COBRA Cooperative Benefits for Road Authorities

ERA-NET ROAD

Mobility:

Getting the most out of Intelligent Infrastructure

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Deliverable 3.1
Impact Assessment

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Revision and history chart

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0.1	18.09.2012	First draft and structure
0.2	28.09.2012	Introduction, Methodology, Description of impacts, Conclusions
0.3	04.10.2012	Revision and comments
0.4	24.10.2012	Comments from TNO and TRL incorporated
0.9	31.10.2012	Internal review and revision of AIT, Glossary, Chapter 4
0.91	12.11.2012	Added literature tables in Chapter 3, finalised bundle values
1.0	21.11.2012	Final revision based on partner comments

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1 Introduction

The COBRA project aims to help road authorities to position themselves to optimally benefit from changes in the field of cooperative systems. It does so by providing insight on the costs and benefits of investments, both from a societal perspective and a business case perspective. These insights will be based on a decision support tool that allows for the comparison of costs and (monetised) benefits of cooperative services in various contexts.

This document presents the results of the impact assessment (COBRA work package 3), which was undertaken as a literature-based study. This report is based on various preceding studies evaluating cooperative systems and the final values are used in the support tool. Therefore, no new simulations or field operational trials were performed within COBRA. The effort focused on

1. identifying results in the literature addressing similar functions and contexts at comparable penetration rates
2. for selected cooperative systems or functions and
3. bundling them according to the overall system design.

The impacts of cooperative systems were determined in terms of the maximum effectiveness at 100% penetration of equipped vehicles and infrastructure, the actual penetration in the assumed scenario and the current situation in terms of traffic indicators for safety, efficiency and environment. The impact values found were incorporated into the COBRA decision support tool, which is the major project outcome.

Ten cooperative systems (i.e. functions) were selected from the multitude of systems and grouped in three bundles:

1. Local Dynamic Events
2. In-vehicle speed and signage
3. Information Services.

The bundles are considered as examples for implementation of cooperative systems.

The lack of impact assessment results presented a serious challenge to the literature-based impact assessment. One reason for the lack of results could be the novelty of cooperative systems resulting in a lack of reliable data or reasonable justification within preceding studies for impact quantification. Not all functions included in COBRA have been evaluated in detail in previous studies. eIMPACT[1] and CODIA[2] are two projects focussing on the impact assessment of stand-alone and cooperative systems. They made informed assumptions regarding the effects of such systems in terms of safety, efficiency and environment at 100% penetration for EU-25. Their results were based on previous results, simulations and expert judgment. Impacts assessments for Cooperative Systems based on Field Operational Tests are expected in the period 2013-2014. The DRIVE C2X[3] project plans to conduct Field Operational Tests in 2013 to evaluate the impact of a wide range of cooperative systems. simTD, a large-scale German Field Operational Test, will have results in 2013. Due to the lack of results for some of the functions in the tool, the experts in the COBRA project consortium made a decision to use results from evaluations of stand-alone systems and made informed assumptions about the additional positive impact that a cooperative technology would contribute.

The literature review revealed that the level of service influences a cooperative function's impact. Therefore, the consideration of level of service (i.e. free flow or congested) seems relevant for the benefits calculation. Integration in the tool requires careful analysis due to data requirements and a variety of congestion definitions (see[1]). A consistent, practical and useful way for the tool to address this will be developed and reported in the D4 Deliverable.

The scope of the COBRA study focuses on the motorway network.

The document is structured into five chapters. Chapter 2 introduces the methodology of the impact assessment (see COBRA Deliverable 2[4] for additional information on the methodology of the project as a whole). Chapter 3 describes the results found in literature and the methodology of combining data from different studies. Chapter 4 presents the combination of the different functions into the three bundles and the final results, which are used in the COBRA decision support tool. This deliverable concludes with final remarks delivering insight into further research.

2 Methodology

A schematic overview about the methodology in COBRA is depicted in Figure 1. It consists of two main parts, where the first is the impact assessment. The impacts of the systems are determined in terms of the maximum effectiveness at 100% penetration of equipped vehicles and infrastructure. The second part is the benefit cost analysis, which includes the deployment scenarios, societal benefit cost calculations and calculations of the business case for the road authority. The figure also shows whether a component is calculated in the decision support tool, whether is it is input by the user of the tool, or whether it is a parameter included at the development of the tool. This report evidence for the parameters in the first block in Figure 1.

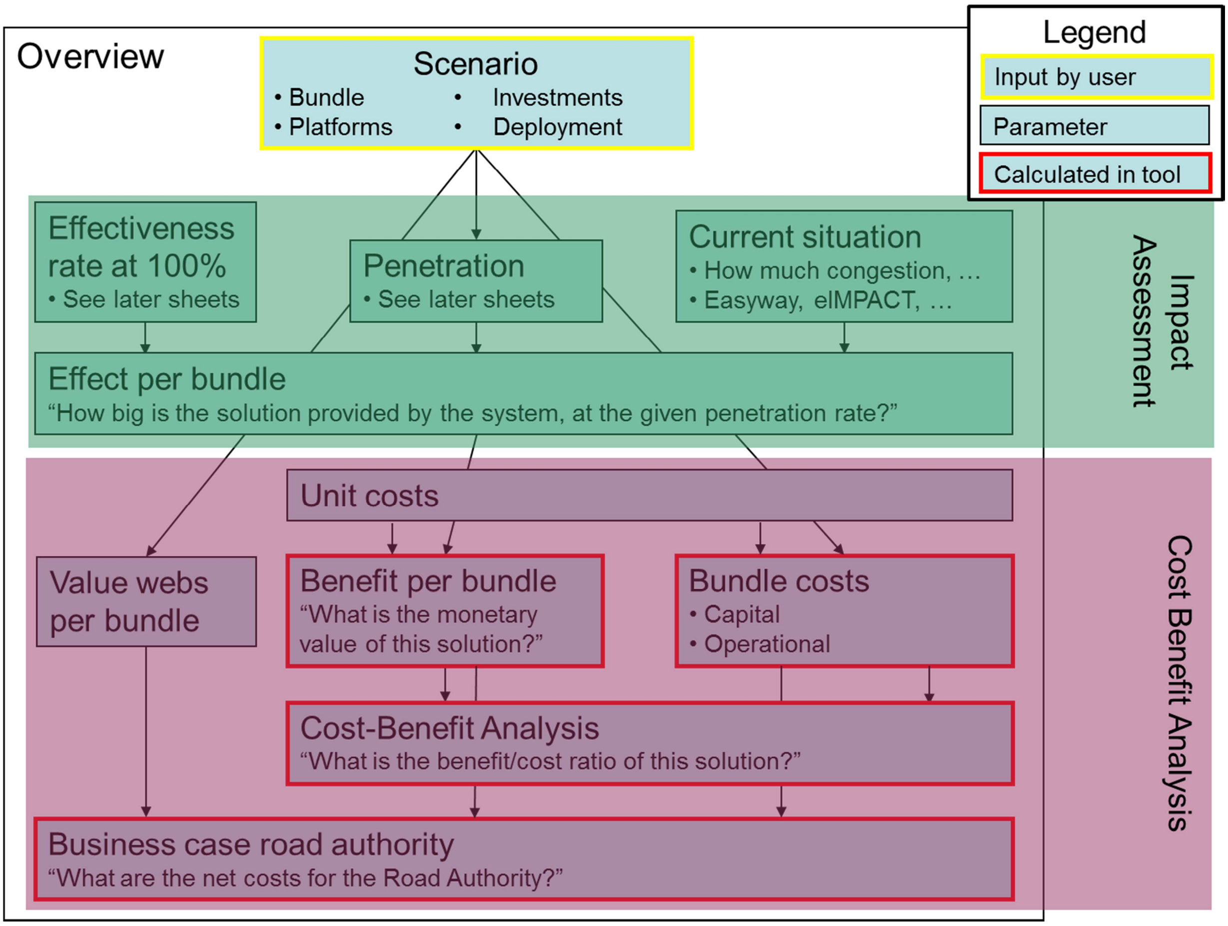


Figure 1: Methodology overview

The following sections explain the functions considered for impact assessment as well as how the values for each impact indicator are derived. Further information can be found in [4].

2.1 Bundles of cooperative functions

The COBRA project chose the approach of assessing the impact of bundles of functions as opposed to individual functions. The large European FOTs (e.g., EuroFOT, TeleFOT, DRIVE C2X) tested several cooperative systems on a single vehicle or device, while manufacturers and service providers are indicating that for services to be viable, they will need to be bundled together. It was therefore assumed. It was therefore assumed that cooperative systems will likely be deployed in a bundle rather than as individual functions. However it is not yet clear how services will be bundled together for deployment. For the purpose of this tool, a number of logical bundles of functions have been defined. These could be deployed together because they can operate on the same platform. These logical bundles should be considered as illustrative examples of possible implementations.

The bundles have been defined based on the 'day one' applications as defined by CEDR and ASECAP combined with preferences of the members of CEDR working group 14 who were consulted at an early stage in the project. The functions were selected using the following criteria:

- Responsibilities of road authorities: traffic management, safety warnings, enforcement

- Infrastructure requirements: Cellular communication infrastructure, wireless beacon (WLAN 802.11p WiFi based) infrastructure;
- Legal perspective: warnings vs. mandatory traffic regulation vs. time critical warnings (automated driving not included); and
- Business case perspective: communication costs vs. infrastructure costs, savings in VMS, savings in static routing signs.

Table 1 shows the resulting three bundles. These three have been selected to be assessed in the decision support tool.

Table 1: Bundles of cooperative functions

Bundle	Function
Bundle 1: Local dynamic events	Hazardous location notification
	Road works warning
	Traffic jam ahead warning
	eCall
Bundle 2: In-vehicle speed and signage	In-vehicle signage
	Intelligent speed adaptation
	Dynamic speed limits
Bundle 3: Information services	Traffic info and recommended itinerary
	Multimodal traffic information
	Parking information and guidance

The user of the COBRA tool makes a selection at the level of a bundle. The effect of the functions in a bundle is dependent on the presence of other functions. In the current version of the COBRA tool, it is not possible to add or select individual functions and assess impacts. It is possible to extend the functionality in future versions of the model to accommodate such functionality.

2.2 Impact assessment method

The project aims at assessing the impacts relevant for road operators in order to provide support for decision-making for the deployment of cooperative systems. The indicators selected are therefore related to assessable outputs that can be used for benefit-cost analyses directly. The impacts determined in the benefit-cost assessment stage are evaluated in monetary terms in order to provide decision support for the COBRA tool.

The impacts are defined as follows:

- **Safety**: The safety potential of cooperative systems is of major importance for road operators. It comprises the effect on numbers of accidents, fatalities and injuries.
- **Traffic efficiency**: The primary efficiency indicator is traffic flow, which is affected by traffic density, volume and vehicle velocities.
- **Environment**: Environmental effects are assessed regarding emissions and fuel consumption.

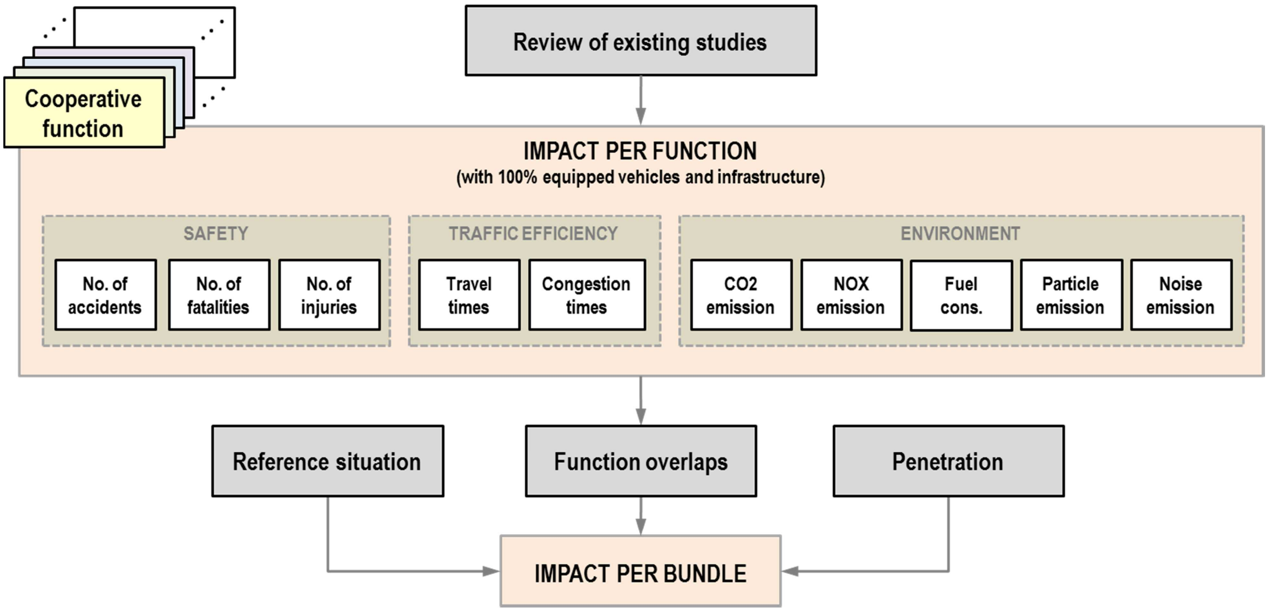


Figure 2: Methodology for assessing the impacts

The concept of impact assessment is depicted in Figure 2. This impact assesment consists of four parts. The first task was the assessment of impact indicators at a 100% cooperative system penetration at the function level. In COBRA, these safety, efficiency and environment indicators are identified from the literature review and data collected in previous studies.

The second task was to determine the *overlap* between the functions within a bundle. This allows us to determine the impact per bundle. Next, the relation between the *penetration* rate of equipped vehicles and infrastructure, and the actual impact was determined. Finally, the potential benefit of the bundle was compared to the *reference situation*. The reference situation refers to the current size of the traffic (safety, efficiency and environment) issues, level of traffic management system deployment and number of motorway kilometers in the country of interest.

Chapter 2.3 describes the indicators. The impacts are assessed for each function, but are later combined to calculate the impact for each bundle. Chapter 2.4 addresses bundle impacts and explains how overlaps between functions are taken into account. The idea of how to relate the expected impact to different penetration scenarios is described in Chapter 2.5.

2.3 Impact indicators

The impact assessment is based on findings and results from previous studies and projects. In COBRA, no particular simulations of traffic flows or emissions were carried out. Instead, previous studies provide relevant information about impact indicators. All data gathered from these studies, as well as assumptions made by the COBRA team, aim to be transparent. This allows assessment results to be updated in the future as results about impact assessment and penetration rates become available. Therefore, a “literature matrix” is used to incorporate review results and data from previous studies. This was undertaken for each cooperative function and for each indicator selected for impact assessment.

The following indicators are used for assessing the impacts of

Safety:

- **Number of injury accidents**: Number of road accidents resulting in personal injuries.
- **Number of fatalities**: Number of fatally injured people caused by a road accident.
- **Number of injuries**: Number of people, who have been slightly or seriously wounded in a road accident.

Traffic efficiency:

- **Travel times**: Measured difference between departure and arrival times of vehicles on a specific road site (corridor).
- **Congestion times**: Time losses due to traffic jams and slower speeds caused by increased physical use of the road, resulting in longer trip times.

Environment:

- **CO2**: Carbon dioxide; Measure in grams per kilometre.
- **NOX**: NOX is a generic term for mono-nitrogen oxides NO and NO2 (nitric oxide and nitrogen dioxide). Measured in grams per kilometre
- **Fuel consumption**: The consumption of fuel (gas or diesel) is typically measured in litres per 100 kilometres. COBRA will not assess the impacts on energy consumption of electric vehicles, since there is still a lack of reliable research studies.
- **Particles**: The burning of fossil fuels in vehicles generates significant amounts of particles with different chemical compositions. They can be seen as small localized objects, depending on the scale. Particles are commonly noted as particulate matter (PM) suspended in air, followed by a number that refers to a maximum particle size. For example, $PM_{2.5}$ refers to particles with an aerodynamic diameter of up to 2.5 µm. The PM emissions will also be measured per kilometre.
- **Noise emissions**: Also known as traffic noise pollution, measured in dB, which can be both annoying and can damage hearing. Traffic noise is estimated to be in the range 50 to 95 dB.

To harmonise differences in the impacts reported by different studies, a weighting approach was used. Differences arose assumptions, regions of interest or methodology applied. In the case of different impact values for one and the same function and penetration, a weighting algorithm was used to produce a harmonised assessment result. The function weighting was based on several impact factors such as study design, sample size, analysis method etc. By doing so, one gains an impression of how meaningful it is to generalise a set of findings of evaluation studies in terms of a weighted average result.

2.4 Assessing the impacts for each bundle

One of the main challenges faced in assessing the impacts of cooperative systems in this approach was to bundle the results per function. The literature provided no results at the bundle level. The previous chapters explained how the effects of each function were judged and valued. The next step before calculating the benefit/cost ratio was to estimate the impact per bundle for each of the indicators.

The impacts assessment per bundle took into account the fact that functions in the same bundle could affect each other. To cope with this, the interrelation between different cooperative functions was included in the assessment methodology. This required assumptions to be made about the extent of overlap between systems. One option was to split the effect by situation, then assume full overlap of functionality for similar situations and no overlap in functionality in others. Situations were defined by the intended effect of the function. This could be characterized by e.g. road type, accident type, etc. For example, two systems that address rear-end collisions may have full overlap, but have no overlap with a system that addresses frontal collisions. An example list of situations for each of the functions is given in Table 4.

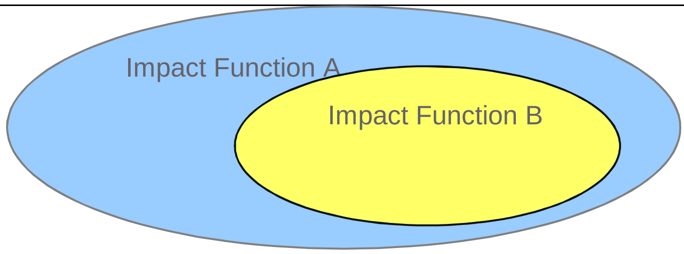
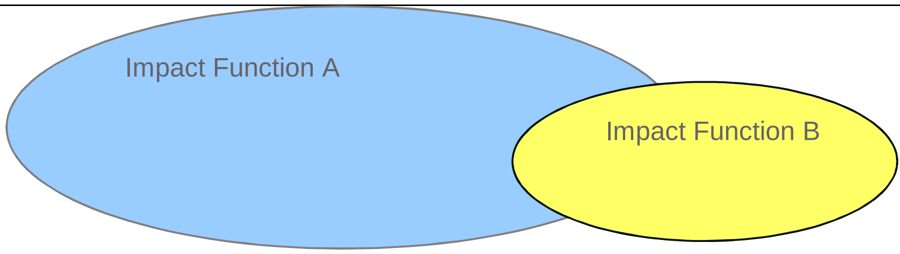
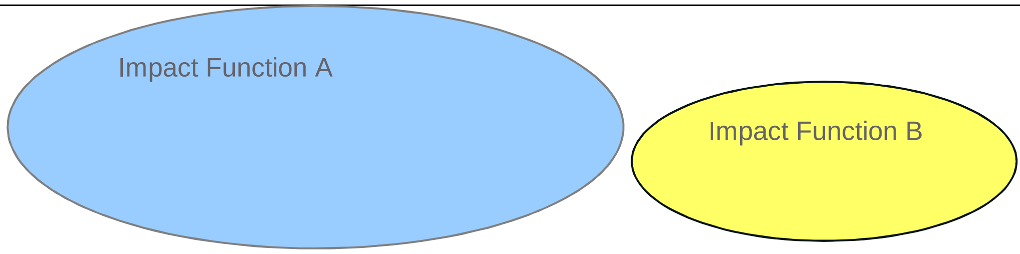
Table 4: Example situations for each function

Bundle	Function	Problem Situation
Local dynamic events	**Hazardous location notification**	Approaching icy road section Approaching oily/slippery road section Approaching road section with poor surface condition Approaching fog
	Road works warning	Approaching a road works zone
	Traffic jam ahead warning	Approaching traffic jam
	eCall	Having a crash
In-vehicle speed and signage	**In-vehicle signage**	Approaching sharp curve Approaching roundabout Approaching pedestrian crossing
	Intelligent speed adaptation	Over-speeding
	Dynamic speed limits	Approaching fog Approaching icy road section Approaching oily/slippery road section Congestion shock wave occurs Exceeding emission limits
Information services	**Traffic info and recommended itinerary**	pre-trip route choice on-trip route choice after incident …
	Multimodal traffic information	pre-trip route choice on-trip route choice after incident …
	Parking information and guidance	Parking

In order to avoid overestimation of impacts per bundle, a simple addition of impacts was only realistic if the individual functions' impacts were not overlapping. For most of the functions within a bundle, this was not the case (e.g. *hazardous location warning* and *traffic jam ahead warning*). Therefore, a distinction was made between full overlap, partial overlap and no overlap, as depicted in Table 5. Therefore, it was necessary to

- identify overlapping functions within a bundle;
- estimate the overlapping range;
- calculate the resulting impact per bundle.

Table 5: Overlapping impacts of cooperative functions within

a.)	Full Overlap	
b.)	Partial Overlap	
c.)	Null Overlap	

The proposed calculation method uses the maximum impact for full overlap (a.), partial added impact (b) and fully added impacts (c):

a) Impact (Bundle) = max (Impact (A), Impact (B), Impact (C),…)

b) Impact (Bundle) = [Impact (A) + Impact (B) + Impact (C)…] – Overlap [Impact (A) + Impact (B)+ Impact (C)…]

c) Impact (Bundle) = Impact (A) + Impact (B) + Impact (C)

The overlap estimation of two functions was based on the situation analysis (see Table 4) and the target objectives (i.e. target accidents for the function Hazardous Location Notification or change of mean speed for the function Intelligent Speed Adaptation). Table 6 shows the corresponding calculation method for each function considering their overlaps. There may be an overlap between bundles, e.g. traffic information affects traffic jams. However, these overlaps were not assessed in COBRA, since the bundles are deployed independently of each other.

Table 6: Bundles and how to deal with overlaps

Bundle	Function	Proposed calculating method
Local dynamic events	Hazardous location notification	A
	Road works warning	A
	Traffic jam ahead warning	A
	eCall	C
In-vehicle speed and signage	In-vehicle signage	B
	Intelligent speed adaptation	B
	Dynamic speed limits	B
Information services	Traffic info and recommended itinerary	A
	Multimodal traffic information	A
	Parking information and guidance	C

Results from preceding studies reported in literature often use several digits after the decimal, indicating precision (e.g. -2.85%). Due to the estimation involved in assessing impacts at the bundle level, the results were rounded off to integers. For completeness the precise values are reported.

2.5 Penetration scenarios

In COBRA, the share of vehicles equipped with cooperative in-vehicle devices in a fleet is defined by the term “fleet penetration”. Likewise, the term “RSU penetration” denotes the share of road kilometres equipped with roadside units (RSU) in a road network. For both terms, the penetration rate defines the change of penetration over time, e.g. the yearly development of vehicles equipped.

However, the essential factor is the number of “informed vehicles”, which depends on fleet and RSU penetration together. This relation is depicted in Figure 3 for the two platforms, “Cellular” and “Wireless Beacons”. For a certain year, the penetration of informed vehicles equals the percentage of vehicles equipped (fleet penetration) multiplied by the percentage of road kilometres equipped with roadside units (RSU penetration). The COBRA tool allows the users to choose between various penetration rates in order to strengthen the decision support for road operators. The rates comprise the current market penetration of both in-vehicle and roadside units necessary for the corresponding function and platform.

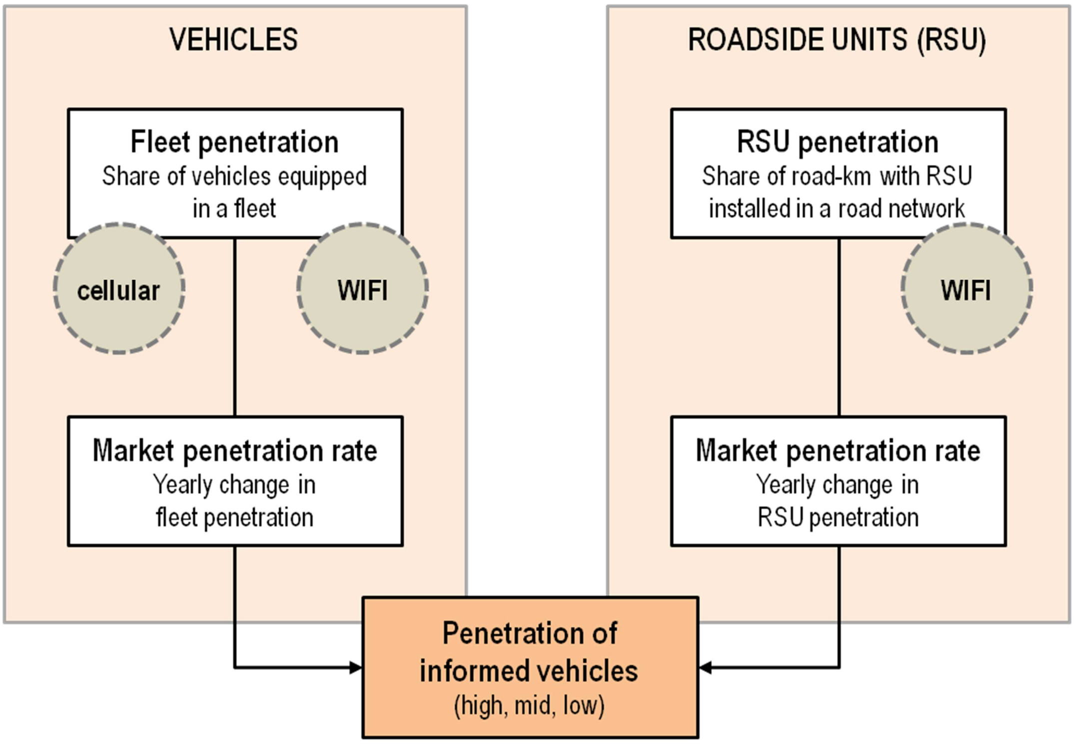


Figure 3: Penetration of informed vehicles

High, medium and low market (in-vehicle) penetration scenarios were determined. The scenarios were based on previous studies (market penetrations of cooperative safety systems from SAFESPOT[5]). In addition, the intended deployment of cooperative road side infrastructure can be specified by the user of the COBRA tool or be taken from EasyWay. The scenario (high, medium, low), as well as the relevant platform (WiFi, cellular or mixed), can be selected by the user of the tool. This step results from the number of cooperative in-vehicle devices sold and cooperative road side units deployed each year.

All impact indicators were assessed for 100% penetration of informed vehicles. According to the scenario (High, Medium or Low) selected by the user, the tool scales this indicator down to the corresponding value according to the penetration scenario. This concept is illustrated in Figure 4, which shows the three penetration scenarios given by functions over time and the impact (for a certain indicator and 100% penetration) depicted as a star. The reference situation refers to the current penetration as a basis for the assessment. The right-hand part of the graph is adapted for every bundle, while the left-hand function must is adapted for every indicator.

The example in the left-hand curve can either be a linear or non-linear function that gives the relationship between a certain impact indicator and the penetration of “informed” vehicles. This function may differ from indicator to indicator and strongly depends on the values found from the literature study. For example, the relation between the eCall penetration and the reduction of fatalities can be assumed as approximately linear in the first years, while other cooperative systems’ penetration may result in an exponential increase of impact. However, these problems were handled on the bundle level instead of at the function level.

When at least two different penetrations (e.g. 50% and 100%) for a certain impact indicator were found in a previous assessment study, the impact was generated by interpolation. For the case, where only one penetration value was available, the project team either made assumptions on the relationship between impact and penetration level or restricted the penetration inputs for the user of the COBRA tool.

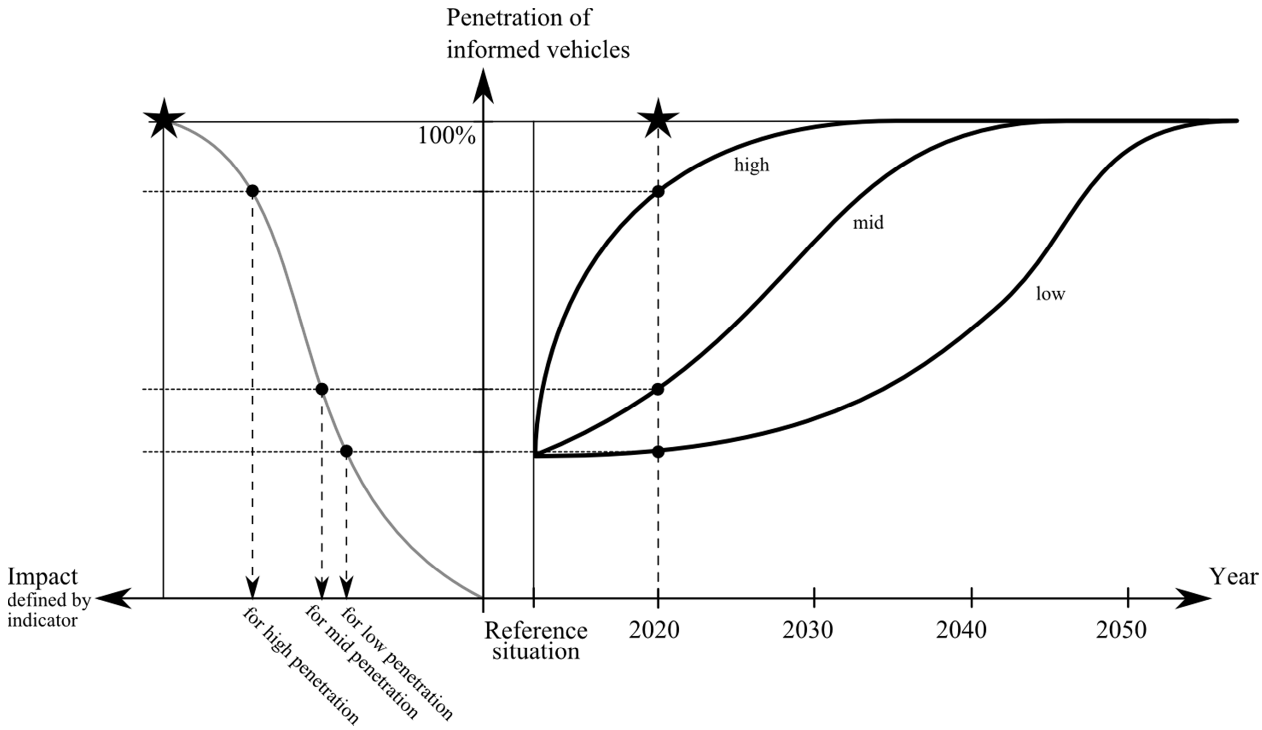


Figure 4: Relationship between impacts and the penetration scenarios high, mid and low

A similar concept as shown in Figure 4 was applied to the deployment of cooperative road side equipment. The ‘penetration’/share of the equipped kilometres of road network was translated into an impact for that penetration. The notion of ‘black spots’, (i.e. sections of the road network where more accidents or congestion or emissions occur), was not used. Black spots suggest that the impact is more than proportional to the share of the road network equipped with cooperative road side equipment. A linear relation is the most conservative estimate and was used in the study.

3 Impact assessment per function

This chapter presents the impacts per function found in literature, which were used in the impact assessment. Further, the methodology is reported for integrating the findings into a final impact at 100% penetration rate per function for each indicator. If not mentioned otherwise, the results were averaged, applicable for the motorway network and included indirect effects, e.g. a reduction in accidents reduces travel time. Where the results have not been averaged, did not include indirect effects or a specific weighting algorithm was necessary (e.g. truck accidents as part of all accidents, weather conditions or accidents as part of hazardous location notification), an expert decision by the COBRA consortium members was made.

Table 2 to Table 4 provide an overview of the studies and projects that were actually used for calculating impact values for COBRA. Besides, numerous other studies were reviewed, but not considered for the impact assessment. The reasons for neglecting some of the study results are given in the respective subchapters of Chapter 3.

The tables show the sources (see References) used for the respective impact indicators, by function. In case of the entry Missing/No useful data, either there were no relevant studies found in literature or the studies found did not provide usable results and were therefore not used in the assessment. In the latter case, the COBRA experts based upon their knowledge and experience either made assumptions or decided there was too little evidence to estimate the effect. Detailed explanations on the sources and why they were considered and/or disregarded can be found in the subchapters for each function.

Table 2: Sources used for bundle 1

Impact indicators		Bundle 1: Local dynamic events			
		Hazardous location notification	Road works warning	Traffic jam ahead warning	E-Call
SAFETY	Number of injury accidents	[6] p. 31	[6] p. 36; [7] p. 6/16	[2] p. 95 [8]	Missing data
	Number of fatalities	[1] p. 90; [2] p. 96,p.100; [6] p. 31	[6] p. 36; [7] p. 6/16	[2] p. 95 [8]	[9]
	Number of injuries	[1] p. 90; [2]; [6] p. 31	[6] p. 36; [7] p. 6/16	[2] p. 95 [8]	[9]
EFFICIENCY	Travel times	[2] p. 125	No useful data	[2] p. 137	Missing data
	Congestion times	Missing data	No useful data	Missing data	[10] p. 159
EMISSIONS	CO2	[2] p. 140	Missing data	[2] p. 143	[10] p. 170
	Fuel consumption	Missing data	No useful data	Missing data	[10] p. 171
	NOX	[2] p. 139	No useful data	[2] p. 143	[10] p. 170
	Particles	[2] p. 140	Missing data	[2] p. 143	[10] p. 170
	Noise emission	[2] p. 157	Missing data	[2] p. 157	Missing data

Table 3: Sources used for bundle 2

Impact indicators		Bundle 2: In-vehicle speed and signage		
		In-vehicle signage	Intelligent speed adaptation	Dynamic speed limits
SAFETY	Number of injury accidents	[2]	[11] p. 5, tbl. 4	Missing data
	Number of fatalities	[2]	[1]; [12]; [13]; [14]	Missing data
	Number of injuries	[2]	[1]; [12]; [13]; [14]; [15]	Missing data
EFFICIENCY	Travel times	[2]	[11]; [15]; [16]; [17]	[18] p. 4-4; [19] p. 6; [20]; [21]
	Congestion times	No useful data	[12]	[21]
EMISSIONS	CO2	[2]	[12]; [14]	[18] p. 8-5
	Fuel consumption	No useful data	[14]; [15]	[18] p. 8-5
	NOX	[2]	[12]; [14]; [15]	[18]
	Particles	[2]	[12]	[18] p. 8-5
	Noise emission	[2]	Missing data	Missing data

Table 4: Sources used for bundle 3

Impact indicators		Bundle 3: Information services		
		Traffic info and recommended itinerary	Multimodal traffic information	Parking information and guidance
SAFETY	Number of injury accidents	No useful data	Missing data	No useful data
	Number of fatalities	Missing data	No useful data	[12] p. 85
	Number of injuries	Missing data	Missing data	[12] p. 85
EFFICIENCY	Travel times	[22] p. 4; [23] p. 244; [24] p. 15	[25] p. ES5; [26]	No useful data
	Congestion times	[23] p. 244	[25] p. ES5; [27] p. 4-3	No useful data
EMISSIONS	CO2	[22] p. 4	Missing data	No useful data
	Fuel consumption	[24] p. 15	[27]	Missing data
	NOX	[22] p. 4	[27]	Missing data
	Particles	Missing data	Missing data	Missing data
	Noise emission	Missing data	Missing data	Missing data

This chapter presents the findings on the impacts for each impact area (safety, traffic efficiency and environmental impacts) by function.

3.1 Hazardous location notification

Hazardous Location Notification provides a warning notification about potential hazardous areas when approaching these areas. It is primarily a safety function. Driving in hazardous areas requires more attention from the driver. This application would have a particular benefit in dynamic situations such as changing weather conditions.

Three projects provided reliable information about the impact of this function on safety, efficiency and environment. EasyWay[6] carried out an analysis of this function as part of a V2V (vehicle to vehicle) bundle. CODIA studied the impact of a system called 'Local danger warning', separating three different types of hazards: accidents, poor weather and congestion. eIMPACT did the same for the 'Wireless Local Danger Warning' system described in depth by the project WILLWARN[28] part of PReVENT[29]. The EasyWay, CODIA and eIMPACT studies made assumptions on the impact of stand-alone and cooperative systems, and scaled the results up to a 100% market penetration scenario.

Hazardous Location Notification is part of the first bundle, which also contains Traffic Jam Ahead Warning. To be consistent with the methodology and argumentation within CODIA and eIMPACT (and to avoid overlap between the two functions) the values for the accidents and poor weather conditions were considered for Hazardous Location Notification. This decision resulted in limiting the values for Traffic Jam Ahead function to the congested situation.

3.1.1 Effects on safety

Impact on road safety was estimated in COBRA by three indicators: number of fatalities, number of injuries and number of injury accidents. In available sources no differentiation between general traffic flow and congested situation was found. In EasyWay a change of -5,3% in the number of injury accidents was estimated. EasyWay was the only project to provide a value for this indicator. For the number of fatalities, CODIA assumed a 4,2% reduction, eIMPACT reached a -4,5% result and EasyWay estimated a decrease of 5,2%., The findings were similar for the number of injuries. eIMPACT assumed a 2,8% reduction, CODIA estimated a 3,1% reduction, while EasyWay estimated a reduction of 5,3% in injuries. Taking into account the similarities of the studies and the used methodology, the average of the three results was used:

- Number of fatalities: -4,6%
- Number of injuries: -3,7%
- Number of injury accidents: -5,3%

3.1.2 Effects on traffic efficiency

Efficiency was evaluated in terms of travel time and congestion time. It was expected that by providing a warning, traffic flow will improve, thus decreasing the risk of congestion. It is estimated that by providing warnings to the drivers, they will decrease their speed earlier, avoiding hard braking but possibly increasing the travel time to the tail of the queue. Only CODIA[2] provided information about travel time, differentiating between the types of hazards and the traffic conditions, giving values for various level of service (LOS). As previously mentioned, a differentiation was made in traffic flow conditions distinguishing two traffic states (i.e. LOS A to D for general traffic flow and levels E and F for congested situations). For the evaluation of traffic efficiency, two types of hazards were taken into consideration: accident and poor weather conditions. A mean value for accidents and poor weather conditions for general/free flowing traffic was calculated and the values for LOS E-F were used for the congested traffic state.

In case of an accident warning, travel time did not increase considerably. CODIA even estimated a reduction of 2,5% in free flow conditions. For levels of service C/D and E/F small increases of 0,2% and 0,7% respectively were assumed. In the case of a poor weather condition warning (e.g. slippery road, fog), CODIA concluded that travel time increased by 4,4% in a free flow scenario, 6,2% for LOS C/D, reaching a 7,2% estimate for congested traffic. However, this study found as well that such estimates of increased travel time under poor weather conditions is not certain for busy or congested traffic conditions, relative to the situation that the warning was not given in those conditions. Therefore, these values were not included in the COBRA impact assessment. Values for congestion time were not assessed in the literature reviewed. The final results for traffic efficiency are presented below:

- Travel time: +2,08% (free flow), +3,95% (congested conditions)

3.1.3 *Effects on environment*

The impact of this function on the environment strongly depends on decreasing speeds, longer travel times and the degree of congestion. The indicators used are: CO_2, fuel consumption, NO_x, particles and noise emissions. CODIA made assumptions regarding the effects of the function on the environment. The estimates were given in the same manner as for traffic efficiency, since the project differentiated between types of hazards in different scenarios of traffic flow.

In case of an accident, the Hazardous Location Notification function was assumed to have a significant effect on emissions. CO_2, NO_x and particles levels will decrease in free flow conditions by 15,7%, 16,9% and 15,1% respectively. As LOS decreases, the effect becomes less significant ranging from -1,2% for CO_2, -1,4% for NO_x and -1,5% for particles in case of medium flow.

In case of poor weather, the assumptions were more conservative in CODIA. At LOS A/B, CO_2 emissions were reduced by 43%, NO_x by 12,2% and the particles level by 2,5%. As the traffic conditions change, the estimates for the three indicators in medium flow conditions ranged from a reduction of 2,8% for CO_2 and 2,6% for particles to a 9% decrease for NO_x emissions. The authors acknowledge the fact that the figures for NO_x decrease seem to be high compared to CO_2 and other particles. In congested traffic flow, CODIA assumed a small increase of 0,4% for CO_2 levels, while NO_x and particles emissions were assumed to decrease by 3,1% and 1%, respectively[2].

The methodology of reaching the final results was the same as for the travel time estimation: an average of the values for accident and poor weather cases in LOS A-D was calculated for the general flow scenario, while the values from LOS E/F were used for the congestion.

CODIA also provided information regarding the effect of this function on noise emissions. Values were given for the three types of hazards, but the levels (although being a dB reduction) were more or less negligible, ranging from 0 to 0,5% reduction:

- CO_2: -6% (free flow), +0,25% (congested conditions)
- NO_x: -9,88% (free flow), -1,45% (congested conditions)
- Particles: -5,43% (free flow), -0,35% (congested conditions)
- Noise: -0,2% (free flow and congested conditions).

3.2 Road Works Warning

Carrying out repairs on a motorway usually involves temporary speed limits, lane changes, lane merges and contra flow running which are managed by temporary signs and portable physical barriers to divide lanes. A linked vehicle-infrastructure system offers much more flexibility, enabling faster reconfiguring of the work zone and allows precise alerts and instructions to drivers regarding lane choices, speeds, too-close following of preceding vehicles etc. Three studies provided assessments of the impact of this function: EasyWay[6], a study of a Traffic Warning System from Norway[7] and a US FOT study[30].

While these two assessed the impact of a cooperative road works warning system, the field trial study from USA made use of a stand-alone warning system. The US study evaluated a lane change merge system at a construction zone on an interstate in Michigan and provided results for travel time and congestion time, fuel consumption and NO_x emissions. After an evaluation of the study it was decided not to use the results, due to the high values of the indicators (e.g. travel time reduction of 38,53%). These high impacts could have been reached due to other factors and it was impossible to make an accurate generalization for the function.

No results were found for the indicators regarding efficiency and environment.

3.2.1 *Effects on safety*

EasyWay estimates an impact of -0,2% for all traffic safety indicators, while the study from Norway[7] makes assumptions on the reduction of injuries and fatalities occurring at road works. To get a comprehensive result, the ratio of road works related accidents out of all crashes occurring on motorways was analysed. Accident statistics were made available from UK, The Netherlands and Austria. Fatalities, injuries and injury accidents occurring at road works account for 3,5%, 3,8% and 4,2% respectively of all accidents. The values from EasyWay are used for the congestion scenario. Based on this data, the final results are:

- Number of fatalities: -1,4% (free flow), -0,2% (congested conditions)

- Number of injuries: -2,3%, -0,2%
- Number of injury accidents: -2,5%, -0,2%

3.3 Traffic Jam Ahead Warning

This function warns drivers when approaching the tail end of a traffic jam. It will cause drivers to be more aware of the situation ahead leading to lower speeds, longer headways and a reduced risk of rear-end collisions. Three studies were found to evaluate the impact of this function. CODIA provided results of the effects of Local Danger Warning system due to congestion, SAFESPOT[31] studied the impact of a Congestion Warning system on traffic efficiency and TRL evaluated the impact of MIDAS (Motorway Incident Detection and Automatic Signaling) automatic queue protection system implemented in the UK[8].

The Congestion Warning System in SAFESPOT was evaluated in terms of efficiency through simulation, using the ITS Modeler, in different traffic scenarios. An increase of 5,94% in travel time was assessed for a 3500 vehicles/hour traffic on a three-lane motorway and the value changes to 48,58% in case of a 4500 vehicles/hour traffic flow. Due to the high variation in results, it was decided not to use the results.

3.3.1 Effects on safety

CODIA[2] gives a reduction of 2% in fatalities and 0,9% in injuries, both for 50% system penetration. The UK study[8] resulted in -13% injury accidents and -2,1% fatalities. Based on those results, an expert decision was made by the consortium members in order to assess the impact of this function. Since there were no results found for injuries, it is considered similar to injury accidents:

- Number of fatalities: -2%
- Number of injuries: -7%
- Number of injury accidents: -7%

3.3.2 Effects on traffic efficiency

By providing the Traffic Jam Ahead Warning, the drivers will decrease their speeds which will lead to longer travel times. Only the results from CODIA were used:

- Travel time: +7,7% (free flow), 0% (congestion)

3.3.3 Effects on environment

The changes in emissions and fuel consumption are strongly connected to the changes in speeds, travel length, congestion time, etc. The values for the indicators were used from CODIA, except the value for NO_x. The study makes an estimate of a 15,2% reduction in NO_x, which COBRA experts found to be excessively high:

- CO_2: +7,6%
- Particles: +4,7%
- Noise emissions: -0,5%.

3.4 eCall

If sensors in the vehicle detect a collision, the vehicle automatically makes a 112 call to the emergency services to give the incident location and provide information about the vehicle and its location. The system opens voice and data channels so that the emergency call centre can talk to the driver or any passengers if they are conscious.

The eCall function has been studied in detail, as it could have a strong impact in reducing fatalities and decreasing the severity of injuries through faster response times. Earlier projects (E-MERGE, TRACE[32], SEiSS[33], etc.) are now considered to have been too optimistic in their assessment. E-MERGE estimated a reduction of 5-10% in fatalities and injuries, SEiSS reached an estimate of 5-15% reduction and eIMPACT assessed the positive benefit on fatalities at a 5,8% reduction. More recent studies tried to make more realistic assumptions on the positive effects of eCall. From all the studies found, the experts' consortium decided to use the most recent, integrative study led by TRL[10] which assessed the impact of eCall at a European level.

3.4.1 Effects on safety

Based on accident data recorded from police and from hospitals regarding the number of fatalities and the severity of injuries related directly to rescue time, the following results were estimated:

- Number of fatalities: -2%
- Number of injuries: -1%

3.4.2 Effects on traffic efficiency

From the two indicators used to evaluate the impact on traffic efficiency, travel time is not applicable for this function. The reduction in congestion time is due to the improved accident response and thus to the faster assistance to the victims and clearing of the crash site. The reduced congestion time is a secondary effect:

- Congestion time: -3%

3.4.3 Effects on environment

Being a safety system, which is activated after the accident occurs, the effect on the environment is negligible. Still, [10] provides information for these indicators due to reduced congestion.

- CO_2: -0,0118% (will be taken as 0%)
- Fuel consumption: -0,55%
- NO_x: -0,0055% (will be taken as 0%)
- Particles: -0,0046% (will be taken as 0%)

3.5 In-vehicle Signage

A vehicle-infrastructure link is used to provide information or a warning to a driver of the content of an upcoming road sign. This can be extended to inform drivers about other oncoming features of the road such as curves, roundabouts, traffic calming installations and road markings such as segregated cycle lanes or bus lanes. This application is often referred to as visibility enhancement - giving the driver information about situations beyond or outside the direct line-of-sight.

After a literature review, it was decided to assess the impact of providing in-vehicle information of speed, accompanied by the reason for change. CODIA assessed the impact of Dynamic Speed Adaptation, due to accidents, poor weather or congestion and provided results for most indicators in different levels of service. The warning came in the form of visual or audio signals.

3.5.1 Effects on safety

By providing speed information, the driver will decrease his speed and become more aware that there is a disruption in the traffic ahead. It was decided by the consortium that in the absence of a value for the number of injury accidents, to assume the same value as the number of injuries:

- Number of fatalities: -7,2%
- Number of injuries: -4,8%
- Number of injury accidents: -4,8%

3.5.2 Effects on traffic efficiency

The CODIA study provided information regarding the effect of this function on travel time, in various situations and traffic scenarios. It was expected that travel time would increase, as drivers will lower their speeds and increase their attention to the traffic. The project gave values for accident, poor weather and congestion scenarios at different levels of service. As mentioned in the methodology, we considered LOS A-D to be the general traffic flow and LOS E-F to represent congested traffic. At free flow, travel time will increase with 5,6% in case of an accident and with 4,4% in poor weather. For levels of service C/D, the increase will be minimum in an accident scenario, CODIA assuming an increase of just 0,7%. For poor weather travel time increases with 6,2%. In case of congestion, the values are different for each scenario. The estimations are 1,4% for an accident, 6,2% in case of poor weather and 9,6% for congestion. Using the same methodology as in other functions, the final results were considered to be the mean of the values at LOS A-D for the general traffic flow scenario and the mean for levels E/F for congestion:

- Travel time: +4,23% (free flow), +6,07% (congested conditions);

3.5.3 Effects on environment

In-Vehicle Signage has a positive impact on the environment, due to lower speeds and management of traffic flow. In case of an accident, CO_2, NO_x and particles will decrease in free flow conditions, by 8,3%, 12% and 8,8% respectively, which represents a significant reduction in emissions. These impacts become less significant as traffic flow increases, reaching -1% for CO_2 and -1,1% for both NO_x and particles. At LOS E/F, reductions are estimated at -0,8% for CO_2, -1,7% for NO_x and -1% for particulate emissions.

In the case of a speed warning due to poor weather, the emissions reductions follow the same trend. At free flow, it is estimated that CO_2, NO_x and particles would reduce by 4,3%, 12,2% and 2,5% respectively. For levels of service C/D, the reduction of CO_2assumed is 2,8%, 9% for NO_x and 2,6% for particulate emissions. In congestion conditions, the effects are the least significant. A slight increase of 0,4% for CO_2 levels and a decrease of 3,1% for NO_x and 1% for particles is estimated.

If the cause of the speed warning is on the approach to a congested road stretch, it is estimated that the levels of CO_2 will increase by 0,7%, NO_x levels will also increase by 1,4%, while the particles emissions would maintain a decrease by 0,8%.

Assumptions for the reduction of noise emissions are also provided in [2] for the three types of scenarios, ranging from -0,7% to a 0% level. This leads to the following impact values:

- CO_2: -4,1% (free flow), +0,1% (congested conditions)
- NO_x: -8,58% (free flow), -1,13% (congested conditions)
- Particles: -3,75% (free flow), -0,93% (congested conditions)
- Noise: -0,25% (free flow), -0,7% (congested conditions)

3.6 Intelligent Speed Adaptation (ISA)

ISA is a system that monitors a vehicle's speed and speed limits on road segments and intervenes if the vehicle is detected as exceeding the speed limit. An ISA system can have additional features to influence driver's behaviour by, for example, a haptic accelerator pedal. Three types of ISA can be distinguished:

- Informative - case in which the driver receives information about the speed limit and various types of warning signals (audio, video);
- Warning – where the driver is alerted of exceeding the speed limit through an active warning, e.g. haptic accelerator pedal; and
- Intervening – in case of exceeding speed, the system takes over and limits the speed through automated braking;

In COBRA, only the first two types of ISA were assessed, as the resistance to the Intervening version is strong. The effects of all types of ISA have been studied in depth since the '90s. Field trials took place during the LAVIA project[13], SafeCar project[14], UK ISA trials[34] and many more. Also numerous simulations were performed to assess the impact of ISA at 100% market penetration, in terms of safety, efficiency and environment.

3.6.1 Effects on safety

By providing information regarding the speed limits and warning the driver through various methods, the risk associated with speeding will be decreased. eIMPACT estimated a reduction of 8,7% in fatalities and 6,2% in injuries, in which a haptic accelerator pedal was assumed. The ITS Test Beds[12] evaluated a warning ISA by performing simulations in different input scenarios. The results indicated a reduction of 3,1% in fatalities and 2,4% in injuries.

The TAC SafeCar project[14] evaluated multiple systems like ISA, Forward Collision Warning (FCW), Rear Collision Warning (RCW) and others by carrying out field operational trials in Australia with over 20 equipped vehicles. Their results showed a reduction of 6,08% in fatalities and 4,58% in injuries. The UK ISA trials were performed for a period of 6 months with 20 vehicles equipped with an informative ISA and reached a result for injury accidents of -4,6%. The LAVIA project was a French FOT, which assessed the positive impacts of all types of ISA on traffic safety. Their results, based on eight weeks of trials with 22 equipped vehicles, indicate a reduction of 4% for fatalities and 2% for injuries. Another important FOT, which was used to evaluate the impact of ISA was performed at Umea, Borlänge, Lund and Lidköping[15]. At each location a different type of ISA was tested. Informative ISA was tested at Umea, providing a result for the reduction of injuries of -3%.

By taking into account all these results from FOTs and simulations, a common result was found by averaging all FOT findings:

- Number of fatalities: -5,45%
- Number of injuries: -3,64%
- Number of injury accidents: -4,6%

3.6.2 Effects on traffic efficiency

There has been much debate concerning the efficiency of this function. Earlier studies stated that ISA can decrease travel time, while more recent ones demonstrated that an increase is inevitable. In the present study, the purpose is to apply ISA to increase traffic safety without a significant effect on traffic efficiency. The FOT trials performed at Umea, Borlänge, Lund and Lidköping estimated no significant impact on travel time. Another FOT trial called PAYS (Pay as you Speed)[34] tried a different method of influencing drivers to not exceed the speed limit by appealing to them with insurance reductions. The field trials lasted from June 2006 until December 2008 and included 153 participants. Their results indicate 0,9% reduction in travel time.

Three studies assessing the impact of ISA through simulations were found. The first one evaluated the network effects of ISA[16] by simulating a road network (east of Leeds) of 8 kilometres, in the morning peak and off peak. The results of the simulation indicate a travel time increase of 2,6% in the morning peak and 6,38% in the off peak. When there are fewer vehicles on the road, more drivers may exceed the speed limit, but with the system this number would decrease, leading to longer travel times. A second study evaluated the impact of ISA in terms of efficiency and emissions through simulation and a field trial.[17] PARAMICS and CMEM were used to simulate a stretch of 6,4 kilometres and evaluate ISA, while the field trial was performed in California on a 22 kilometres segment with a car equipped with ISA. A non-equipped vehicle drove at the same time to provide data for comparison. The results of the simulation indicated an increase of 7,7% in travel time and the field trial showed an increase of 6%. The third study evaluated all three types of ISA by simulating in SIGSIM, a two-lane link of 1,5 kilometres, in different traffic scenarios. Their results show an increase of 60% in travel time at free flow, a decrease of 4,85% at a medium traffic flow and again an increase of 46% in congested flow. Due to the high variation of results, it was decided not to use this study in the final assessment of this indicator. The value for the indicator of congestion time was taken from the evaluations made by the ITS Test Beds.

Due to the combination of results from field trials and simulations, it was decided to weigh the results of the simulations half the values from field tests. In this case, a formula was developed to calculate the impact on travel time. For the general traffic condition, the travel times are weighted using

$$t = \frac{1}{7} \cdot 6{,}38\% + \frac{2}{7} \cdot 6\% + \frac{2}{7} \cdot 0\% - \frac{2}{7} \cdot 1\% = 2{,}4\%.$$

This leads to following results:

- Travel time: +2,4%;(general flow); 0% (congested condition)
- Congestion time: 0% (congested condition)

3.6.3 Effects on environment

A positive impact of ISA is the potential of decreasing congestion by aiding traffic flow. Implicitly this may lead to a decrease in fuel consumption and emissions. The ITS Test Beds assess the potential impact of ISA through simulations, estimating a reduction of 1,5% in CO_2, 2% in NO_x and 1% in particulate emissions. The results of the field trial performed at Lund indicate a 2% reduction in fuel consumption and 8% for NO_x emissions, while the SafeCar Australian FOTs[14] showed a reduction of 3,1% in CO_2, 2,2% in fuel consumption and only 2,3% in NO_x. The final values were reached by making a mean between all the available results per indicator:

- CO_2: -2,3%
- Fuel consumption: -2%
- NO_x: -4%
- Particles: -1%

3.7 Dynamic Speed Limits

Speed limits are set on a road segment according to the infrastructure (e.g. geography, road alignment, etc.), type of road, traffic flow and other factors. Dynamic speed limits have the advantage of being more flexible. They take into account traffic flow in different conditions and times of day, weather conditions and other environmental factors. Both field trials and simulations have been performed to assess the impact of dynamic speed limits, in certain conditions.

Dynamic speed limits have been implemented since the '90s as road side systems. The majority of studies do not assess the impact of a cooperative system. Multiple field trials have been conducted to evaluate the impact of variable speed limits, such as on the M25 Motorway[35] and at Birmingham[18], both in the UK. In the Netherlands, evaluations were carried out in the Dynamax project[21],[36] at five different locations, where the speed limit was lowered or increased due to certain influencing factors like traffic flow, weather conditions, emissions reduction, etc.

Simulations have also been used to assess the impact of this function using different dedicated tools. A study undertaken on an urban freeway in Toronto, Canada evaluated variable speed limits in terms of efficiency in different traffic conditions (off peak, near peak, peak)[19]. Two studies were found to assess the impact of a cooperative dynamic speed limits system. A study, part of the COOPERS project, used micro-simulation to evaluate the function on a segment of the M6 motorway in UK[20], while a study conducted at the University of Lidköping, Sweden made a comparison between a road side system and a cooperative version[37] in terms of emissions reduction.

3.7.1 Effects on safety

Two projects were reviewed that evaluated dynamic speed limits in terms of safety. The assessment of the M25 Controlled Motorway system revealed a 12% reduction in accidents according to accidents statistics, a 10% reduction when comparing police reports and a 15% reduction according to a summary report from 2006[38]. The study performed on a 17 kilometres segment of a motorway near Birmingham showed that a year after implementation, the number of fatalities fell to zero and the number of injuries decreased by 64%. Due to the high variation in results as the DSL were applied to hotspots, the consortium decided not to use any of those results.

3.7.2 Effects on traffic efficiency

The system is used to manage traffic flow, which translates mostly in a decrease in speed. This will lead to an increase in travel time. The evaluation performed at Birmingham showed a 9% increase in travel time, while the trial done on the A58 at Tilburg (within the Dynamax project) revealed also an increase, but only of 1,4%. Within the same project, the system was also evaluated on the A1 at Naarden, where the speed limit was increased in certain conditions. The results show a decrease in travel time of 7%. The study, which simulated a freeway in Toronto[19] assessed the impact of variable speed limits in different traffic conditions. The results show an increase of 1,3% off peak, 25% near peak and 11% in a peak scenario. Finally, the simulation performed part of the COOPERS project, revealed an increase of 3,2% in travel time. The change in congestion time was studied only in the Dynamax project at Voorburg on the A12. At this location, the speed limits varied between 80km/h and 100km/h depending on traffic flow and measured speed of the vehicles. The results showed a decrease of 65% in congestion time, but due to the high value of the indicator and the small length of the segment it was decided not to use this result in this study.

The difficulty to combine results from field trials and simulations was solved by applying different weights. It was decided to weigh results from field trials with higher trustworthiness than simulation results. In this case, a formula was developed to apply the weighting, depending on traffic flow conditions. For the general traffic, the formula is:

$$t = 1{,}3\% \cdot \frac{1}{3} + 1{,}4\% \cdot \frac{2}{3} = 1{,}37\%$$

For the congestion scenario, the formula is:

$$t = (-7\%) \cdot \frac{2}{5} + 9\% \cdot \frac{2}{5} + 3{,}2\% \cdot \frac{1}{5} = 1{,}44\%$$

This leads to the following results:

- Travel time: +1,37% (free flow); +1,44% (congested condition)

3.7.3 Effects on environment

The positive benefits of the function were evaluated in [18] and [37], where a road side system and a cooperative one were compared. Due to the fact that the latter study did not provide a base reference, their results were not used. This leads to the following results:

- CO_2: -4%
- Fuel consumption: -4%
- NO_x: -5%
- Particles: -10%

3.8 Traffic information and recommended itinerary

This function recommends a route for the vehicle navigation system to direct the driver around congested locations and dangerous roads and to distribute the traffic load on alternative routes. Three projects were reviewed to evaluate this system. The first one is a study, part of the euroFOT project, of a dynamic navigation system, which took dynamic traffic information into account and rerouted if necessary[24]. However, due to a lack of replicability of the results, the impact of this system was not estimated for EU-27. The next two studies both used simulations to evaluate a cooperative system[22] and a stand-alone one[23]. The first one evaluated a route navigation system on a road network of 8,25 km^2, while the other one studied its impact on a route network in Salt Lake City containing 27 intersections.

3.8.1 Effects on safety

Due to the fact that this system mostly focused on improving the efficiency and the management of traffic flow, an evaluation in terms of safety could not be found easily. The only study, which provides some information regarding safety is euroFOT, whose results showed a reduction of 5,4% in incidents, without making a differentiation between fatalities, injuries, accidents. It was decided not to use this data.

3.8.2 Effects on traffic efficiency

All three studies evaluated the impact of route navigation systems on traffic efficiency in terms of reducing travel time and congestion time. The euroFOT results showed a decrease of 9,4% in travel time, but a negligible impact in the reduction of congestion time. The simulation undertaken on the network in Salt Lake City indicates a reduction of 8,3% in travel time and 6,9% in congestion time, while the simulation performed in the third study indicated a reduction of 16,96% in travel time. Based on these results, final values for the indicators were assessed. As in the previous functions, different weightings were attributed to the values (i.e. calculate the travel time with ½ impact from simulation compared to field trials). Travel time was calculated with the formula:

$$t = (-9{,}4\%) \cdot \frac{1}{2} + (-8{,}3\%) \cdot \frac{1}{4} + (-16{,}96\%) \cdot \frac{1}{4} = 11{,}02\%$$

This leads to the following results:

- Travel time: -11%
- Congestion time: -6,9%

3.8.3 Effects on environment

By providing an efficient route, congestion and other traffic conditions may be avoided, leading to improvements in the management of traffic flows and significantly reduced congestion. This was translated into reduced emissions, fuel consumption and other environmental benefits. The field trial performed in euroFOT found an overall reduction of 3,08% in fuel consumption, but an increase of 0,9% in fuel consumption on motorways. The COBRA team decided to take a 0% change in fuel consumption, because the study gives no reasonable explanation. In [23], the simulation done on the road network of 8.25 km^2 provides more optimistic results. A decrease of 9,14% was found for CO_2, a 9,37% reduction in fuel consumption and 14,7% drop in NO_x emissions. No values were found for the impact on particulate matter or noise emissions. Final results were assessed, based on the data found and the experts' opinions represented within the consortium as the correlation between the values of fuel consumption and emissions from the research seemed low:

- CO_2: -9,14%
- Fuel consumption: 0%
- NO_x: -4,9%

3.9 Multimodal travel information

This function aids drivers by providing information regarding travel time, schedules and routing information door-to-door by using different types of sources such as built-in vehicle devices, the internet, mobile devices, etc. This function can be approximated by an Advanced Traveller Information System, a function which has been studied in depth. Four studies were found to describe and evaluate such a system, which is primarily focused on the optimization of travel efficiency. Due to this fact, no information was found regarding the impact on traffic safety. The first study was undertaken with a method called HOWLATE (Heuristic On line Web linked Arrival Time Estimation)[25], by using information collected from a road network of 1200 square miles in Washington and estimating the positive effects of Advanced Traveller Information System (ATIS) on traffic efficiency. The second study evaluated the system based on data collected for 5 days on a Los Angeles highway network[26] and made the distinction between proving historical, en route and predictive data to drivers. The TravTek FOTs[39] evaluated a travel information system in terms of traffic efficiency and emissions reductions with 100 equipped vehicles which were linked to the traffic management centre in Orlando. The fourth study assessed the impact of this function, by simulating a road network of 120 square miles for a period of 120 days. The impacts were assessed at 1%, 3%, 6% and 10% penetration levels. Due to the type of assessment, the decision was not to use the results of this latter study.

3.9.1 Effects on traffic efficiency

The main aim of this system is to improve travel time and reduce congestion. A study made in the Washington area[25] revealed a reduction of 2,18% in travel time and 92% in congestion. The latter value is not used in the COBRA assessment, since it seems too high for an EU-27 estimate. The study in Los Angeles [26] showed a 9,1% reduction of travel time if providing en route information and a 11,8% reduction when providing predictive data to the driver. Finally, the TravTek project[39] showed a 12% reduction in travel time during their trials. Based on these findings, a final value for travel time reduction was calculated as a mean between the results found in the three studies:

- Travel time: -8,77%

3.9.2 Effects on environment

The only study providing information regarding the impact of this function on the environment was the TravTek project[39]. It indicated an 11% reduction in fuel consumption and a 6% reduction in NO_x emissions:

- Fuel consumption: -11%
- NO_x: -6%

3.10 Parking Information and Guidance

This function is a service provided to drivers who need a parking place. It monitors the number of available places in a parking facility, detects the location of vehicles in real time, finds a parking place and provides routing information on how to reach the reserved place. The payment is organized automatically. The research done for this function revealed a small number of studies which evaluate the impact of a parking information system in terms of safety, efficiency and environment. Most studies assess the impact in terms of occupation, likeability and willingness to pay. In the COBRA project, the focus of this function was on truck parking systems. Only one study was found to evaluate a road side parking information system in terms of safety[40]. The study was made on a truck parking system situated on the Interstate I-81 in Virginia, USA. The primary impact area for truck parking systems is on safety.

3.10.1 Effects on safety

As mentioned above, one study evaluated the impact of a truck parking system. The results were provided by estimating the reduction in truck related fatalities and injuries. To obtain the values for the impact of this system on overall safety, COBRA used accident statistics from Austria, UK and the Netherlands. Based on the ratio of truck related accidents, the final values were calculated. The COBRA experts highlight that this calculated figures seem rather high:

- Fatalities: -8,55%
- Injuries: -9,77%

4 Impact assessment per bundle

It is widely believed that the deployment of cooperative systems will take place by offering several functions in a single package. For this purpose of this tool, three bundles of functions have been defined.

In order to avoid any overestimation of the impacts per bundle, the project carefully determined how to avoid double or triple counting. Clearly, a simple addition of impacts is only realistic if the individual functions' impacts are not overlapping. For most of the functions within a bundle, this is not the case (e.g. hazardous location warning and traffic jam ahead warning). By taking all these facts into consideration, a method of estimating the impact of each bundle was proposed.

4.1 Bundle 1: Local dynamic events

Assessing the impact of the first bundle means estimating the impact of four functions: Hazardous Location Notification (HLN), Traffic Jam Ahead Warning (TJW), Road Works Warning (RWW) and eCall. Upon further discussion it was agreed that the first three functions might overlap to some extent (e.g. traffic jam ahead warning and hazardous location notification in case of road works ahead). eCall is seen complimentary and has only limited or no overlap as it is triggered only in the case of an accident. The studies and results found supported this interpretation. The COBRA consortium decided to bundle the first four functions by taking the maximum value for each indicator for the first three (partially overlapping) functions and add the values from eCall (i.e. max(HLN, TJW, RWW)+ eCall). The values in Table 5 represent the final values used in the COBRA tool.

Table 5: Combined impact indicators for Bundle 1 (rounded to integer)

Impact indicators		General impact	Impact at congestion
Road Safety	Number of fatalities	-7%	-7%
	Number of non-fatally injured	-8%	-5%
	Number of injury accidents	-7%	-5%
Time spent in traffic	Travel time	+8%	+4%
	Congestion time	-3%	-3%
Fuel consumption	Gasoline/Diesel	-1%	-1%
Noise	Noise emissions in db	-1%	0%
Emissions	CO2	+2%	0%
	NOx	-10%	-1%
	PM-2.5	-1%	-2%

4.2 Bundle 2: In-vehicle information and signage

The second bundle contains three functions: In-vehicle Signage (IVS), Intelligent Speed Adaptation (ISA) and Dynamic Speed Limits (DSL). All of them deal in a certain way with varying the speed of a vehicle in order to increase safety and harmonize traffic. Due to this fact, an overlap is inevitable between the three. In order to accurately assess the overall impact of the bundle, it was decided to take the maximum value of each indicator from the functions (i.e. max (IVS, ISA, DSL)). The results listed in Table 6 are used in the COBRA tool.

Table 6: Combined impact indicators for Bundle 2 (rounded to integer)

Impact indicators		General impact	Impact at congestion
Road Safety	Number of fatalities	-7%	-7%
	Number of non-fatally injured	-5%	-5%
	Number of injury accidents	-5%	-5%

Time spent in traffic	Travel time	+4%	+7%
	Congestion time	+6%	0%
Fuel consumption	Gasoline/Diesel	-4%	0%
Noise	Noise emissions in db	-4%	0%
Emissions	CO2	-4%	0%
	NOx	-9%	-1%
	PM-2.5	-10%	-1%

4.3 Bundle 3: Information services

The third bundle refers to Traffic Information and Recommended Itinerary (TIN), Multimodal Travel Information (MTI) and Parking Information and Guidance (PIG). All three functions have the common aim of aiding the driver by providing routing and navigation, while managing traffic flows efficiently. Unfortunately, no values were found for operations in congested conditions and Table 7 only contains the impacts for free traffic flow. The data collected from the literature review showed an overlap between the first two functions, as both of them are strongly related to route guidance according to various traffic conditions.

The method of bundling agreed upon was to take the maximum value for each indicator of the first two functions added to the third one (i.e. max(TIN, MTI)+ PIG). The last function provides aid for truck drivers in efficiently finding parking places. Safety impacts only were found for this function, which is not representative for the bundle. Therefore, the COBRA experts assumed the safety impacts to be lower for the bundle.

Table 7: Combined impact indicators for Bundle 3 (rounded to integer)

Impact indicators		**Impact**
Road Safety	Number of fatalities	-4%
	Number of non-fatally injured	-5%
	Number of injury accidents	-5%
Time spent in traffic	Travel time	-11%
	Congestion time	-7%
Fuel consumption	Gasoline/Diesel	-10%
Noise	Noise emissions in db	Not found
Emissions	CO2	-9%
	NOx	-6%
	PM-2.5	Not found

5 Conclusion and outlook

The aim of the COBRA project is to develop a support tool aiding road authorities in the decision making process on implementation of cooperative systems technologies. In this decision making process three factors are important: impacts, the socio-economic costs and benefits and the business models. The final COBRA decision support tool shall use the current state of the art in cooperative systems (technologies, impacts and costs-benefits). In order to process the benefits and assess the impacts (COBRA WP3) of currently known and considered cooperative functionalities, an innovative methodology was developed. The aim was to have impact figures as estimated percental change in key performance indicators for safety, efficiency and environment compared to the current situation. The estimates found in literature were based on either field trials or simulation studies. Both methods have limitations in the accuracy of their estimates. Due to spatial limitations of Field Operational Tests geographic and regional effects will have an influence on the results, making it difficult to extrapolate to a general (i.e. country specific) value. In terms of simulations the limitations result in greater complexity and/or inherent systematic errors. Both limitations may introduce a bias in the final results. The methodology within COBRA for the impact assessment is entirely based on the findings from the literature. No additional simulation or field operational trials were carried out to validate or support the results. In the methodology, the accuracy and limitations of various approaches within different studies were presented and considered. Of course, this approach within COBRA (i.e. applying a literature based impact assessment) has limitations and challenges as well, notably:

1. How to combine different impact values deduced from different studies to one single value per indicator?
2. How to combine different functions within one bundle to one single impact per bundle?

The difficulties ranged from reported positive and negative impacts per indicator to a large variety of values within different studies (e.g. one change derived from simulation the other from a Field Operational Test). How the conclusion and final values were estimated is a crucial point in assessing the overall impact of a function.

From the literature review and the assessments performed, some conclusions can be drawn, in order to provide some guidelines for further research.

- The developments in cooperative systems have until this point focused on technical development. The impacts in terms of safety, efficiency and environment are not yet well researched or piloted, although results are expected soon for a limited number of systems.
- The functions that have been studied were analysed mostly through simulations. The reliability and accuracy of the findings from simulations are usually less trustworthy than from Field Operational Tests.
- The methodology for an impact assessment should be properly described in order to allow for conclusive thoughts on the final results (i.e. percentage change values per indicator).
- In many studies information or documentation on how estimates were deduced was not reproducible.
- Further research in impact assessment requires considering all constraints and assumptions that yield an impact to be reported.
- Further considerations towards a generalized methodology are needed for translating results from Field Operational Tests from a lower geographic level to generalized figures (i. e. per national member state or country specific values).
- Little is known about how drivers use cooperative systems, mainly because the initial systems are expected to be information, or warnings, and would not be mandatory. Therefore, it is difficult to make a decision on how to assess the results found from multiple studies, as each study has its own scenarios and conditions.
- Only a few studies systematically address the full range of conditions in which functions will be used, or estimate the impacts under all conditions.

Glossary

Term	Definition
(Penetration) scenario	The COBRA tool allows the users to choose between various penetration scenarios (high/mid/low) in order to strengthen the decision support for road operators. The rates comprise the current market penetration of both in-vehicle and roadside units necessary for the corresponding function and platform.
(Technology) platforms	This includes the technology platforms Cellular, WiFi or both.
Bundle	Three logical bundles combine several cooperative functions that could be deployed together.
Cooperative function	In COBRA, a single Cooperative System with a specific functionality is called function.
Cooperative System	A co-operative ITS is a subset of the overall ITS that communicates and shares information between ITS Stations to give advice or facilitate actions with the objective of improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems
Reference situation	The reference situation refers to the current size of the traffic (safety, efficiency and environment) issues, level of traffic management system deployment and number of motorway kilometers in the country of interest.
RSU	Road side unit; in contrast to in-vehicle devices (onboard units), RSU are part of the road infrastructure.
V2I	Vehicle-to-Infrastructure communications is the wireless exchange of data between vehicles and road infrastructure.
V2V	Vehicle-to-Vehicle (also Car-to-Car) Communications is the dynamic wireless exchange of data between nearby vehicles.

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Appendix 1: List of cooperative functions

Name	Description
Dynamic speed limits	Speed limits are set on a road segment according to the infrastructure (e.g. geography, road alignment, etc.), type of road, traffic flow and other factors. Dynamic speed limits have the advantage of being more flexible. They take into account traffic flow in different conditions and times of day, weather conditions and other environmental factors.
eCall	If sensors in the vehicle detect that a collision has occurred, the vehicle can automatically make a telephone call to the emergency services to give the incident location, and provide some information about the vehicle and its location. The system opens voice and data channels so that the emergency call centre can talk to the driver or any passengers if they are conscious. The post crash warning part of the application warns drivers when approaching a crashed car either via a message from the crashed car itself or via a following car that detects a crashed vehicle warning ahead.
Hazardous location notification	Provides a warning notification about potential hazardous areas when approaching them. These areas statistically have more collisions and incidents, and thus require more attention This application would have a particular benefit in dynamic situations such as changing weather conditions.
Intelligent speed adaptation (ISA)	ISA is a system that monitors a vehicle's speed and the speed limit on the road being used and intervenes if the vehicle is detected exceeding the speed limit. An ISA can have additional features to influence driver's behaviour by e.g. haptic gas pedal.
In-vehicle signage	A vehicle-infrastructure link is used to give information or a warning to a driver of the content of an upcoming roadside sign. This can be extended to inform drivers about other oncoming features of the road such as chicanes, roundabouts, traffic calming installations and road markings such as segregated cycle lanes or bus lanes. This application is often referred to as Visibility enhancement - giving the driver information about situations beyond or outside the direct line-of-sight.
Multimodal traffic information	This function aids drivers by providing information regarding travel time, schedules and routing information door-to-door by using different types of sources such as built-in vehicle devices, the internet, mobile devices, etc. This function can be approximated by an Advanced Traveller Information System, a function which has been studied in depth.
Parking information and guidance	This function is a service provided to drivers who need a parking place. It monitors the number of available places in a parking facility, detects the location of vehicles in real time, finds a parking place and provides routing information on how to reach the reserved place. The payment is organized automatically.

Name	Description
Road works warning	Carrying out repairs on a live carriageway usually involves temporary speed limits, lane changes, lane merges and contra flow running which are managed by temporary signs and portable physical barriers to divide lanes. A linked vehicle-infrastructure system offers much more flexibility, enabling faster reconfiguring of the work zone and allows precise alerts and instructions to drivers regarding lane choices, speeds, too-close following of preceding vehicles etc.
Traffic info and recommended itinerary	Recommends a route for the vehicle navigation system to direct the driver around congested locations and dangerous roads and to distribute the traffic load on alternative routes.
Traffic jam ahead warning	It will cause drivers to be more aware of the situation ahead leading to lower speeds, longer headways and a reduced risk of rear-end collisions.