Costs and benefits of cooperative ITS for road authorities: the COBRA decision-support tool

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Abstract
The COBRA project aims to help road authorities to position themselves to realise the potential offered by developments in Vehicle-to-Infrastructure cooperative systems. It does so by providing insights into the costs and benefits of investments, both from a societal perspective and a business case perspective. These insights are provided on the basis of a decision support tool, which enables costs and (monetised) benefits of cooperative services to be compared in various contexts. This paper describes the project methodology, namely the scenarios available for selection and the types of benefits and costs included in the tool. This paper also includes a summary of some example results, which demonstrate the scope and capabilities of the tool and the relative influence of different types of factors on the case for investment. There is a high-level assessment of the benefits that may be achieved for road authorities, including potential cost savings.

Keywords: Cooperative systems, cost benefit analysis, decision support tool

Introduction
Cooperative systems share information using Vehicle-to-Infrastructure and/or Vehicle-to-Vehicle communications. In so doing, the systems can give advice or take actions with the objectives of improving safety, sustainability, efficiency and comfort, thus contributing to a road authority’s objectives. However the nature of the benefits and scale of costs to road authorities vary between services, and only a limited amount of work has been carried out to quantify them. The business case for road authorities depends not only on these benefits and costs, but also on the business model for delivering services.

The COBRA project aims to help road authorities to position themselves to realise the potential offered by developments in Vehicle-to-Infrastructure cooperative systems. It does so by providing insights into the costs and benefits of investments, both from a societal perspective and a business case perspective. These insights are provided on the basis of a decision support tool, which enables costs and (monetised) benefits of cooperative services to be compared in various contexts.

The method used in the COBRA analysis tool is based on recommended techniques for societal cost benefit analysis (CBA) developed in European projects and uses a synthesis of published evidence on the impacts of services. Societal cost benefit analysis (CBA) is based on the principle of welfare economics, which assesses whether or not society as a whole is expected to be better off as a result of introducing a measure, so that the estimated benefits
are greater than the estimated costs incurred. The resource savings made (capital equipment, labour, time, fuel etc) are assumed to be deployed elsewhere in the economy at least as productively as before the measure was introduced. CBA is a tool that allows those who gain from an intervention to compensate the losers if that is considered desirable.

This paper describes the project methodology, namely the scenarios available for selection and the types of benefits and costs included in the tool. This paper also includes a summary of some example results, which demonstrate the scope and capabilities of the tool and the relative influence of different types of factors on the case for investment. There is a high-level assessment of the benefits that may be achieved for road authorities, including potential cost savings.

**Methodology**

*Scenarios: bundles, platforms, deployment, existing infrastructure, country, business models*

The tool enables road authorities to consider two scenarios simultaneously for investment in cooperative systems. There are three ‘bundles’ of services, each consisting of several cooperative functions:

1. “Local Dynamic Event Warnings”: Hazardous location notification, road works warning, traffic jam ahead warning and post-crash warning (eCall)
2. “In-vehicle Speed and Signage”: In-vehicle signage, dynamic speed limits and Intelligent Speed Adaptation
3. “Travel Information and Dynamic Route Guidance”: Traffic information and recommended itinerary, multi-modal travel information and truck parking information and guidance.

For the first and second of these bundles, the options within the tool enable users to choose between two communications platforms for delivery: cellular network communications (e.g. mobile phone) or wireless beacons at the roadside. The third bundle is unlikely to be deployed using wireless beacons, so cellular is the only communications platform offered in the tool for this bundle.

The analysis is performed for the national road authority’s road network, which consists mostly of the motorways. It is possible to choose between two countries in the tool: the Netherlands and the UK, although there is the facility to input data for an additional country.

On the end-user side, the bundles can be deployed as a separate service, or combined with other services. This may have consequences for the fraction of the in-vehicle capital and operational costs that is to be attributed to this bundle. Therefore, several options ranging from no cost to full cost are available in the tool.

The user can select either Low, Medium or High deployment curves for the in-vehicle penetration rates. This relates to OEM-fitted equipment for the wireless beacons scenario, and to aftermarket equipment or smartphones in the cellular scenario.

The cooperative services are assumed to be the same as equivalent services delivered by means of existing technology. The user of the tool must therefore specify the percentage of the network that is equipped with three types of existing infrastructure. An alternative way to consider this assumption is “the percentage of the network for which the cooperative systems have no impact”. In practice there may be some additional benefits on sections of the network with existing infrastructure.
The tool also includes a limited facility to explore business cases by identifying which costs and benefits directly affect a road authority. The time horizon in the tool is from 2012 to 2030. An overview of how to use the tool was a deliverable from the project.

**Benefits and impacts**

The tool itemises the main benefits in monetary terms for each bundle of services considered. Monetised benefits arise both from societal benefits, such as the cost saving of preventing a fatal accident, and from where the implementation of a (bundle of) cooperative services leads to a direct saving to the road authority, for example by reducing infrastructure costs. Some types of benefit are not represented, such as economic benefits that are long term or indirect, like changes in land use or employment. The tool is based on the principle of making conservative estimates to reduce the likelihood of over-optimistic assessments.

In order to monetise the benefits an impact assessment was conducted using data from existing research studies. The literature study placed emphasis on previous field operational tests (FOT), as well as simulation studies of cooperative functions similar to those defined in COBRA. More than 40 studies were reviewed, including the related projects CODIA [1], EasyWay [2] and eIMPACT [3]. Future studies can be considered to keep impact values up to date.

Safety impacts were expressed by the expected percentage change of the number of injury accidents, fatalities and injuries. Indicators for environmental impacts were defined as the expected percentage change of emissions, i.e. CO$_2$, NO$_X$ and particulate matter. Impacts on traffic efficiency were expressed through the percentage change in travel time and fuel consumption; i.e. the price paid at the pump for petrol/diesel, less tax. All these indicators were assessed for each single cooperative function, but were later combined to calculate the impact for each of the three bundles. The benefits are monetised by multiplication with a unit cost value obtained from the literature, which may vary over the years.

All impact indicators were assessed for 100% penetration of informed vehicles, which equals the percentage of vehicles equipped (fleet penetration) multiplied by the percentage of road kilometres equipped with communications. All indicators were assessed for “general conditions”; i.e. a mixture of free-flowing and congested conditions.

One challenge was how to combine different impact values from different studies to one value per indicator. There were large variations in the impacts reported in the literature and so a weighting approach was applied. The weighting for each function was based on factors such as study design, sample size, length of the road network studied and analysis method; for example, FOTs were given higher weighting than simulation studies.

Since the literature provided no results for bundles of services, another challenge was how to combine different functions within one bundle to one impact value per bundle. A simple addition of impacts would only be reasonable if the individual functions’ impacts did not overlap. For most of the functions within a bundle, this is not the case, e.g. hazardous location warning and traffic jam ahead warning do overlap when a traffic jam originates from a hazardous location. To address this, different approaches were defined for full, partial and no overlap.

The resulting impact values were incorporated into the COBRA tool (see Table 1). However, flexibility is built in to allow for future development and value updates. Since all indicators were assessed for 100% penetration, the COBRA tool scales the respective indicator down to the value according to the penetration scenario selected by the user.
It should be noted that the underlying research is far from complete and impacts need to be treated with caution. Due to a lack of results for some of the functions considered in COBRA, the project consortium used results from evaluations of stand-alone systems and made informed assumptions about the additional impact that a cooperative technology would contribute.

Table 1: Impact indicator values assessed for each bundle

<table>
<thead>
<tr>
<th>Impact indicators</th>
<th>Bundle 1</th>
<th>Bundle 2</th>
<th>Bundle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Safety</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of fatalities</td>
<td>-7%</td>
<td>-7%</td>
<td>-4%</td>
</tr>
<tr>
<td>Number of non-fatal injuries</td>
<td>-8%</td>
<td>-5%</td>
<td>-5%</td>
</tr>
<tr>
<td>Number of injury accidents</td>
<td>-7%</td>
<td>-5%</td>
<td>-5%</td>
</tr>
<tr>
<td>Travel time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time spent travelling</td>
<td>+0%</td>
<td>+4%</td>
<td>-11%</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petrol and Diesel</td>
<td>-1%</td>
<td>-4%</td>
<td>-10%</td>
</tr>
<tr>
<td>Emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>+2%</td>
<td>-4%</td>
<td>-9%</td>
</tr>
<tr>
<td>NOₓ</td>
<td>-10%</td>
<td>-9%</td>
<td>-5%</td>
</tr>
<tr>
<td>PM-2.5</td>
<td>-1%</td>
<td>-10%</td>
<td>Not found</td>
</tr>
</tbody>
</table>

Costs

The societal costs in the tool are the monetary costs of the cooperative service, and any negative societal impacts. The monetary costs include both capital investment costs and operational costs. A complicating factor is that societal costs of in-vehicle units are typically not equal to the price paid by the end-user, because this will include wages and profits that should be subtracted as societal gains. This may make it difficult to assess the true societal costs. An often used rule of thumb is that societal costs are approximately 1/3 of the off-the-shelf costs. The following cost components are distinguished:

- In-vehicle costs: costs associated with the in-vehicle components of the cooperative service: in-vehicle units, subscription and communication costs.
- Roadside wireless beacons: costs of installing and maintaining wireless beacons.
- Back office etc.: the one-off costs of adapting a back-office and developing a software application, plus the associated maintenance and replacement costs.

Negative societal impacts may appear when a particular service is deployed that has negative side effects, or when a beneficial service is phased out (see the section on cost savings).

Results

Example results - summary

Eight example runs of the tool were carried out to illustrate how the costs and benefits change over time for a range of scenarios. This set of example situations was developed to demonstrate the working and flexibility of the tool and should be regarded only as a starting point for examining the impact of cooperative services.

Nevertheless, two key themes did emerge from the results:

- For the bundles of services investigated, the case for roadside infrastructure for cooperative systems on motorways (i.e. wireless beacons) is weak because of the high cost, but there may be other services (such as safety services) where the case is stronger.
There appears to be a case for road authorities to become involved in delivering services based on smartphones if issues with driver distraction are overcome (e.g. if the app is used by a passenger, not the driver). This is particularly the case if third parties bear the cost of developing the apps and also if the annual communication and subscription costs are low.

For simplicity, the tool was first run for each of the three bundles with all in-vehicle costs set to zero; for these runs the bundles were considered at Medium and High penetration. There was then an assessment of the impact of including in-vehicle annual communication and subscription costs and also one-off in-vehicle equipment costs. The tool was then run to show the effect of choosing the cellular or wireless beacons platforms and also the effect for the road authorities of choosing different business models. Finally there was a comparison between the UK and the Netherlands.

**Bundle 1: Local Dynamic Event Warnings**

The bundle of cooperative services called “Local Dynamic Event Warnings” generates positive societal benefits, particularly in terms of fuel consumption and safety. If the services are delivered through cellular network communications to smartphone apps, such that there are no additional in-vehicle costs, and communication costs are negligible, then the benefit cost ratio is positive and increases over time. If the service is delivered through beacons, then the costs greatly exceed the benefits, due to the investment in the roadside beacons.

If the operating costs are sufficiently modest, this scenario offers a very good societal cost-benefit ratio from an early stage of deployment and investment in this bundle could be very worthwhile. However, it is important to bear in mind that it was assumed that there would be no additional costs for equipping further sections of the network with fixed sensors and in practice such investment might be needed.

The functions of this bundle were assumed to overlap with existing roadside infrastructure in the form of “Queue Protection” VMS. The deployment of these systems is relatively high in the Netherlands and the UK, so it may be expected that the relative benefits of this bundle may be greater in countries with less existing infrastructure.

For a national road authority, dynamic information provision is becoming a core part of road operations. There are choices about whether such services are delivered in-vehicle or on road signs and whether by the road operator or other service providers. It is likely that the back office requirements to deliver the information would be similar for all delivery channels. However, there would be a relatively small additional cost of supporting an in-vehicle app in order to deliver the service through cellular networks and smartphones. This cost could be absorbed by the road authority or could be part of a public-private delivery with the app supported by a private provider.

**Bundle 2: In-vehicle Speed and Signage**

The bundle of cooperative services called “In-vehicle Speed and Signage” achieves a benefit-cost ratio slightly higher than 1 in the examples considered where it is delivered via cellular networks. Although the bundle generates societal benefits in terms of road safety with reduced fuel consumption and emissions, in monetary terms this is matched by the dis-benefit of increased travel times due to drivers slowing down, who normally exceed the speed limit.

For a national road authority, safety considerations may, of course, be more important than cost-benefit analysis. Also, since the ISA provides information, it is for individual drivers to decide which speed to adopt, but a road authority would want to promote adherence to
national speed limits. As with the Local Dynamic Event Warnings bundle, provision of an app as a private service would slightly reduce a road authority’s costs of supporting this bundle.

**Bundle 3: Travel Information and Dynamic Route Guidance**

The bundle of cooperative services called “Travel Information and Dynamic Route Guidance” is already available in some countries as a commercial service. The bundle generates relatively small benefits to safety, mostly from increased driver awareness. The most substantial benefit is delivered through savings in travel time as a result of being aware of problems and re-routing. This, consequently, generates additional benefits in terms of fuel consumption and emissions.

In societal benefit cost terms, the bundle becomes beneficial when the societal in-vehicle operating costs are approximately 30 Euros per year. Many drivers are prepared to pay for this service commercially at this level of subscription.

For a national road authority, information and route guidance services are becoming a core part of road operations. However, there are choices about whether such services are delivered in-vehicle or on road signs and whether by the road operator or other service providers. Road authorities need to consider to what extent they are willing to “lose control” over their network for provision of core services.

**Critical parameters**

Any factors associated with in-vehicle costs are likely to have a large influence on the results. This is mainly due to the very large numbers of vehicles involved. Factors may include: one-off capital costs (equipment and installation); annual operational costs (subscriptions and cellular communication costs); lifetimes of in-vehicle equipment; forecasted number of vehicles; deployment levels; the balance between “smartphone” (no equipment costs) and “aftermarket” (some equipment costs) in the cellular scenario.

The societal problem costs were quantified for the two example countries, the UK and the Netherlands. These were based on the best information available; nevertheless, they are only estimates/projections and so should be treated with caution. It was found that any factors relating to travel time have a large influence on the results, relative to the other societal costs. This is because although the unit cost is relatively low, it is multiplied by a very large amount of time spent travelling; see Figure 1 for the societal problem cost for the UK in the years 2012 and 2030.

![Figure 1: Estimated societal problem costs in the UK (TERN network): 2012 and 2030](image)
The road safety societal problem cost was found to be relatively small in comparison, because although the unit cost is high, it is multiplied by a relatively small number of occurrences. However, this is not to say that “road safety is not important”. Some road authorities have adopted the approach that “No loss of life is acceptable”, such as the Swedish “Vision Zero” concept. Furthermore, it should be noted that the scope of the project was to consider the TERN network, which is predominantly motorway, and has relatively lower numbers of fatalities and injuries compared to rural and urban roads. Additionally, the two example countries have relatively safer roads compared to other European countries.

Another part of the tool that is likely to have a large influence on the results is the assumption that the bundles only have an impact on the sections of network that are not equipped with existing infrastructure. Coupled with this, is the “hotspots” assumption that the sections of road are equipped first where the greatest benefits can be reaped. The two example countries have a large amount of existing infrastructure and so these parameters have a large effect.

Cost savings and business cases

The successful deployment and operation of a bundle of cooperative services depends on an adequate business model that defines the roles of the stakeholders that are involved, the services that they deliver and the financial flows between them. A necessary condition for deployment is that all parties have a positive business case. The COBRA tool supports the assessment of the business case for the road authorities with a selection of business models. These define the stakeholders’ roles and responsibilities, and determine which part of the monetary costs and savings fall to the road authorities.

An advanced feature of the tool is the ability to include the effect of phasing out of the existing roadside system. This feature is called the “cost savings” option, because in this way the road authority can actually reduce their monetary outlay. Indeed, when the level of deployment of existing roadside systems is reduced, the road authority will save on maintenance and replacement costs. This feature and the business model are illustrated in Figure 2.

In Scenario 1, the road authority keeps their existing roadside travel information and dynamic route guidance system up to present standards, and also a privately financed cooperative service with similar functionality is deployed. In Scenario 2, a publicly financed cooperative service of this type is deployed and partially replaces the existing roadside Variable Message Signs (VMS) system.

Figures 2.1 and 2.2 show that the cost savings option of Scenario 2 is detrimental for the societal benefits and the societal benefit-cost ratio, but Figure 2.3 shows that the road authority benefits through cost savings. In this example the existing system is apparently beneficial to society, so from that perspective should not be phased out (as in Scenario 1). However, if a replacement cooperative service is deployed, the road authority can choose to trade in some of that benefit for monetary gains, while still maintaining a healthy benefit-cost ratio (as in Scenario 2).

The diagrams also show the influence of the business model: in Scenario 1, the cooperative service is privately financed so there is no cost to the road authority (as seen in Figure 2.3). In Scenario 2 the service is publicly financed and hence the road authority has to pay for the back office adaptations and the application development.

This part of the tool is only an initial step towards exploring potential cost savings, because the impact of removing VMS was not in the scope of the impact assessment. Other factors like equity or legal obligations of the road authority may also weigh in. Results from use of
the tool should be viewed as a starting point for policy decisions (e.g. about provision of VMS) rather than providing definitive policy directions.

![figure 2](image.png)

**Figure 2:** Example outputs: two scenarios for a travel information and dynamic route guidance service. 2.1 shows the societal costs and benefits; 2.2 shows the cumulative benefit-cost ratio; and 2.3 shows the monetary costs and benefits for the road authority.

**Conclusions**

This paper has demonstrated the scope and use of the COBRA cost-benefit analysis tool. This tool aims to help road authorities in making investment decisions concerning bundles of cooperative services that can enhance or replace their existing roadside systems. It can assess costs and benefits both on the societal level and on the level of the road authority. The tool is highly interactive and allows the user to freely explore a large range of deployment scenarios. There is also the option to modify parameter values or add further parameter sets, for example to include countries not yet represented in the tool. The tool may benefit from further improvements, which are outlined in the final deliverable of the project.

An assessment of the relative benefits and costs is just one part of an investment decision. Factors such as policy priorities, distributional effects, political will and synergy with other initiatives are also important influences on investment decisions. Such factors are not included in the tool and road authorities will need to weigh up these non-monetised factors alongside the estimated benefits and costs, when making investment decisions.

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References

