ITS G5 communication. The short and medium term excludes 5G cellular, due to the uncertainty in the required developments and subsequent standardisation required for the mobility applications. The Tool allows the choice of a wide range of other parameters, from services to be deployed to equipment rates of vehicles and infrastructure. Deliverable 3.2 [Ognissanto et. al., 2017] provides an overview of the parameter choices.

This deliverable demonstrates the application of the COBRA+ Tool to three use cases, one each in the Netherlands, England and Austria. The use cases were defined together with with the Project Executive Board country representatives and their colleagues. Each country’s use case investigates questions and issues that can support decision making with respect to Connected and Cooperative Intelligent Transport System (C-ITS) deployment. The issues involve the implications of specific Business Models, the speed at which deployment takes place, the austerity measures taken for existing traffic management (legacy) systems and the simultaneous roll-out of C-ITS and the associated costs and benefits. Each use case makes use of fixed and variable parameters, which are presented along with the use case.

Each use case makes use of country-specific scenarios. These scenarios include country-specific data and forecasts on the road network, problem size and existing roadside ITS (legacy) systems. The scenarios include the specific parameter choices in the COBRA+ Tool for deployment of C-ITS. These include the choice of service or bundle or C-ITS services, communication platform (cellular or hybrid), the speed of deployment, the use of infrastructure costs savings and the choice of business model. Infrastructure savings arise from the decision of a road authority to scale back legacy systems on the road network while deploying C-ITS. The cellular platform makes use of 3G/4G. The hybrid platform includes an on-board unit that enables both ITS G5 and cellular communication; both the roadside ITS-G5 units and cellular networks can be used. The outputs of the COBRA+ Tool are Benefit-Cost Ratios (BCR), costs and benefits in different categories, payback period, and percentage of costs of the Road Authority, were used in the analyses.

The scenarios for the Netherlands examined both the full roadway network of the National Road Authority (NRA), Rijkswaterstaat, as well as the C-ITS Corridor in the Netherlands that includes the A16, A58, A2 and A67. The scenarios examined varied the road network analysed, the communication platform, the level of in-vehicle penetration, the percentage of infrastructure equipped for ITS-G5 communication, whether infrastructure savings was turned on or not, and the choice of business model. In total, almost 600 scenarios were analysed.

The scenarios for England examined scenarios for the A2/M2 corridor in England using In-Vehicle Signage. The scenarios were chosen based on consultation with Highways England representatives and reflect Highways England priorities. The scenarios examined varied the communication platform, the level of in-vehicle penetration, the percentage of infrastructure equipped for ITS-G5 communications and the choice of business model. For England, no infrastructure savings resulting from scaling back legacy systems were assumed. In total, twenty-two scenarios were analysed.

The Austrian use case was done to examine different scenarios for a corridor on the A1 from Vienna to Linz, which may be of the C-ITS corridor from Rotterdam to Vienna. It comprises 171km of road and consists of areas with more densely-equipped roadside infrastructure as well as areas with less roadside infrastructure. The scenarios explored the effects of varying the amount of infrastructure equipped with ITS-G5 beacons, the OEM vehicle penetration and the deployment of Local Dynamic Events Warning and In-Vehicle Signage. In total, twelve scenarios were analysed.

The Austrian scenarios differ so much from the Dutch and English scenarios that they are discussed separately.

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. The analyses also showed that the increasing in-vehicle penetration while keeping all other parameters fixed, resulted in the lower BCRs. The costs of the cellular communication are large, keeping the BCR for cellular lower than for hybrid. The costs of the cellular communication also outweigh the additional benefits generated as the vehicle equipment levels increase.

The BCRs investigated on the Dutch full road network showed a significantly higher BCR for the full road network than for the C-ITS Corridor in all scenarios analysed. The lower BCR for the corridors can be partially explained by the fact that the same absolute total vehicle costs (subscription, in-vehicle units) are incurred for the corridor as for the full network. The corridors are a subset of the full road network and thus a stepping stone to deployment on the full roadway network, where the full potential can be realised. Therefore, all use cases should consider both the local deployment as well as the potential of nationwide roll-out. Figure 1 shows a typical outcome showing the difference between the Benefit Cost Ratio of the Dutch Corridor (scenario 1) compared to the full road network (scenario 2) for a given scenario of deploying the bundle “In-Vehicle Signage” using the hybrid implementation. The parameters for the scenarios are identical except for the choice of network. The number in the lower left-hand corner of the figure indicates the figure number from the COBRA+ Tool.

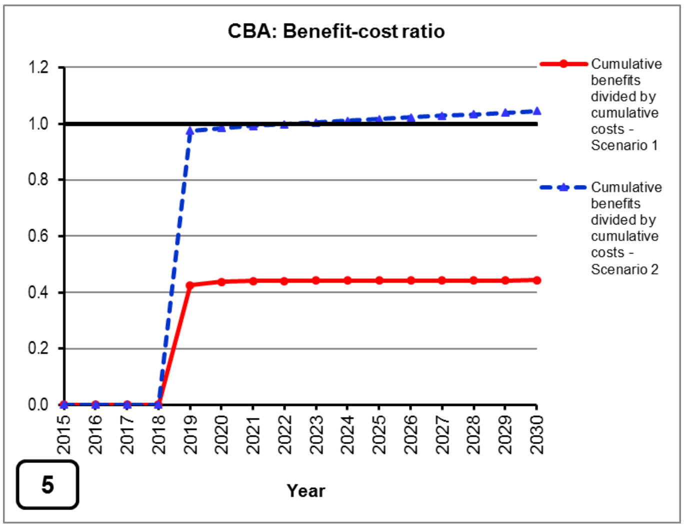

Figure 1: Annual Benefit Cost Ratio on the Dutch Corridor (Scenario 1) vs the full network (Scenario 2) for a hybrid implementation of the In-Vehicle Signage Bundle

The use cases in the Netherlands and England revealed differences in important indicators, even with the same scenario parameter choices. A simple exercise was carried out using the same set of input parameters, but country-specific data, either for England or the Netherlands The BCRs on the C-ITS Corridor in the Netherlands are lower than the BCRs on the English Corridor. Figure 2 shows an example of a hybrid scenario. The lower BCR in the Netherlands can be explained by country-specific aspects: legacy systems equip the entire Dutch Corridor, resulting in only a marginal benefit of the C-ITS deployment. Furthermore, the absolute problem size in the Netherlands is significantly smaller than in England. The overall absolute impact that can be achieved by C-ITS deployment is therefore smaller in the Netherlands than in England.

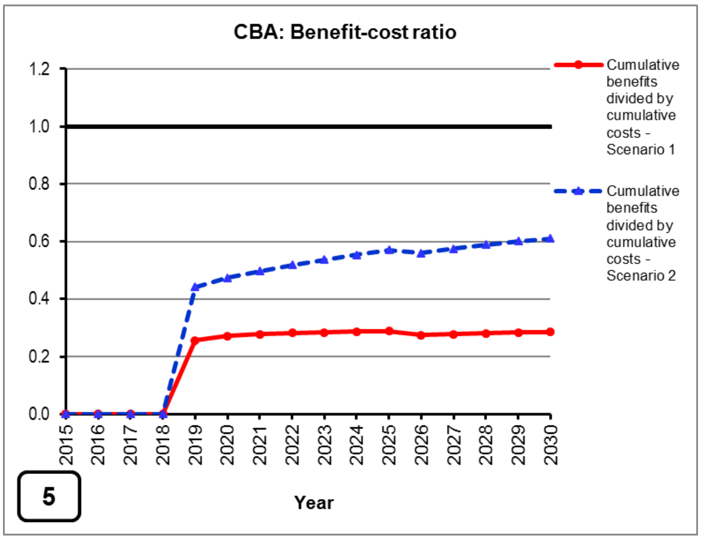

Figure 2: BCR on the Dutch Corridor (Scenario 1) and English Corridor (Scenario 2) for a Hybrid implementation with 20% roadside equipment (ITS G5)

The Austrian scenarios showed a higher Benefit-Cost ratio on the corridor compared to the Dutch and English corridors. This finding is specific to the Austrian Corridor and the choice of scenario parameters.

The Benefit-Cost ratios on the Austrian Corridor showed negligible differences between the low and medium OEM penetration curves, i.e., a higher OEM vehicle penetration has only minor impact on the overall benefits and costs. Furthermore, it could be observed that the societal benefits such as safety, emissions or fuel consumption remain almost the same with an increased percentage of infrastructure equipment.. This can be explained by the limited length of the corridor analysed (171 km), which therefore represents a relatively small societal problem size, e.g. with very few fatalities. The benefits would be different for a larger network.

Additional insight into results based on the results of almost 600 model outcomes in the Netherlands concern impacts of different services and the effects of making use of the austerity measure “infrastructure savings”.

- The Benefit-Cost ratios for the Local Dynamic Event Warning Bundle (including Local Hazard Warning, Traffic Jam Ahead Warning, Road Works Warning – short distance and Shockwave Damping) are lower than those for the In-Vehicle Signage Bundle. Since the Local Dynamic Event Warning Bundle comprises safety applications, the benefit in the Netherlands is limited in absolute terms due the relatively high level of safety on the Rijkswaterstaat network. Of course, any reduction in fatalities and injuries is extremely valuable, but the absolute numbers remain small. The effect of the Local Dynamic Event Warning Bundle on traffic efficiency and emissions is small. Looking forward to implementation, it can be considered somewhat artificial to focus on a single bundle as it is very likely that the Local Dynamic Event Warning Bundle will be deployed slightly earlier or at the same time as the services in the In-Vehicle Signage Bundle.

- The infrastructure cost savings option, an austerity measure in which reductions take place in current roadside traffic management equipment, has an enormous influence on the benefits and costs, the Benefit-Cost Ratio, and the payback year for both the National Road Authority and in terms of the socio-economic analysis. Careful analysis of the achieved or required level of C-ITS deployment (roadside and vehicle units) with the timing of the start of decommissioning and the rate of decommissioning over time needs to take place to ensure that levels of road safety, traffic performance and environmental impacts are maintained and improved. Until such analyses have been carried out, the decision to make use of infrastructure savings should be delayed.

Overall, the calculation of benefits and costs of C-ITS deployment in different countries is sensitive to country-specific data and parameter choices in the COBRA+ Tool. Direct comparison between countries should take this background into account in explaining differences in outcomes.

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1 Introduction

1.1 Background

The trans-national research programme “Call 2014: Mobility and ITS” was launched by the Conference of European Directors of Roads (CEDR). CEDR is an organisation which brings together the road directors of European countries. The aim of CEDR is to contribute to the development of road engineering as part of an integrated transport system under the social, economic and environmental aspects of sustainability and to promote co-operation between the National Road Administrations (NRAs). The Mobility and ITS call has three sub-themes, one of which is “The business case for connected and co-operative vehicles”. The ANACONDA project falls into this theme.

Cooperative systems communicate and share information dynamically between vehicles or between vehicles and the infrastructure. In so doing, cooperative systems can give advice or take actions with the objective of improving safety, sustainability, efficiency and comfort to a greater extent than stand-alone systems, thus contributing to road operators’ objectives.

The ANACONDA project builds on the COBRA (COoperative Benefits for Road Authorities) project. That project developed the spreadsheet-based COBRA tool for NRAs to use to examine the business case for deployment of Cooperative Intelligent Transport Systems (C-ITS) on their roads, using evidence gained in an investigation of impacts and deployment issues. The ANACONDA consortium will continue this support to NRAs by:

- Extending the number of countries, functionality and C-ITS covered by the original COBRA tool
- Assisting CEDR countries in the preparation and use of the updated tool, COBRA+
- Developing the COBRA+ Monitor, an online tool for the monitoring of C-ITS implementations by CEDR members
- Developing a roadmap for transition to C-ITS-equipped motorways.

This deliverable presents an analysis of three use cases to which the COBRA+ Tool was applied. The analysis made use of the data collected for the three countries, The Netherlands, England and Austria. It also used the new COBRA+ Tool developed in the ANACONDA project.

The use cases focus on calculating benefits and costs, for the Benefit Cost Ratio and Business Models and other indicators. The Cost-Benefit Analysis is a straightforward calculation of the costs and the benefits incurred compared to the reference scenarios for each of the use cases. The Benefit-Cost Ratios calculated are expected to be lower bounds for a full Cost Benefit Analysis. The Benefit-Cost Ratio is expected to be an underestimate because extra benefits or revenues such as job generation, the benefits of innovation and its spin-offs, other unquantified benefits and the benefits of Vehicle-to-Vehicle communication between ITS-G5 equipped vehicles (for the hybrid implementations) are not included. The cost components in the model have been updated using country-specific information as well as the findings of the Working Group Cost Benefit Assessment of the C-ITS Platform [C-ITS Platform Final Report, 2016].

For each use case, the scenarios and parameter values were chosen together with the country representatives in the PEB. The parameters were used to run the COBRA+ Tool. Analyses of each of the use cases were carried out and reported on in this deliverable.

1.2 Document Structure

This document is structured as follows.

Section 2, 3 and 4 present the use cases, parameter choices and analyses for the Netherlands, England and Austria, respectively.

Section 5 draws brief conclusions.

2 Use Case the Netherlands

2.1 Introduction

The Netherlands is a densely-populated country with an intensely used national road network. It is relatively safe, measured in the number of fatalities and injuries annually, especially the part of the network managed by the National Road Authority, Rijkswaterstaat (RWS), although every fatality and injury is one too many. The network is heavily utilized, leading to traffic congestion and vehicle lost hours being major traffic issues in peak hours.

Furthermore, the RWS network is well-equipped. Figure 3 shows the loops (red), cameras (blue), Dynamic Route Information Panels (yellow), prisms (green) and mist detectors (light blue) in the RWS network. Clearly, large investments have been made in roadside equipment.

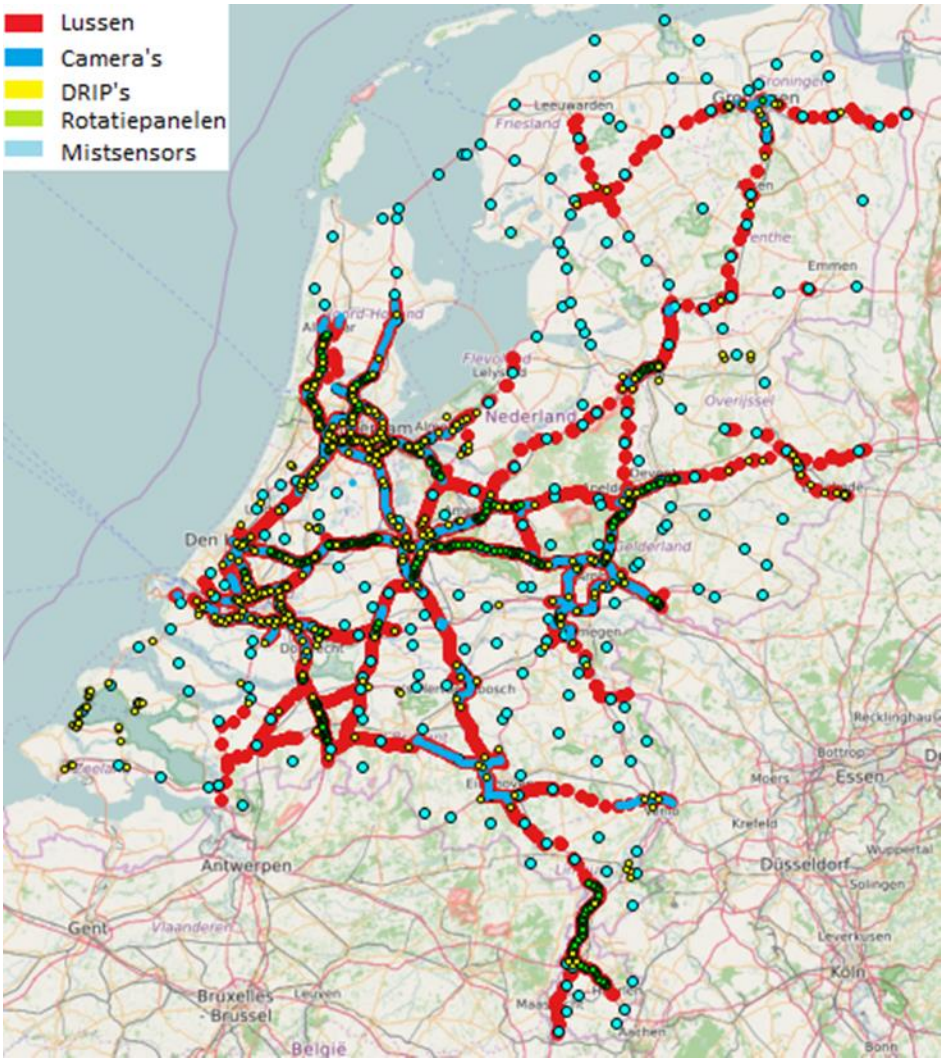

Figure 3: Equipment of the RWS network Source: Rijkswaterstaat NIS (2016)

RWS is exploring the possibility of replacing roadside signage and information provision by in-vehicle provision in the long term. In the short term, extra services and / or information can be provided, in addition to the existing or a reduced set of roadside signage. Currently, a hybrid approach is envisioned, in which cellular and ITS G5 are used as communication media.

The Netherlands is a partner in the Cooperative ITS Corridor project, in which road operators in the Netherlands, Germany and Austria are working with industrial partners to take the first step towards the introduction of cooperative services in Europe on the route between Rotterdam, Frankfurt/M and Vienna. The goal of the introduction is to improve road safety, reduce the number of incidents and traffic jams, make more efficient use of the road network and reduce CO_2 emissions [itscorridor.mett.nl].

To facilitate these services, road operators are planning to install beacons (ITS G5) along the corridor. These beacons communicate with the on-board units of approaching vehicles using Wi-Fi-p. It is expected that car manufacturers will install these on-board units in many vehicles in the coming years. Using a data communications network, the beacons will also communicate with the traffic information centres where traffic will be monitored. Beacons may be mobile or fixed. Mobile beacons will be fitted to the information display vehicles placed near road works. Fixed beacons will be installed on the existing roadside infrastructure.

Figure 4 provides an overview of the whole C-ITS Corridor road network and services. Table 1 provides an overview of the services in the Netherlands and the roads on which they will be provided.

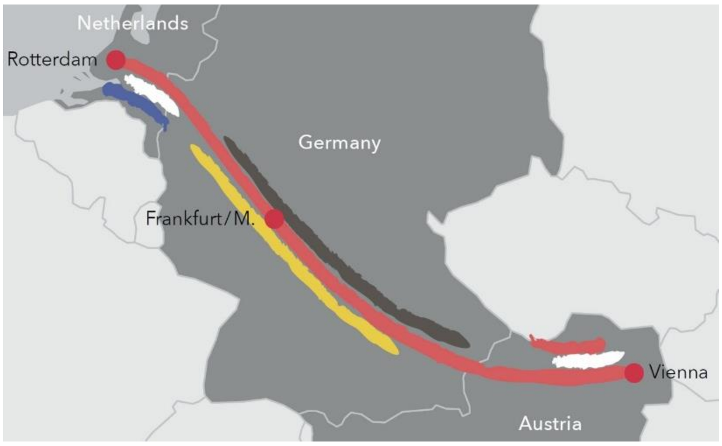

Figure 4 The C-ITS Corridor road network (from itscorridor.mett.nl)

Table 1 Planned C-ITS Corridor services and specifications of the road network

List of common services	Road network
• Road works warning (RWW) • Probe Vehicle Data (PVD)	• NL: A16, A58, A2, A67

This chapter begins with an introduction to the scenarios analysed for the Netherlands in Section 2.2, followed by the analysis in Section 2.3.

2.2 Scenarios analysed

Rijkswaterstaat is interested in investigating scenarios related to deployment of Local Dynamic Event Warnings (Bundle 1) and In-Vehicle Signage (Bundle 2) on both the C-ITS Corridor and the full road network operated by Rijkswaterstaat (an explanation on bundles is included in the next section). Traffic Information and Road Works Warning (long distance) (Bundle 3) was not analysed here. Within each of these networks, the effects of platform choice, infrastructure savings and the choice of business model of interest to Rijkswaterstaat were investigated. These aspects are explained in the next section. There are many parameters that can be varied. Discussions with Rijkswaterstaat took place to strike a balance between the questions posed by Rijkswaterstaat and the number of tool runs. Almost 600 scenarios were simulated and combined into groups for comparison. Section 2.2.1 provides a brief introduction to the important parameters in the COBRA+ Tool. All the scenarios share some common characteristics, which are described in Section 2.2.3; while the elements which determine the differences are discussed in Section 2.2.4. The reference scenario, also called the “Business as Usual”, is described in Section 2.2.2.

2.2.1 *Discussion of important parameters*

This section defines and discusses important parameters for the Dutch use cases in the COBRA+ Tool.

Infrastructure savings

“Infrastructure savings” is an austerity measure. It refers to the reduction of current roadside traffic management equipment which results in infrastructure savings. Rijkswaterstaat aims to provide a good level of service of road users, while reducing the costs of traffic management equipment. The roll-out of C-ITS is expected to provide as good or even better traffic and transport services to road users. Rijkswaterstaat aims to find the balance between reducing the legacy systems with deployment of C-ITS to achieve its goals of improving traffic safety, traffic throughput and reduced environmental impact.

Infrastructure savings has two effects. Firstly, this means that the systems are no longer used. This reduces the costs of operation and maintenance of roadside systems, and is a benefit. However, if these roadside systems are no longer operational, the benefits that they generate can no longer be reaped, potentially leading to less traffic safety and throughput, and increased environmental pollution.

Infrastructure cost savings means that the amount of legacy roadside systems decreases over time. Figure 5 shows the diminishing deployment level of roadside legacy systems over time resulting in infrastructure savings. Legacy systems that will be affected by infrastructure savings are all types of variable message signs. A decrease in roadside legacy systems means less infrastructure alongside the road. The COBRA+ Tool takes this fact into account by increasing the societal problem size. Safety-related indicators will increase by 3% and the time spent travelling will increase by 5%, based on expert opinion and Dutch literature summarized by TrafficQuest (2015) on effects on implementing legacy road side systems.

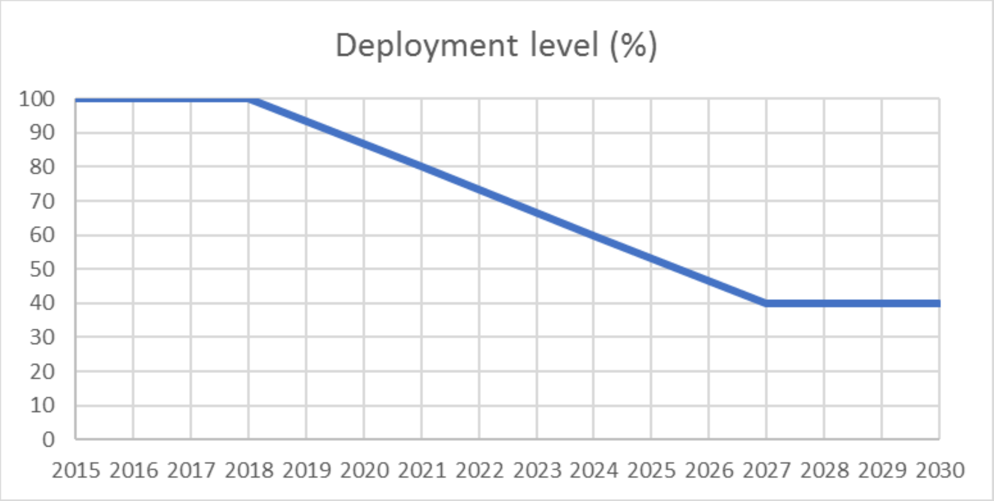

Figure 5: Decreasing deployment of Roadside Legacy Systems in the Road Network in case of infrastructure savings, 2015-2030.

Business Models

Rijkswaterstaat and the Dutch government expect that the market will play a role in the future in providing traffic management. The business models investigated in the use cases reflect this approach. Four business models are investigated in the use cases: mixed and private for the cellular and hybrid deployments. The private model assumes that the market carries out most of the traffic management activities, as suggested by the name. The mixed model assumes a less market-oriented business model, but one in which the market does play a significant role. Both the mixed and private models investigated assume that the driver pays for the services received. In the COBRA+ tool, the business models are used to determine whether the costs are to be incurred by the road operator or not. Deliverable 3.2 [Ognissanto et al., 2017] provides a detailed description of the 18 business models. Appendix 2: Business Model Summary provides a summary of the business models.

Services and Bundles

The use cases investigate 2 bundles: Local Dynamic Event Warnings, Bundle 1, includes the services Hazard Warning, Road Works Warning (short distance), Traffic Jam and Shockwave Damping. In-vehicle Signage, Bundle 2, includes static and dynamic road signs and speed limits.

Deployment of ITS G5 Roadside Infrastructure

Different deployment levels for the ITS G5 roadside infrastructure are assumed for the Corridor and the full road network. The corridor is assumed to be equipped rapidly with the ITS G5 roadside infrastructure, so that by 2027 25% of the Corridor is assumed to be equipped. The full road network contains many more kilometres all over the Netherlands. The roll-out as a percentage of the total kilometres of road is assumed to be lower in 2027 at 10%.

2.2.2 *Reference Scenario ("Business as Usual")*

All scenarios defined in the COBRA+ Tool are compared to a reference scenario, the Business as Usual scenario. The Business as Usual scenario describes a situation over time regarding the legacy infrastructure, the developments in future network coverage and societal and economic developments that affect the model data.

In the Business as Usual scenario, the network coverage and the coverage in kilometres of legacy systems will remain the same for all years and are summarized in Table 2 and Table 3.

Table 2: Rijkswaterstaat Network and Coverage by Legacy Systems

Full network	**Motorway (km)**	**Non-Motorway (km)**
Network length	6451	1160
Coverage by legacy systems	4413	40.5

Table 3: The Dutch Corridor and Coverage by Legacy Systems

Corridor only	**Motorway (km)**	**Non-Motorway (km)**
Network length	316	0
Coverage of legacy systems	316	0

The presence of legacy systems means that the C-ITS services will not have a full impact on those sections in the network with legacy systems. The assumption is that legacy systems and C-ITS services will coexist together. To incorporate a reduced impact of C-ITS overlap, reduction factors are used in the impact modelling.

The list of existing infrastructure (legacy systems) included in the cost-benefit analysis in the COBRA+ tool is:

- Prism displays
- Full text variable message signs
- Matrix variable message signs
- Roadside variable message signs
- CCTV cameras
- Induction loops
- Detector stations

Full details on the number of units, costs and lifetimes can be found in the report, “Report on data collection and processing” [Nitsche et. al., 2017].

In the scenario that does not make use of infrastructure cost savings, the deployment level of legacy systems will not change over time. Only in the case of infrastructure savings, the deployment level will decrease.

Also, future developments are implemented in the COBRA+ Tool. Forecasts were collected for safety measures such as the number of fatalities, injuries, travel time forecasts, fuel consumption and emission developments. For the Netherlands, most forecast data is taken from the study ‘Nederland in 2030-2050: twee referentiescenario’s – Toekomstverkenning Welvaart en Leefomgeving’ (referred to as WLO, 2015). In this study two economic developments for The Netherlands are described; one with a moderate growth scenario, and the second with high growth. After discussion with Rijkswaterstaat, an average of the moderate and high growth scenarios for the relevant indicators was used for the forecast in the COBRA+ Tool. Full details on specific forecast numbers can be found in “Report on data collection and processing” [Nitsche et. al., 2017].

2.2.3 *Fixed Parameters*

The common characteristics to all the scenarios analysed are summarised in Table 4. These cover the CAPEX, OPEX and development costs (costs incurred prior to roll-out); time frames and some requirements on the deployment of the road infrastructure for the ITS-G5 cases.

Table 4 List of the common characteristics in the analysed scenarios

Fixed parameters	Value
Start year for deployment of ITS-G5 wireless beacons roadside units	2018
End year for deployment of ITS-G5 wireless beacons roadside units	2027
% of the ITS-G5 beacons that are installed on existing poles / gantries	80
% of the ITS-G5 beacons that are installed on new poles	20
% of the ITS-G5 beacons that are installed on the NRA's motorways	80
% of the ITS-G5 beacons that are installed on the NRA's other roads	20
Year that the service goes live (i.e. when start accruing benefits)	2019
Year that the costs are borne from the back office / other costs	2018
Include in-vehicle OPEX costs?	Yes
Include development costs?	Yes: 4.6MEURO
Time horizon	2030

2.2.4 *Variable Parameters*

The aspects that characterise the different scenarios are listed in Table 5. These concern the network, the percentage of infrastructure equipped with ITS-G5 technology in the end year, which bundle (Local Dynamic Event Warnings or In-Vehicle Signage) was deployed, whether infrastructure savings is on or off, the penetration of the aftermarket/OEM devices, and the business model.

The low, medium or high penetration curves are defined in the CORA+ Tool User Guide [Ognissanto et. al, 2017].

Table 5 List of the differentiating characteristics in the analysed scenarios

Variable parameters	Values
The network (e.g. the geographic area)	C-ITS Corridor in the Netherlands / Full Network
% infra equipped in end year (for hybrid)	25% on the Corridor/ 10% on the full network
A service or bundle	Local Dynamic Event Warnings (Bundle 1) / In-Vehicle Signage (Bundle 2)
Cost savings (for one of the options relevant to the chosen service or bundle): yes or no.	Yes/no
Penetration curve (of aftermarket and OEM):	All combinations of low/medium/high of in-vehicle and aftermarket

Include in-vehicle CAPEX costs?	No
Platform	**Cellular**
Business Model for cellular: mixed 2b – Driver pays service, private 3b -- Driver pays service.	mixed 2b, private 3b
Platform	**Hybrid**
Business Model for hybrid: mixed 5b, private 6b – Driver pays service;	mixed 5b, private 6b

2.3 *Analysis of results*

This section reviews the results of the scenarios from the COBRA+ Tool. Table 6 and ***Table 11*** provide an overview of the Benefit Cost Ratios (BCR) and percentage of costs borne by the National Road Authority, respectively. The choice of bundle, network, whether infrastructure savings are on or off and the platform are made explicit. All the other parameters varied are included in the ranges provided.

Table 6: Range of Benefit Cost Ratio (BCR) by bundle, type of network, infrastructure savings on/off and platform, excluding capital costs of in-vehicle equipment

Bundle	**Network**	**Infrastructure savings on**		**Infrastructure savings off**	
		Cellular	**Hybrid**	**Cellular**	**Hybrid**
Local Dynamic Event Warnings					
	Corridor	0.16-0.20	0.19-0.24	0.00-0.01	0.01
	Full Road Network	0.73-0.79	0.77-0.82	0.11-0.12	0.13
In-Vehicle Signage	**Corridor**	0.39-0.43	0.42-0.44	0.27-0.29	0.31
	Full Road Network	1.02-1.03	1.04-1.05	1.01-1.03	1.04-1.05

* Excluding capital costs of in-vehicle equipment

The BCR ranges from 0 to just over 1. The BCR is affected by the network analysed, whether infrastructure savings are off or on, and the choice of bundle.

2.3.1 *Differences in results between the Corridor and Full Network*

A consistently higher BCR is achieved for the full road network than the corridor, when all other elements are fixed. Table 7 shows the relevant pairs outlined in green of Corridor / Full road Network to compare. Several factors contribute to this outcome. The corridor is already well-equipped with existing roadside traffic management systems. The whole corridor is equipped with legacy 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. The in-vehicle equipment for the two scenarios is the same – meaning that the operating and, when included, the capital costs incurred for the entire equipped fleet are the same for the corridor and full network scenarios.

Thus, the benefits generated on the corridor will always be lower than that of the full network, because the corridor is a subset of the full network. Finally, note that for the hybrid scenarios that 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. Relatively speaking, more costs are incurred per kilometre for ITS G5 deployment on the corridor than for the full network.

Table 7: Range of Benefit Cost Ratio (BCR). The green outline highlights the comparison of corridor to the full road network.

Bundle	**Network**	**Infrastructure savings on**		**Infrastructure savings off**	
		Cellular	**Hybrid**	**Cellular**	**Hybrid**
Local Dynamic Event Warnings					
	Corridor	0.16-0.20	0.19-0.24	0.00-0.01	0.01
	Full Road Network	0.73-0.79	0.77-0.82	0.11-0.12	0.13
In-Vehicle Signage	**Corridor**	0.39-0.43	0.42-0.44	0.27-0.29	0.31
	Full Road Network	1.02-1.03	1.04-1.05	1.01-1.03	1.04-1.05

* Excluding capital costs of in-vehicle equipment

Figure 6 shows a typical example outcome showing the difference between the Benefit Cost Ratio of the Dutch Corridor compared to the full road network for a given scenario of deploying Bundle 2 using the hybrid implementation. The parameters for the scenarios are identical except for the choice of network. Scenario 1 represents the calculation for the corridor, and Scenario 2 for the full road network. The number in the lower left-hand corner of the figure indicates the figure number from the COBRA+ Tool.

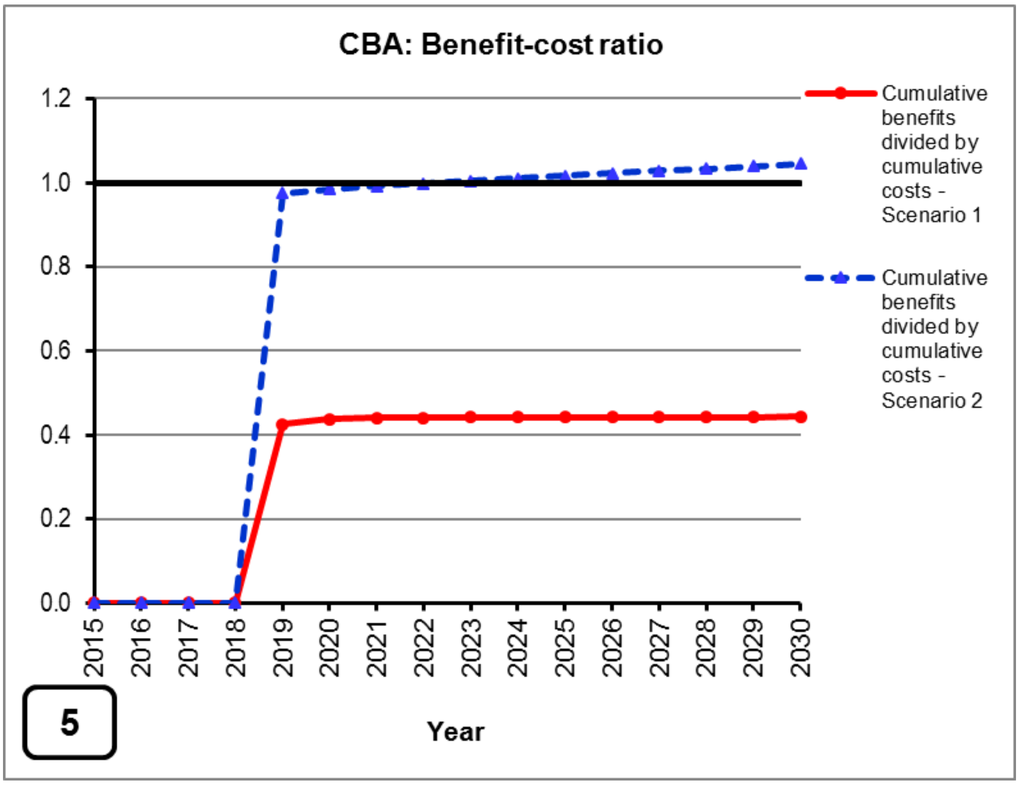

Figure 6: Annual Benefit Cost Ratio on the Dutch Corridor (Scenario 1) vs the full network (Scenario 2) for a hybrid implementation of the In-Vehicle Signage Bundle

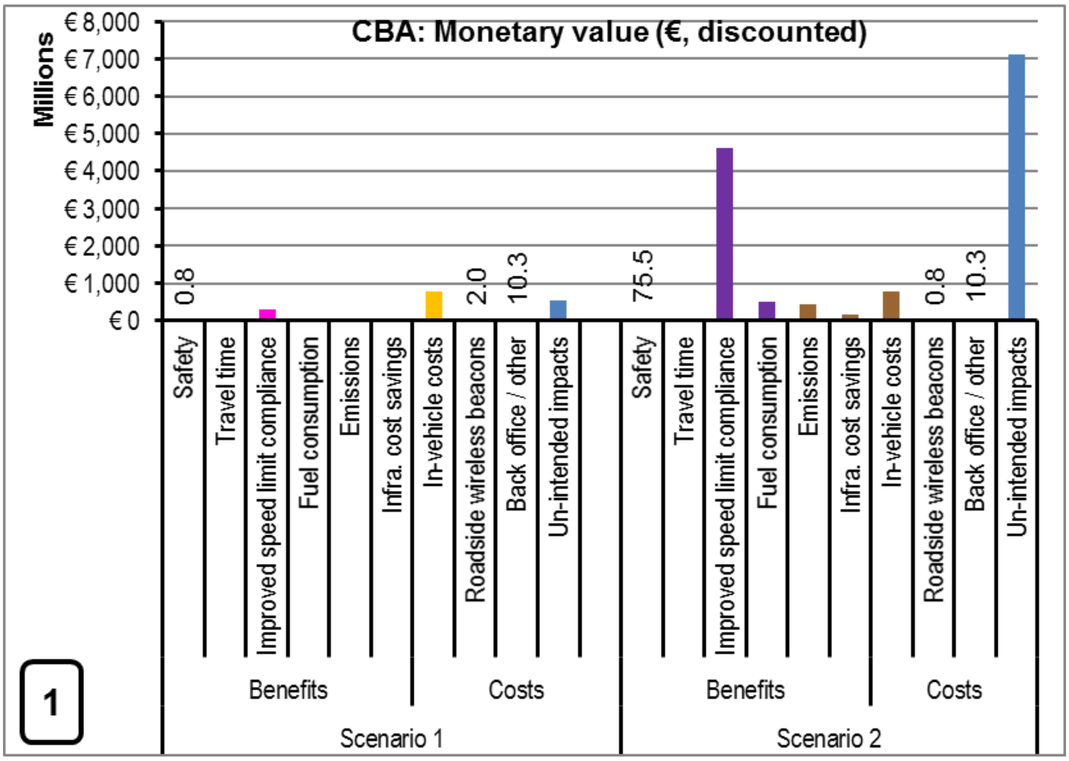

Figure 7: Detailed Benefits and Costs of Scenario 1 (Corridor) and Scenario 2 (Full Network), for a Hybrid Implementation

2.3.2 *Choice of Platform*

The choice of platform (hybrid or cellular) affects the BCR, but not dramatically. Holding all other parameters fixed, the choice of platform has a small impact on the BCR. The hybrid deployment results in a slightly higher BCR than the cellular deployment in all cases. Table 8 shows the relevant pairs to compare outlined in green of Corridor / Full road Network.

Table 8: Range of Benefit Cost Ratio (BCR). The green outline highlights the comparison of the cellular to hybrid results.

Bundle	**Network**	**Infrastructure savings on**		**Infrastructure savings off**	
		Cellular	**Hybrid**	**Cellular**	**Hybrid**
Local Dynamic Event Warnings					
	Corridor	0.16-0.20	0.19-0.24	0.00-0.01	0.01
	Full Road Network	0.73-0.79	0.77-0.82	0.11-0.12	0.13
In-Vehicle Signage	**Corridor**	0.39-0.43	0.42-0.44	0.27-0.29	0.31
	Full Road Network	1.02-1.03	1.04-1.05	1.01-1.03	1.04-1.05

* Excluding capital costs of in-vehicle equipment

For a given bundle, the hybrid implementation is more effective than the cellular implementation in terms of achieving benefits, but is limited to the area where the ITS G5 roadside units are located. The ITS G5 did not cover the network examined. 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. Figure 8 shows the benefits and costs of a cellular (Scenario 1) and hybrid (Scenario 2) implementation. Note that the figures do not include the in-vehicle capital costs. The hybrid scenarios 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. At this moment, little to no data directly comparing the effectiveness of the cellular vs hybrid communication are available. The inputs to the COBRA+ Tool, documented in Deliverable 4.1 [Nitsche et. Al., 2017], assume a greater effectiveness of ITS G5 communication for Local Dynamic Event Warning (Bundle 1), due to ITS G5's lower latency and higher reliability. The cellular implementation of Local Dynamic Event Warning is assumed to have 80% of the effectiveness of the hybrid implementation. There is no difference in the effectiveness between the two implementations for the In-Vehicle Signage Bundle. Furthermore, the hybrid implementation does not take into account the safety and traffic throughput benefits of Vehicle-to-Vehicle (V2V) 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.

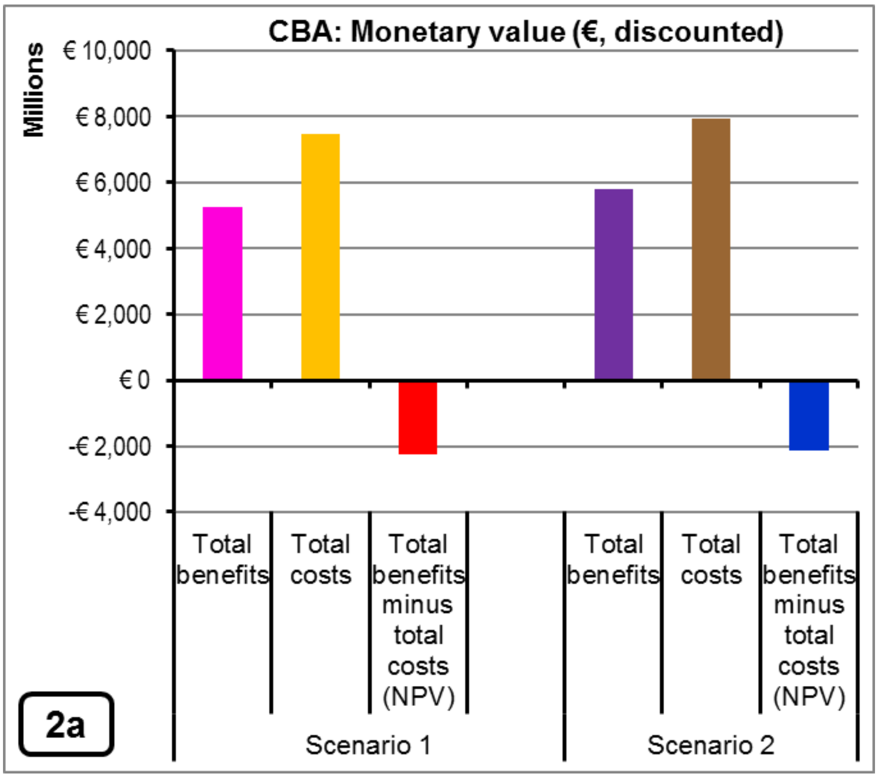

Figure 8: Net Present Value of Total Benefits, Total Costs, and Total benefits minus total costs for Scenario 1 (cellular) and Scenario 2 (hybrid)

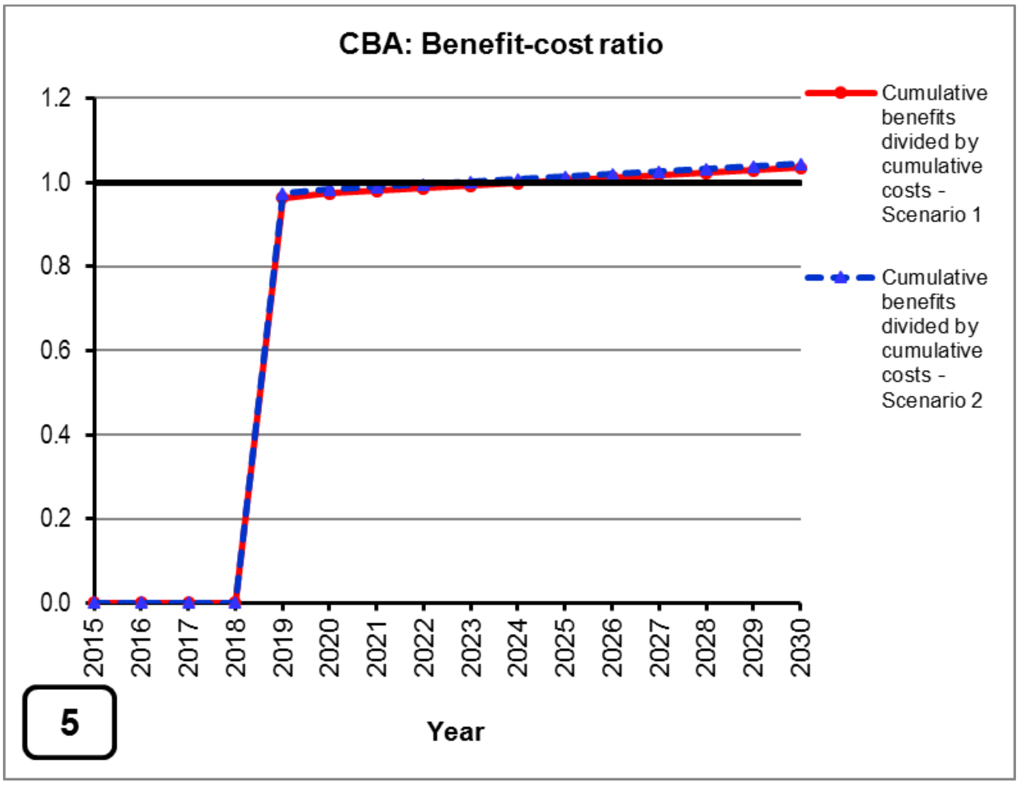

Figure 9: Cumulative, Annual Benefit-Cost Ratio of Scenario 1 (cellular) and Scenario 2 (hybrid)

2.3.3 *Infrastructure Savings*

Turning infrastructure savings on has a large positive impact on the BCR in most scenarios. Holding all other parameters fixed, turning on the infrastructure savings reduces the costs incurred in maintenance and operation of the existing roadside systems. Compared to the business as usual scenario, these are benefits: they represent funds that would have been spent in the reference scenario but they are not. However, "turning off" some current legacy systems result in a decrease in safety, increase in travel time, and/ or increase in emissions. The COBRA+ Tool takes these unintended disbenefits into account. Table 9 shows the relevant pairs to compare outlined in green of the difference in infrastructure savings on vs off.

Table 9: Range of Benefit Cost Ratio (BCR). The green outline highlights the comparison of infrastructure savings turned on or off.

Bundle	Network	Cellular		Hybrid	
		Infrastructure savings on	Infrastructure savings off	Infrastructure savings on	Infrastructure savings off
Local Dynamic Event Warnings					
	Corridor	0.16-0.20	0.00-0.01	0.19-0.24	0.01
	Full Road Network	0.73-0.79	0.11-0.12	0.77-0.82	0.13
In-Vehicle Signage	Corridor	0.39-0.43	0.27-0.29	0.42-0.44	0.31
	Full Road Network	1.02-1.03	1.01-1.03	1.04-1.05	1.04-1.05

* Excluding capital costs of in-vehicle equipment

Figure 10 shows the annual costs and benefits of two scenarios which are identical except for that Scenario 1 makes use of infrastructure savings, and that Scenario 2 does not. Although the BCR is virtually identical over time, there is a large difference between the costs and benefits in Scenario 1 and those in Scenario 2. The infrastructure savings in Scenario 1 generates financial benefits relative to the reference scenario. Figure 11 shows the additional benefits in Scenario 1. However, unintended disbenefits are incurred (decrease in safety, increase in travel time, etc.). These disbenefits are added to the costs in Scenario 1 in Figure 11. The deployment of the C-ITS itself generates benefits that, in this configuration of infrastructure savings and deployment of C-ITS, compensate each other in this case. Overall, Scenario 1 has higher costs, due to the disbenefits; and higher benefits, due to the additional financial savings. The size of the disbenefits are expressed financially in the BCR, but this is an ethical issue is well. Care must be taken to balance the deployment of the in-vehicle and roadside C-ITS equipment to compensate for the reduced benefits of the decommissioned existing roadside units.

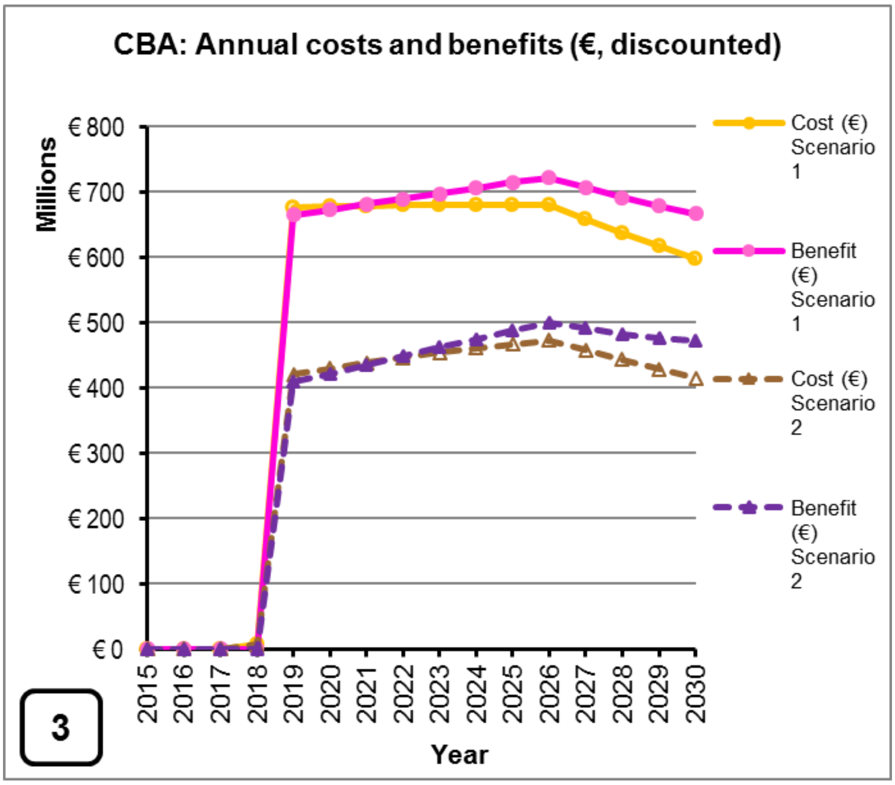

Figure 10: The annual Benefit-cost ratio for two cellular scenarios. Scenario 1 with Infrastructure Cost Savings, Scenario 2 without

Figure 11 shows the cumulative net costs on an annual basis with Infrastructure Savings on (scenario 1) and infrastructure savings off (scenario 2) for a full road network and hybrid implementation, for a mixed business model. These are the costs less the realized infrastructure savings. In 2018, the deployment of the ITS G5 units starts. In 2019, the infrastructure savings start, and continue to 2027. After 2027, the savings relative to the reference scenario continue.

Relative to the reference scenario, making use of infrastructure cost savings significantly decreases the overall cost expenditure of deployment of C-ITS. The costs for Scenario 1 and Scenario 2 do not differ until 2019, when the infrastructure savings start. In Scenario 1, the cumulative costs are less than the savings realized, already in 2021.

The scenario details can be found in Table 31 in the Appendix.

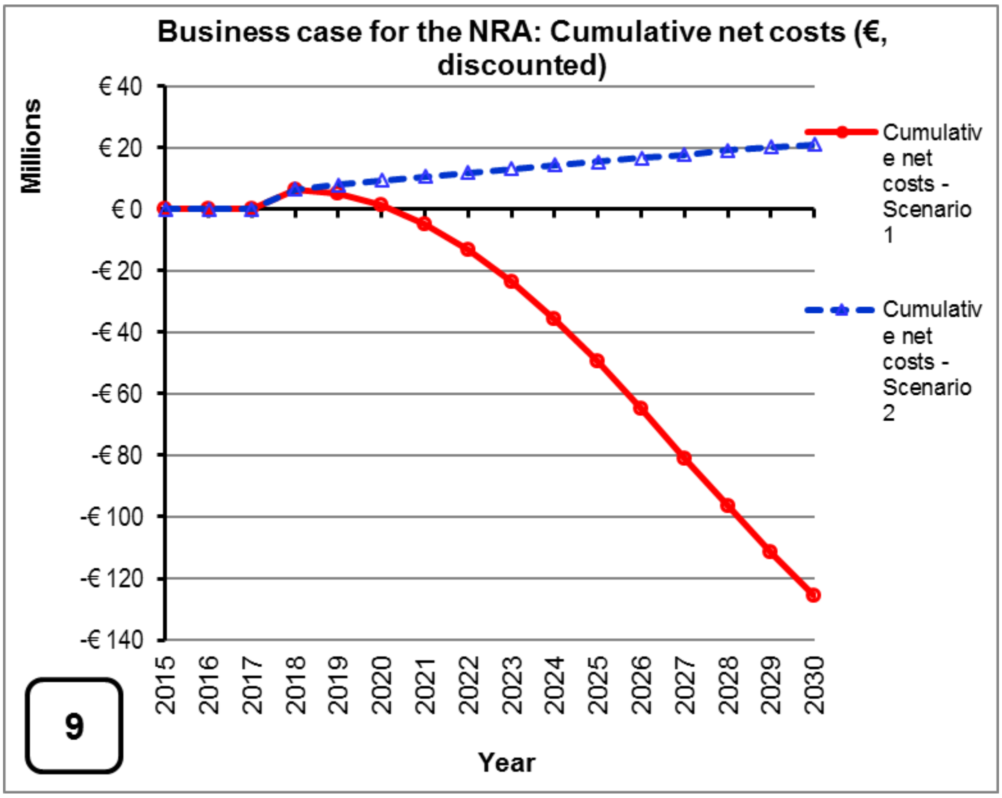

Figure 11: Difference in cumulative costs and benefits with Infrastructure Savings off (Scenario 1) and Infrastructure Savings On (Scenario 2) for a full network and hybrid implementation

Turning infrastructure savings on or off affected the payback year of the investment for the National Road Authority. With infrastructure savings on, the payback year was significantly earlier than when infrastructure savings was turned off. For the scenarios examined, the payback year for the National Road Authority varied according with the platform, network and business model. In scenarios in which infrastructure savings is turned on, the cellular implementation achieved payback for the National Road Authority before 2030. In the scenarios for the Full Network, payback was reached in 2020, given the business models chosen. In scenarios in which infrastructure savings is turned on, the hybrid implementation achieved payback significantly earlier when considering the Full Network (around 2020), given the business models chosen. Table 10 presents the payback years for almost 600 scenarios combined.

Table 10: Payback year for the National Road Authority by bundle, type of network, infrastructure savings on/off and platform, excluding capital costs of in-vehicle equipment*

Bundle	**Network**	**Infrastructure savings on**		**Infrastructure savings off**	
		Cellular	**Hybrid**	**Cellular**	**Hybrid**
Business Model (BM)		**BM 2b/3b**	**BM 5b/6b**	**BM 2b/3b**	**BM 5b/6b**
Local Dynamic Event Warnings					
	Corridor	2025/2029	Not before 2030/2025	Not before 2030	Not before 2030

	Full Road Network	2020	2021/2020	Not before 2030	Not before 2030
In-Vehicle Signage	**Corridor**	2029/2025	Not before 2030/ 2025	Not before 2030	Not before 2030
	Full Road Network	2020	2021/ 2020	Not before 2030	Not before 2030

* Excluding capital costs of in-vehicle equipment

2.3.4 *Share of the costs borne by the National Road Authority*

Table 11 shows that the percentage of the costs borne by the road operator under the business models investigated are all under 2%. 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. Table provides the total costs in the scenarios. The mixed model has a higher percentage of the costs for the National Road Authority than the private model. The difference between the two models is that, in the mixed model, the National Road Authority 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 National Road Authority 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.

Table 11: Percentage of costs for the National Road Authority for Bundle 1 by type of network, infrastructure savings on/off and platform, excluding capital costs of in-vehicle equipment

Bundle	**Network**	**Business Model**	**Infrastructure savings on**		**Infrastructure savings off**	
			Cellular	**Hybrid**	**Cellular**	**Hybrid**
Local Dynamic Event Warnings						
	Corridor	**Mixed**	<1%	0.9-1.2%	0.9-1.2%	~1.5%
	Corridor	**Private**	<0.5%	<1%	0.3-0.5%	<0.5%
	Full Road Network	**Mixed**	~0.3%	~0.7%	~1%	2-3%
	Full Road Network	**Private**	~0.1%	~0.3%	~0.5%	1-2%
In-Vehicle Signage	**Corridor**	**Mixed**	~0.7%	~0.8%	0.7-0.9%	0.8-1%
	Corridor	**Private**	~0.3%	~0.3%	~0.3%	~0.4%
	Full Road Network	**Mixed**	~0.1%	~0.3%	<0.3%	0.3-0.4%
	Full Road Network	**Private**	<0.1%	~0.1%	~0.1%	~0.2%

* Excluding capital costs of in-vehicle equipment

The total costs are different between scenarios. The total costs are higher in the In-Vehicle Signage Bundle for both the cellular and hybrid scenarios. The In-Vehicle Signage scenarios include in the costs the extra costs for increased travel time[1]. The total costs in the scenarios for which the infrastructure savings are turned on are higher than the total costs in the scenarios in which the infrastructure savings are turned off. The reason is that infrastructure savings can result in unintended disbenefits (decrease in safety, increase in travel time, etc.), as explained in Section 2.2.1.

Table 12: Total costs in each scenario

Bundle	**Network**	**Infrastructure savings off**		**Infrastructure savings on**	
		Cellular	**Hybrid**	**Cellular**	**Hybrid**
Local Dynamic Event Warnings	**Corridor**	991 – 1,254 MEUR	1,041 – 1,304 MEUR	806 – 1,069 MEUR	809 – 1,071 MEUR
	Full Road Network	2,766 – 3,029 MEUR	3,286 – 3549 MEUR	806 – 1,069 MEUR	825-1,099 MEUR
In-Vehicle Signage	**Corridor**	1,309 – 1,630 MEUR	1,340 – 1,699 MEUR	1,061 – 1,380 MEUR	1,091 – 1,446 MEUR
	Full Road Network	7,479 – 8,666 MEUR	7,951 – 9744 MEUR	4,881-6,046 MEUR	5,343 – 7,100 MEUR

2.3.5 *Effect of including capital costs of in-vehicle equipment in the Benefit-Cost Ratio*

Table 13 shows the results of a limited comparison of Benefit-Cost Ratios for scenarios differing only in that the capital costs of in-vehicle equipment are included and excluded (outlined in green). Turning on inclusion of the CAPEX in the Benefit-Cost calculations results in a lower Benefit-Cost Ratio, as would be expected. However, the Benefit-Cost Ratio does not decrease dramatically. Similar results hold for the Corridor results (see Appendix 3: Additional Results).

Table 13: Benefit-Cost Ratios in Full Road Network scenarios in which capital costs of in-vehicle equipment are included and excluded

Bundle	**Platform**	**In-vehicle equipment OEM-factory fitted / Aftermarket**	**Infrastructure savings on**		**Infrastructure savings off**	
			CAPEX off	**CAPEX on**	**CAPEX off**	**CAPEX on**

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[1] The extra costs for increased travel time in the In-Vehicle Signage bundle are compensated in the benefits on an annual basis. The reason for the compensation is that drivers are observing the speed limits better which is a societal benefit.

Local Dynamic Event Warnings						
	Cellular	**Low/Low**	0.79	0.76	0.12	0.11
		Medium/Medium	0.76	0.71	0.11	0.10
		High/High	0.73	0.65	0.11	0.08
	Hybrid	**Low/Low**	0.82	0.80	0.13	0.12
		Medium/Medium	0.79	0.75	0.13	0.11
		High/High	0.77	0.69	0.13	0.10
In-Vehicle Signage	**Cellular**	**Low/Low**	1.03	1.02	1.03	1.01
		Medium/Medium	1.03	1.01	1.02	0.99
		High/High	1.02	0.98	1.01	0.95
	Hybrid	**Low/Low**	1.04	1.03	1.04	1.02
		Medium/Medium	1.04	1.02	1.04	1.01
		High/High	1.04	1.00	1.04	0.99

2.4 Conclusions

The COBRA+ tool was used to investigate almost 600 possible C-ITS deployment scenarios for the Netherlands. The results presented in this document include scenarios for the bundles Local Dynamic Event Warnings (Bundle 1) and In-vehicle signage (Bundle 2) on both the C-ITS Corridor and the full network operated by Rijkswaterstaat. Within each of these networks, the effects of platform choice, infrastructure savings (from reduction of legacy systems) and the choice of business model of interest to Rijkswaterstaat were investigated. The indicators used to draw conclusions about these scenarios comprised the Benefit-Cost Ratio (BCR), and business model, the payback year for the National Road Authority and the percentage of costs that the National Road Authority is responsible for.

The analyses of the costs and benefits of C-ITS deployment on the C-ITS Corridor and the Rijkswaterstaat full network show differences in the BCRs. For the full network, the BCR is higher than for the corridor. The Corridor is a subset of the Full Network. The Corridor is the starting point for C-ITS deployment, with a vision of further deployment beyond the Corridor. The fact that the BCR on the Corridor is lower than that of the full network, is logical given the following. The equipment rate in the hybrid scenarios and thus investment (per kilometre) is higher on the corridor (25%) than on the full network (10%). Secondly, the vehicle operating costs in absolute terms are the same for both the full network as for the corridor. The in-vehicle equipment for the two scenarios is the same – meaning that the operating and, when included, the capital costs incurred for the entire equipped fleet are the same for the corridor and full network scenarios. Thirdly, the total safety, congestion and environmental problems are relatively small on the Corridor and thus the benefits to be generated are also relatively small.

The BCR is higher for In-Vehicle Signage than for Local Dynamic Event Warnings bundle, which is directly a result of what is known about the impacts of these systems. The Local Dynamic Event Warnings bundle is a safety-oriented bundle. Given the high level of safety already present on the Rijkswaterstaat road network, the absolute improvement is relatively small.

The difference in the BCR between the cellular and hybrid implementations appears rather small. Several things contribute to this appearance. The benefits of the hybrid implementation are underestimated. The additional benefits provided by Vehicle-to-Vehicle (V2V) services are not taken into account. Furthermore, the hybrid implementation is expected to provide higher benefits than the cellular implementation due to ITS G5’s low latency and reliability. Due to a lack of evidence on the difference in impacts, a conservative estimate was used.

Infrastructure savings is part of a plan to maintain and improve levels of safety, traffic throughput and environmental impacts while reducing the overall costs. Reducing costs is a benefit, but unintended disbenefits will be incurred. Careful analysis and research is necessary to realize the benefits of infrastructure savings while carefully balancing the disbenefits with the generation of benefits through deployment of C-ITS. Careful analysis of the achieved or required level of C-ITS deployment (roadside and vehicle units) with the timing of the start of decommissioning and the rate of decommissioning over time needs to take place to ensure that levels of road safety, traffic performance and environmental impacts are maintained and improved. Until such analyses have been carried out, the decision to make use of infrastructure savings should be delayed. Infrastructure savings realized through the reduction of loops (not yet implemented in the COBRA+ Tool) and buying Floating Vehicle Data instead have yet to be investigated.

Given current thinking about the future public-private cooperation for deployment and delivery of C-ITS, the National Road Authority will be responsible for at most of 2% of the total costs. This figure was generated making use of various public-private Business Models. Efforts to implement these Business Models with partners in a sustainable way is a next crucial step in deployment. The NRA needs to engage with the relevant stakeholders.

3 Use Case England

3.1 *Introduction*

Highways England is preparing to deliver a connected vehicle corridor on the A2/M2 between London and the ferry port of Dover (Figure 12). This corridor covers urban roads in London, the Strategic Road Network, and local roads in Kent. The route includes both local and inter-urban roads, and is an important link for freight as well as private motorists.

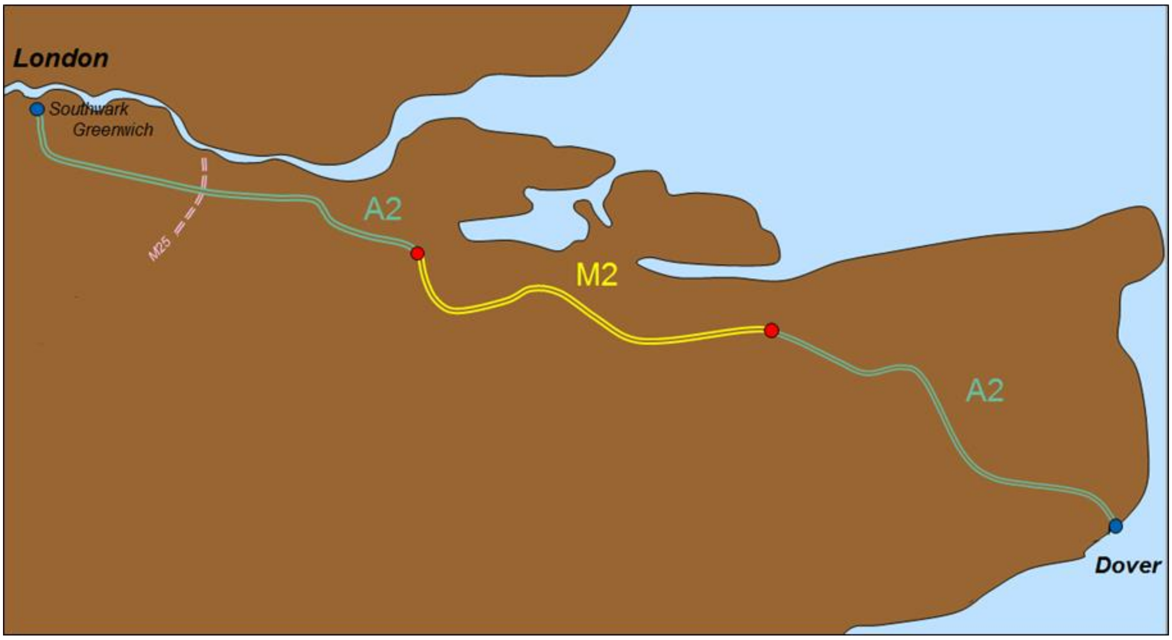

Figure 12 Outline of the A2/M2 corridor connecting the cities of Dover and London. The yellow stretch is the Motorway trunk.

3.2 *Scenarios analysed*

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 road operator sponsors hybrid in-vehicle devices to stimulate the take up of services. Business models are compared in which drivers pay for the services with those where the road operator pays for the service. Twenty-two scenarios have been simulated and combined in 15 pairs for comparison. All the scenarios share some common characteristics, which are described in Section 3.2.1; while the elements which determine the differences are discussed in Section 3.2.2. The combination analysed are presented in Section 3.2.3.

3.2.1 *Fixed elements*

The common characteristics to all the scenarios analysed are summarised in Table 14. These cover the services provided; the CAPEX, OPEX and development costs; time frames and some requirements on the deployment of the road infrastructure for the ITS-G5 cases. Cost savings from phasing out existing infrastructure are not considered in the analysis; the reason is that over the time period of this assessment, while there are vehicles using the road that are not equipped to receive the in-vehicle signage information, the road operator would not anticipate phasing out roadside signs.

Table 14 List of the characteristics in common among the analysed scenarios

Fixed elements	Value
Service or bundle	In-Vehicle Signage (Bundle 2)
Geographic area (network or corridor)	A2/M2 corridor
Start year for deployment of ITS-G5 wireless beacons roadside units	2018
End year for deployment of ITS-G5 wireless beacons roadside units	2030
% of the ITS-G5 beacons that are installed on existing poles / gantries	50
% of the ITS-G5 beacons that are installed on new poles	50
% of the ITS-G5 beacons that are installed on the NRA's motorways	80
% of the ITS-G5 beacons that are installed on the NRA's other roads	20
Year that the service goes live (i.e. when start accruing benefits)	2019
Year that the costs are borne from the back office	2018
Include in-vehicle CAPEX costs in the calculation?	Yes
Include in-vehicle OPEX costs in the calculation?	Yes
Include development costs?	Yes: €4.6m
Time horizon	2030
Take account of cost savings (from reducing current infrastructure provision)	No

3.2.2 *Variable elements*

The aspects that characterise the different scenarios are listed in Table 15. These concern the business model, the penetration of the aftermarket/OEM devices, plus the percentage of infrastructure equipped with ITS-G5 technology in the end year.

The business models selected are all of type “public”, that is, the road operator takes the approach of providing the content and the service (see the User Guide D3.2 for more details); but they differ accordingly to who pays for the service, the National Road Authority (NRA) or the driver.
The low, medium or high penetration curves are defined in the User Guide (Ognissanto et. al, 2017).

Table 15 List of the characteristics which differentiate the analysed scenarios

Variable elements	Values
Platform	**Cellular**
BM for cellular: public 1a – NRA pays service	Public 1a
BM for cellular: public 1b – Driver pays service	Public 1b
Penetration curve (of aftermarket and OEM): low, medium high	Low, Medium, High
Platform	**Hybrid**
BM for hybrid: public 7a, NRA pays service, NRA sponsors device	Public 7a
BM for hybrid: public 7b, Driver pays service, NRA sponsors device	Public 7b
Penetration curve (of aftermarket and OEM): low, medium high	Low, Medium, High
% infrastructure equipped in end year (for hybrid) 5/10/20%	5, 10, 20%

3.2.3 *Combinations analysed*

The type of comparisons performed can be split into two groups:

- Comparison between two scenarios having the same type of communication platform and the same penetration of in-vehicle devices in the market (aftermarket or OEM), but a different business model.
- Comparison between two scenarios based on different communication platforms, but with the same penetration of in-vehicle devices in the market (aftermarket or OEM) and an analogous business model.

Fifteen tests have been run as summarised in Table 16. The percentage of the road network on which ITS-G5 infrastructure is deployed at the end of the assessment period has been varied in order to compare results with low (5%), medium (10%) and high (20%) combined with low, medium and high penetrations of the in-vehicle devices. Figure 13 shows the in-vehicle equipment penetration curves used in the model. The working hypothesis is that OEM in-vehicle penetration increases during the timeframe considered, while the aftermarket in-vehicle penetration shows an initial increase and a following decrease due to the spreading of the OEM in-vehicle devices (more details are provided in the User Guide [Ognissanto et. al., 2017]).

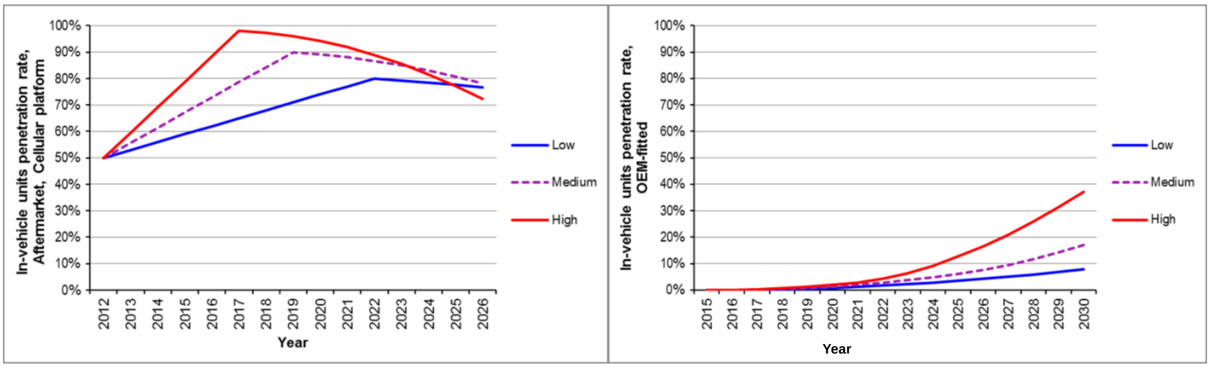

Figure 13 Curves available in the model for describing the penetration rate of after-market in-vehicle equipment (on the left) and of OEM in-vehicle equipment (on the right)

Table 16 Use cases analysed

Test	Communication network and level of ITS G5 deployment on the network in 2030	Penetration (aftermarket or OEM)	Business model
1	Cellular	Low	1a. Cellular - public - NRA pays service
	Cellular	Low	1b. Cellular - public - Driver pays service
2	Cellular	High	1a. Cellular - public - NRA pays service
	Cellular	High	1b. Cellular - public - Driver pays service
3	Hybrid 5%	Low	7a. Hybrid - public - NRA pays service - NRA sponsors device
	Hybrid 5%	Low	7b. Hybrid - public - Driver pays service - NRA sponsors device
4	Hybrid 20%	Low	7a. Hybrid - public - NRA pays service - NRA sponsors device
	Hybrid 20%	Low	7b. Hybrid - public - Driver pays service - NRA sponsors device
5	Hybrid 5%	Medium	7a. Hybrid - public - NRA pays service - NRA sponsors device
	Hybrid 5%	Medium	7b. Hybrid - public - Driver pays service - NRA sponsors device
6	Hybrid 20%	Medium	7a. Hybrid - public - NRA pays service - NRA sponsors device
	Hybrid 20%	Medium	7b. Hybrid - public - Driver pays service - NRA sponsors device
7	Hybrid 5%	High	7a. Hybrid - public - NRA pays service - NRA sponsors device
	Hybrid 5%	High	7b. Hybrid - public - Driver pays service - NRA sponsors device
8	Hybrid 20%	High	7a. Hybrid - public - NRA pays service - NRA sponsors device
	Hybrid 20%	High	7b. Hybrid - public - Driver pays service - NRA sponsors device
9	Cellular	Low	1a. Cellular - public - NRA pays service
	Hybrid low 5%	Low	7a. Hybrid - public - NRA pays service - NRA sponsors device
10	Cellular	Medium	1a. Cellular - public - NRA pays service

Test	Communication network and level of ITS G5 deployment on the network in 2030	Penetration (aftermarket or OEM)	Business model
	Hybrid 10%	Medium	7a. Hybrid - public - NRA pays service - NRA sponsors device
11	Cellular	High	1a. Cellular - public - NRA pays service
	Hybrid 20%	High	7a. Hybrid - public - NRA pays service - NRA sponsors device
12	Cellular	High	1a. Cellular - public - NRA pays service
	Hybrid 20%	High	7a. Hybrid - public - NRA pays service - NRA sponsors device
13	Cellular	Low	1b. Cellular - public - Driver pays service
	Hybrid 5%	Low	7b. Hybrid - public - Driver pays service - NRA sponsors device
14	Cellular	Medium	1b. Cellular - public - Driver pays service
	Hybrid 10%	Medium	7b. Hybrid - public - Driver pays service - NRA sponsors device
15	Cellular	High	1b. Cellular - public - Driver pays service
	Hybrid 20%	High	7b. Hybrid - public - Driver pays service - NRA sponsors device

3.3 Results

3.3.1 *Benefit Cost Ratios in 2030*

The cumulative Benefit Cost Ratios (BCR) in 2030 are not favourable. Values range between 0.47 and 0.61 (Table 17), according to the level of in-vehicle penetration; the higher the in-vehicle penetration, the smaller the ratio. As expected, they are not affected by the business model, since the difference between type ‘a’ and ‘b’ is not in the benefits or costs values, but in who bears the service costs (the NRA or the user).

Table 17 BCR in 2030

Communications platform	Cellular	Hybrid
Business model	**1a/1b**	**7a/7b**
In-vehicle penetration - Low	0.58	
In-vehicle penetration - Medium	0.54	
In-vehicle penetration - High	0.47	

In-vehicle penetration Low & 5% Infrastructure equipped for hybrid in 2030	0.61
In-vehicle penetration Low & 20% Infrastructure equipped for hybrid in 2030	0.61
In-vehicle penetration Medium & 5% Infrastructure equipped for hybrid in 2030	0.58
In-vehicle penetration Medium & 10% Infrastructure equipped for hybrid in 2030	0.58
In-vehicle penetration Medium & 20% Infrastructure equipped for hybrid in 2030	0.58
In-vehicle penetration High & 5% Infrastructure equipped for hybrid in 2030	0.54
In-vehicle penetration High & 20% Infrastructure equipped for hybrid in 2030	0.54

Two general trends are immediately identified:

1. At all levels of in-vehicle penetration, the cellular scenario has a lower BCR compared to the hybrid scenario (regardless of the percentage of infrastructure equipped); for example, for low in-vehicle penetration, the cellular scenario achieves a BCR of 0.58, while the hybrid scenarios, which require the deployment of new infrastructure, have ratios equal to 0.61, 0.58 and 0.54 for 5%, 10% and 20% of equipped infrastructure, respectively (see section 3.3.5).

   This difference can be explained by the lower costs for the data communication for devices using the ITS-G5 technology compared to the cellular.

2. Higher in-vehicle penetrations are associated with lower BCRs. For example, the cellular BCR values range from 0.58 to 0.47 for the low and high in-vehicle penetration respectively; the BCR for the hybrid scenario with 5% of equipped infrastructure varies from 0.61 to 0.54.

   This reveals that the service and data communication costs have higher impact in the BCR than the benefits accrued from the spreading of the technology use. In Figure 14 an example for cellular scenarios with low and high in-vehicle penetration is shown (scenario 1 and scenario 2 respectively). It can be noticed that the increase in the in-vehicle costs is significantly higher than the increase in the benefits. The number in the lower left-hand corner of the figure indicates the figure number from the COBRA+ Tool. Due to the fact that under the hypothesis adopted for the model the cost of the data communication is higher for the cellular than for the hybrid platform, the BCR of the cellular scenario is more sensitive to the level of in-vehicle penetration than the hybrid scenarios; in fact, the BCR variation from a low to a high in-vehicle penetration scenario is -23% when the communication platform is cellular based (arrow in Figure 15), while it is about the half this figure when the hybrid technology is implemented (Table 18).

The characteristics described in the list above have as consequence that the highest BCR that is attainable corresponds to a hybrid scenario with low in vehicle-penetration.

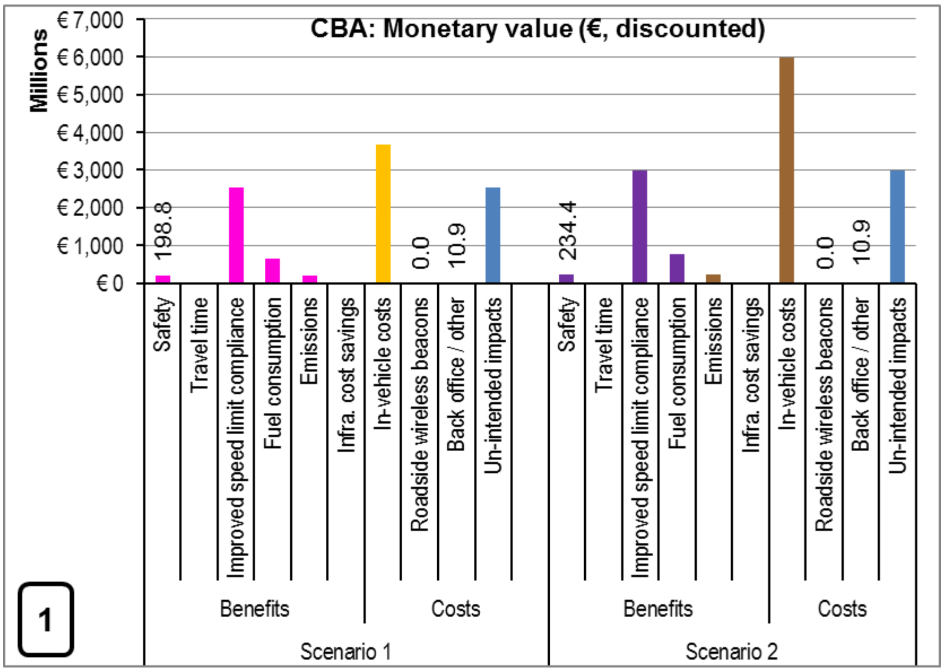

Figure 14 Costs and benefits for cellular scenarios with low in-vehicle penetration (scenario 1) and high in-vehicle penetration (scenario 2)

Table 18 Percentage variation of the BCR as a function of the in-vehicle penetration

Communication platform	**BCR variation from low to high in-vehicle penetration**
Cellular	-23%
Hybrid	-12% (regardless of the percentage of equipped infrastructure)

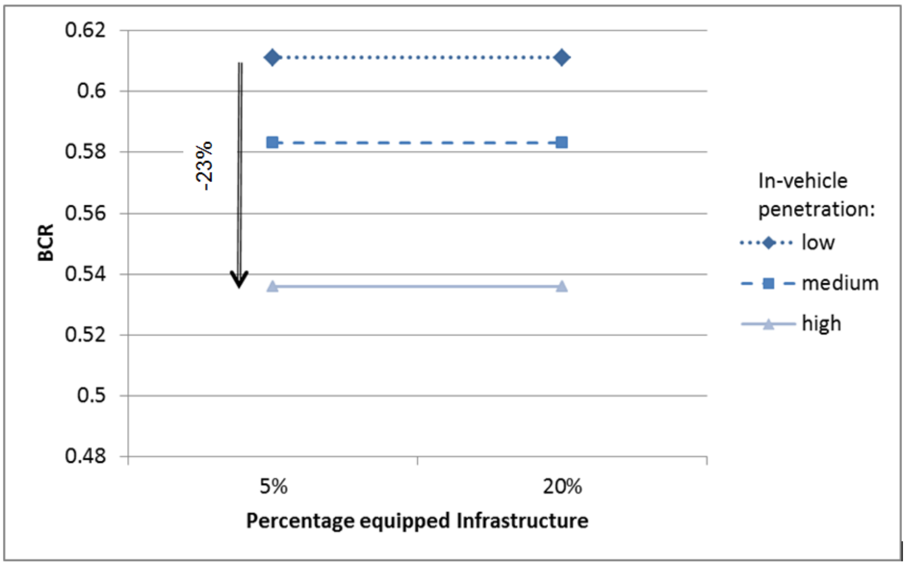

Figure 15 BCRs for the analysed hybrid scenarios

As mentioned earlier, the BCR in the hybrid scenarios does not appear to depend on the percentage of equipped infrastructure. This is highlighted in Figure 15, where the BCR values for two scenarios with the same in-vehicle penetration but different percentage of equipped infrastructure are compared. This is because the costs are dominated by the in-vehicle and not by the roadside beacons costs (Figure 16).

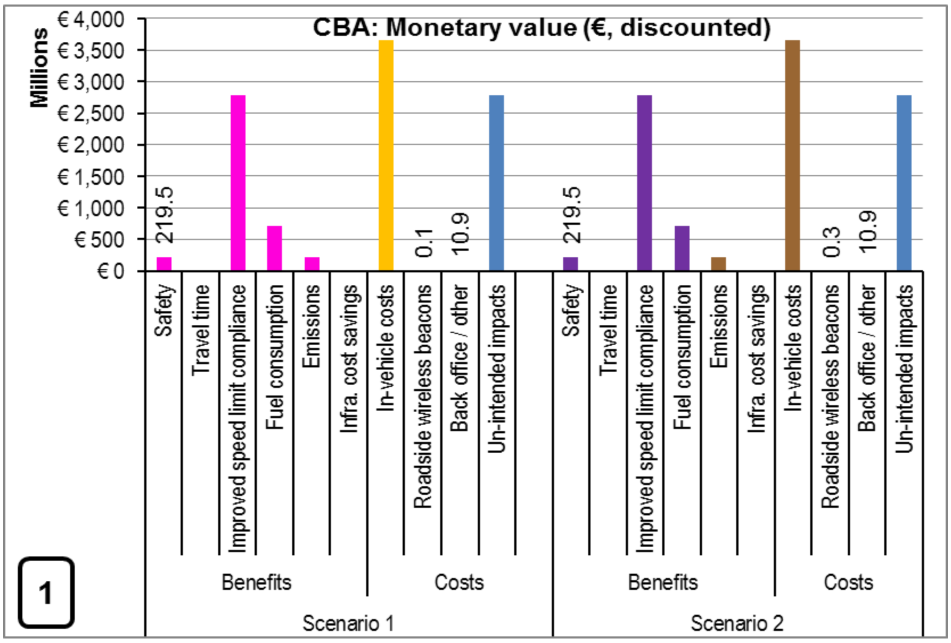

Figure 16 Costs and benefits for hybrid scenarios with low in-vehicle penetration and 5% (scenario 1) and 20% (scenario 2) of equipped infrastructure

3.3.2 *Percentage of costs borne by NRA*

Table 19 summarise the percentage of the costs borne by NRA. It can be noticed that 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 road operator 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.

Table 19 Percentage of cost borne by NRA

Communications platform	Cellular		Hybrid	
Business model	**1a**	**1b**	**7a**	**7b**
In-vehicle penetration - Low	0.18%	0%*		
In-vehicle penetration - Medium	0.15%	0%*		
In-vehicle penetration - High	0.12%	0%*		
In-vehicle Low & 5% Infrastructure equipped for hybrid			55%	4.8%
In-vehicle Low & 20% Infrastructure equipped for hybrid			55%	4.8%
In-vehicle Medium & 5% Infrastructure equipped for hybrid			54%	6.6%
In-vehicle Medium & 10% Infrastructure equipped for hybrid			54%	6.6%
In-vehicle Medium & 20% Infrastructure equipped for hybrid			54%	6.6%
In-vehicle High & 5% Infrastructure equipped for hybrid			53%	9.9%
In-vehicle High & 20% Infrastructure equipped for hybrid			53%	9.9%

* 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 NRA

Another significant difference between the two business models is that when the Road Authorities are in charge of the costs of the service (BM of type a), the percentage of the borne costs decreases as the vehicle penetration increases, while the opposite trend is shown in the case where the user pays for the service. In particular, the percentage of costs borne by the NRA increases from about 5% to 10% in the hybrid scenario with business model type 7b, when the in-vehicle penetration varies from low to high. As mentioned earlier, the cellular scenario with business model 1b does not involve costs for the NRA.

3.3.3 *Cellular scenarios and in vehicle penetration*

Table 20 reports some results for two cellular scenarios in terms of absolute values of costs and benefits from the NRA point of view as well as the societal benefits accrued; while Figure 17 offers a graphical comparison, where the benefits are expressed in terms of monetary values. As mentioned in the previous section and highlighted in Table 19, adopting a business model of the type in which the driver pays for the service would imply for the NRA higher monetary benefits than costs, so that the expenditure would be covered from the first year when the service goes alive. In the other case, the payback year is not reached during the considered time frame and under the assumed monetary costs.

As expected, as a larger number of drivers have access to the service, there are wider impacts on society as a whole. Even if small in terms of absolute figures, the societal benefits, such as, safety, time spent travelling, fuel consumption and, consequently, pollutant emissions, are higher for higher in-vehicle penetration levels.

Table 20 Comparison between cellular scenarios with low and medium in-vehicle penetration

									Absolute impacts in 2030				
In-vehicle penetration	**BM**	**BCR 2030**	**Total cost (billions €)**	**Total benefits (billions €)**	**Payback year NRA**	**Sum cost NRA (billions €)**	**Sum benefits (€) NRA**	**%cost NRA**	**No. Fatalities**	**No. Injuries**	**Travel Time (millions of hours)**	**CO_2 emission (millions tonnes)**	**Fuel consumption (millions litres)**
Low	**1a**	0.57	6.1	3.5	Not before 2030	0.01	0.0	0.18%	-6.2	-311	-33	-0.41	-174
	1b	0.57	6.1	3.5	2016	0.0	2.9	0%	-6.2	-311	-33	-0.41	-174
Medium	**1a**	0.54	7.4	4.0	Not before 2030	0.01	0.0	0.15%	-6.3	-318	-34	-0.42	-177
	1b	0.54	7.4	4.0	2016	0.0	3.2	0%	-6.3	-318	-34	-0.42	-177

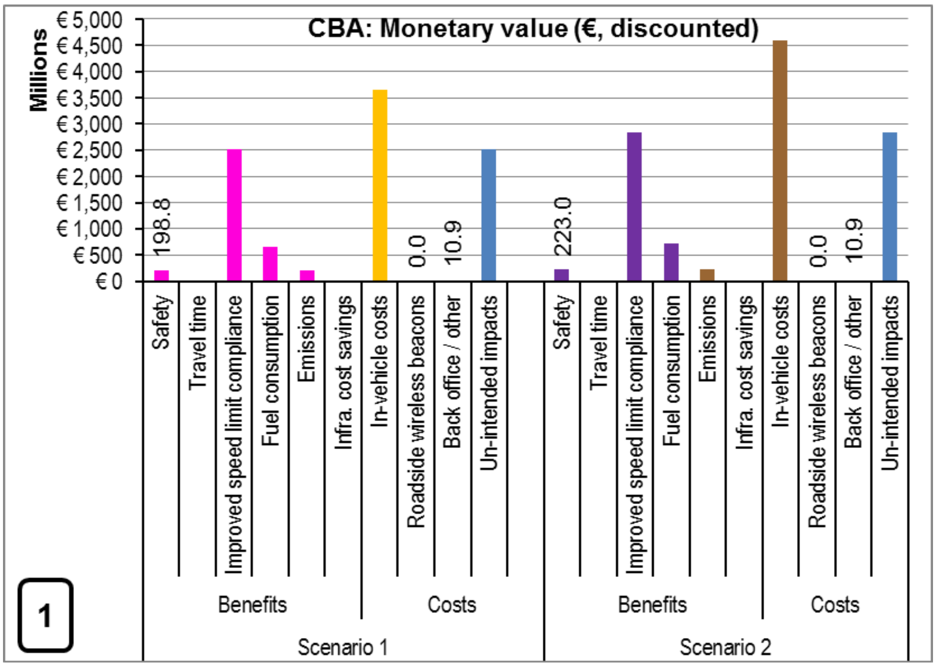

Figure 17 Comparison between two cellular scenarios characterised by the same business model (type 1a in this example) and different in-vehicle devices penetration, low in Scenario 1 and medium in scenario 2

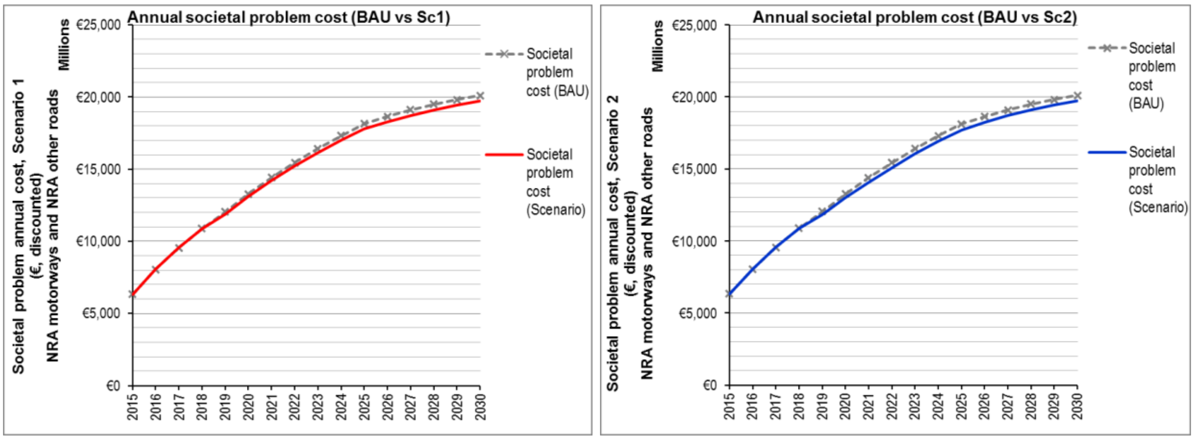

Figure 18 Annual societal problem cost for two cellular scenarios with low and high in-vehicle penetration (Sc1 and Sc2, respectively) compared to the business as usual (BAU)

Figure 18 shows the comparison of the societal costs between two cellular scenarios (low and high n-vehicle penetration in red and blue respectively) and the business as usual case (grey curve). In terms of monetary values the difference from the BAU scenario is not appreciable; neither is the variation between the two cellular scenarios. A similar result is shown in the other use cases.

3.3.4 *Hybrid scenarios comparisons*

As noted in section 3.3.1, a higher percentage of equipped infrastructure does not seem to correspond to higher societal benefits. In fact, even increasing the percentage of equipped infrastructure to 20%, but leaving a low in-vehicle penetration, would not lead to higher figures than those reported in the first row in Table 21 as benefit. This is due to the fact that they are masked by the considerable higher in-vehicle costs (see also Figure 19). What we observe is that the independent variable is actually the in-vehicle penetration, which leads to higher costs, but also to higher benefits for society. For example, based on the working assumptions, going from low to high in-vehicle penetration would imply having about 80 fewer people injured and saving an additional 200 thousand tonnes of CO_2 in the final year.

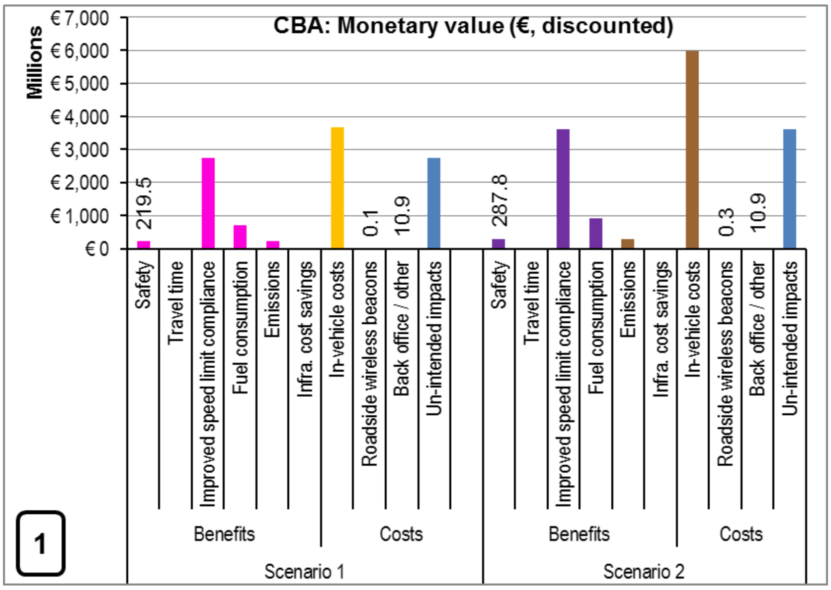

Figure 19 Comparison between two hybrid scenarios. On the left chart: low in-vehicle penetration and 5% of equipped infrastructure. On the right chart: high in-vehicle penetration and 20% of equipped infrastructure.

Table 21 Comparison between two hybrid scenarios; 5% equipped infrastructure and low in-vehicle penetration compared with 20% equipped infrastructure and high in-vehicle penetration.

									Absolute impacts in 2030				
In-vehicle penetration & %infrastructure	**BM**	**BCR 2030**	**Total cost (billions €)**	**Total benefits (billions €)**	**Payback year NRA**	**Sum cost NRA (billions €)**	**Sum benefits (€) NRA**	**%cost NRA**	**No. Fatalities**	**No. Injuries**	**Travel Time (millions of hours)**	**CO$_2$ emission (millions tonnes)**	**Fuel consumption (millions litres)**
Low & 5%	**7a**	0.61	6.4	3.9	Not before 2030	3.5	0.0	54.5%	-7	-340	-36	-0.4	-190
	7b	0.61	6.4	3.9	Not before 2030	0.3	0.0	4.8%	-7	-340	-36	-0.4	-190
High & 20%	**7a**	0.53	9.6	5.1	Not before 2030	5.1	0.0	52.9%	-8	-426	-45	-0.6	-238
	7b	0.54	9.6	5.1	Not before 2030	0.9	0.0	9.9%	-8	-426	-45	-0.6	-238

3.3.5 *Cellular and hybrid scenarios comparison*

As mentioned in item 1 in section 3.3.1, the comparison between communication platforms for two otherwise identical scenarios, reveals that the BCR is slightly higher for hybrid implementations. An example for two scenarios with high in-vehicle penetration (and 20% of equipped infrastructure for the hybrid scenario) is shown in Figure 20. Costs are more than the double than the benefits for the cellular scenario (by a factor of 2.2); the proportion is lower for the hybrid scenario (1.9). Overall the net cost is similar for the two cases, €4.8 billion and €4.5 billion for the cellular and hybrid scenario respectively.

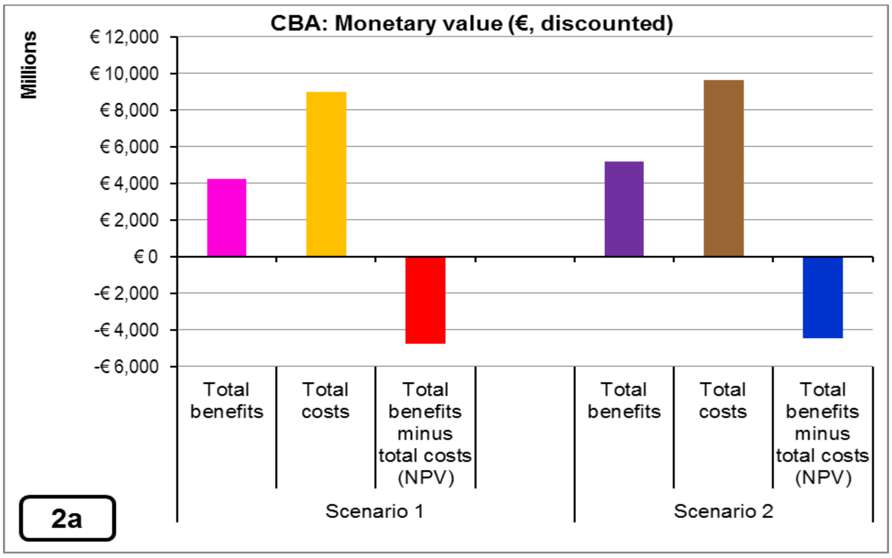

Figure 20 Comparison between a cellular scenario (Scenario 1) and a hybrid scenario with 20% of infrastructure equipped for ITS-G5 (Scenario 2). Both scenarios have high in-vehicle penetration.

The overall difference in the cumulative societal benefits is of about €0.9 billion in favour of the hybrid scenario, split as shown in Table 22; also the overall costs are higher (of approximately one billion euros in the example, see Table 23) mainly due to a higher travelling time.

Table 22 Benefit comparison between a cellular scenario and a hybrid scenario with 20% of infrastructure equipped for ITS-G5. Both scenarios have high in-vehicle penetration.

Communications platform	**Safety**	**Improved speed limit compliance**	**Fuel consumption**	**Emissions**
Cellular, **medium In-vehicle penetration**	€0.23 billions	€2.9 billions	€0.76 billions	€0.24 billions
hybrid, **medium In-vehicle penetration, 10% Infrastructure equipped**	€0.29 billions	€3.6 billions	€0.94 billions	€0.29 billions

Table 23 Comparison between a cellular scenario and a hybrid scenario with 20% of infrastructure equipped for ITS-G5. Both scenarios have high in-vehicle penetration.

									Absolute impacts in 2030				
Scenario	**Communication platform**	**In-vehicle penetration & % equipped infrastructure**	**BCR 2030**	**Total cost (billions €)**	**Total benefits (billions €)**	**Payback year NRA**	**Sum cost NRA (billions €)**	**%cost NRA**	**No. Fatalities**	**No. Injuries**	**Travel Time (millions of hours)**	**CO_2 emission (millions tonnes)**	**Fuel consumption (millions litres)**
1	**Cellular**	High	0.47	8.9	4.2	Not before 2030	0.01	0.12%	-6	-294	-31	-0.4	-162
2	**Hybrid**	High & 20%	0.54	9.6	5.1	Not before 2030	5	53%	-8	-426	-45	-0.5	-238

3.4 Conclusions

The use cases investigated scenarios for C-ITS deployment to provide in-vehicle signage services (Bundle 2), along the A2/M2 corridor in England in which existing road sign infrastructure is not phased out during the assessment period. Through the COBRA+ Tool the potential societal impacts, as well as the monetary implications for the NRA, were investigated. From the comparison of the scenarios it was possible to explore the effects of parameters such as the communication platform, the level of in-vehicle penetration, the percentage of infrastructure equipped for ITS-G5 communications and the business model. In particular, the impact on the Benefit Cost Ratio (BCR), the payback year and the percentage of costs for the National Road Authorities (NRA) were analysed.

The results showed that the BCR was well below one for all the scenarios, ranging between 0.5 and 0.6. In particular, cellular communications results tend to be less advantageous from this point of view; this can be explained by the lower communication costs of the ITS-G5 platform compared with the costs of data communications on cellular networks.

Higher in-vehicle penetration levels correspond to smaller BCRs, implying that the higher benefit arising from more widespread use of the in-vehicle signage services do not compensate for the increase in the communication costs. The weight of these costs is evident also in the hybrid scenarios with different percentages of the road network equipped with ITS-G5 technology. In fact, the BCR was not more favourable for higher percentages of equipped road network, as one might expect, showing that the effect is actually masked by the presence of relatively high in-vehicle costs. Thus, of the scenarios analysed, the results show that the best option from the BCR point of view is a hybrid scenario with low in-vehicle penetration level.

The analysis of the percentage of costs borne by the NRA shows that if the business model is of type a (i.e. the service is paid by the NRA) these costs can be as small as 0.1%-0.2% for cellular scenarios, and between 53% and 55% for hybrid scenarios. If the business model is type b (where the user pays for the service) the proportion of costs borne by the NRA is 5%-10% if the communication platform is hybrid while the NRA accrues benefits if cellular communication is used. Of the scenarios analysed, this last scenario is the only one in which the payback year is reached before 2030.

The results indicate that although deployment of in-vehicle signage services on the corridor would be expected to result in societal benefits in reduced deaths and injuries, shorter journey times and lower fuel consumption and emissions over the period to 2030, under the scenarios analysed these benefits are outweighed by the costs of providing the services, and particularly the communication costs – data costs in the cellular scenarios and the costs of deploying beacons for ITS-G5 communications in the hybrid scenarios. Hardware and data communication costs were discussed in Deliverable 4.1 [Nitsche et. al., 2017]. The in-vehicle equipment costs were estimated to be approximately €173 and €100 for the OEM and the aftermarket devices, respectively; while the annual subscription and communications costs about €13. The cost for the Roadside ITS-G5 beacons and their installation on existing or new poles/gantries was €4.500 and €13.500, respectively; while the operation and maintenance expenditure per unit was estimated to be around €493. The costs are a sensitive factor in determining BCR; different assumptions about these costs could be made which could lead to a substantially different outcome. These costs could be re-visited in future work.

Faced with these results, an NRA using the COBRA+ tool might then investigate other options. These could include establishing a wider range of services based on the same communications infrastructure, thus improving the BCR and bringing forward the payback year, or investigating a longer time horizon in which it might be feasible to start phasing out existing infrastructure as it reaches the end of its life, thus reducing on-going costs to the NRA.

4 Use Case Austria

4.1 Introduction

The Austrian motorway and expressway network is managed and operated by ASFINAG and comprises 2,200 km of roads. This includes about 380 km of tunnels and 340 km bridges. In accordance with the conditions of the Federal Highways Toll Act 2002, ASFINAG is authorised, depending on the maximum permissible weight of the vehicle used, to collect a time-based toll (toll sticker for vehicles up to and including 3.5 tonnes) or a mileage-based toll (over 3.5 tonnes). The revenues flow exclusively into building, financing and maintaining the roads.

The mileage-based toll is collected by a fully electronic truck tolling system in a multi-lane configuration, which allows tolling to occur while vehicles are travelling. This free-flow system is characterized by gantries placed above the lanes, using transceivers mounted on the gantries to communicate with on-board units (OBUs) 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 (see Figure 21). ASFINAG intends to use the gantries for the installation of ITS-G5 beacons for cooperative traffic services.

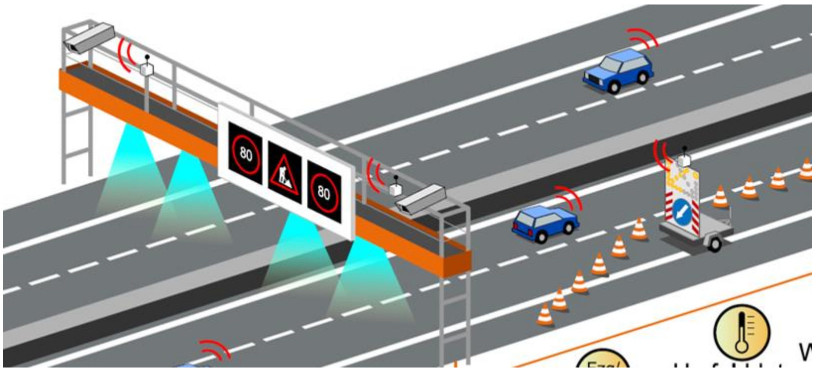

Figure 21: Gantry-based C-ITS infrastructure on the ASFINAG road network

Austria is a partner in the Cooperative ITS Corridor project. ECo-AT (European Corridor – Austrian Testbed for Cooperative Systems) is the Austrian project to create harmonised and standardised cooperative ITS applications jointly with partners in Germany and the Netherlands. ECo-AT is structured into two phases. The result of phase 1 is a full system specification for C-ITS, which is tested and verified by the ECo-AT industry partners and by 3rd parties (until 03/2017). Thereafter in phase 2, ASFINAG is the only partner of the ECo-AT project and performs, after positive evaluation of the framework conditions, the tendering of the C-ITS system. All “use cases” (i.e. cooperative traffic services) deployed in the scope of ECo-AT Phase 2 are called “Day 1 use cases”:

1. **Road Works Warning (RWW)**: drivers get information of road works ahead, their relevant parameters and associated obstructions (e.g. closed lanes).
2. **In-Vehicle Information (IVI)**: drivers get information about present speed policy/advices and other relevant (hazard) information.
3. **CAM, DENM Aggregation**: the collection of anonymized information from vehicle ITS stations enlarges the information basis for traffic management decisions. This is the pre-stage for Probe Vehicle Data (day 2).
4. **Intersection Safety (ISS)**: cooperative Traffic Lights will provide information on their status (SPaT – Signal Phase and Timing).
5. **Other DENM based applications**: DENM messages can be generated by stationary ITS stations and contain hazardous locations warnings.

6. **Multimodal information (MIF)**: the provision of multimodal information is an option which will be analysed within a feasibility study.

In ANACONDA, a certain section of the ECo-AT corridor is analysed, namely the A1 motorway from Vienna West to Linz (exit Ansfelden) (see ***Figure 22***). It comprises 171 km of road and consists of areas with densely equipped ITS infrastructure around Linz and Vienna as well as areas with fewer infrastructure available. The following ANACONDA C-ITS services will be analysed:

- **Bundle 1 (Local Dynamic Event Warnings)**, which includes “RWW“ and “Other DENM based applications”
- **Bundle 2 (In-Vehicle Signage)**, which corresponds to the “IVI“ use case in ECo-AT. The use cases “Intersection Safety“ and “Multimodal Information“ are not considered in this analysis.

Figure 22: The Austrian C-ITS corridor analysed in ANACONDA

4.2 Scenarios analysed

4.2.1 Fixed parameters

The common characteristics to all the scenarios analysed are summarised in Table 24. Apart from the C-ITS corridor, it has been agreed that the communication platform will be hybrid, with the ITS G5 beacons mounted on existing overhead gantries. The business model is 4b, where the driver pays for the service that is offered by ASFINAG as a public body. It is assumed that the aftermarket/smartphone vehicle penetration is low. The deployment is planned to start in 2017 and to end in 2020, with the service going live in 2019. Also in 2019 it is assumed that the costs are borne by the back office.

The ITS-G5 beacons will be installed on existing gantries to 100% on the motorway and expressway network, with an approximate number of 1 beacon every 4 km. In-vehicle CAPEX and OPEX costs as well as development costs are not included in the analysis. The parameter “Take account of cost savings (from reducing current infrastructure provision)” has been set to “Yes”. While this option has been discussed for the Netherlands to find the balance between reducing the legacy systems with deployment of C-ITS, this is currently not a particular goal for ASFINAG. However, in this use case the possible effect of reducing the costs of traffic management equipment is demonstrated, assuming that novel C-ITS will provide as good or even better traffic and transport services.

Table 24: List of the characteristics in common among the analysed scenarios for Austria

Fixed elements	Value
Geographic area (network or corridor)	A1 corridor
Communications platform	Hybrid
Role/business model	4b - Hybrid - public - Driver pays service
Aftermarket/Smartphone vehicle penetration curve	Low
Start year for deployment of ITS-G5 wireless beacons roadside units	2017
End year for deployment of ITS-G5 wireless beacons roadside units	2020
% of the ITS-G5 beacons that are installed on existing poles / gantries	100
% of the ITS-G5 beacons that are installed on new poles	0
% of the ITS-G5 beacons that are installed on the NRA’s motorways	100
% of the ITS-G5 beacons that are installed on the NRA’s other roads	0
Year that the service goes live (i.e. when start accruing benefits)	2019
Year that the costs are borne from the back office	2019
Include in-vehicle CAPEX costs in the calculation?	No
Include in-vehicle OPEX costs in the calculation?	No
Include development costs?	No
Take account of cost savings (from reducing current infrastructure provision)	Yes
Time horizon	2030

4.2.2 *Variable parameters*

There are basically two variable elements in the Austrian Use Case analysis, namely the OEM vehicle penetration curve, which is varied between low and medium, as well as the percentage of infrastructure equipped with ITS-G5 wireless beacons. For this use case, it is assumed that only overhead toll gantries will be equipped with beacons. The estimated number of gantries is one every 4 km, i.e., 43 gantries on the selected corridor of 171 km. The percentage of equipped gantries is varied between 25%, 50% and 75%. Assuming a coverage of 0.33 km range of ITS-G5 communication, this equals a total coverage of 2.07%, 4.15% and 6.22% for the whole network.

In the scope of ECo-AT, ASFINAG will deploy their own C-ITS bundle, as mentioned above. In principle, this is a combination of the ANACONDA bundles 1 and 2. Since they are separated in the tool, the bundles will be a third variable element and analysed individually.

Table 25: List of the characteristics which differentiate the analysed scenarios for Austria

Variable elements	Value
Service or bundle	Bundle 1 (Local Dynamic Event Warnings) / Bundle 2 (In-Vehicle Signage)
OEM vehicle penetration curve	low / medium
% of infrastructure equipped with ITS-G5 wireless beacons roadside units in end year	2.07 / 4.15 / 6.22 (equivalent to 25 / 50 / 75% equipped gantries)

4.3 Analysis of results for Local Dynamic Event Warnings

The following sections discuss the effects of the parameter variations for the C-ITS Bundle 1 (Local Dynamic Event Warning). The graphs are extracted from the COBRA+ tool and are described in detail. Note that all costs and benefits are calculated until the year 2030.

4.3.1 Effects of varying percentage of infrastructure equipped

4.3.1.1 NRA-specific costs and benefits

The first part of this use case analysis explores the differences between varying levels of ITS-G5 infrastructure equipment on the corridor. Figure 23 shows the monetary value of the infrastructure cost savings (benefits, i.e. "negative costs") and the main types of costs to the road authority until 2030. Assuming that infrastructure savings are taken into account, this reduces the costs incurred in maintenance and operation of the existing road infrastructure. Compared to the business as usual scenario, these are benefits: They represent funds that would have been spent in the reference scenario but they are not. However, removal of current legacy systems result in a decrease in safety, increase in travel time and/or increase in emissions.

Two scenarios are compared to each other, namely Scenario 1 with 25% of the overhead gantries equipped with ITS-G5 beacons and Scenario 2 with 75% equipped gantries. Note that all of the following results are based on the setting "OEM vehicle penetration curve: Low". Differences between low and medium penetration will be analysed in a later section.

Increasing the percentage of equipped gantries from 25% to 75% would result in an increase of the costs for installation as well as annual operation and maintenance of the beacons. For both scenarios, the cost savings due to a continuous removal of existing ITS infrastructure such as VMS equipment are the same. Due to the selected business model 4b, where the driver pays for the service and in-vehicle equipment, there are no in-vehicle costs to be borne by the NRA. However, back office costs would have to be borne by the NRA for operating the C-ITS services.

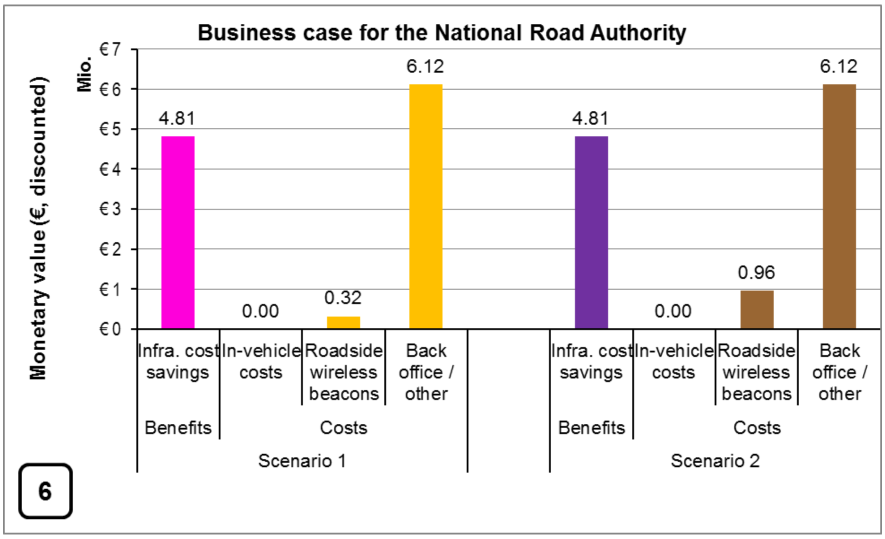

Figure 23: Total benefits and costs for the road authority until 2030, for 25% equipped gantries (Scenario 1, left) compared to 75% equipped gantries (Scenario 2, right), C-ITS Bundle 1 (Local Dynamic Event Warnings)

Figure 24 shows the total monetary value of the direct benefits (cost savings) and costs to the road authority and the total net costs. The sum of benefit and cost values is negative with -1.63 Mio. euros for Scenario 1 and -2.27 Mio. euros for Scenario 2, which means that the payback year will not be before 2030. However, note that societal benefits such as savings due to increased safety, improved speed limit compliance or reduced emissions and fuel consumption are not included in this calculation, but described in Section 4.3.1.2.

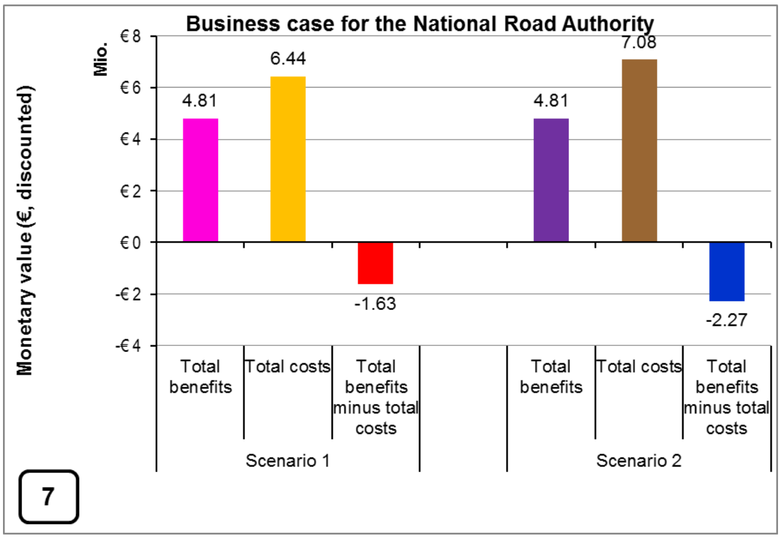

Figure 24: Sum of total benefits and costs for the road authority until 2030, for 25% equipped gantries (Scenario 1, left) compared to 75% equipped gantries (Scenario 2, right), C-ITS Bundle 1 (Local Dynamic Event Warnings)

Figure 25 shows the calculated annual costs for ASFINAG from 2015 to 2030, for Scenario 2 with 75% equipped gantries. In 2019, when the services start accruing benefits and the costs are borne by the NRA, the overall costs increase to 2.6 Mio. Euros, including 2.35 Mio. Euros for back office and traffic management centre, 188,000 Euros for additional back office costs and 172,000 Euros for ITS-G5 beacons. The latter investment is taken from 2018 to 2020, as well as 10 years later for replacement. Accordingly, replacement costs for the back office occur after a period of 10 years.

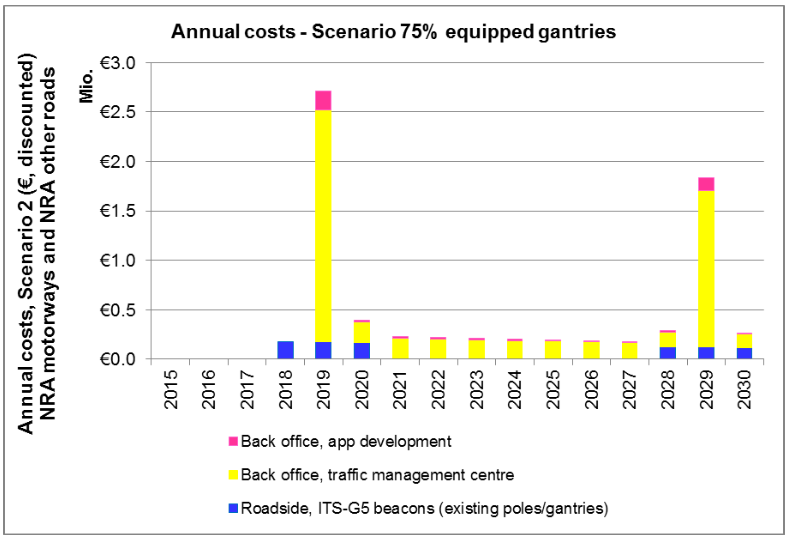

Figure 25: Annual costs for ASFINAG with 75% equipped gantries and low OEM in-vehicle penetration curve, C-ITS Bundle 1 (Local Dynamic Event Warnings)

For a better visualisation of total costs and benefits, Figure 26 depicts the cumulative values from 2015 to 2030. As Figure 24 already showed, the costs reach a maximum of 6.44 Mio. and 7.08 Mio. in 2030, for Scenario 1 and 2 respectively. The two steep inclines in 2019 and 2029 correspond to the investment in and the replacement of the back office.

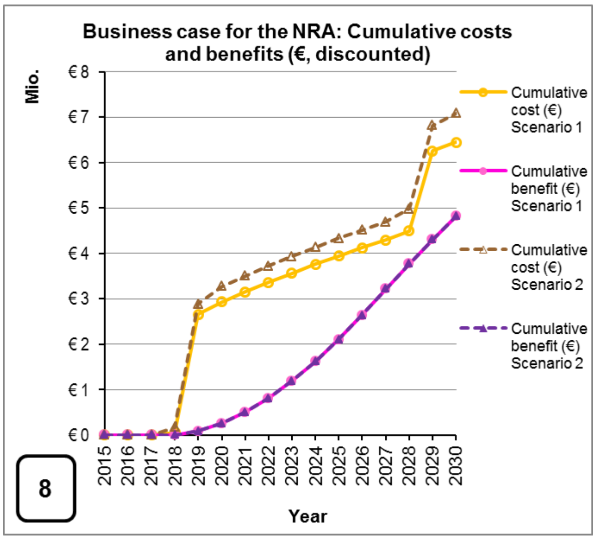

Figure 26: Cumulative costs and benefits per year (Scenario 1: 25% equipped gantries, Scenario 2: 75% equipped gantries), C-ITS Bundle 1 (Local Dynamic Event Warnings) and low OEM in-vehicle penetration curve

4.3.1.2 Societal benefits and costs

Figure 27 shows the distribution of the monetary value of the main types of benefits and costs for Scenario 1 (left, 25% equipped gantries) and Scenario 2 (right, 75% equipped gantries). The graph includes the unintended impacts, which are the benefits that may be seen as negative (such as additional travel time). Note that “Travel time” also appears as benefit due to speed reduction. In fact, this case implies improved speed limit compliance, therefore longer travel times cannot be considered as a dis-benefit.

In Figure 27, it can be seen that Bundle 1 affects safety benefits only, according to the ANACONDA impact assessment study (see Deliverable 4.1 [Nitsche et. al., 2017]). Besides the change of wireless beacon costs, there is only one difference between the two scenarios, namely the safety benefits. They increase slightly from 31.463 to 31.502 Mio. Euros until 2030. This can be explained by the slightly higher number of drivers informed about local dynamic events.

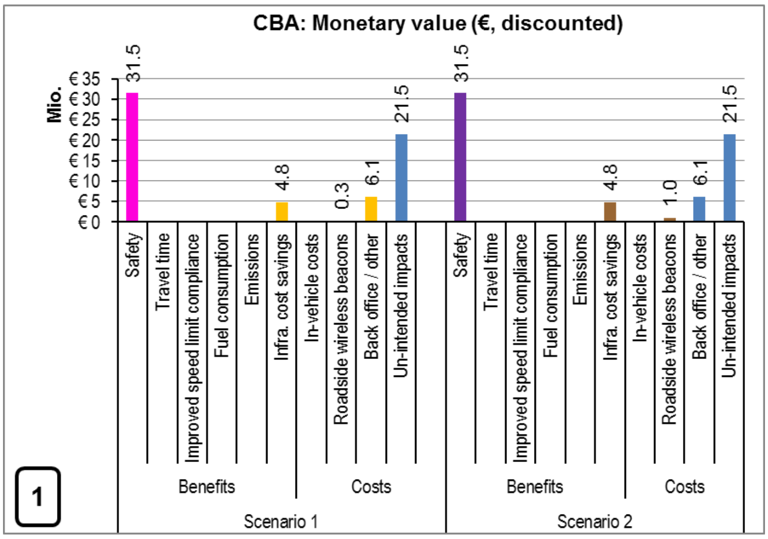

Figure 27: Benefits and costs for Scenario 1 (left, 25% equipped gantries) and Scenario 2 (right, 75% equipped gantries), C-ITS Bundle 1 (Local Dynamic Event Warnings) and low OEM in-vehicle penetration curve

Figure 28 depicts the comparison between the two scenarios (25% vs. 75% equipped gantries) of the BCR over time (cumulative benefits divided by cumulative costs). In 2030, Scenario 1 shows a BCR of 2.07 compared to Scenario 2 with 2.02. There is a drop of the BCRs in 2029, when the back-office replacement costs occur.

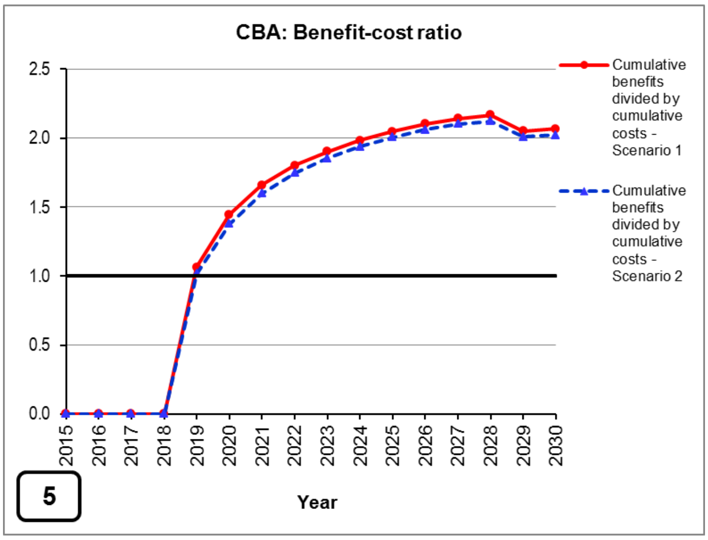

Figure 28: Benefit-cost ratios by year (Scenario 1: 25% equipped gantries, Scenario 2: 75% equipped gantries), C-ITS Bundle 1 (Local Dynamic Event Warnings) and low OEM in-vehicle penetration curve

4.3.2 *Effects of low vs. medium OEM vehicle penetration*

For estimating the OEM vehicle penetration curves, it has been considered that in the base year 2015 there are no such vehicles, that is, the penetration of factory built-in in-car components is 0%. The rate assumed for the new vehicles for the low scenario is an increase of 1% per year for eleven years and 2% the last three years. This small increment allows for the possibility of alternative technologies overtaking it or a financial crash slowing developments. The high penetration scenario assumes there will be an EC mandate for equipping all new models in 2020, which would become effective from 2024; therefore, considering the vehicles model lifecycle, we have that all new vehicles would be equipped from 2032. The medium penetration curve is a middle way between the two extremes.

This analysis investigates low and medium penetration (see ***Figure 29***):

- **Low**: 1% penetration in 2017, 1% increase per year until the late 2020s, 2% increase later on.
- **Medium**: 2% penetration in 2017, 1.5% increase for four years, 2% increase for the following four years, 5% increase later on.

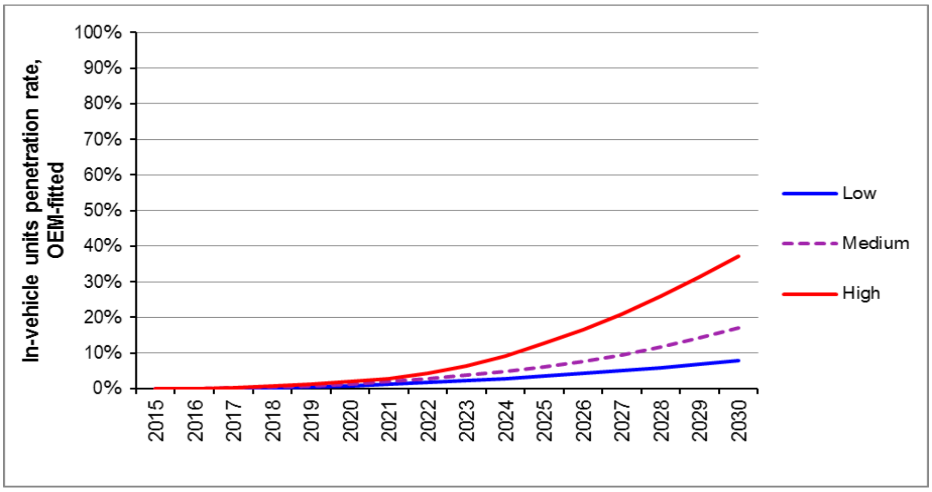

Figure 29: Three curves available to select for penetration rate of OEM in-vehicle equipment

It can be expected that an increase in the OEM vehicle penetration curve will affect the number of informed drivers and hence the benefits of increased safety, travel time or emissions. On the other hand, it can be expected that there is no effect on the NRA business case, because it won't affect the costs for roadside C-ITS installation, operation and maintenance or cost savings due to reduced existing infrastructure. Both assumptions were confirmed by the tool's results, as given in Figure 30. The safety benefit slightly increases from 31.5 Mio. (Scenario 1/low) to 32.6 Mio. Euros (Scenario 2/medium), with the percentage of equipped gantries set to 75%. All other values remained the same.

In Figure 31, the BCR curve over time shows that the difference of the two scenarios low vs medium increases with time, which corresponds to the penetration curves in Figure 29.

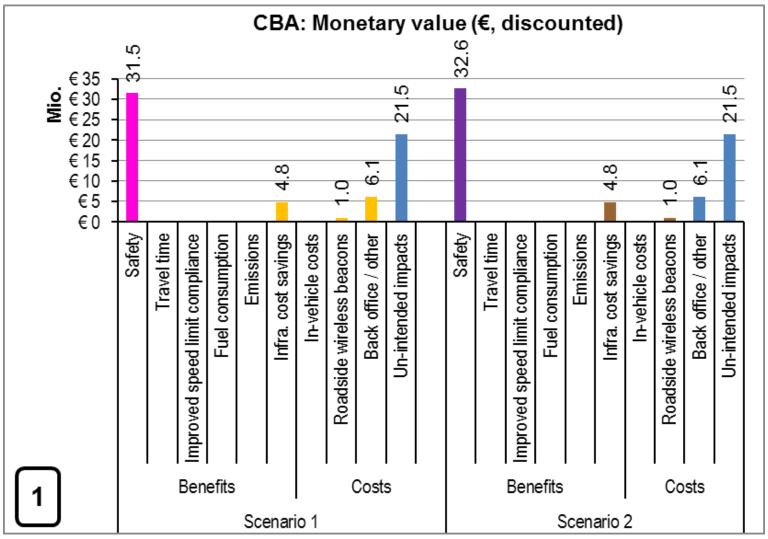

Figure 30: Benefits and costs for Scenario 1 (left, low OEM vehicle penetration) and Scenario 2 (right, medium OEM vehicle penetration), for 75% equipped gantries and C-ITS Bundle 1 (Local Dynamic Event Warnings)

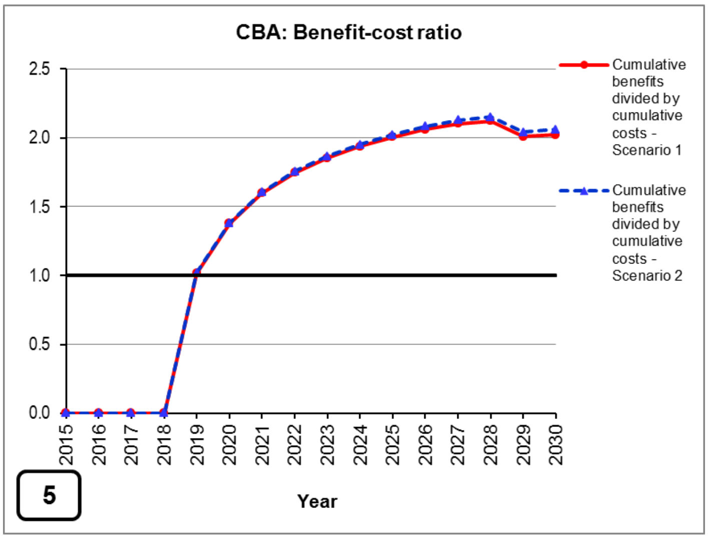

Figure 31: Benefit-cost ratios by year for Scenario 1 (red, low OEM vehicle penetration) and Scenario 2 (blue, medium OEM vehicle penetration), for 75% equipped gantries and C-ITS Bundle 1 (Local Dynamic Event Warnings)

4.4 Analysis of results for In-Vehicle Signage

The following sections discuss the effects of the parameter variations for the C-ITS Bundle 2 (In-Vehicle Signage). The graphs are extracted from the COBRA+ tool and are described in detail.

4.4.1 Effects of varying percentage of infrastructure equipped

Compared to Local Dynamic Event Warnings, there are no differences in the direct costs and benefits for the road authority, i.e., in terms of infrastructure cost savings, ITS-G5 beacon costs or back office costs. This is because development costs such as research, prototyping, testing, rollout as well as regular operation, which might differ between the different C-ITS services, are not taken into account in this analysis. However, there are differences, when analysing the overall societal benefits and costs, as Figure 32 shows. It depicts the distribution of the monetary value of the main types of benefits and costs for Scenario 1 (left, 25% equipped gantries) and Scenario 2 (right, 75% equipped gantries), both with low OEM vehicle penetration. The graph includes the unintended impacts, which are the benefits which may be seen as negative (such as additional travel time).

In general, In-Vehicle Signage has lower benefits in terms of safety than Local Dynamic Event Warnings, but strongly affects improved speed limit compliance, fuel consumption and emissions. It can further be observed that all benefits remain the same in Scenario 2. The unintended impacts, i.e., costs of additional travel time, do not change either. Not surprisingly, the costs for wireless beacons increase from 0.32 Mio. euros to 0.96 Mio euros, as for Local Dynamic Event Warnings.

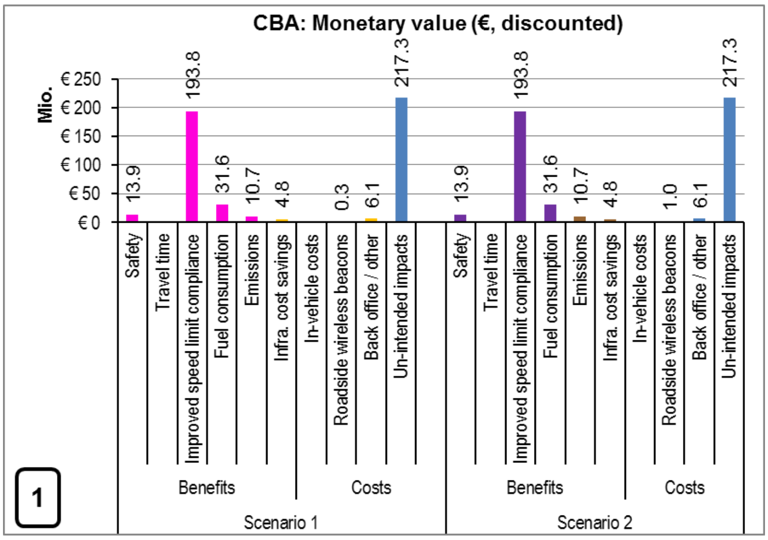

Figure 32: Benefits and costs for Scenario 1 (left, 25% equipped gantries) and Scenario 2 (right, 75% equipped gantries), for low OEM vehicle penetration and C-ITS Bundle 2 (In-Vehicle Signage)

Figure 33 depicts the comparison between the two scenarios (25% vs. 75% equipped gantries) of the BCR over time (cumulative benefits divided by cumulative costs). In 2030, Scenario 1 has the same BCR as Scenario 2 with 1.24. In general, In-Vehicle Signage results in lower BCRs than Local Dynamic Event Warnings, mainly due to the unintended impacts of increased travel time.

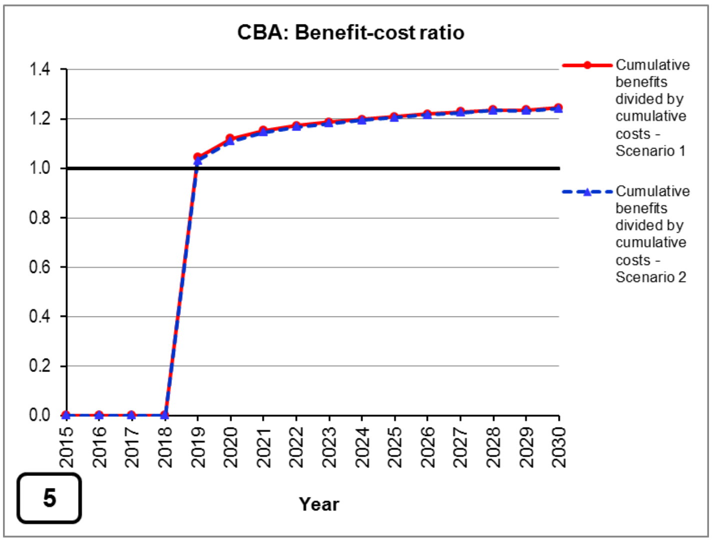

Figure 33: Benefit-cost ratios by year (Scenario 1: 25% equipped gantries, Scenario 2: 75% equipped gantries), for low OEM vehicle penetration and C-ITS Bundle 2 (In-Vehicle Signage)

4.4.1 *Effects of low vs. medium OEM vehicle penetration*

As in Local Dynamic Event Warnings, it can be expected that an increase of the OEM vehicle penetration curve will affect the number of informed drivers and hence the benefits of increased safety, travel time or emissions. On the other hand, it can be expected that there is no effect on the NRA business case, because it does not affect the costs for roadside C-ITS installation, operation and maintenance or cost savings due to reduced existing infrastructure. Both assumptions were confirmed by the tool's results, as given in Figure 34. The safety benefit slightly increases from 13.9 Mio. (Scenario 1/low) to 14.4 Mio. euros (Scenario 2/medium) in 2030. In-Vehicle Signage has major impacts on improved speed limit compliance, fuel consumption and emissions. The cost savings due to those benefits also increase with an increased OEM vehicle penetration.

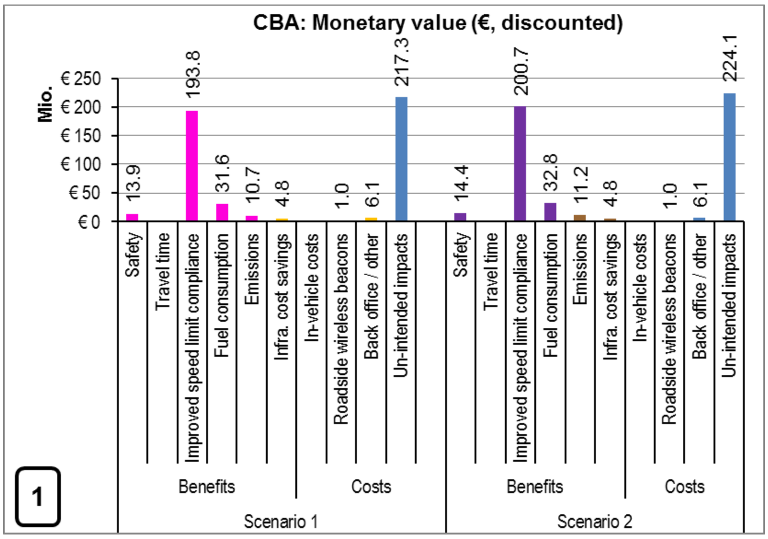

Figure 34: Benefits and costs for Scenario 1 (left, low OEM vehicle penetration) and Scenario 2 (right, medium OEM vehicle penetration), for 75% equipped gantries and C-ITS Bundle 2 (In-Vehicle Signage)

In Figure 35, the BCR curve over time shows that both scenarios (low vs medium) remain the same until 2030.

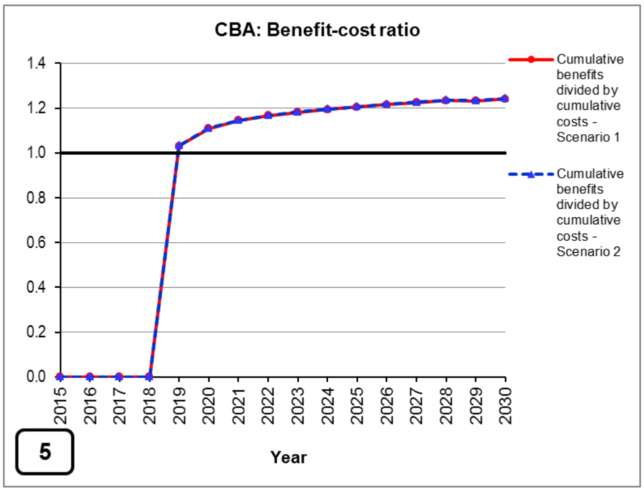

Figure 35: Benefit-cost ratios by year for Scenario 1 (red, low OEM vehicle penetration) and Scenario 2 (blue, medium OEM vehicle penetration), for 75% equipped gantries and C-ITS Bundle 2 (In-Vehicle Signage)

4.5 Summary of benefit cost ratios in 2030

Table 26 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 BCRs (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. Overall, the most favourable combination (measured by the BCR metric) in this case study is a medium OEM vehicle penetration curve and 25% equipped gantries. A slight decrease of BCR can be seen when increasing the gantry equipment rate to 75%. This can be explained by the limited length of the corridor analysed (171 km), which therefore represents a quite small societal problem size. The smaller the problem size, meaning the level of safety, traffic throughput and environmental problems, the smaller the benefit that can be realized when C-ITS services are deployed. Hence, an increase of gantries equipped with ITS-G5 equipment to 75% does not necessarily create more benefit for this example. A different picture would be drawn if the calculations were done on a larger road network. However, the differences between 25%, 50% and 75% gantry-equipment rate are negligible.

Table 26: BCR and payback year for the given combinations in the Austrian Use Case

C-ITS Bundle	**Bundle 1 Local Dynamic Event Warnings**		**Bundle 2 In-Vehicle Signage**	
	BCR 2030	Payback year	BCR 2030	Payback year
In-vehicle penetration Low & 25% of gantries equipped in 2030	2.07	2019	1.24	2019
In-vehicle penetration Low & 50% of gantries equipped in 2030	2.04	2019	1.24	2019
In-vehicle penetration Low & 75% of gantries equipped in 2030	2.02	2019	1.24	2019
In-vehicle penetration Medium & 25% of gantries equipped in 2030	2.10	2019	1.25	2019

In-vehicle penetration Medium & 50% of gantries equipped in 2030	2.08	2019	1.24	2019
In-vehicle penetration Medium & 75% of gantries equipped in 2030	2.06	2019	1.24	2019

Figure 36 compares the cumulative benefits and costs between Local Dynamic Event Warning and In-Vehicle Signage. The cumulative benefits are much higher for In-Vehicle Signage due to its impacts on speed limit compliance, fuel consumptions and emissions. The costs are higher, too, because of the unintended impacts of travel times.

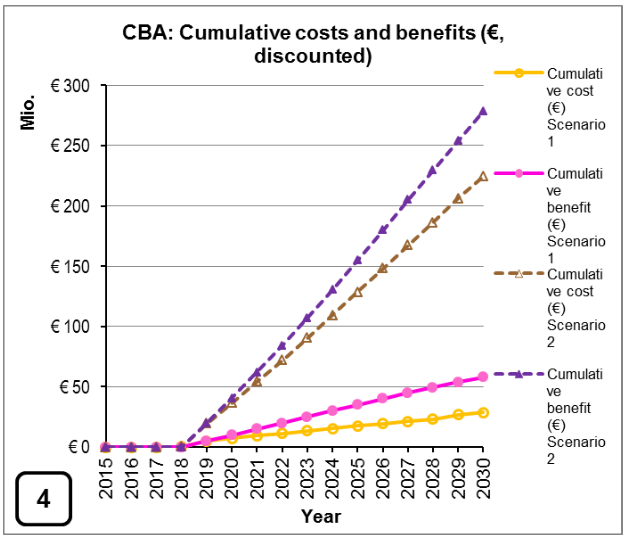

Figure 36: Comparison of the cumulative benefits and costs between Bundle 1 (Scenario 1, yellow/pink) and Bundle 2 (Scenario 2, brown/violet), for low OEM vehicle penetration and 75% equipped gantries.

4.6 Conclusions

The results presented in this report demonstrate how to interpret the graphs and figures created by the COBRA+ Tool, by giving the example of an Austrian C-ITS corridor. Note that the use case calculations are based on a number of assumptions provided by ASFINAG. The case study presented is not intended to deliver recommendations for investments or infrastructure adaptations. The values and assumptions can be modified by the user for further, more detailed cost-benefit analyses.

The analysis was grouped into the two ANACONDA bundles 1) “Local Dynamic Event Warnings” and 2) “In-Vehicle Signage”. The C-ITS services within those bundles will be implemented on the ASFINAG network as part of the ECo-AT project. The main difference between the two bundles is that Local Dynamic Event Warnings has stronger impacts on safety, while In-Vehicle Signage mainly affects travel times and emissions.

ASFINAG is particularly interested in investigating the effects of varying the amount of infrastructure equipped with ITS-G5 beacons, for both low and medium OEM vehicle penetration. For both bundles, the differences between low and medium penetration curve are negligible, i.e. a medium equipment rate of new vehicles has only minor impact on the overall benefits and costs compared to the lower rate.

Furthermore, it could be observed that the societal benefits such as safety, emissions or fuel consumption remain almost the same with an increased percentage of equipped gantries. For Local Dynamic Event Warnings, even a slight decrease of BCR can be seen when increasing the equipment rate to 75%. This can be explained by the limited length of the corridor analysed (171 km), which therefore represents a quite small societal problem size, e.g. with very few fatalities. Overall, the most favourable combination of the twelve scenarios examined in this case study is a medium OEM vehicle penetration curve and equipping 25% of the gantries.

5 Conclusions

This report contains results produced by the COBRA+ Tool for both the Dutch, English and Austrian motorway operator networks. Almost 600 scenarios were analysed for the Dutch case, twenty-two for the English case and twelve for the Austrian case. The English scenarios focused on the A2/M2 Corridor, the Austrian scenarios on the A1 from Vienna to Linz, while the Dutch scenarios examined both the full network as well as the C-ITS Corridor in the Netherlands. The Dutch analyses allow a broader set of conclusions to be drawn. Firstly, similar scenarios from the Dutch and English cases are chosen for comparison to identify similarities and differences. The Austrian scenarios differ greatly from the Dutch and English scenarios and are therefore discussed separately. A broader analysis based on the richness of the Dutch results follows.

Overall, the calculation of benefits and costs of C-ITS deployment in different countries is sensitive to country-specific data and parameter choices in the COBRA+ Tool. Direct comparison between countries should take this background into account in explaining differences in outcomes.

5.1 Comparison of the Dutch and English results

The Dutch and English use cases show similarities and differences in the results. Below, first the results of the analysis of the Corridors where the parameters were similar is discussed. That includes the impact of varying the communications platform (cellular and hybrid), the percentage of the corridor equipped with roadside ITS G5 units in the hybrid scenarios (20% and 25% on the English and Dutch Corridors, respectively), and the effect of the business model choice.

5.1.1 Commonalities in the Dutch and English Use Cases

Both the Dutch and English Use Cases showed commonalities. Firstly, at a given level of in-vehicle penetration, the cellular scenario has a lower BCR compared to the hybrid scenario. Secondly, higher in-vehicle penetration is associated with lower BCRs. This reveals that the service and data communication costs have higher impact in the BCR than the benefits accrued from higher deployment.

5.1.2 Differences between the Use Cases

Differences were found between countries when comparing similar scenarios. The scenarios are: For the Netherlands, the Corridor with either cellular or hybrid (25%) deployment. For England, the corridor with either cellular or hybrid (20%) deployment. For consistency between the use cases, the in-vehicle CAPEX was turned on, and the infrastructure cost savings was turned off.

The BCR on the C-ITS Corridor in the Netherlands is lower than the BCR on the Corridor in England. For the cellular implementation, the BCR for England ranged from 0.47-0.58 with the equipment rate of vehicles and users, while that of the Netherlands ranged from 0.27-0.29. For the hybrid implementation on the corridors, the BCR for equipping 20% of the English Corridor with ITS G5 beacons range from 0.54-0.61. The BCR's for equipping 25% of Dutch corridor are 0.24 - 0.29, when in-vehicle CAPEX is included and infrastructure savings are turned off. Reasons for the higher BCR on the corridor in England are:

- The coverage of the Corridors by legacy systems is higher in the Netherlands than in England: The Dutch Corridor is 100% covered by legacy systems. When C-ITS are deployed, the marginal benefit of the C-ITS contributes to additional benefits, markedly lower than the full benefits if the C-ITS were to be deployed on roadways with no legacy systems. The English Corridor has a lower level of legacy-system coverage: 71% on the motorway and 41% on the other Highways England roads. On the road segments without legacy systems, 100% of the impact of C-ITS can be realized; on the road segments with legacy systems, only the marginal additional benefit of the C-ITS is realized. Overall, a higher impact is expected as a result of deployment of C-ITS on the English Corridor compared to the Dutch Corridor.

- The problem size on the Dutch Corridor is significantly smaller than the English Corridor: The larger the problem size, meaning the level of safety, traffic throughput and environmental problems, on the Corridor, the greater the benefit to be realized when C-ITS are deployed. The problem size on the Corridor in the Netherlands is significantly smaller than for the English Corridor for all the measures – fatalities, serious and slight injuries, injury accidents, etc. To provide some examples, the number of fatalities and severe injuries on the Dutch Corridor are forecast to remain unchanged in the period 2016-2030 at 3 and 12 respectively. Note that the Dutch Corridor only includes motorways. The number of fatalities and severe injuries on the English Motorway Corridor are forecast to increase in the period 2016-2030 from 9 to 34 and 61 to 202, respectively. On the other roads on the Corridor, the number of fatalities and severe injuries on the English Motorway Corridor are forecast to increase in the period 2016-2030 from 12 to 49 and 88 to 292, respectively. Clearly, the absolute impact of the C-ITS deployment will have a large impact on safety in England. Similar conclusions can be drawn for the remaining safety, traffic throughout and environmental problems.

Comparisons between the Dutch corridor and the full road network revealed a consistently higher BCR for the full network for all cellular and hybrid scenarios. Figure 6 illustrates this for one scenario.

Highways England and Rijkswaterstaat requested different business models be investigated. The English Corridor made use of Public business models, whereas the Dutch Corridor analysis made use of Mixed and Private business models. The difference between Public model 1a vs 1b is that the driver pays for the service provided in 1b, whereas the NRA pays for the service in model 1a. In the four business models Mixed 2b (cellular) and 5b (hybrid) and Private 3b (cellular) and 6b (hybrid), the driver pays for the service provided.

Interesting differences emerged among the percentage of costs borne by the NRA over the business models. Table 27 shows that the percentage of costs borne by the NRA for the hybrid deployment on the corridor in the mixed and private business models investigated for the Dutch Corridor are significantly lower than the public models for the English Corridor. The difference between the Public business model 1a and 1b on the English Corridor is that the NRA collects the service payments by the users in model 1b, lowering the net costs paid in this model by the NRA compared to model 1a.

The percentage of costs borne by the NRA for the cellular implementations are low, less than 1% in the use cases examined. It seems counterintuitive that the public models for the cellular implementation for the English Corridor are even lower than the mixed and private business models for the Dutch Corridor, it makes sense. The vehicle-related costs dominate the costs in the cellular deployment. There are fewer differences in the required investments between the public, mixed and private models. However, there are approximately three times as many vehicles in England than in the Netherlands. This greater number of vehicles increases the total costs of deployment significantly, without increasing the costs that need to be borne by the NRA. Therefore, the percentage of costs covered by NRA is smaller for the English Corridor than for the Dutch Corridor.

Table 27: Overview of percentage of costs borne by the NRA

Bundle	**Business Model**	**English Corridor**		**Dutch Corridor -- Infrastructure savings off, including in-vehicle CAPEX**	
In-Vehicle Signage		**Cellular**	**Hybrid** **(20% Roadside equipment ITS G5)**	**Cellular**	**Hybrid** **(25% Roadside equipment ITS G5)**
	Public – 1a	0.12-0.18%	53-55%		
	Public – 1b	0%*	4.8-9.9%		
	Mixed – 2b/5b			<0.9%	<1%
	Private – 3b/6b			<0.35%	<0.5%

* 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 NRA.

5.2 Discussion of the Austrian use case results

The Austrian use case results differ from the other two, because the assumptions of fixed and varying parameters were different. Therefore, a direct comparison with the Netherlands and the UK cannot be made. For example, in-vehicle CAPEX and OPEX costs and development costs were not included in the Austrian analysis. Furthermore, a difference to mention is that only existing toll gantries are assumed to be equipped with ITS-G5 beacons. The coverage of ITS-G5 was therefore calculated by considering an approximate number of gantries within the corridor.

It could be observed that the BCRs for the Austrian use case are much higher (up to 2.10) than for the Netherlands or the UK. This can be partially explained by the exclusion of in-vehicle CAPEX and OPEX costs, and the choices of not including development costs and making use of infrastructure savings. Changing some of these settings results in a lower BCR.

5.3 Further conclusions based on the Dutch analyses

The analysis in the Netherlands made use of the results of almost 600 model outcomes. The most important parameters were varied in order to understand their impacts on decisions in the short- and medium-term. These parameters are Benefit-Cost ratios for the C-ITS Corridor and the full network of Rijkswaterstaat, the bundle of services rolled out, the choice of communication platform and making use of the austerity measure “infrastructure savings”.

The Benefit-Cost ratio is more interesting for the full network than for the C-ITS Corridor. The C-ITS Corridor, a subset of the full network, has few societal problems. The legacy systems coverage of the C-ITS Corridor is very good, and it is much better than many parts of the Rijkswaterstaat road network. Thus, deployment of C-ITS on the C-ITS Corridor results in smaller benefits on a kilometre basis compared to the full network, while incurring the same absolute total vehicle costs (subscription, in-vehicle units) as in the full network. The C-ITS Corridor deployment should thus be seen as a first phase of deployment, with the full potential realised further in the future. Note that for the hybrid scenarios that 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.

The Benefit-Cost ratios for the Local Dynamic Event Warning Bundle are lower than those for the In-Vehicle Signage Bundle. Since the Local Dynamic Event Warning Bundle comprises safety applications, the benefit in the Netherlands is limited in absolute terms due the relatively high level of safety on the Rijkswaterstaat network. Of course, any reduction in fatalities and injuries is extremely valuable, but the absolute numbers remain small. The effect of the Local Dynamic Event Warning Bundle on traffic efficiency and emissions is small. Looking forward to implementation, it can be considered somewhat artificial to focus on a single bundle as it is very likely that the Local Dynamic Event Warning Bundle will be deployed slightly earlier or at the same time as the services in the In-Vehicle Signage Bundle.

The higher Benefit-Cost ratios for hybrid deployment than for the cellular deployment may seem counterintuitive. The data communication costs for all the equipped vehicles in the cellular deployment add up to a very large cost and dominate the total costs in the cellular scenarios. It is important to keep in mind that these data communication costs may change in the future. When these communication costs change, they will have an impact on the benefit-cost ratio for the cellular scenarios.

The fact that the benefits of Vehicle-to-Vehicle (V2V) services are not included in the hybrid scenario benefits result in an underestimation of the hybrid scenario Cost-Benefit ratio. Furthermore, it is hypothesised that the lower latency and the more reliable communication via ITS G5 will result in greater safety benefits when services are provided via ITS G5 rather than 3G/4G cellular. No empirical results are available for these differences. However, the COBRA+ Tool contains an assumption that there ITS G5 is slightly more effective than cellular implementation for two services in the Local Dynamic Event Warning Bundle, resulting in an overall reduced impact of this bundle. Finally, given the focus on the study on the decision-making in the next 2-7 years, cellular 5G was not considered. 5G was considered outside the timeline, due to the uncertainty in the required developments and subsequent standardisation required for the mobility applications.

The infrastructure cost savings option, an austerity measure in which reductions take place in current roadside traffic management equipment, has an enormous influence on the benefits and costs, the Benefit-Cost Ratio, and the payback year for both the National Road Authority and in terms of the socio-economic analysis. Careful analysis of the achieved or required level of C-ITS deployment (roadside and vehicle units) with the timing of the start of decommissioning and the rate of decommissioning over time needs to take place to ensure that levels of road safety, traffic performance and environmental impacts are maintained and improved. Until such analyses have been carried out, the decision to make use of infrastructure savings should be delayed.

6 Glossary and definitions

Aftermarket	In-vehicle device fitted after purchasing the vehicle, usually permanently connected to the vehicle's systems
BAU	Business As Usual
BCR	Benefit Cost Ratio
BM	Business model
CAPEX	Capital costs of equipment to support a service
CBA	Cost Benefit Analysis
Cellular network	Communications platform to support long range communications e.g. mobile phone
GDP	Gross Domestic Product
ITS	Intelligent Transport System
Managed motorways	An integrated set of traffic management systems to improve traffic flow and road capacity; in the UK, they primarily involve variable speed limits and hard shoulder running.
NRA	National Road Authority
OEM	Original Equipment Manufacturer (e.g. vehicle manufacturer)
OPEX	Operational costs of running or using a service
Payback year	The first year in which the cumulative benefits of a service exceed the cumulative costs invested in it
Penetration rate	Proportion of vehicles which are equipped to participate in a service
Queue protection	Automatic traffic management system used to detect sudden traffic disruption and warn traffic approaching the scene to protect vehicles at the back of the queue from rear-end collisions
Smartphone	Mobile telephone used to deliver a variety of other services to users, via Apps
Unintended impact	Dis-benefits occurring as a result of the cooperative system. In calculating the benefit: cost ratio in the tool, these are treated as if they were additional costs
VMS	Variable Message Sign to display a number of messages, and which can be switched on or off as required; various types of sign are available involving different technologies and costs. It is assumed here that these are large signs which can provide several lines of text and colour graphics, providing the existing infrastructure for information delivery for all of the three bundles of services considered here: warnings, speed limits, travel information and route guidance
Wireless beacon	Communications beacon to support short range communications between vehicles and the roadside. It is assumed that each beacon has a range of 300 metres.

7 References

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8 Appendix 1: Use Case Settings the Netherlands

Use case for the Netherlands: tables show fixed elements, variable elements and combinations

Fixed elements	**Values for the Netherlands**
Start year for deployment of ITS-G5 wireless beacons roadside units	2018
End year for deployment of ITS-G5 wireless beacons roadside units	2027
% of the ITS-G5 beacons that are installed on existing poles / gantries	80
% of the ITS-G5 beacons that are installed on new poles	20
% of the ITS-G5 beacons that are installed on the NRA's motorways	80
% of the ITS-G5 beacons that are installed on the NRA's other roads	20
Year that the service goes live (i.e. when start accruing benefits)	2019
Year that the costs are borne from the back office / other costs	2018
Include in-vehicle CAPEX costs?	No
Include in-vehicle OPEX costs?	Yes
Include development costs?	Yes: 4.6MEURO
Time horizon	2030

Variable elements	**Values for the Netherlands**
Geographic area	C-ITS Corridor in the Netherlands / Full Network
% infra equipped in end year (for hybrid)	25% on the Corridor/ 10% on the full network
A service or bundle	Bundle 1 / Bundle 2
Cost savings (for one of the options relevant to the chosen service or bundle): yes or no.	Yes/no
Penetration curve (of aftermarket and OEM):	All combinations of low/medium/high of in-vehicle and aftermarket
Platform	Cellular
Business Model for cellular: mixed 2b – Driver pays service, private 3b -- Driver pays service.	mixed 2b, private 3b
Platform	Hybrid
Business Model for hybrid: mixed 5b, private 6b -- – Driver pays service;	mixed 5b, private 6b

9 Appendix 2: Business Model Summary

1a. Cellular - public - NRA pays service
1b. Cellular - public - Driver pays service
2a. Cellular - mixed - NRA pays service
2b. Cellular - mixed - Driver pays service
3a. Cellular - private - NRA pays service
3b. Cellular - private - Driver pays service
4a. Hybrid - public - NRA pays service
4b. Hybrid - public - Driver pays service
5a. Hybrid - mixed - NRA pays service
5b. Hybrid - mixed - Driver pays service
6a. Hybrid - private - NRA pays service
6b. Hybrid - private - Driver pays service
7a. Hybrid - public - NRA pays service - NRA sponsors device
7b. Hybrid - public - Driver pays service - NRA sponsors device
8a. Hybrid - mixed - NRA pays service - NRA sponsors device
8b. Hybrid - mixed - Driver pays service - NRA sponsors device
9a. Hybrid - private - NRA pays service - NRA sponsors device
9b. Hybrid - private - Driver pays service - NRA sponsors device

10 Appendix 3: Additional Results

Table 28: Benefit-Cost Ratios in Corridor scenarios in which capital costs of in-vehicle equipment are included and excluded

Bundle	Platform	In-vehicle equipment OEM-factory fitted / Aftermarket	Infrastructure savings on		Infrastructure savings off	
			CAPEX off	CAPEX on	CAPEX off	CAPEX on
Bundle 1						
	Cellular	Low/Low	0.20	0.18	0.01	0.00
		Medium/Medium	0.18	0.15	0.00	0.00
		High/High	0.16	0.12	0.00	0.00
	Hybrid	Low/Low	0.24	0.22	0.01	0.01
		Medium/Medium	0.21	0.18	0.01	0.01
		High/High	0.19	0.15	0.01	0.01
Bundle 2	Cellular	Low/Low	0.43	0.40	0.29	0.26
		Medium/Medium	0.41	0.36	0.28	0.24
		High/High	0.39	0.31	0.27	0.21
	Hybrid	Low/Low	0.44	0.42	0.31	0.29
		Medium/Medium	0.43	0.38	0.31	0.27
		High/High	0.42	0.34	0.31	0.24

Table 29, Table 30 and Table 31 contain the parameters for the figures in Chapter 2 of the report.

Table 29: Parameter values for Figure 6: Annual Benefit Cost Ratio on the Dutch Corridor (Scenario 1) vs the full network (Scenario 2) for a hybrid implementation of the In-Vehicle Signage Bundle

and Figure 7: Detailed Benefits and Costs of Scenario 1 (Corridor) and Scenario 2 (Full Network), for a Hybrid Implementation

	Scenario 1	Scenario 2
Country	The Netherlands	The Netherlands
Full NRA Network or corridor	Corridor	Full NRA Network
C-ITS services (bundles or individual)	Bundle 2. In-vehicle signage	Bundle 2. In-vehicle signage
Communications platform	Hybrid	Hybrid
Role/business model	5b. Hybrid - mixed - Driver pays service	5b. Hybrid - mixed - Driver pays service
Aftermarket/Smartphone vehicle penetration curve	Low	Low
OEM vehicle penetration curve	Low	Low
Start year for deployment of ITS-G5 wireless beacons roadside units	2018	2018

End year for deployment of ITS-G5 wireless beacons roadside units	2027	2027
% of infrastructure equipped with ITS-G5 wireless beacons roadside units in end year	0.25	0.1
Include in-vehicle CAPEX costs?	No	No
Include in-vehicle OPEX costs?	Yes	Yes
Include infrastructure cost savings?	Yes	Yes
Time horizon	2030	2030
Parameters: **10**	Number of wireless beacons per km= 3.3; Total number of back offices= 1; Discount rate= 4.5%; Exchange rate= 1.259; For Cellular scenario, the balance (adding up to 100%) between Aftermarket (i.e. some equipment costs) and Smartphone (i.e. no equipment costs)= 20/80 to 0/100	

Table 30: Parameter values for Figure 8: Net Present Value of Total Benefits, Total Costs, and Total benefits minus total costs for Scenario 1 (cellular) and Scenario 2 (hybrid) and Figure 9: Cumulative, Annual Benefit-Cost Ratio of Scenario 1 (cellular) and Scenario 2 (hybrid)

	Scenario 1	**Scenario 2**
Country	The Netherlands	The Netherlands
Full NRA Network or corridor	Full NRA Network	Full NRA Network
C-ITS services (bundles or individual)	Bundle 2. In-vehicle signage	Bundle 2. In-vehicle signage
Communications platform	Cellular	Hybrid
Role/business model	2b. Cellular - mixed - Driver pays service	5b. Hybrid - mixed - Driver pays service
Aftermarket/Smartphone vehicle penetration curve	Low	Low
OEM vehicle penetration curve	Low	Low
Start year for deployment of ITS-G5 wireless beacons roadside units	2018	2018
End year for deployment of ITS-G5 wireless beacons roadside units	2027	2027
% of infrastructure equipped with ITS-G5 wireless beacons roadside units in end year	0.25	0.1
Include in-vehicle CAPEX costs?	No	No
Include in-vehicle OPEX costs?	Yes	Yes
Include infrastructure cost savings?	Yes	Yes

Time horizon	2030	2030
Parameters: 10	Number of wireless beacons per km= 3.3; Total number of back offices= 1; Discount rate= 4.5%; Exchange rate= 1.259; For Cellular scenario, the balance (adding up to 100%) between Aftermarket (i.e. some equipment costs) and Smartphone (i.e. no equipment costs)= 20/80 to 0/100	

Table 31: Parameter values for Figure 10: The annual Benefit-cost ratio for two cellular scenarios. Scenario 1 with Infrastructure Cost Savings, Scenario 2 without and Figure 11: Difference in cumulative costs and benefits with Infrastructure Savings off (Scenario 1) and Infrastructure Savings On (Scenario 2) for a full network and hybrid implementation

	Scenario 1	**Scenario 2**
Country	The Netherlands	The Netherlands
Full NRA Network or corridor	Full NRA Network	Full NRA Network
C-ITS services (bundles or individual)	Bundle 2. In-vehicle signage	Bundle 2. In-vehicle signage
Communications platform	Hybrid	Hybrid
Role/business model	5b. Hybrid - mixed - Driver pays service	5b. Hybrid - mixed - Driver pays service
Aftermarket/Smartphone vehicle penetration curve	Low	Low
OEM vehicle penetration curve	Low	Low
Start year for deployment of ITS-G5 wireless beacons roadside units	2018	2018
End year for deployment of ITS-G5 wireless beacons roadside units	2027	2027
% of infrastructure equipped with ITS-G5 wireless beacons roadside units in end year	0.1	0.1
Include in-vehicle CAPEX costs?	No	No
Include in-vehicle OPEX costs?	Yes	Yes
Include infrastructure cost savings?	Yes	No
Time horizon	2030	2030
Parameters:	Number of wireless beacons per km= 3.3; Total number of back offices= 1; Discount rate= 4.5%; Exchange rate= 1.259; For Cellular scenario, the balance (adding up to 100%)	

10	between Aftermarket (i.e. some equipment costs) and Smartphone (i.e. no equipment costs)= 20/80 to 0/100