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

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1 Introduction

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

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

The focus of this document is on summarising the C-ITS service impact data, which were used as inputs to TRT's ASTRA and TRUST models.

1.1 C-ITS service impact data overview

1.1.1 Impact data collected

For each C-ITS service included in the C-ITS deployment scenarios, data related to the following parameters was collected:

1. Traffic efficiency i.e. the percentage change in average speed for a vehicle equipped with C-ITS services.
2. Fuel consumption i.e. the percentage change in fuel consumption for a vehicle equipped with C-ITS services.
3. Polluting emissions i.e. the percentage change in NO_x, CO, VOC and PM emissions for a vehicle equipped with C-ITS services
4. Safety i.e. the percentage change in accident rates (classified by fatalities, serious injuries, light injuries and material damages) for a vehicle equipped with C-ITS services.

The data collected for each C-ITS service is discussed in turn in this document, which is divided into three key sections as follows:

- Section 1: this section provides an introduction to the data collection task, summarises the key objectives and assumptions, and lists the main data sources.
- Section 2: this section discusses the impact data collected for each C-ITS service.
- Section 3: this section discusses C-ITS service overlap and how this was accounted for in the modelling.
- Section 4: this section includes a full list of data sources used in the C-ITS service impacts data collection.

In addition, an Excel document accompanying this report summarises all impacts data inputted into the modelling.

1.1.2 Impacts categorisation

C-ITS services can have varying impacts depending on the road type and vehicle type in which they are deployed. Furthermore, some services are not applicable to some road or vehicles types. Where available, impact data was therefore collected for the road and vehicle types modelled in the deployment scenarios.

The categories of roads modelled in the deployment scenarios are as follows:

- TEN-T Corridors
- Core TEN-T
- Comprehensive TEN-T
- Non-motorway non-urban
- Urban roads

Impacts on TEN-T Corridors, Core TEN-T and Comprehensive TEN-T were assumed to be the same, as these are all motorways.

The categories of vehicles modelled in the deployment scenarios are as follows:

- Passenger car
- Light trucks
- Heavy trucks
- Buses

Impacts on freight vehicles (light trucks and heavy trucks) were assumed to be the same.

1.1.3 Key assumptions

Data was collected for services at maximum effectiveness, i.e. at 100% deployment in infrastructure and in the vehicle fleet. The actual effectiveness applied in the ASTRA and TRUST modelling is estimated through taking into account this maximum effectiveness alongside the predicted vehicle/aftermarket and infrastructure penetration rates.

In future years, it is conceivable that C-ITS technology could improve to deliver greater impacts. However, the modelling assumes that there will be no improvement in technology/performance over the time period covered in this cost-benefit analysis (2015-2030).

Whilst our objective was to collect data for each road type and vehicle type described above, many C-ITS services are currently at field operational trial (FOT) or pilot project stage and an extensive search of the literature revealed that detailed, publically available results are extremely limited, despite a number of deployment projects carried out in Europe in recent years. Where necessary, a number of assumptions were employed to fill the data gaps, as detailed below:

- Impact data was not available for individual vehicle types, therefore impacts were assumed to be the same for all vehicle types.

- Safety impacts were collected for fatalities and injuries wherever possible. Where this split was available, it was assumed that the magnitude of accident impacts would be the same for serious injuries, light injuries and material damages. Where this split was not available, the impact was assumed to be the same across all accident types.
- Impact data was collected for different road types wherever possible. In the case of data gaps, it was assumed that impacts would be the same on all road types where the service was seen as relevant (in these cases, urban-focused services were not applied to inter-urban roads and vice versa).

Furthermore, change in speed is only modelled on urban roads in TRT's ASTRA model, therefore traffic efficiency data was not modelled for motorways (TEN-T corridors, TEN-T core roads and the comprehensive TEN-T network) and non-motorway non-urban roads.

1.2 Sources of information

1.2.1 Literature

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

- 013 - DRIVE C2X Deliverable D11.4. Impact Assessment and User Perception of Cooperative Systems.
- 113 - EasyWay Business case and benefit-cost assessment of EasyWay priority cooperative services
- 017 - eIMPACT Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe. Deliverable D4. Impact assessment of Intelligent Vehicle Safety Systems.
- 046 - SAFESPOT Deliverable SP6 – BLADE – Business models, Legal Aspects, and DEployment
- 040 - CODIA Deliverable 5 – Final study report
- 045 - eSafetyForum Intelligent Infrastructure Working Group – Final Report
- 124 – TNO Impact of Information and Communication Technologies on Energy Efficiency in Road Transport – Final Report
- 004 – COMeSafety2 D2.3 Cost Benefits Analysis & Business Model Elements for Deployment
- iMobility Effects database

The most commonly used data sources are described in more detail in a series of boxes when they are first referenced throughout this document.

Where C-ITS service impact data was not directly available from literature, a number of approaches were used to fill the data gaps, including:

- Identifying impacts from other non-C-ITS services or technologies which are expected to operate through a similar mechanism to specific C-ITS services, for example 'lane change assist' as one component of the Day 1.5 service Cooperative Collision Risk Warning.
- Estimating impacts from first principles based on, for example using known accident data linked to specific accident types targeted by certain C-ITS services to estimate the impact of a specific C-ITS service on accident rates.

The detailed assumptions used for each C-ITS service are listed under each service heading in Section 2.

1.2.2 Expert input

In addition to the desk-based data collection, various draft impacts data points were discussed with individual experts from within and outside of WG1 over the course of July-September 2015. For example, where data was inconsistent between studies or where gaps remained from the literature review, a number of industry experts (mainly from within WG1) were contacted either unilaterally or in groups (via email or by teleconference) as part of Task 8 (cross cutting stakeholder engagement task). Ricardo Energy & Environment invited industry experts to:

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

This resulted in a number of revisions to the impacts data included in this document.

2 Input data for services

2.1 Emergency electronic brake light (EBL)

2.1.1 Service overview

The emergency electronic brake light is a service aimed at preventing rear end collisions by informing drivers of hard braking by vehicles ahead. Using this information, drivers will be better prepared for slow traffic ahead and will be able to adjust their speed accordingly.

2.1.2 Technical information

- Day 1 vehicle-to-vehicle (V2V) service, likely based on ITS-G5 communication
- Bundle 1

In response to a vehicle suddenly braking, a message is sent to following vehicles to warn drivers of an abrupt decrease in traffic speed ahead. Emergency electronic brake lights are displayed in the following vehicles, giving drivers the opportunity to adjust their speed to avoid a potential collision. This service is applicable on all road and vehicle types, although it is envisaged to be particularly useful on congested, high speed roads, or in areas where visibility is poor. In this situation, following vehicles may not be able to see the brake lights of all vehicles ahead of them and would therefore have very limited time to react to hard braking without the service. This service predominantly relies on V2V ITS-G5 communication, although a number of projects are looking to demonstrate its effectiveness using high-speed (e.g. 4G/5G) cellular networks.

2.1.3 Impact data

The main data source for the impacts of the emergency electronic brake light was from FOTs in the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1. This service was only tested in Germany, in partnership with the sim^{TD} project (simTD, 2013). A US DoT cost-benefit analysis report was also used as a comparison (John A. Volpe National Transportation Systems Center, 2008).

Box 1: Overview of key data source – DRIVE C2X project

The DRIVE C2X project used log data resulting from Field Operational Tests (FOTs) carried out on several test sites in different EU countries (Finland, France, Germany, Italy, the Netherlands, Spain, and Sweden).

The study aimed to harmonise the testing conditions as far as possible, in order to allow the data across the pilot sites to be combined. Nevertheless, several aspects differed significantly from one test site to others. These differences can be explained by cultural, country specific aspects as well as acquisition related influences (private drivers vs. employees).

The FOTs focused on functions that provide information or warnings to drivers. This means that the impact is dependent on whether and how the driver responds. Thus, the impact assessment first aimed to measure driver behaviour in order to provide input data for an impact assessment in four target areas: safety, efficiency, mobility, and environment.

Driver behaviour data was collected in two main ways: controlled tests” (CTs) and naturalistic driving (ND). In CT, drivers were called into the test and followed the driving instructions provided by the Test-Site Instructor, allowing the driver to encounter specific test situations. In the ND approach, drivers were monitored in their daily driving. Data on driver behaviour was then pooled across the test sites and used as input for the assessment of impacts.

Safety impacts were calculated by making use of previous expert assessments found in the literature and expert assessment. Traffic efficiency and environmental impact assessment made use of simulation models. The mobility impact assessment in Drive C2X was based on the mobility model

developed in TeleFOT project, which relied mainly on a qualitative evaluation using stakeholder input against a number of mobility indicators. The scaling up of the effects to the EU-level made use of external data.

Source: (TNO, 2014)

Other studies that considered the impacts include the eIMPACT project (TNO, VTT, Movea, PTV, BASt, 2008) and a cost-benefit analysis performed for the U.S. Department of Transport (John A. Volpe National Transportation Systems Center, 2008). We have chosen to prioritise the DRIVE C2X data ahead of these source as it was published in 2014 (compared to 2008 for the other sources), is based on FOT data and its primary focus is on the EU, compared to the US DoT study.

2.1.3.1 Traffic efficiency

The primary effect of emergency electronic brake light is intended to be on safety, hence the traffic efficiency impacts are expected to be minimal. No traffic efficiency effects are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider traffic efficiency effects for this service.

2.1.3.2 Fuel consumption and CO_2

The primary effect of emergency electronic brake light is intended to be on safety, hence the fuel efficiency impacts are expected to be minimal. No fuel efficiency benefits are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on fuel consumption for this service.

2.1.3.3 Environmental and emissions impacts

The primary effect of emergency electronic brake light is intended to be on safety, hence the emissions impacts are expected to be minimal. No effects on emissions are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on polluting emissions for this service.

2.1.3.4 Safety

The primary objective of this service is to prevent rear end collisions, although other types of accident may also be prevented. Specifically, this service is thought to reduce the number of panic manoeuvres performed by vehicles, due to the early warning. This service can act via two mechanisms (TNO, 2014):

- Direct in-vehicle modification of the driver task – the driver behind the braking vehicle has more time to react to the braking vehicle ahead.
- Modification of interaction between vehicles – following drivers (with or without emergency brake light capability) will also have more time to react to the braking vehicle ahead.

In the DRIVE C2X study, impacts were assessed separately for: a) motorways and high speed rural roads (with a speed limit of at least 80 km/hour) and b) urban roads and low speed rural roads. The assumptions made in the DRIVE C2X study in scaling up these impacts are detailed below (TNO, 2014).

Rear-end collisions prevented via direct in-vehicle modification of the driving task:

- 60-80% of fatalities and injuries on rural roads occur on high speed rural roads, whilst all fatalities and injuries on motorways are considered to be high-speed (>80km/h).
- It is assumed that 50-70% of rear end collisions occurring on motorways and high speed rural roads could be influenced by the emergency brake light service.
    - 20-30% of these fatalities and injuries could be prevented by the emergency electronic brake light.
- It is assumed that 10-25% of rear end collisions occurring on urban roads and low speed rural roads (the remaining 20-40% of rural roads) could be influenced by the emergency brake light service.
    - 30-40% of these fatalities and injuries could be prevented by the emergency electronic brake light.

Other collision types (other than rear-end) prevented via direct in-vehicle modification of the driving task:

- Magnitude of the safety benefit was estimated to be 5-10% of the impact for rear collisions (as described above) per accident type.

Rear-end collisions prevented via modification of interaction between road users:

- When a driver reacts to hard braking ahead, following vehicles will also have increased time to react.
    - On motorways and high speed rural roads, a 0.10-0.15% reduction in fatalities is expected.
    - On motorways and high speed rural roads, a 0.02-0.03% reduction in injuries is expected.
    - On urban roads and low speed rural roads, a 0.15-0.30% reduction in fatalities is expected.
    - On urban roads and low speed rural roads, a 0.10-0.20% reduction in injuries is expected.

The relatively low effectiveness of this service for interactions between road users is due to the high element of surprise and very small time margins involved in these types of crashes.

Overall for the EU-28, the DRIVE C2X study calculated a decrease in fatalities between 25-304 in 2030) and a decrease in injuries between 1322-16219 in 2030.

We used the DRIVE C2X high penetration scenario as an input to the model, which corresponds to a **2.7% decrease in fatalities and a 2.5% decrease in injuries**.

The US DoT also assessed the potential safety impact of this service in 2030 as part of a cost-benefit analysis and calculated a 0.88% decrease in annual light vehicle crashes, which is a significantly lower figure than DRIVE C2X (John A. Volpe National Transportation Systems Center, 2008). The discrepancy is likely to be due to the differences in road and driving characteristics in the USA and EU and higher traffic density on European roads.

2.1.3.5 Other impacts

As part of DRIVE C2X, user acceptance tests were not carried out for the emergency brake light functionality. The sim^{TD} project reported that driver behaviour was not significantly affected by the emergency brake light, however recommends further studies to support this theory (Mühlbacher, 2013). The sim^{TD} project questions whether there are benefits for drivers further behind the braking vehicle and again proposes that further research should be carried out to determine the impact of this service on all vehicles in a queue.

2.2 Emergency vehicle approaching (EVA)

2.2.1 Service overview

This service aims to give an early warning of approaching emergency vehicles, prior to the siren or light bar being audible or visible. This should allow vehicles extra time to clear the road for emergency vehicles and help to reduce the number of unsafe manoeuvres.

2.2.2 Technical information

- Day 1 V2V service, likely based on ITS-G5 communication
- Bundle 1

Approaching emergency vehicles will communicate with vehicles ahead to warn drivers to clear the road. The advance warning provided by this service will give vehicles extra time to clear the road for approaching emergency vehicles in a safe and timely manner. This service is applicable for all road and vehicle types. This service predominantly relies on V2V ITS-G5 communication, although a number of projects are looking to demonstrate its effectiveness using high-speed (e.g. 4G/5G) cellular networks.

2.2.3 Impact data

The main data source for the impacts of the emergency vehicle approaching service was the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1. Trials of this service were carried out at test sites in Germany, Italy and Spain. Data for this service was very limited, perhaps due to the limited real world opportunities to trial this type of service. To our knowledge, there are no other publically available studies that examine the emergency vehicle approaching service specifically.

2.2.3.1 Traffic efficiency

The primary effect of the emergency vehicle approaching service is intended to be on safety, hence the traffic efficiency impacts are expected to be minimal. No traffic efficiency effects are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider traffic efficiency effects for this service.

2.2.3.2 Fuel consumption and CO_2

The primary effect of the emergency vehicle approaching service is intended to be on safety, hence the fuel efficiency impacts are expected to be minimal. No fuel efficiency benefits are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on fuel consumption for this service.

2.2.3.3 Environmental and emissions impacts

The primary effect of the emergency vehicle approaching service is intended to be on safety, hence the emissions impacts are expected to be minimal. No effects on emissions are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on polluting emissions for this service.

2.2.3.4 Safety

A reduction in collisions can be expected when this service is implemented due to the increased time drivers have available to inform their driving decisions.

The DRIVE C2X study used French accident statistics to estimate the impact of the emergency vehicle approaching warning (TNO, 2014). These show that 0.8% of fatal accidents and 1.1% of injuries included an emergency vehicle. This does not include accidents where the emergency vehicle was not directly involved. A multiplier of 1-5 was used for these accidents, based on another study (Clawson, 1997). Of these additional accidents, it was estimated that only 1-5% would result in injuries or fatalities.

The accidents were then categorised according to whether they occurred at an intersection or on a link section of road. Here, the following assumptions were made:

- 50-70% of emergency vehicle related (directly or indirectly) fatalities and injuries occur at intersections (Auerbach, 1988; Elling, 1988).
- 50-70% of emergency vehicle related (directly or indirectly) fatalities and injuries occurring at intersections could be prevented by the emergency vehicle approaching service.
- 60-80% of emergency vehicle related (directly or indirectly) fatalities and injuries occurring at links (the remaining 30-50% of total fatalities and injuries) could be prevented by the emergency vehicle approaching service. This higher figure is due to the lower complexity of the road layout and reflects the fact that it is likely to be easier for drivers to give way to emergency vehicles.

The results in the DRIVE C2X report were presented in terms of the overall impact in the EU-28 in 2030. It was estimated that 14-84 fatalities and 933-4954 injuries could be prevented (TNO, 2014). This equates to a **0.8% reduction in fatalities and a 0.8% reduction in injuries**.

2.2.3.5 Other impacts

A survey of test participants during the DRIVE C2X study revealed some interesting insights regarding this service. 92% of participants viewed the service as useful (the highest in the study), however only 41% indicated they would be willing to pay for this feature (TNO, 2014). On a scale of 1 to 7, the average increased feeling of safety was rated at 5.6-6.0, suggesting that this service can offer an improved driving experience.

No impact on modal shift was reported.

2.3 Slow or stationary vehicle(s) warning (SSV)

2.3.1 Service overview

Slow or stationary vehicle(s) warning, is intended to deliver safety benefits by warning approaching drivers about slow or stationary/broken down vehicle(s) ahead, which may be acting as obstacles in the road. The warning helps to prevent dangerous manoeuvres as drivers will have more time to prepare for the hazard. This service can also be referred to as car breakdown warning.

2.3.2 Technical information

- Day 1 V2V service, likely based on ITS-G5 communication
- Bundle 1

Slow or stationary vehicle(s) signal to nearby vehicles to warn approaching drivers of their presence. These messages can then be relayed to following drivers, who can consequently plan to take an alternative route, or make evasive manoeuvres, thus improving traffic fluidity, safety and delivering efficiency benefits. This service is applicable to all road and vehicle types. As for the emergency electronic brake light service, it is anticipated that this service will be especially useful for warning vehicles of the potential danger of a rear end collision when visibility is poor. This service predominantly relies on V2V ITS-G5 communication, although a number of projects are looking to demonstrate its effectiveness using high-speed (e.g. 4G/5G) cellular networks.

2.3.3 Impact data

The main data source for the impacts of slow or stationary vehicle(s) warning was the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1. This service was tested at sites in Finland, Italy, Spain and Sweden. In DRIVE C2X, this service is evaluated alongside ‘obstacle warning’ and ‘roadworks warning’, as the services perform a similar function, act via similar mechanisms and present information to drivers in a similar manner.

The eIMPACT project (TNO, 2014) evaluated the impacts of a service called ‘wireless local danger warning’, which is based on V2V communication. An overview of the general methodology is provided in Box 2.The eIMPACT definition of this service includes both obstacle/stationary vehicle warning and weather warning functionality.

Box 2. Overview of key data source – eIMPACT project

The eIMPACT project assessed the socio-economic effects of Intelligent Vehicle Safety Systems (IVSS) and their impacts on safety and traffic efficiency. Results from the impact assessment (Deliverable D4) were then used to inform a cost-benefit analysis (Deliverable D6).

The results of the study were published in 2008 and calculated the potential impacts of IVSS in the years 2010 and 2020. The impact assessment was performed for low (business as usual) and high (policy incentives) scenarios for both years. For each scenario, the fleet penetration varied by service, vehicle type (passenger car or goods vehicle) and by year (2010 or 2020). In addition to the scenarios, the maximum effectiveness of each service based on 100% penetration at EU-25 level was also calculated as part of eIMPACT. Results were given for the EU-25 as a whole and are not separated by road type, or vehicle type. We have used the values based on 100% penetration as a source of data in this project.

Twelve services were evaluated, although only three were defined as having cooperative functionality:

- Intersection safety - the description of this service in the eIMPACT report also includes GLOSA/TTG functionality and is not limited to signalised intersections (also provides right of way assistance and left turn assistance).
- Speed alert - considers the service to have V2I functionality in 2020 but not in 2010.

- Wireless local danger warning - includes weather warnings and obstacle/stationary vehicle warnings, both of which are based on V2V communication.

Another service, pre-crash protection of vulnerable road users, was also evaluated. This is similar to the vulnerable road user protection service evaluated in this study, however in eIMPACT it was not considered to be a cooperative system and was assumed to operate by detecting vulnerable road users via sensors. The two services are likely to present information to the driver in a similar manner and safety impacts will occur via similar mechanisms, therefore we believe the data presented can be of some value.

Safety impacts were calculated by making use of expert estimations and were scaled up to EU-25 level based on current accident statistics. In addition to this, consultation with key stakeholders was an integral part of the eIMPACT project.

Sources: (TNO, VTT, Movea, PTV, BASt, 2008) (eImpact, 2008)

2.3.3.1 Traffic efficiency

The traffic efficiency impacts of the slow or stationary vehicle(s) service are expected to be minimal as its purpose is to improve safety, rather than prevent traffic jams (TNO, 2014). In addition to this, broken down, stationary, or exceptionally slow vehicles (such as tractors) on the road are relatively infrequent events, therefore effects on traffic on an EU level will be negligible. This impact is therefore not included in our model.

2.3.3.2 Fuel consumption and CO_2

The primary effect of the slow or stationary vehicle warning is intended to be on safety, hence the fuel efficiency impacts are expected to be minimal. No fuel efficiency benefits are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on fuel consumption for this service.

2.3.3.3 Environmental and emissions impacts

The primary effect of the slow or stationary vehicle warning is intended to be on safety, hence the emissions impacts are expected to be minimal. No effects on emissions are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on polluting emissions for this service.

2.3.3.4 Safety

This service is expected to work by informing drivers of slow or stationary vehicle(s) before they would be aware of the hazard without the service and may be particularly beneficial if the hazard is in an area with low visibility. This should enable drivers to have more time to prepare and navigate safely past the slow/stationary vehicle. In the DRIVE C2X study, a decrease in speed was observed for vehicles participating in the trial.

The DRIVE C2X study used accident statistics for single vehicle accidents with an object other than a pedestrian for three road types (motorways, rural roads and urban roads) to scale up the FOT results to EU level. The following assumptions were then made to scale up the potential safety impacts:

- 10-20% of accidents with an object other than a pedestrian the object would be a broken down vehicle.
- The effectiveness of car breakdown warning would vary depending on road type. The percentage of accidents prevented by road type is given below.
    - Motorways: 90%
    - Rural roads: 65-85%
    - Urban roads: 30-50%

Using these findings, the authors presented data in terms of the number of expected injuries and fatalities prevented (TNO, 2014). For the year 2030, this has been estimated to be between 12-125 fatalities and 427-2794 injuries (figures assume 100% vehicle penetration). These values equate to an average **1.1% decrease in fatalities and a 0.7% decrease in injuries**.

The eIMPACT study also covered this service as part of the wireless location danger warning (one aspect of which is obstacle/stationary vehicle warning). In total, this service is estimated to have a 4.5% reduction in fatalities and a 2.8% reduction in injuries. This estimate assumes 100% penetration and the results are presented for EU-25 level. These values are much larger than those predicted by DRIVE C2X, however this is likely due to the fact that in eIMPACT, weather conditions were also considered as part of the wireless location danger warning service.

To check for agreement between the two sources, the DRIVE C2X safety impacts for slow or stationary vehicle(s) and weather warning were added together. This gave a total impact of 4.56% on fatalities and a 4.04% impact on accidents. The impact on fatalities compares well to eIMPACT data, however the combined impact on injuries for slow or stationary vehicle and weather warning predicted by DRIVE C2X is larger than that predicted by eIMPACT.

The DRIVE C2X data has been used in preference to the eIMPACT data for input into the model, as it is based on FOT data and because it provides a separate impact for slow or stationary vehicle warning, whereas eIMPACT does not.

Table 2-1. Summary of safety impacts of the slow or stationary vehicle warning service

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
DRIVE C2X	1.13%	0.69%	100% penetration EU-28, 2030
eIMPACT	4.5%	2.8%	100% penetration EU-25, 2020

2.3.3.5 Other impacts

User acceptance for the car breakdown, or slow or stationary vehicle warning was one of the highest observed during the DRIVE C2X project and was widely noted to be a very helpful feature. Drivers particularly liked the increased feeling of safety gained by reducing the surprise of encountering a slow, stationary, or broken down vehicle in the road (TNO, 2014).

2.4 Traffic jam ahead warning (TJW)

2.4.1 Service overview

The Traffic Jam Ahead Warning (TJW) provides an alert to the driver on approaching the tail end of a traffic jam at speed - for example if it is hidden behind a hilltop or curve. This allows the driver time to react safety to traffic jams before they might otherwise have noticed them themselves. The primary objective is to avoid rear end collisions that are caused by traffic jams on highways.

2.4.2 Technical information

- Day 1 V2V service, likely based on ITS-G5 communication
- Bundle 1

This service is applicable for all road and vehicle types, however its main benefit is expected to be on high speed roads (TEN-T Corridors, TEN-T Core and TEN-T Comprehensive network), where the system will be able to warn of traffic ahead faster than the driver is capable of identifying the danger. This service predominantly relies on V2V ITS-G5 communication, although a number of projects are looking to demonstrate its effectiveness using high-speed (e.g. 4G/5G) cellular networks.

2.4.3 Impact data

The main data source for the impacts of TJW was the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1.

For TJW, Field tests were carried out at the test sites in Spain, Italy and Germany. The test site in Germany had such a small number of traffic jams that no impacts were found. Italy also had a small number of events recorded – since real vehicle queues did not occur at all, artificial TJW events were triggered manually in high traffic density situations on motorways. Similarly, the test site in Spain had few traffic jams occurring, mainly in urban areas. Since the TJW events from Italy and Spain came from two different traffic scenarios (highway vs. urban roads respectively), it was difficult to draw a conclusion on the effectiveness from the pooled data. Nevertheless, an assessment was made using the available information and expert judgement.

Other studies that considered the safety impacts of TJW include the eIMPACT and EasyWay studies (EasyWay, 2012; TNO, VTT, Movea, PTV, BASt, 2008). The EasyWay figures were based on the eIMPACT project from 2008, which scaled the values up to EU-25 level, therefore the DRIVE C2X data were used in preference. An overview of the methodology for the EasyWay project is provided in Box 3.

Box 3. Overview of key data source – EasyWay project

The cost-benefit analysis carried out in the EasyWay study considered the impacts of C-ITS on road safety, efficiency and congestion as well as fuel consumption and emissions. The analysis was carried out for the year 2030 and assumed 100% of all vehicles will be equipped with some form of communication device that can facilitate cooperative services. The study assumed that one third will be installed by OEMs, one third will be aftermarket devices and one third will be nomadic devices.

Primary data (for 2010), including:

- Vehicle fleet compositions
- Vehicle kilometres driven by road type
- Road accident statistics by severity (i.e., fatalities, injured, property damage etc)
- Congestion (i.e., delays),
- Emissions (NO_x, CO, PM2.5)
- Fuel Economy/CO_2 emissions for diesel and petrol cars
- and road infrastructure deployment

was obtained from national representatives and usually came from gathered national statistics. In cases where data was missing, the missing data was estimated by interpolating/extrapolating between countries with similar characteristics (left undefined by authors), the resulting estimates were then sent for approval form that country's representatives in the task.

To make more robust estimates for C-ITS impacts, adaptations were made to account for changes in driving behaviour and travel behaviour. These adaptations were based on simple models taken from various literature sources. The key sources were:

- Kulmala, R.; Leviäkangas, P.; Sihvola, N.; Rämä, P.; Francics, J.; Hardman, E.; Ball, S.; Smith, B.; McCrae, I., Barlow, T.; Stevens, A. (2008). **CODIA** Deliverable 5: Final Study Report. CODIA Co-Operative systems Deployment Impact Assessment. Submitted to European Commission DG-INFSO
- Wilmink I., Janssen W., Jonkers E., Malone K., van Noort M., Klunder G., Rämä P., Sihvola N., Kulmala R., Schirokoff A., Lind G., Benz T., Peters H. & Schönebeck S. (2008). Impact assessment of Intelligent Vehicle Safety Systems. **eIMPACT** Deliverable D4. Version 1.0 April 2008.
- Janssen W.H., Brouwer R.F.T. and Huang Y. (2004). Risk trade-offs between driving behaviour and driver state. **AIDE** Deliverable D2.3.2.
- Nilsson G. (2004). Traffic Safety Dimensions and the Power Model to describe the effect of speed and safety. Bulletin 221. Department of Technology and Society. Lund University. Sweden.

The data required to parametrise these models were usually taken from the same papers that presented the models. For example, for *hazardous location notification*

- It is assumed that it comprises of low friction warnings and low visibility warning. The corresponding estimated safety improvements are: 5% and 12% reductions in injury crashes, respectively; and 10% and 23% reductions in fatal crashes, respectively [Kulama et. al. (2008) Nilsson (2004)]
- Following Kulmala et. al. (2008) and Janssen et. al. (2006), the effects of increased awareness is assumed to further reduce the risk of accidents by 11%
- Kulmala et. al. (2008), utilising the results of Janssen et. al. (2006) estimated an overall headway-related crash risk decrease of 4%
- Assuming that speed awareness and headway effects are independent (an assumption that is made for all mechanism and sub-mechanisms in adapting for behavioural changes) safety impacts for *hazardous location notification* is -22% (0.915 x 0.89 x 0.96 = 0.78) for injuries and -29% (0.835 x 0.89 x 0.96 = 0.71) for fatal accidents/fatalities.

Finally, the forecasts for 2030 were estimated from the 2010 data by utilising any existing national forecasts and the forecasts provided by the eIMPACT (Wilmink et al. 2008) and CODIA projects (Kulmala et al. 2008). In addition, the general energy use and CO_2 forecast were taken from European Energy and Transport Trends to 2030 (published in 2007)[1]. Note that for safety, the 2020 forecast was used for the 2030 forecast because the authors assumed that almost all additional safety improvement between 2020 and 2030 would result from cooperative systems. As for the other estimates, all forecasts were validated by the national representatives.

Source: (EasyWay, 2012)

2.4.3.1 Traffic efficiency

In DRIVE C2X, the traffic efficiency impacts of TJW were examined using traffic simulation, which did not show any statistically significant changes in traffic efficiency (TNO, 2014). This is because TJW affects how a driver approaches the tail of a traffic jam and will not affect the duration of the traffic jam. Multiple simulation runs also found that there were no second order effects impacting the characteristics

[1] http://ec.europa.eu/dgs/energy_transport/figures/trends_2030_update_2007/energy_transport_trends_2030_update_2007_en.pdf

of an existing traffic jam (TNO, 2014), and hence this impact was considered insignificant for the purposes of this study. Therefore, zero impact was assumed for this impact category in the model.

2.4.3.2 Fuel consumption and CO_2

The primary effect of TJW is intended to be on safety. Hence the fuel efficiency impacts are expected to be minimal. Minor reductions in fuel consumption could occur if a driver were able to decelerate more economically. Nevertheless, the effects are small and valid only for a short distance influenced by the traffic jam. The results from DRIVE C2X confirmed that impacts on fuel efficiency were statistically insignificant and could not be scaled up to the EU level (TNO, 2014).

2.4.3.3 Environmental and emissions impacts

The primary effect of TJW is intended to be on safety. Hence the environmental impacts are expected to be minimal. Minor reductions in pollutant emissions could occur if a driver were able to decelerate more economically. Nevertheless, the effects are small and valid only for a short distance influenced by the traffic jam. The results from DRIVE C2X confirmed that impacts on pollutants were statistically insignificant and could not be scaled up to the EU level (TNO, 2014).

2.4.3.4 Safety

The primary safety benefit provided by TJW is to avoid a rear-end collision due to ensuring earlier driver awareness of a traffic jam tail. (TNO, 2014). In case of high traffic flow, there might be problems of side-by-side collisions and other accident types as well if drivers carry out panic manoeuvres.

In DRIVE C2X, safety effects were presented as a percentage reduction in fatalities or injuries in 2030, corresponding to various penetration scenarios.

Specifically, positive effects that were expected are:

- The driver will slow down earlier than without TJW.
- The driver will slow down to a lower speed than without TJW.
- The driver will not slow down earlier, but be able to react faster on approach to the traffic jam.
- The driver may also brake more smoothly when reaching the traffic jam, or to keep the lane in case of high traffic flow.

A possible rebound effect is that the driver would pay less attention to potential traffic jams due to relying on the system. However, the information provision is dependent on equipped vehicles being present to send the warning.

When the user of TJW approaches the traffic jam more smoothly, the non-users behind will most likely do so, too. The amount of fatalities and injuries in rear collisions caused by traffic jam to be prevented was assessed to be 1-5% for all driving environments due to smoother non-user driving behaviour. The impact was assessed to be 5-10% of the impact for rear collisions to other accident types except frontal collisions.

In DRIVE C2X, FOT results were scaled up to EU-level based on the number of traffic jams in the EU-27. This was based on data from the Netherlands, since information for the EU was not available.

The overall safety impact of TJW (for equipped cars only) was calculated to be up to 193 prevented fatalities and up to more than 16,600 prevented injuries per year in EU28 in 2030. This is equivalent to a 1.7% reduction in fatalities and a 2.5% reduction in injuries.

The EasyWay project calculated the impact of the traffic jam ahead warning service on injury and fatal accidents. The results from this study are shown below:

- Injury accidents and injuries: Average 2.8% reduction in injuries
    - (-4.9% on motorways, -4.1% on interurban and rural roads, and -2.0% on urban roads)
- Fatal accidents and fatalities: Average 2.4% reduction in fatalities
    - (-3.3% on motorways, -2.8% on interurban and rural roads, and -1.6% on urban roads)

These values are higher than those calculated by the DRIVE C2X report (Table 2-2), however the benefits are separated by road type, as desired for the modelling. It was decided to use the DRIVE C2X data as an input to the model (given the fact that it is based on FOTs) but the impact was scaled for each road type based on the ratios from the EasyWay studies. This gave the following safety impacts:

- **Motorways: 2.4% reduction in fatalities, 4.4% reduction in injuries**
- **Non-motorway non-urban roads: 2.0% reduction in fatalities, 3.7% reduction in injuries**
- **Urban roads: 1.2% reduction in fatalities, 1.8% reduction in injuries**

Table 2-2. Summary of safety impacts of the traffic jam ahead warning service stated in various EU studies

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
DRIVE C2X	1.74%	2.52%	100% penetration EU-28, 2030
EasyWay	2.4% (average) 3.3% (motorways) 2.8% (interurban roads) 1.6% (urban roads)	2.8% (average) 4.9% (motorways) 4.1% (interurban roads) 2.0% (urban roads)	100% penetration EU-27, 2030

2.4.3.5 Other impacts

Subjective assessment carried out in DRIVE C2X using stakeholder input suggested that TJW could help to achieve very slight decreases in stress and uncertainty, and contribute to slightly increased feelings of safety and comfort (TNO, 2014). The scores provided on a rating scale however fell close to the middle (i.e. a neutral impact) and therefore the effects are considered in this study to be insignificant overall. User acceptance was relatively high, with 79% of the respondents in the DRIVE C2X survey willing to use the function (TNO, 2014).

There were no indications of any impact on modal shift (TNO, 2014).

2.5 Hazardous location notification (HLN)

2.5.1 Service overview

This service gives drivers an advance warning of upcoming hazardous locations in the road. Examples of these hazards include a sharp bend in the road, steep hill, pothole, obstacle, or slippery road service. Using this information, drivers will be better prepared for upcoming hazards and will be able to adjust their speed accordingly.

2.5.2 Technical information

- Day 1 V2V service, likely based on ITS-G5 communication
- Bundle 1

Hazardous locations are automatically detected by vehicles in response to changing driving behaviour or information gained from vehicle information systems. For example, a sharp bend may be detected by rapid braking and change of vehicle direction, while a pothole may be detected by a vehicle's electronic stability control system. Information concerning the specific location and type of danger is retained and sent to vehicles in the surrounding area, warning of the hazard. This service is suitable for all vehicles and road types and may be used in combination with data gained from V2I services such as weather warning and in-vehicle signage. Whilst it is expected to rely primarily on V2V ITS-G5 communication, a number of projects are looking to demonstrate its effectiveness using high-speed (e.g. 4G/5G) cellular networks.

2.5.3 Impact data

The main data sources for the impacts of the hazardous location notification service are the EasyWay, eIMPACT, CODIA and eSafetyForum Intelligent Infrastructure Working Group reports. The EasyWay and CODIA projects uses estimates from eIMPACT. An overview of the general methodology for the eSafetyForum Intelligent Infrastructure Working Group Report is provided in Box 5, while an overview of CODIA is provided in Box 4.

Box 4. Overview of key data source - CODIA

The CODIA study (Co-Operative Systems Deployment Impact Assessment) aimed to evaluate the costs, impacts and benefits of five C-ITS services, namely:

- Speed adaptation due to weather conditions, obstacles or congestion (V2I)
- Reversible lanes due to traffic flow (V2I)
- Local danger / hazard warning (V2V)
- Post crash warning (V2V)
- Cooperative intersection collision warning (V2V and V2I)

The potential impacts of the selected C-ITS services were assessed up to the year 2030 and considered the entire vehicle fleet in EU-25 countries. Data was obtained from a wide range of literature sources including scientific journals, relevant EU R&D projects (in particular the COOPERS, CVIS and SAFESPOT projects) and the US DoT, For the impact assessment. The majority of vehicle, accident and traffic data was obtained from the eIMPACT project.

As many systems were not fully defined while the study was being carried out, assumptions and key findings were validated with experts from the European Commission, related European research projects, industry, and academia.

Source: (VTT, TRL, 2008)

Box 5. Overview of key data source - eSafetyForum Intelligent Infrastructure Working Group Final Report

The eSafetyForum Intelligent Infrastructure Working Group (II WG) was formed to define Intelligent Infrastructure. The II WG aimed to answer five key questions, which are addressed in the Final Report:

- What is intelligent infrastructure?
- Which services contribute to the implementation of Intelligent Infrastructure?
- Which technological resources are necessary for these services and which business areas need to implement them?
- What needs to be done to assist/promote the implementation of these technological resources and services?
- What is the relation between Intelligent Infrastructure and Intelligent Vehicles?

As part of this report, a literature review, surveying over 20 papers was performed to assess the potential benefits and added value for a number of C-ITS services. Data for three impact categories (impact on fatalities/injuries, impact on congestion, impact on CO_2 emissions) were gathered for a variety of services. Services covered which are relevant to this study are: real time event information, real time traffic information, travel time information, weather information, speed limit information, parking information and guidance, local hazard warning, dynamic route guidance, emergency vehicle warning, wrong way driving warning, road user charging, requesting green/signal priorities, and intelligent truck parking.

The final report mentions a number of limitations of the values presented, noting that “figures are all based on detailed specifications of the system in question” and that “similar systems with a different technology set-up or different content quality may have largely deviating estimates of effectiveness with regard to safety, efficiency, mobility and environment”. The report stresses that local effects will be vastly different to EU scale impacts, however does not state whether the results presented are for single events, or for EU level. Further to this, penetration rates are not given for the impact data and results are not broken down by vehicle type, road type, or accident type (in the case of safety impacts).

At the time of publication (2010), few evaluation studies for cooperative systems had been performed and furthermore, the authors stated that very few quantitative estimates of the impacts have been produced. As a result, data from this study was treated with caution and was only used in the absence of any other data.

2.5.3.1 Traffic efficiency

The eSafetyForum Intelligent Infrastructure Working Group Final Report found a 2-10% reduction in congestion. The report does not specify penetration level, vehicle type or road type (eSafetyForum, 2010). Further to this, it is unclear whether this is the impact of a single event, or whether the results were scaled up to EU level (as discussed in Box 5). The lower end of this range was therefore assumed, i.e. an impact of **2% improvement in speed across all vehicle types**.

2.5.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed. The primary effect of the hazardous location service is intended to be on safety, hence the fuel efficiency impacts are expected to be minimal. No fuel efficiency benefits are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model.

2.5.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed. The primary effect of the hazardous location service is intended to be on safety, hence the emissions impacts are expected to be minimal. No emissions benefits are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model.

2.5.3.4 Safety

The safety impacts of this service were covered by several papers. The EasyWay study calculated the impact of the hazardous location service on injuries and fatalities by taking into consideration the expected change in vehicle speed (as discussed in Box 3). The impacts were also calculated by road type, therefore this data is used in preference to those given by the eSafetyForum Intelligent Infrastructure Working Group Final Report and the CODIA study. Furthermore, the EasyWay study builds on the CODIA study in their calculation of safety impacts.

The impact on injuries and accidents calculated by EasyWay were used in the model as they build on the CODIA study and are broken down by road type. The impacts are as follows:

- Injury accidents and injuries: Average 3.1% reduction
    - This is equivalent to **-5.3% on motorways, -5.3% on interurban and rural roads, and -1.9% on urban roads**
- Fatal accidents and fatalities: Average 4.1% reduction
    - This is equivalent to **-5.2% on motorways, -5.3% on interurban and rural roads, and -1.7% on urban roads**

The eSafetyForum report (eSafetyForum, 2010) gives a value of 2-10% for the estimated reduction in fatalities/injuries. Assuming the average of this range is taken (6%), this value is significantly larger than the averages reported by EasyWay. The objective of the eSafetyForum report was to given an indication of the possible benefits, therefore the range is likely to capture all estimates, regardless of whether some data points may be outliers.

The CODIA report (VTT, TRL, 2008) also assessed the impact of local danger warnings. At 100% penetration, the authors state that a 4.2% reduction in fatalities and a 3.1% reduction in injuries is expected, provided that the system is used for all vehicle kilometres driven.

Table 2-3. Summary of safety impacts for the hazardous location service, as reported in EU C-ITS studies

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
EasyWay	4.1% (average) 5.2% (motorways) 5.3% (interurban and rural roads) 1.7% (urban roads)	3.1% (average) 5.3% (motorways) 5.3% (interurban and rural roads) 1.9% (urban roads)	100% penetration EU-27, 2030
eSafetyForum	2-10%	2-10%	Not stated
CODIA	4.2%	3.1%	100% penetration, expected impact if all vehicles were equipped, regardless of year

2.5.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.6 In-vehicle signage (VSGN)

2.6.1 Service overview

In-vehicle signage is a vehicle-to-infrastructure (V2I) service that informs drivers of relevant road signs in the vehicle's vicinity, alerting drivers to signs that they may have missed, or may not be able to see. The main purpose of this service is to provide information, give advance warning of upcoming hazards and increase driver awareness.

2.6.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 2

Via V2I communication, information about relevant road signs is provided to the driver. Roadside units may be mounted on traffic signs and key points along roads, informing drivers of potentially dangerous road conditions ahead, speed limits and upcoming junctions. Alternatively this information may be transmitted via the local cellular network. This service is applicable to all vehicle and road types, however may have particular benefits on motorways.

2.6.3 Impact data

Data availability for impacts directly related to in-vehicle signage was extremely limited. The DRIVE C2X project tested six specific road signs (children, merge, pedestrian crossing ahead, pedestrian crossing, stop, yield), however trials were on a small scale and quantitative assessments of specific impacts were limited to two very specific road signs (pedestrian crossing and children sign) (TNO, 2014). An overview of the general methodology of DRIVE C2X is provided in Box 1.

A report by the US Department of Transport NHTSA also estimated the impact of several road signs, however impacts were only given in terms of reduction in accidents and were not further categorised by severity.

2.6.3.1 Traffic efficiency

Although in-vehicle signage may influence traffic in a very local environment the effects are expected to be limited on an EU level, with the primary effect intended to be on safety. As in-vehicle signage is not expected to have a significant effect this impact is not included in the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on traffic efficiency for this service.

2.6.3.2 Fuel consumption and CO_2

The primary effect of in-vehicle signage is intended to be on safety, hence the fuel efficiency impacts are expected to be minimal. No fuel efficiency are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on fuel consumption for this service.

2.6.3.3 Environmental and emissions impacts

The primary effect of in-vehicle signage is intended to be on safety, hence the emissions impacts are expected to be minimal. No emissions benefits are therefore anticipated on an EU level as a consequence of this service and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on emissions for this service.

2.6.3.4 Safety

The DRIVE C2X study estimated safety impacts based on small scale trials of only two signs: pedestrian crossing and child sign. The impact data for the high penetration scenario is as follows:

- Impact on fatalities: 1.04% reduction
- Impact on injuries: 0.46% reduction

As DRIVE C2X only based the impacts on the pedestrian crossing and child road signs, the impacts of other types of road signs were estimated based on data from the US DoT report (John A. Volpe National Transportation Systems Center, 2008). This report estimates that a stop sign violation warning is expected to lead to a 0.088% reduction in annual light vehicle crashes. The same impact for a merge was assumed, stop and yield sign, leading to the following impacts per road type:

- Motorways:
    - Impact on **fatalities: 1.04% reduction** (from DRIVE C2X)
    - Impact on **injuries: 0.46% reduction** (from DRIVE C2X)
- Non-motorway non-urban roads:
    - Impact on fatalities: 1.04% (from DRIVE C2X) + (3 x 0.088%) (applying the value of 0.088% from US DoT report for stop sign violation and assuming the same impact for merge, stop and yield signs) = **1.30% reduction in fatalities**
    - Impact on injuries: 0.46% (from DRIVE C2X) + (3 x 0.088%) (applying the value of 0.088% from US DoT report for stop sign violation and assuming the same impact for merge, stop and yield signs) = **0.72% reduction in injuries**
- Urban roads:
    - Impact on fatalities: 1.04% (from DRIVE C2X) + (3 x 0.088%) (applying the value of 0.088% from US DoT report for stop sign violation and assuming the same impact for merge, stop and yield signs) = **1.30% reduction in fatalities**
    - Impact on injuries: 1.04% (from DRIVE C2X) + (3 x 0.088%) (applying the value of 0.088% from US DoT report for stop sign violation and assuming the same impact for merge, stop and yield signs) = **1.30% reduction in injuries**

2.6.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.7 In-vehicle speed limits (VSPD)

2.7.1 Service overview

In-vehicle speed limits are intended to prevent speeding and bring safety benefits by informing drivers of speed limits. Speed limit information may be displayed to the driver continuously, or targeted warnings may be displayed in the vicinity of road signs, or if the driver exceeds or drives slower than the speed limit.

2.7.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 2

Roadside units at key points along roads can broadcast information to drivers about speed limits, ensuring that drivers are aware of the permitted driving speed. Alternatively this information may be transmitted via the local cellular network. This service is applicable to all vehicle and road types, however may have particular benefits when warning drivers of changing speed limits when travelling along high speed roads.

2.7.3 Impact data

The main data source for the impacts of in-vehicle speed limits was the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1. This service was trialled at test sites in Finland, Italy, Spain and Sweden in DRIVE C2X and the data was used to produce EU-level impact data reported in the DRIVE C2X impact assessment.

Other studies that considered the impacts of in-vehicle speed limits include eIMPACT, eSafetyForum Intelligent Infrastructure Work Group and SAFESPOT (TNO, VTT, Movea, PTV, BASt, 2008; eSafetyForum, 2010; SAFESPOT, 2010). DRIVE C2X refers to and builds on many of these studies; we therefore believe the DRIVE C2X study is a more reliable source of data as it is based on more recent estimates and FOT results. For information, an overview of the general methodology of the SAFESPOT study is provided in Box 6.

Box 6. Overview of key data source - SAFESPOT

The objective of the SAFESPOT study was to carry out a socio-economic assessment in order to compare two bundles of cooperative intelligent transport systems. One bundle contained only V2V services, while the other contained only V2I services. Services of relevance to this study include: road intersection safety (V2V), road condition status/slippery road (V2V), longitudinal collision (V2V), intelligent cooperative intersection safety (V2I), reduced friction or visibility (V2I), speed alert (V2I).

Source: (SAFESPOT, 2010)

2.7.3.1 Traffic efficiency

The primary objectives of the in-vehicle speed limit service are to decrease speed and improve safety. The increase in delay per vehicle-km found in the DRIVE C2X study (TNO, 2014) is therefore not surprising and can be attributed to a higher awareness of speed limits. Many traffic efficiency effects observed in the DRIVE C2X study were not statistically significant, with the only significant results being found for motorways and rural roads during off-peak times. The authors argue that this is because the impact was measured at specific point on the road (which may be subject to larger variations) rather than if speed was measured over a long stretch of road. The overall delay for different road types is shown below:

- 0.6 seconds per kilometre on motorways
- 1.1 seconds per kilometre on rural roads

- No significant effect on delay on urban roads

The eIMPACT and eSafetyForum Intelligent Infrastructure Working Group studies also considered the impact of in-vehicle speed limits on speed. The results of these studies are summarised below:

- eSafetyForum: Speed limit information 2-10% reduction in congestion.
- eIMPACT - average change in speed:
    - Motorways: 1.1% increase (low demand), 0.6% increase (high demand)
    - Rural roads: 1.0% decrease (low demand), 0.9% decrease (high demand)
    - Urban roads: 1.4% decrease (low demand), 1.7% decrease (high demand)

Change in speed was only modelled for urban roads in TRT's ASTRA model. DRIVE C2X showed that in-vehicle speed limits did not have a statistically significant impact on urban roads, however further trials are needed to confirm this.

As an input to the model the average speed change from the eIMPACT project was therefore scaled for urban roads based on vehicle kilometres driven in high demand and low demand situations, to give an average **1.40% reduction in vehicle speed in urban areas**. The reduction was only applied to passenger cars and not to public transport.

2.7.3.2 Fuel consumption and CO_2

Fuel consumption benefits were seen for the in-vehicle speed limits function in the DRIVE C2X study, which is likely to be due to a smoother driving style. Specifically, greater awareness of speed limits may reduce sudden acceleration and braking manoeuvres. The DRIVE C2X FOT only found a statistically significant reduction in fuel consumption on motorways and on rural roads. The DRIVE C2X study provides impact data for two scenarios:

- speed limit information shown only in the vicinity of road signs
- speed limit information displayed continuously

A much greater impact was observed when speed limit information was displayed continuously (TNO, 2014). In practice, speed limit information may not be displayed continuously if a variety of C-ITS services are implemented into a vehicle, therefore we have chosen to use the values for speed limit information shown only in the vicinity of road signs.

The impacts of in-vehicle speed limits were scaled up from FOT scale to EU-27 level based on the number of vehicle-kilometres travelled, in order to determine absolute fuel savings (in tonnes). We converted these figures to percentages based on the share of vehicle kilometres travelled on each road type, which gave a **2.3% fuel saving on motorways** and a **3.5% fuel saving on non-motorway non-urban roads**. These values are in the range suggested by the eSafetyForum study, which stated a 2-10% reduction in CO_2 emissions (eSafetyForum, 2010).

2.7.3.3 Environmental and emissions impacts

Minor environmental benefits were seen on motorways for the in-vehicle speed limits function in the DRIVE C2X study, which is likely to be due to a smoother driving style. Specifically, greater awareness of speed limits may reduce sudden acceleration and braking manoeuvres. However on non-motorway-non-urban roads, DRIVE C2X estimates a small increase in emissions, particularly PM emissions, likely due to increased braking or speed changes when approaching new speed limits. No significant effect was observed in urban areas.

The absolute emissions changes stated in DRIVE C2X were converted to percentage savings on each road type, based on vehicle-kilometres driven on EU roads. The following values were inputted into the model:

- **NO_x: 0.5% reduction (motorways), 0.4% reduction (non-motorway non-urban roads), zero change (urban roads)**
- **PM: 0.4% decrease (motorways), 4.2% increase (non-motorway non-urban roads), zero change (urban roads)**

- **CO: 0.2% reduction (motorways), 0.2% increase (non-motorway non-urban roads), zero change (urban roads)**
- **VOCs: 0.1% increase (motorways), 0.5% increase (non-motorway non-urban roads), zero change (urban roads)**

2.7.3.4 Safety

The primary function of in-vehicle speed limits is intended to be reducing speeding; an improvement in road safety is therefore expected. The DRIVE C2X study confirms this assertion and reports significant reductions in both injuries and fatalities, however the magnitude of these impacts varies depending on whether speed-limit information is shown to the driver continuously or only in the vicinity of road signs. If speed limit information is only shown in the vicinity of road signs the number of prevented fatalities is estimated to be 121-768 in 2030, whereas if information is provided continuously, an estimated 566-1772 prevented fatalities is expected. In practice, speed limit information may not be displayed continuously if a variety of C-ITS services are implemented into a vehicle, therefore the values for speed limit information shown only in the vicinity of road signs were selected for the modelling inputs.

The values for the high penetration scenario were converted to percentages based on projected EU fatalities in 2030 (as stated in the DRIVE C2X report). This is equivalent to a **6.9% reduction in fatalities** and a **3.9% reduction in injuries, applied to passenger cars and freight for all road types in the modelling.**

A number of other studies covered the safety impacts of in-vehicle speed limits, as summarised in Table 2-4.

Table 2-4. Summary of safety impacts of in-vehicle speed limits

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
DRIVE C2X	6.93%	3.93%	100% penetration EU-28, 2030
eIMPACT	8.7%	6.2%	100% penetration EU-25, 2020
SAFESPOT	7.1%	4.9%	100% penetration EU-25, 2020
eSafetyForum	2-10%	2-10%	Not stated
CODIA	7.2%	4.8%	100% penetration for light/heavy vehicles, 55% of driven km

The eIMPACT project estimated an 8.7% reduction in fatalities and a 6.2% reduction in injuries, assuming 100% penetration at EU-25 level. In comparison with DRIVE C2X data, the impact on both fatalities and injuries is higher.

SAFESPOT also assesses the impact of in-vehicle speed alerts And estimates a 7.1% reduction in fatalities and a 4.9% reduction in injuries at an EU-25 level, assuming 100% penetration in 2020 (SAFESPOT, 2010). The estimation of impacts are based on the eIMPACT and CODIA studies and are comparable to those stated in DRIVE C2X.

The eSafetyForum study estimates a 2-10% reduction of fatalities/injuries. The average of this (6%) is comparable with the DRIVE C2X figure for fatalities avoided, however it is much higher than the figure for injuries. This may be because the impacts on fatalities and injuries were not treated separately as part of the eSafetyForum literature review.

CODIA estimated the effect of a service called ‘dynamic speed adaptation’ at a 100% penetration rate. The expected reduction in fatalities was stated as 7.2%, while the reduction in injuries was estimated to be 4.8%. These figures are comparable to a number of studies covered here.

We have used the DRIVE C2X figures as inputs to the model as the values are based on FOT data and build on the findings of earlier EU studies in this field.

2.7.3.5 Other impacts

Stakeholder inputs during the DRIVE C2X project (TNO, 2014) suggest that user acceptance for in-vehicle speed limits is in-line with other C-ITS services. Drivers found warning messages useful when they exceeded the speed limit, however only 28% felt that the system provided benefits that were not provided by other functions on the market. This is likely due to satellite navigation systems providing this capability.

Qualitative effects of in-vehicle speed limits were a reported improvement in comfort and safety, however the impact on stress was questionable. Mean values for these impacts were assessed at 4.2-5.2 for comfort (on a scale from 1, strongly disagree to 7, strongly agree), and 5.2 for safety.

There were no reported impacts on modal shift.

2.8 Probe Vehicle Data (PVD)

2.8.1 Service overview

The purpose of probe vehicle data is to collect and collate vehicle data, which can then be used for a variety of applications. For example, road operators may use the data to improve traffic management.

2.8.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 2

Also known as Floating Car Data (FCD), probe vehicle data refers to the collection of data generated by vehicles. Information on a variety of vehicle parameters may be collected, including positional information, time stamp and direction of motion. Driver actions such as steering, braking, flat tyre, windscreen wiper status, air bag status, as well as weather and road surface conditions can also be transmitted and collated. This probe vehicle data is used to manage traffic flows, maintain roads and to alert users in hot spots, where the danger of accidents accumulates. This service is applicable to all road and vehicle types, however may be most useful on motorways. It has the potential to deliver safety, efficiency, vehicle operation and environmental benefits. It can be delivered via the presence of roadside units to aggregate and re-transmit the data, or via the use of cellular networks.

2.8.3 Impact data

The main data sources for the impacts of the probe vehicle data service were the EasyWay and eIMPACT projects. To our knowledge, there are no other publically available studies that examine probe vehicle data specifically. Probe vehicle data is assumed to not be relevant for urban roads or public transport, therefore all impacts for urban areas and public transport were set to zero in the modelling.

2.8.3.1 Traffic efficiency

In TRT's ASTRA model, traffic efficiency impacts are only modelled on urban roads. The majority of the benefits of probe vehicle data are expected to be realised on motorways, therefore the impact of this service on traffic efficiency on urban roads was assumed to be zero.

2.8.3.2 Fuel consumption and CO_2

In the CODIA study, two services called speed adaptation due to accident and speed adaptation due to poor weather were assessed. If added together, these services have similar functionality to the probe vehicle data service described in this project. CODIA estimated the impact on carbon dioxide emissions to be as follows (at 100% penetration in EU-25 countries):

- Speed adaptation due to accident: 58.5 tonnes reduction
- Speed adaptation due to poor weather: 27,682 tonnes reduction
- Speed adaptation total: 27,741 tonnes reduction (EU-25)

The carbon dioxide emissions were scaled up to EU-27 level based on vehicle kilometre data from TRT's ASTRA and TRUST models, and then divided by the total EU carbon dioxide emissions stated in DRIVE C2X. This is equivalent to a **0.006% reduction in fuel consumption** in EU-27 countries.

2.8.3.3 Environmental and emissions impacts

Impacts on emissions were also given in the CODIA study for the dynamic speed adaptation service (includes speed limit advice given as a consequence of weather, obstacles and congestion). The results calculated in the study on an EU-25 level for a 100% penetration scenario are summarised below:

Impact on NO_x emissions:

- Speed adaptation due to accident: 0.7 tonnes reduction
- Speed adaptation due to poor weather: 490 tonnes reduction

- Speed adaptation total: 491. tonnes reduction

Impact on PM emissions:

- Speed adaptation due to accident: 0.015 tonnes reduction
- Speed adaptation due to poor weather: 5.13 tonnes reduction
- Speed adaptation total: 5.12 tonnes reduction

These values are equivalent to the following percentages at EU level:

- **0.003% reduction in NO_x emissions**
- **0.001% reduction in PM emissions**

As no further data was available, we have assumed the same CO reduction as for fuel consumption (assuming a linear relationship between carbon content and emissions). For VOC emissions, we have also applied the same percentage reduction as for fuel consumption (0.006%).

2.8.3.4 Safety

Safety impacts of probe vehicle data were reported in the EasyWay study (EasyWay, 2012). The following impacts were estimated (for EU-27, 100% penetration):

- Injury accidents and **injuries**: overall 2.8% reduction (**4.9% on motorways, 4.1% on interurban and rural roads, and 2.0% on urban roads**)
- Fatal accidents and **fatalities**: overall 2.4% reduction (**3.3% on motorways, 2.8% on interurban and rural roads, and 1.6% on urban roads**)

The safety impacts of the dynamic speed adaptation service (includes speed limit advice given as a consequence of weather, obstacles and congestion) from the CODIA study are as follows (for EU-25, 100% penetration):

- 7.2% reduction in fatalities
- 4.8% reduction in injuries

These values are substantially higher than the EasyWay figures, however this may be due to overlap with the in-vehicle speed limits service and also with V2V services such as slow or stationary vehicle(s) and weather warnings. We have selected the EasyWay figures for input into the model as they are reported specifically for probe vehicle data.

2.8.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.9 Roadworks warning (RWW)

2.9.1 Service overview

Roadworks warnings enable road operators to communicate information about road works and restrictions to drivers. This allows drivers to be better prepared for upcoming roadworks and potential obstacles in the road, therefore reducing the probability of collisions.

2.9.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 2

Roadside units are mounted on road works, enabling messages and instructions to be sent to approaching drivers, either directly via ITS-G5 communications, or via the cellular network. This service is applicable to all road and vehicle types.

2.9.3 Impact data

The main data source for the impacts of roadworks warning was the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1. For roadworks warning, tests were carried out at test sites in Finland, Italy and Sweden. In DRIVE C2X, this service is evaluated in the same section as ‘obstacle warning’ and ‘car breakdown warning’, as the services perform a similar function, act via similar mechanisms and present information to drivers in a similar manner.

To our knowledge, there are no other publically available studies that examine roadworks warning specifically.

2.9.3.1 Traffic efficiency

The traffic efficiency impacts of the roadworks warning service are expected to be minimal as its purpose is to improve safety, rather than prevent traffic jams (TNO, 2014). No traffic efficiency impacts are expected when scaled up to EU level and it is not included as part of the model. This is confirmed by the DRIVE C2X study, which did not consider the effect on traffic efficiency for this service.

2.9.3.2 Fuel consumption and CO_2

Fuel efficiency impacts are expected to be negligible for this service when scaled up to an EU level. This is confirmed by the DRIVE C2X study, which did not consider the effect on fuel consumption for this service.

2.9.3.3 Environmental and emissions impacts

Impacts on vehicle emissions impacts are expected to be negligible for this service when scaled up to an EU level. This is confirmed by the DRIVE C2X study, which did not consider emissions impacts for this service.

2.9.3.4 Safety

The key objective of the roadworks warning service is to improve safety, which as described in the DRIVE C2X study can be achieved by reducing the likelihood of several different types of collisions. The types of collisions expected to be prevented the most by this service are side-by-side collisions, single vehicle collisions with obstacles and rear collisions (TNO, 2014). Specifically, the service is expected to:

- Warn drivers about upcoming roadworks (especially those outside of the field of vision) and therefore limit unsafe manoeuvres.
- Increase driver alertness.
- Help to avoid sudden braking or steering/swerving manoeuvres.
- Reduce speed in the proximity of roadworks, thus decreasing the severity of potential injuries.

DRIVE C2X scaled up safety impacts based on Swedish road safety statistics (Liljegren, 2014), which estimate that 2.3% of injuries and 3% of fatalities occur due to roadworks. The study assumes 100% infrastructure and vehicle penetration and also details the following assumptions:

- Roadworks warning would only be effective for accidents caused due to inattention or lack of awareness (80-90% of accidents).
- Includes winter road maintenance work which does not take place in all parts of EU28. In those countries, the number of road works may be higher overall and may be made all year round (in Nordic countries, road works only take place in the summer).
- Effectiveness of the system was estimated to be 80-90% for rear collisions, single vehicle collisions with pedestrians and other obstacles. This high level of effectiveness is due to drivers expecting these types of hazards and has been based on previous naturalistic driving studies (Dingus, 2006).
- 80-90% system effectiveness was also assumed for ‘other single vehicle accidents’. This category primarily includes driving off road during a panic manoeuvre, which would most likely disappear if roadworks warnings were operational.
- The effectiveness was estimated to be 70–80% for frontal collisions. This also represents panic manoeuvres.
- 60-70% effectiveness for other accident types. This lower effectiveness is due to the unexpected nature of these types of accident.

In DRIVE C2X, the overall safety impact for this service was calculated to be 209 prevented fatalities and 9939 prevented injuries in in EU-28 countries if the service was deployed in 100% of passenger cars. This is equivalent to a **1.9% decrease in fatalities** and a **1.5% decrease in injuries**, which were used as inputs to the model. Impacts were assumed to be the same on all road types.

2.9.3.5 Other impacts

Subjective assessment carried out during the DRIVE C2X study using stakeholder input suggested that roadworks warning has limited usefulness, however the willingness to use the service remained rather high at 79%. Further assessment suggested that the impacts of the service on stress, comfort and feelings of uncertainty were minimal. There were no reported impacts on modal shift, or a change in travel patterns in the DRIVE C2X study.

2.10 Weather conditions (WTC)

2.10.1 Service overview

The objective of this service is to increase safety through providing accurate and up-to-date local weather information. Drivers are informed about dangerous weather conditions ahead, especially where the danger is difficult to perceive visually, such as black ice or strong gusts of wind.

2.10.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 2

Vehicles are sent information from roadside units warning the driver of dangerous, or changeable weather conditions. Alternatively, the messages may be transmitted via the cellular network. This service is applicable to all roads and vehicle types.

2.10.3 Impact data

The main data source for the impacts of the weather conditions service was the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1. FOTs took place in Finland and Spain as part of this project, with a total of 39 participants. In Finland, slippery road warnings were presented in winter conditions, while in Spain warnings about rainy conditions were shown.

Other studies that considered the impacts include eIMPACT (TNO, VTT, Movea, PTV, BASt, 2008), CODIA (VTT, TRL, 2008), eSafetyForum (eSafetyForum, 2010), EasyWay (EasyWay, 2012) and SAFESPOT (SAFESPOT, 2010). Much of the safety impacts data in these projects build on and the eIMPACT study. As the DRIVE C2X project incorporates FOT results into their estimates, values from this data source were used.

2.10.3.1 Traffic efficiency

The primary effect of the weather conditions warning is intended to be on safety, hence the traffic efficiency impacts are expected to be minimal.

The DRIVE C2X study did not assess the effect of this service on traffic efficiency, citing a lack of results to be able to qualitatively evaluate the service. CODIA assessed a “local danger warning due to poor weather” service, which led to an increase of 28,489 thousand hours on the road per year in EU25 at a 100% penetration rate. When converted to a percentage, the effect on time spent on the road is **less than 0.1%, applied to both cars and public transport on all road types in the modelling.**

Another service, ‘speed adaptation due to poor weather’ was also separately assessed in CODIA. The impacts associated with this service have not been included in this study as the service definition for weather warning does not state that speed limit information will be provided to the driver.

2.10.3.2 Fuel consumption and CO_2

The primary effect of the weather conditions warning is intended to be on safety, hence the fuel consumption impacts are expected to be minimal on an EU level. The DRIVE C2X study did not assess the effect of this service on fuel consumption, however CODIA assessed a service called ‘local danger warning due to poor weather’. At a 100% penetration level, a 47,407 tonnes per year reduction in carbon emissions at EU-25 level was calculated (VTT, TRL, 2008). This was scaled to EU-27 level based on vehicle kilometre data from TRT’s TRUST and ASTRA models. The resulting value (48,444) was divided by the total annual EU CO_2 emissions stated in DRIVE C2X. This gives a **0.005% reduction in fuel consumption** at an EU-27 level**, which was applied to both cars and public transport on all road types in the modelling.**

2.10.3.3 Environmental and emissions impacts

Minor emissions benefits for the 'local danger warning due to poor weather' service were reported in CODIA. At a 100% penetration level, the following impacts on emissions were calculated by CODIA (VTT, TRL, 2008):

- 752.50 tonnes per year reduction in NO_x emissions at EU25 level
- 9.15 tonnes per year reduction in particulate matter emissions at EU25 level

These values are equivalent to the following percentages at EU level:

- **0.02% reduction in NO_x emissions**
- **0.01% reduction in PM emissions**

As further data was not available, we have assumed the same CO reduction as for fuel consumption (assuming a linear relationship between carbon content and emissions). For VOC emissions, we have also applied the same percentage reduction as for fuel consumption. These values were applied **to cars and freight vehicles on all road types in the modelling.**

2.10.3.4 Safety

The objective of this service is to increase safety in adverse weather conditions such as ice, fog, rain, snow, sleet, hail and wind. The main impacts are expected to occur via direct in-vehicle modification of the driving task after drivers receive information about adverse weather conditions. Specifically, this service is expected to have a number of impacts:

- In conditions where the danger can easily be perceived (such as heavy rain), the notification serves as a reminder of the potential danger ahead, and increasing driver awareness.
- In situations where the danger cannot be easily be perceived (such as strong cross-winds, or black ice) drivers will receive valuable information regarding local weather conditions/hazards that they otherwise would not have known about.
- In both of the above situations, the driver will be more prepared for the hazard and will have the opportunity to adjust their speed accordingly, preventing sudden braking, accelerating, swerving or overtaking manoeuvres.

It is thought that any rebound effects from over-reliance on the system will be negligible. This is because the information used to deliver the service will come partially from other vehicles further ahead and therefore drivers cannot assume that there will always be suitably-equipped vehicles ahead (TNO, 2014).

DRIVE C2X scaled up safety impacts based on the impact on driver speeds, driver awareness and the headway between vehicles, using values from FOT data, expert estimates and estimates from the CODIA and eIMPACT projects. For 2030, this resulted in a projected **3.43% reduction in fatalities** and a **3.35% reduction in injuries, applied to cars and freight on all road types in the modelling.**

Potential safety impacts of the weather conditions service are covered in many other studies, as summarised in Table 2-5. The values from DRIVE C2X are used as an input to the modelling in this project as they are based on FOT data and build on previous EU studies. A discussion of results from other studies is provided below for comparison.

Table 2-5. Summary of safety impacts of weather conditions services from EU studies

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
DRIVE C2X	3.43%	3.35%	100% penetration EU-28, 2030
EasyWay	16.5% (average)	8.5% (average)	100% penetration EU-27, 2030
eIMPACT	4.5%	2.8%	100% penetration

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
			EU-25, 2020
SAFESPOT	1.6% (V2I) 16.4% (V2V)	0.7% (V2I) 8.6% (V2V)	100% penetration EU-25, 2020
eSafetyForum	2-4%	2-4%	Not stated

Estimations in the EasyWay project are based on the methodology from the CODIA project and state that if the base speed is 80km/h, there will be a 5% decrease in injury crash risk in adverse conditions, if low friction warnings are displayed, while a 12% decrease in injury collisions is expected for a fog warning. For a fatal crash risk, the percentage reductions are 10% for low friction warning and 23% for fog warnings. EasyWay averaged these figures to give overall impacts of 8.5% on injury crashes and 16.5% on fatal crashes.

eIMPACT evaluated a service called wireless location danger warning, one aspect of which is weather warning. A 4.5% reduction in fatalities and a 2.8% reduction in injuries was estimated, assuming 100% penetration on an EU-25 level. These values are slightly higher than those estimated by DRIVE C2X, however this is likely to be because eIMPACT also considered stationary vehicle warning to be part of this service.

SAFESPOT assesses the impact of two weather warning services: road departure (V2V) and hazard and incident warning (V2I). The road departure (V2V) use case informs the drivers of road conditions, such as a slippery road. SAFESPOT estimates an 8.6% reduction in injuries and a 16.4% reduction in fatalities, which is based on values obtained from the eIMPACT and CODIA projects. These figures are almost identical to EasyWay. The hazard and incident warning (V2I) use case includes weather conditions that result in reduced friction on the road or reduced visibility, such as ice, rain or fog and was shown to be significantly less effective than the V2V service. The estimation of impacts are again based on the eIMPACT and CODIA studies. SAFESPOT estimates a 1.6% reduction in fatalities and a 0.7% reduction in injuries at an EU-25 level, assuming 100% penetration in 2020 (SAFESPOT, 2010). These values are slightly lower than other reports reviewed in this section.

Finally, eSafetyForum reported that a weather conditions service could lead to a 2-4% reduction of fatalities/injuries. This is consistent with the DRIVE C2X figures.

2.10.3.5 Other impacts

A survey of drivers in the DRIVE C2X study indicated that 76% of drivers agreed that the weather conditions warning was useful, which is lower than the average for all services tested. This is likely due to the fact that drivers were more enthusiastic about particular types of weather warnings than others. For example, qualitative feedback provided by test drivers showed they were particularly receptive to warnings about potentially more serious hazards such as ice on the road, however they were less enthusiastic about receiving repetitive rainy conditions warnings while driving along a straight road. User acceptance is therefore likely to be dependent on the type of weather warning and how drivers value each type of weather warnings.

Further assessment showed that test drivers felt an increased sense of safety and comfort as a result of this service. On a scale of 1 (strongly disagree) to 7 (strongly agree), the mean value for increased feeling of comfort was 4.8 and for safety was 5.5.

There were no reported impacts on modal shift, or a change in travel patterns in the DRIVE C2X study.

2.11 Shockwave damping (SWD)

2.11.1 Service overview

Shock wave damping aims to smooth the flow of traffic, by damping traffic shock waves.

2.11.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 2

Real-time traffic data is used to feed advisory speeds to cars to smooth out speed variations. This service is applicable to all vehicle types and is particularly relevant to motorways. Again, it could be delivered via roadside units, or the cellular network.

2.11.3 Impact data

The main data source for the impacts of shockwave damping was the CODIA project (VTT, TRL, 2008). To our knowledge, there are no other publically available studies that specifically examine this service. The majority of the benefits of shockwave damping are expected to be on motorways, therefore the impact of this service on urban roads and non-urban, non-motorway roads is assumed to be zero.

2.11.3.1 Traffic efficiency

CODIA assessed a dynamic speed adaptation due to congestion service that closely matches our definition of the shockwave damping service. As a consequence of this service, the authors estimated an increase of time spent on the road of 63.5 thousand vehicle hours per year in EU25 at 100% penetration rate. In TRT's ASTRA model, traffic efficiency impacts are only modelled on urban roads. This service is not expected to have an impact on urban roads, therefore the impact on traffic efficiency was **assumed to be zero**.

2.11.3.2 Fuel consumption and CO_2

The dynamic speed adaptation due to congestion service assessed in CODIA estimates a reduction of 26,232 tonnes per year of carbon emissions at EU-25 level in a 100% penetration scenario (VTT, TRL, 2008). When calculated as a percentage, these effects are extremely small (**0.005% reduction**). It is assumed that all fuel consumption benefits will occur **on motorways** and that there will be zero impact on fuel consumption on non-motorway non-urban, and urban roads.

2.11.3.3 Environmental and emissions impacts

The dynamic speed adaptation due to congestion service assessed in CODIA calculated the following impacts on vehicle emissions if the service is deployed at a 100% penetration level in EU-25 countries (VTT, TRL, 2008):

- 363 tonnes per year reduction in NO_x emissions at EU25 level
- 6.0 tonnes per year reduction in particulate matter emissions at EU25 level

When calculated as a percentage, these effects are extremely small (**less than 0.1%**).

2.11.3.4 Safety

One of the primary objectives of this service is to improve safety on high-speed roads. In CODIA, estimates of safety impacts were presented for the dynamic speed adaptation due to congestion/obstacles at a 100% penetration level (VTT, TRL, 2008). The study estimates a 13% reduction in fatalities and a 10.3% reduction in injuries on motorways.

The inclusion of obstacle warnings in the CODIA definition results in additional functionality to the shockwave damping service defined in this study, therefore the safety impacts of the hazardous location service were subtracted from the figures reported in CODIA. This gave the following values, which were used in the modelling:

- **Reduction in fatalities on motorways: 7.8%**
- **Reduction in injuries on motorways: 5.0%**

2.11.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.12 Green Light Optimal Speed Advisory (GLOSA) / Time to Green (TTG)

2.12.1 Service overview

GLOSA provides speed advice to drivers approaching traffic lights, reducing the likelihood that they will have to stop at a red light, and reducing the number of sudden acceleration or braking incidents. This is intended to provide traffic efficiency, vehicle operation (fuel saving) and environmental benefits by reducing unnecessary acceleration.

2.12.2 Technical information

- Day 1 V2I service, likely based on ITS-G5 communication
- Bundle 3

Traffic lights are connected to a roadside unit, which broadcasts information to nearby vehicles informing them of the traffic light phase schedule. This will enable vehicles to calculate optimal speed of approach. Time to green information may also be presented to drivers. It is applicable to all vehicle types and is particularly suitable in urban areas, where intersections are generally sited. Whilst it is expected to rely primarily on V2I ITS-G5 communication, a number of projects are looking to demonstrate its effectiveness using high-speed (e.g. 4G/5G) cellular networks.

2.12.3 Impact data

The main data source for the impacts of GLOSA was the DRIVE C2X project (TNO, 2014). An overview of the general methodology is provided in Box 1. For GLOSA, tests were carried out at test sites in Germany, Spain and Sweden. However, the number of events available after filtering in Sweden was too low to provide a good comparison of with and without-service behaviour. Similarly, the data from the Spanish test site was interpreted as a first order effect rather than an effect of GLOSA. Hence, pooling the GLOSA data was not straightforward due to the large differences in experimental set-up

Other studies that considered the impacts include the Dutch ODYSA project and subsequent follow-ons; Beek et al. 2013 and van Katwijk et al. These studies were taken into account in the DRIVE C2X results and hence were not considered further here.

2.12.3.1 Traffic efficiency

In DRIVE C2X, traffic efficiency was assessed by naturalistic driving tests on urban roads and by simulations. The results were dependent on the level of traffic, with tests showing a slight overall increase in delay per traffic light, which was attributed to the slower speed of approach. The time spent stationary at traffic lights may be reduced by this service but the effects **are not statistically significant**. Results from the test site in Germany indicated that driver behaviour may become smoother and results from the literature surveyed by the authors of DRIVE C2X are inconclusive. The DRIVE C2X study team fed FOT data into a model, in order to calculate impacts. They reported an unexpected results of a 9% increase in delay for the implementation of GLOSA, however this was probably due to the way the yellow light was simulated in the model.

Overall, the effects on traffic efficiency are assumed to be small because (1) the system is not necessary when the driver arrives at a light that is already green; and (2) GLOSA has limited potential to affect the possibility of a driver arriving at a red light.

As the results currently stated in the literature are inconclusive, it is assumed that this service will **not have an impact on traffic efficiency** in urban areas.

2.12.3.2 Fuel consumption and CO_2

The primary effect of GLOSA is expected to be on fuel efficiency and environmental impacts due to reduced braking and acceleration while passing through traffic lights. The DRIVE C2X study shows that impacts are dependent on vehicle technology, with hybrids showing lower potential for improvement. The impact on motorways is assumed to be negligible, since GLOSA is only effective at traffic light controlled intersections. The study reported the following specific effects on urban roads, in the high penetration scenario:

- A reduction in fuel consumption of 3% when approaching an intersection. The authors scaled this impact to EU-27 level based on the number of approaching vehicles at signalised intersections in EU-27 countries. The number of approaching vehicles per year at signalised intersections in the EU-27 was estimated to be 1.708 trillion, concentrated on rural and urban roads (estimated to be 70% for urban and 30% for rural), as shown in Table 2-6. Although the amount of signalised intersections was known at the EU level, the number of approaching vehicles was estimated based on data from the Netherlands, as information for the EU was not available.

Table 2-6. Estimation of the number of vehicles approaching intersections in EU-27 countries per year (Source: DRIVE C2X)

Road type	Low demand (billions)	High demand (billions)
High speed roads	0	0
Rural roads	358.7	153.7
Urban roads	837.0	358.7

- An overall reduction in fuel consumption of 219,729 tonnes on rural roads and 512,702 on urban roads when scaled up to EU-27 level.
- This is equivalent to a **0.1% reduction in fuel consumption on rural roads and a 0.7% reduction in fuel consumption on urban roads**.

The DRIVE C2X values are lower than an earlier TNO study which estimated that traffic signal optimisation could lead to a 2% reduction in CO_2 emissions on an EU-27 level. We have opted to use the DRIVE C2X figures in the modelling as they are based on FOT data.

2.12.3.3 Environmental and emissions impacts

Only the DRIVE C2X study presented detailed results about the impact of GLOSA on vehicle emissions. Per intersection approach, the following effects were observed:

- Reductions in CO and HC emissions of 15.5% and 40.2%. The levels of changes to these pollutants are large because they are highly sensitive to acceleration and braking.
- Reduction in NO_x emissions of 3.2%

The authors scaled these figures up to EU-27 level by road type to give the impact on each pollutant in tonnes per year. These absolute emissions reductions were converted to percentages based on the annual pollutant emissions by road type from TRT's ASTRA and TRUST models. The following inputs were used in the model:

- **CO: 0.3% reduction (non-motorway non-urban roads), 0.8% (urban roads)**
- **NOx: 0.1% reduction (non-motorway non-urban roads), 0.2% (urban roads)**
- **VOCs: 0.5% reduction (non-motorway non-urban roads), 0.6% (urban roads)**
- **PM: 0.1% reduction (non-motorway non-urban roads), 0.0% (urban roads)**

2.12.3.4 Safety

GLOSA was found to have minor safety benefits in the DRIVE C2X study (TNO, 2014), mainly as a consequence of the lower number of vehicles needing to stop at traffic lights. Since the primary objective of GLOSA is not safety-related, it is to be expected that the overall impacts are small.

Specifically, positive effects that were expected are:

- On average, drivers will need to stop at traffic lights less with GLOSA. The probability of a rear-end collision is therefore reduced.

- Smoother driving behaviour is expected on the approach to traffic lights, reducing both the risk and severity of a collision.
- Drivers will, on average, approach traffic lights at a lower speed with GLOSA.
- Abrupt and indecisive braking behaviour will be eliminated due to the information GLOSA provides to drivers. This will reduce the risk and impact of rear-end crashes, limit red light violations and reduce angle-crashes.

However, the study also suggests that GLOSA may be less effective and less reliable for adaptive or actuated traffic lights, as these are dependent on unpredictable traffic flows. The service may also distract drivers, resulting in decreased attention on the road ahead, due to focussing on the in-vehicle advisory system. This is expected to be minor and may be limited further by good design on the in-vehicle interface.

The effectiveness of GLOSA was found to be highly dependent on penetration rate and traffic intensity. Safety effects were presented as a percentage reduction in fatalities or injuries in 2030 for 100% infrastructure penetration. In 2030, the average **fatalities** prevented was estimated to be 0**.1% on both urban and rural roads**, while the average number of **injuries** prevented was estimated to be **0.1% on rural roads and 0.3% on urban roads**.

2.12.3.5 Other impacts

Stakeholder inputs during the DRIVE C2X project suggest that user acceptance for GLOSA is very high, with 86% of drivers rating the service as useful, while 50% claimed they would be willing to pay for use of the feature if it was available in their vehicle (TNO, 2014).

Qualitative effects of GLOSA were reported as improvements in terms of decreased stress and uncertainty, and an increased feeling of safety and comfort. The typical mean agreement values for comfort were 4.9-5.6 (on a scale from 1, strongly disagree to 7, strongly agree), for safety approximately 4.8 and for stress 4.7-5.2. Stress and uncertainty were also assessed on a scale from -3 to 3 (decrease-increase), and the typical mean values for those scales were approximately -0.5 for stress and from -1.0 to -0.2 for uncertainty.

There were no reported impacts on modal shift.

2.13 Signal violation/Intersection safety (SigV)

2.13.1 Service overview

The primary objective of this service is to reduce the number and severity of collisions at signalised intersections.

2.13.2 Technical information

- Day 1 V2I service, likely based on ITS-G5 communication
- Bundle 3

This service, also known as the Red Light Violation Warning (RLVW), allows for drivers to be warned when they are in danger of violating a red light, or when it is probable that another vehicle is going to make a red light violation. It is applicable to all vehicle types and is particularly suitable in urban areas, where intersections are generally sited.

2.13.3 Impact data

The main data sources for the impacts of signal violation/intersection safety were the eIMPACT project (TNO, VTT, Movea, PTV, BASt, 2008) and SAFESPOT study. An overview of the general methodology for these studies is provided in Box 2 and Box 6 respectively.

2.13.3.1 Traffic efficiency

The SAFESPOT study assumes that no traffic impacts are experienced but refers to the statement in the eIMPACT study that traffic effects are expected but have not been proven (SAFESPOT, 2010). As no quantitative estimates have been given in the literature, it is assumed that this service will not have an impact on traffic efficiency.

2.13.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed. Fuel consumption impacts for this service are assumed to be zero.

2.13.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed. Impacts on vehicle emissions for this service are assumed to be zero.

2.13.3.4 Safety

The primary objective of this service is to improve safety at traffic intersections. A review of the reports covering this service revealed that the intersection safety service is defined differently depending on the study, with some studies including additional functionality such as GLOSA. A summary of the safety impacts stated in the studies reviewed is given in Table 2-7.

Table 2-7. Summary of safety impacts of the intersection safety service reported in other European studies

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
eIMPACT	3.9% (includes GLOSA / TTG)	7.3% (includes GLOSA / TTG)	100% penetration EU-25, 2020
SAFESPOT	0.7% (V2V left-turn assist only) 3.1% (V2I red light violation, left and right turn assistance)	2.2% (V2V left-turn assist only) 4.8% (V2I red light violation, left and right turn assistance)	100% penetration EU-25, 2020

Study	Fatalities (reduction)	Injuries (reduction)	Scenario
CODIA	3.7%	6.9%	100% penetration, assuming all vehicles were equipped, regardless of the year.

The eIMPACT study states 3.9% reduction in fatalities, 7.3% reduction in injuries, assuming 100% penetration in at EU-25 level in 2020. GLOSA/TTG functionality is also included in the eIMPACT definition of this service. If the safety impacts of GLOSA (the DRIVE C2X study estimates a 0.1% reduction in fatalities and a 0.3% reduction injuries) are subtracted from the impact predicted by eIMPACT, the impact would be a 3.8% reduction in fatalities and a 7.0% reduction in injuries. These are very similar to those suggested by CODIA (VTT, TRL, 2008).

The SAFESPOT study evaluated two intersection safety functions. The first function, a V2V service called "lateral collision – road intersection safety" assessed the impact of in-vehicle left-turn assistance (SAFESPOT, 2010). Assuming 100% penetration in the EU-25 in 2020, the estimated impact of this service is a 0.7% reduction in fatalities and a 2.2% reduction in injuries. These results are based on the PReVAL project, which follows the same methodological approach implemented by the eIMPACT study. Another intersection safety function evaluated by SAFESPOT was the "Intelligent Cooperative Intersection Safety system – IRIS" service, which is based on V2I communication. This service primarily aims to prevent red light violations, although also includes left and right turn assistance. The estimated impact of this service, assuming 100% penetration, is a 3.1% reduction in fatalities and a 4.8% reduction in injuries at EU-25 level (SAFESPOT, 2010). These results are based on the findings of the eIMPACT and CODIA projects. If the impacts of the two SAFESPOT intersection safety services are added together, a 3.8% reduction in fatalities and a 7.0% reduction in injuries is found.

The CODIA study also assessed the impact of cooperative intersection collision warning. This report estimated a 3.7% reduction in fatalities and a 6.9% reduction in injuries at a 100% penetration rate, providing the system is used in all intersections in the EU (VTT, TRL, 2008).

Based on the above, the most appropriate figure was selected as the eIMPACT estimation (with GLOSA impacts subtracted). A **3.8% reduction in fatalities and a 7.0% reduction in injuries on urban roads, and non-motorway non-urban roads** were used as inputs to the modelling. These percentages were applied to **all vehicle types** and are very similar to those stated by the SAFESPOT and CODIA studies.

2.13.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.14 Traffic signal priority request by designated vehicles (TSP)

2.14.1 Service overview

The traffic signal priority request by designated vehicles allows drivers of priority vehicles (for example emergency vehicles, public transport, HGVs) to be given priority at signalised junctions.

2.14.2 Technical information

- Day 1 V2I service, likely based on ITS-G5 communication
- Bundle 3

This service works by either extending or terminating the current traffic light phase, to ensure that the required phase is displayed. Different levels of priority can be applied, depending on the vehicle type. For example, emergency vehicles may be given the highest priority, whereas the appropriate level of green priority for a public transport vehicle may be dependent on its current status, i.e. whether it is on-time or behind schedule. This has the potential to deliver a variety of benefits. Safety benefits may be gained by extending the phase for emergency vehicles travelling at speed, efficiency benefits for public transport and environmental benefits gained when reducing the need for vehicles to repeatedly brake and accelerate through signalised intersections. This service is most suitable for urban environments and is applicable for all vehicle types except passenger cars. Whilst it is expected to rely primarily on V2I ITS-G5 communication, a number of projects are looking to demonstrate its effectiveness using high-speed (e.g. 4G/5G) cellular networks.

2.14.3 Impact data

The main data sources for the impacts of the traffic signal priority request by designated vehicles service were the eSafetyForum Intelligent Infrastructure Working Group's Final Report and the COMeSafety project. An overview of the general methodology of the eSafetyForum report is provided in Box 5.

To our knowledge, despite several European FOTs trialling this service, there are no other publically available studies that specifically examine traffic signal priority request by designated vehicles as a C-ITS service.

The limited information from the above two reports was therefore supplemented by additional desk research into traffic signal priority systems – this yielded one particularly useful source of information, namely a study by the UITP Working Group (TfL, TRL, University of Southampton, 2009) on the interaction of buses and signals at road crossings. This study analysed a number of European city bus priority projects, summarising travel time reduction data for buses equipped with a variety of bus priority systems allowing them to interact with traffic lights to smooth their passage through signalised intersections. One such example is the SCOOT system currently being trialled by Transport for London. Whilst not using the ITS-G5 protocols discussed in this study, some of the systems discussed in this study could loosely fall within the definition of C-ITS services and operate through very similar mechanisms to the C-ITS service discussed here. It was therefore deemed appropriate to use input data from this study to estimate impacts data from first principles.

2.14.3.1 Traffic efficiency

Traffic signal priority request will only be available to certain vehicles on non-motorway non-urban roads and urban roads. For the purposes of the modelling, it is assumed that this service will only apply to public transport and not passenger cars or freight vehicles. In most situations, there will also be secondary effects on non-bus users. This is captured in the modal shift element of TRT's ASTRA model.

The eSafetyForum literature review suggests that requesting green/signal priorities can lead to a 1-2% reduction in congestion, however this cannot be easily translated into an impact on urban travel speed, which is the required input for the modelling.

In the absence of data from specific C-ITS studies, data from the UITP Working Group report was therefore used as an input to the model. Quantitative estimates of travel time savings for bus priority systems were given for trials in the following cities: Aalborg, Cardiff, Genoa, Gothenburg, Helsinki, Prague, Stockholm, Stuttgart, Toulouse and Turin. The average saving was a **9.2% reduction in travel time for buses** equipped with some form of traffic signal priority system.

2.14.3.2 Fuel consumption and CO_2

Reduced fuel consumption is one of the main objectives of this service. The eSafetyForum report suggests that requesting green/signal priorities can lead to a 1-3% impact reduction in carbon dioxide emissions, while results of the FREILOT project show that HGVs equipped with this service reported reductions in fuel consumption of up to 20% (CRF, BASt, ERTICO, VOLVO, Hess-Consult, BMW, 2014). The FREILOT project was a FOT based on 11 intersections, with 7 trucks equipped with a number of services, including traffic signal priority, energy efficient driving (which provided speed advice and indicated when to shift up or down in order to save energy) and remote parking spot booking for loading and unloading. However given the lack of references in the eSafetyForum output and the difficulty in separating traffic signal priority from other services in the FREILOT project, it was decided to estimate fuel consumption and CO_2 savings using the results of the UITP Working Group study referenced above.

To this end, the average speed of buses without any traffic signal priority service installed was estimated from the UITP Working Group study at 15.3 kph, alongside the improved speed (9.2% reduction in time spent travelling) of 17.2 kph. This difference in speed was used as an input to Ricardo Energy and Environment's speed-emissions curve model, which is able to estimate the impact on CO_2/fuel consumption, NO_x and PM_{10} emissions.

The total improvement in fuel consumption and CO_2 emissions was therefore estimated as **8.28% across all buses in urban environments**.

2.14.3.3 Environmental and emissions impacts

NO_x and PM emissions were estimated using the same speed-emissions curve model as for fuel consumption/CO_2. Total improvement in **NO_x and PM** emissions were estimated at **8.04% and 8.17% respectively across all buses in urban environments**.

For **CO and VOC emissions**, these were assumed to be proportional to fuel consumption savings, and therefore estimated at an **8.28% reduction for urban buses**.

2.14.3.4 Safety

No data was identified for this impact category in the reports reviewed and given that this service will most likely only be available to a limited number of vehicles, it is assumed that the impact on safety at an EU-level will be negligible for this service and it is not included in the model.

2.14.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.15 On street parking information and management (Pinfo)

2.15.1 Service overview

The provision of on-street parking information is intended to bring efficiency benefits to drivers and help to reduce emissions in urban areas by reducing the time spent 'cruising' at low speeds.

2.15.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 4

Parking space availability is provided to interested vehicles, decreasing the amount of time spent searching for a safe, and appropriate place to park. This service is anticipated to be most applicable for urban roads, where on-street parking space availability is often limited and therefore in high demand. It is applicable for all vehicle types except public transport but will be most useful for drivers of cars. As for off street parking information, this service may include the functionality to book parking spaces in advance.

2.15.3 Impact data

The only data source which covered the potential impacts of the on street parking information service was the eSafetyForum Intelligent Infrastructure Working Group's Final Report. An overview of the general methodology of the eSafetyForum report is provided in Box 5.

The information from this report was supplemented by additional desk research into the provision of parking information services and the time spent searching for parking spaces. A number of reports were used to estimate the impact of this service from first principles, as referenced below.

2.15.3.1 Traffic efficiency

Traffic efficiency improvements are expected to be the main benefit of this service. No data was identified for this impact category in the reports reviewed. The following methodology was therefore used to estimate impacts on traffic efficiency from first principles:

- Identify the time spent looking for a parking space in a Member State.
    - In France, an estimated 70 million hours per year is spent 'cruising' trying to find parking (Gantelet & Lefauconnier, 2006).
- Scale this to EU level, based on total vehicle kilometres driven in urban areas (based on data for the EU-27 from TRT's ASTRA model).
    - Gives an estimated 450,272,549 hours 'cruising' per year for the EU
- Apply an effectiveness factor to the parking information C-ITS service.
    - 3.5 times less time spent cruising for parking to final destination when parking information is shown (or a 71% effectiveness), according to a report published by the University of Zurich (Tsiaras, Hobi, Hofstetter, Liniger, & Stiller, 2015).
- Use this number to estimate the total change in time spent driving on urban roads from deploying parking information services to all vehicles at an EU level.
    - **0.61% reduction in travel time/improvement in speed in urban areas across passenger and freight vehicles**.

2.15.3.2 Fuel consumption and CO_2

The average speed of vehicles when 'cruising' for parking spaces in urban areas was estimated at half the average speed limit for urban areas (Tsiaras, Hobi, Hofstetter, Liniger, & Stiller, 2015), i.e. 15 kph in the EU.

This speed was used as an input to Ricardo Energy and Environment's speed-emissions curve model, which is able to estimate the impact in g/km on CO_2/fuel consumption, NO_x and PM_{10} emissions. Using the total time spent 'cruising' and average speed of 'cruising' referenced above, a total EU-level cruising distance could be determined, from which the total EU-level emissions impacts could be estimated.

The total resultant **improvement in fuel consumption and CO_2 emissions** was estimated from the above methodology as **0.79% across passenger and freight vehicles in urban environments**.

2.15.3.3 Environmental and emissions impacts

NO_x and PM emissions were estimated using the same speed-emissions curve model as for fuel consumption/CO_2. Total improvement in **NO_x and PM** emissions were estimated at **0.26% and 0.07% respectively across all passenger and freight vehicles in urban environments**.

For **CO and VOC emissions**, these were assumed to be proportional to fuel consumption savings, and therefore estimated at a **0.79% reduction for urban passenger and freight vehicles**.

2.15.3.4 Safety

The eSafetyForum reports that parking information and guidance will have zero impact on safety. Whilst there may be secondary impacts due to reduced congestion in urban areas, no data exists to support this and the safety impacts were therefore assumed to be zero.

2.15.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.16 Off street parking information and management (PMang)

2.16.1 Service overview

The provision of on-street parking information is intended to bring efficiency benefits to drivers and help to reduce emissions in urban areas by reducing the time spent 'cruising' at low speeds.

2.16.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 4

Parking space availability is provided to interested vehicles, decreasing the amount of time spent searching for a safe and appropriate place to park. This service is applicable for all road types and all vehicle types except for public transport. It may be particularly useful for long-distance HGV drivers. In the future, this service may include advance booking capability. This will deliver efficiency and environmental benefits.

2.16.3 Impact data

To our knowledge, there are no other publically available studies that specifically examine off street parking information. Impacts for off street parking were assumed to be similar to on street parking, therefore the same values have been used as inputs to the modelling.

2.16.3.1 Traffic efficiency

No data was identified for this impact category in the reports reviewed, therefore the same value as for on street parking was used: a **0.61% reduction in travel time/improvement in speed in urban areas across passenger and freight vehicles** was used as the modelling input .

2.16.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed, therefore the same value as for on street parking was used: a **0.79% reduction in fuel consumption/CO_2 in urban areas across passenger and freight vehicles** was used as an input to the modelling.

2.16.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed, therefore the same values as for on street parking were used as inputs to the modelling. These are summarised below:

- **NO_x: 0.26% reduction in urban areas across passenger and freight vehicles**
- **PM: 0.07% reduction in urban areas across passenger and freight vehicles**
- **CO: 0.79% reduction in urban areas across passenger and freight vehicles**
- **VOC: 0.79% reduction in urban areas across passenger and freight vehicles**

2.16.3.4 Safety

The eSafetyForum Intelligent Infrastructure Working Group Report suggested that parking information services will have zero impact on safety. Whilst there may be secondary impacts due to reduced congestion in urban areas, no data exists to support this and the safety impacts were therefore assumed to be zero.

2.16.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.17 Park & Ride information (P&Ride)

2.17.1 Service overview

The provision of Park & Ride information is intended to reduce congestion in urban areas and also shift travel from cars to public transport.

2.17.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 4

In combination with other parking information services, this will allow drivers to determine the most suitable parking option, while also allowing maximum utilisation from the perspective of the operator. This improves overall network efficiency and can deliver efficiency and environmental benefits. This service is applicable to all road types and is most applicable to personal cars.

2.17.3 Impact data

To our knowledge, there are no other publically available studies that specifically examine the impacts of this service.

2.17.3.1 Traffic efficiency

Park and ride schemes are designed to reduce congestion in urban areas, therefore some traffic efficiency impacts are to be expected. However, these urban efficiency gains do not occur directly with the vehicle using the service, since the impact of the service will be to increase the likelihood of the vehicle in question using Park & Ride services – thereby preventing it entering the congested urban area. This makes it very difficult to estimate the impact on efficiency from first principles. In the absence of any data for this impact category in the reports reviewed, it was assumed that the service would have **zero impact** on speed in urban areas.

2.17.3.2 Fuel consumption and CO_2

Park and ride schemes are designed to reduce congestion in urban areas and to shift travel by car to public transport. Some passenger car fuel consumption benefits are to be expected, however there is a lack of data quantifying this effect in the literature. As an input to the modelling the same fuel saving as for the on-street parking service was assumed, i.e. **0.79% for passenger cars only**.

2.17.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed. As an input to the modelling the same impacts as for the on-street parking service were used, as shown below:

- **NO_x: 0.26% reduction in urban areas for passenger vehicles**
- **PM: 0.07% reduction in urban areas for passenger vehicles**
- **CO: 0.79% reduction in urban areas for passenger vehicles**
- **VOC: 0.79% reduction in urban areas for passenger vehicles**

2.17.3.4 Safety

The eSafetyForum Intelligent Infrastructure Working Group Report suggested that parking information services will have zero impact on safety. Whilst there may be secondary impacts due to reduced congestion in urban areas, no data exists to support this and the safety impacts were therefore assumed to be zero.

2.17.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.18 Information on alternative fuelled vehicle charging and fuelling stations (iFuel)

2.18.1 Service overview

The objective of this service is to broadcast electric vehicle charging point availability and AFV fuelling point information to relevant vehicles.

2.18.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 4

This service allows users to be informed of and book charging point time windows for fuelling and charging stations for alternative fuels. This enables a more convenient driving experience and allows for vehicle owners to plan routes according to the location of appropriate refuelling points; eBilling information may also be included. This service is applicable on all road types and is currently focussed on cars, bringing vehicle operation and efficiency benefits. As technologies advance and fleet composition changes, this service may be applicable to additional vehicle types.

2.18.3 Impact data

To our knowledge, there are no publically available studies that specifically examine the impacts of this service. This service has a large overlap with the traffic information and smart routing service. This services is therefore considered to be included within the traffic information and smart routing service for the purpose of the modelling.

2.18.3.1 Traffic efficiency

All impacts are included within the traffic information and smart routing service for the modelling.

2.18.3.2 Fuel consumption and CO_2

All impacts are included within the traffic information and smart routing service for the modelling.

2.18.3.3 Environmental and emissions impacts

All impacts are included within the traffic information and smart routing service for the modelling.

2.18.3.4 Safety

All impacts are included within the traffic information and smart routing service for the modelling.

2.18.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.19 Traffic information and smart routing (SmartR)

2.19.1 Service overview

The provision of traffic information and smart routing services to vehicles is intended to improve traffic efficiency and aid traffic flow management.

2.19.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 5

Traffic flow management is achieved by optimising routes based on traffic flows, traffic lights and speed limits and by offering re-routing suggestions to vehicles based on real-time traffic information status alerts. This service is applicable to all road and vehicle types (except public transport) and is expected to deliver efficiency, vehicle operation and environmental benefits by limiting congestion.

2.19.3 Impact data

The main data sources for the impacts of the traffic information and smart routing service were the eSafetyForum Intelligent Infrastructure Working Group's Final Report, the iMobility Effects Database (VTT, 2010) and the TNO report on the impact of information and communication technologies on energy efficiency in the road transport sector.

2.19.3.1 Traffic efficiency

The only report to assess traffic efficiency was the eSafetyForum report. This reported results for three related services: real time event information, real time traffic condition information, and travel time information. All services show a 1-15% reduction in congestion. In the absence of more precise data, the mid-point of this range was used for the modelling, i.e. an **8% improvement in traffic speed for both passenger and freight vehicles** – only applicable in urban areas.

2.19.3.2 Fuel consumption and CO_2

The eSafetyForum report presents results for three services: real time event information, real time traffic condition information, and travel time information, which all show a 1-10% reduction in fuel consumption/CO_2 emissions. Further information about this service is not given and the report does not state whether these are the expected benefits at an EU-level.

In a study performed by TNO on the impact of information and communication technologies on energy efficiency in the road transport sector (TNO, 2009), a service called 'fuel efficient route choice' was assessed. This was calculated to have a 2.1% impact on fuel consumption at an EU level. As the emphasis of this service was on maximising fuel efficiency, rather than shortest journey time, the fuel savings benefits are expected to be lower than this value.

Another similar service assessed by TNO is the freight specific, trip departure planning service. The objective of this service is to ensure fleet journey time is minimised, based on real, current and predicted traffic conditions. This is a similar function as the traffic information and smart routing service defined in this report. In the TNO study, the trip departure planning service was estimated to have a 1.8% (reduction) impact on fuel consumption/CO_2 emissions at an EU level, if implemented in all freight vehicles.

Due to limited other data for the traffic information and smart routing service, an average of the figures stated for the two TNO services was used and applied to all vehicles (except public transport) and road types. This gives a **1.95% impact on fuel consumption/CO_2 emissions for passenger and freight vehicles across all road types**. This figure is supported by the iMobility Effects Database, which reports a 2% impact on CO_2 emissions at an EU level. (VTT, 2015)

2.19.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed, therefore emissions impacts were scaled using the ratio between fuel/CO_2 impacts and emissions impacts for the in-vehicle speed limit service in urban areas. This resulted in the following impacts on emissions:

- **NO_x: 0.4% reduction on motorways, 1.7% reduction on non-motorway non-urban roads, 0.5% reduction on urban roads**
- **PM: 0.3% reduction on motorways, 0.8% reduction on non-motorway non-urban roads, 0.1% reduction on urban roads**
- **CO: 0.2% reduction on motorways, 4.2% reduction on non-motorway non-urban roads, 2.3% reduction on urban roads**
- **VOCs: 0.1% increase on motorways, 6.5% reduction on non-motorway non-urban roads, 1.7% reduction on urban roads**

2.19.3.4 Safety

No data was identified for this impact category in the reports reviewed. It is likely that this service could indirectly lead to safety benefits due to reduced driver hesitation and reduced congestion, however no reports quantify this effect. In the modelling this service is assumed to have no impact on safety.

2.19.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.20 Zone access control for urban areas (ZACM)

2.20.1 Service overview

The zone access control service is intended to manage access to specified zones. Using this information, drivers will be better informed and will be able to select the most appropriate route for their journey.

2.20.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 6

Zone access control is likely to assist with the management of low emission zones (LEZs) and congestion charging schemes through communication between the vehicle and roadside sensing infrastructure. Drivers will be informed when entering a managed zone and may be charged depending on the type of access control implemented and/or the exhaust emissions characteristics of the vehicle. This service is intended to reduce congestion and bring environmental benefits. It is mainly applicable to urban areas and HGVs/cars, although could potentially be implemented on any road or vehicle type.

2.20.3 Impact data

The main data sources for the impacts of the zone access control for urban areas service were the eSafetyForum Intelligent Infrastructure Working Group's Final Report and a study by TNO on the impact of information and communication technologies on energy efficiency in road transport (eSafetyForum, 2010; TNO, 2009). An overview of the general methodology of the eSafetyForum report is provided in Box 5.

2.20.3.1 Traffic efficiency

The impact of zone access control will be dependent on the individual schemes implemented in each urban area. Very little data is available about this service, therefore it is assumed that the impact on traffic efficiency impact on cars and buses is zero.

2.20.3.2 Fuel consumption and CO_2

Information about the impact of zone access control for urban areas was limited to congestion charging zones; no information was found about zones that do not charge vehicles for entry. The eSafetyForum report estimated a 10-20% reduction in carbon dioxide emissions for road user charging, however the level of information provided was not sufficient enough for us to realistically scale this value to an EU-level, as required for the modelling (eSafetyForum, 2010). The TNO report calculated the impact of congestion charging to be a **0.5% reduction in CO_2 emissions** in the EU-27, which is equivalent to a **0.5% reduction in fuel consumption** (TNO, 2009). This value is used as the input to the modelling for this service and is **applied to freight and passenger vehicles in urban areas**.

2.20.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed, therefore emissions impacts were scaled using the ratio between fuel/CO_2 impacts and emissions impacts for the in-vehicle speed limit service in urban areas. This resulted in the following impacts on emissions:

- **0.12% reduction in NO_x emissions across freight and passenger vehicles in urban areas**
- **0.04% reduction in PM emissions across freight and passenger vehicles in urban areas**
- **0.58% reduction in CO emissions across freight and passenger vehicles in urban areas**
- **0.44% reduction in VOC emissions across freight and passenger vehicles in urban areas**

2.20.3.4 Safety

No specific data was identified for this impact category in the reports reviewed, however a number of reports have suggested that congestion charging zones may indirectly lead to safety impacts.

For example, a study recently published by the University of Lancaster Management School suggested that implementation of the London Congestion Charge Zone has had an impact on road safety. The authors suggested that the policy caused a reduction in the number and severity of accidents within the congestion zone and surrounding areas.

While this service may have indirect safety benefits, this is not the primary objective of the service and with insufficient evidence to attribute a specific safety impact to this service, the safety impact was assumed to be zero.

2.20.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.21 Loading zone management (LZM)

2.21.1 Service overview

This service is intended to support the driver, fleet manager and road operator in the booking, monitoring and management of urban parking zones specific to freight vehicles.

2.21.2 Technical information

- Day 1 V2I service, which is based on a hybrid communications concept (cellular or ITS-G5, depending on the infrastructure equipment)
- Bundle 6

The driver or fleet operator can book urban loading bays in advance, specifying the planned delivery time, loading/unloading time required and vehicle type. Additional information such as desired flexibility in the delivery time and the estimated time to reach the parking zone may also be provided. This feature may utilise interaction with other C-ITS services, such as traffic information and smart routing. The fleet operator can therefore optimize delivery times, reduce driver stress and anticipate congestion problems, whereas the road operator can optimize the management of loading zones through increased knowledge of the delivery time period and duration. This service is primarily applicable in urban areas.

2.21.3 Impact data

Despite several European FOTs incorporating this service, to our knowledge, there are no publically available studies that specifically examine the impacts of this service.

2.21.3.1 Traffic efficiency

No data was identified for this impact category in the reports reviewed. Loading zone management is only applicable to freight vehicles. The ASTRA traffic efficiency model used in this study only takes into consideration cars and buses, therefore this service was not modelled for this impact category.

2.21.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed, although this service is expected to have similar impacts to parking services discussed in previous sections. As no other data specific to freight vehicles was available, the same input data was used as for the on-street parking information and management service. A 0.**79% reduction in fuel savings/CO_2 emissions for light trucks and heavy trucks on urban roads** was therefore used as an input to the modelling.

2.21.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed, although this service is expected to have similar impacts to parking services discussed in previous sections. The following impacts on emissions were therefore assumed:

- **NO_x: 0.26% reduction for light trucks and heavy trucks travelling on urban roads**
- **PM: 0.07% reduction for light trucks and heavy trucks travelling on urban roads**
- **CO: 0.79% reduction for light trucks and heavy trucks travelling on urban roads**
- **VOCs: 0.79% reduction for light trucks and heavy trucks travelling on urban roads**

2.21.3.4 Safety

No data was identified for this impact category in the reports reviewed.

2.21.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.22 Vulnerable road user protection – pedestrians and cyclists (VRU)

2.22.1 Service overview

This is a safety focussed service, which is intended to protect vulnerable road users. In this vase vulnerable road users are considered to be pedestrians and cyclists only.

2.22.2 Technical information

- Day 1.5 V2X (where X signifies a pedestrian or cyclist), likely to be based on ITS-G5 communication
- Bundle 7

This service is designed to increase safety by alerting drivers of the presence of vulnerable road users (those outside the vehicle such as pedestrians, cyclists).This may be achieved via communication with a smartphone, or in the case of cyclists, via communication with a C-ITS device fitted on the bike. In the case that installing ITS-G5 capability is not practical within smartphones, this service could be based on a cellular technology, provided it offers sufficiently low latency. Vulnerable road user protection is applicable to all vehicle types and is expected to bring safety benefits to all road types, however the majority of benefits are expected to be on urban roads.

2.22.3 Impact data

To our knowledge, there are no publically available studies that specifically examine the impacts of this service, however the eIMPACT project evaluated a non-cooperative intelligent transport service called "pre-crash protection of vulnerable road users". This is similar to the vulnerable road user protection service evaluated in this study, however in eIMPACT it was not considered to be a cooperative system and was assumed to operate by detecting vulnerable road users via sensors. The two services are likely to present information to the driver in a similar manner and safety impacts will occur via similar mechanisms, therefore the data presented can be applied to the cooperative service.

2.22.3.1 Traffic efficiency

No data was identified for this impact category in the reports reviewed. It is assumed that this service will not have an impact on traffic efficiency at an EU level.

2.22.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed. It is assumed that this service will not have an impact on fuel consumption at an EU level.

2.22.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed. It is assumed that this service will not have an impact on vehicle emissions at an EU level.

2.22.3.4 Safety

Due to the absence of other data, data from the eIMPACT project for the "pre-crash protection of vulnerable road users" was referenced. This was not considered to be a cooperative system, however the results provide a good indication of the expected impacts of a similar cooperative service, as both services are expected to display similar information to the driver.

Assuming a 100% penetration in EU-25 countries, the eIMPACT study estimated a 1.8% reduction in fatalities and a 1.9% reduction in injuries for the pre-crash protection of vulnerable road users (TNO, VTT, Movea, PTV, BASt, 2008). Discussions with experts confirmed that the majority of benefits of this service will be seen in urban areas. **A 1.8% reduction in fatalities and a 1.9% reduction in injuries has therefore been used for non-motorway non-urban roads, and urban roads**, **applied to all vehicle types**. This service was assumed to have no impact on safety on motorways in the modelling.

2.22.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.23 Cooperative collision risk warning (CCRW)

2.23.1 Service overview

The cooperative collision risk warning is intended to minimise the risk of collisions between vehicles, for example when overtaking, or when merging with traffic.

2.23.2 Technical information

- Day 1.5 V2V safety focussed service, likely to be based on ITS-G5 communication
- Bundle 8

If a collision is likely, warning messages can be sent between vehicles, meaning that drivers can be immediately alerted about a collision risk and take evasive action where necessary. This service is particularly useful if the danger is outside of the driver's field of vision or in an area where there is poor visibility (for example when a vehicle is turning in the road, overtaking, or merging with traffic). This service is applicable to all road and vehicle types. Given the uncertainty around Day 1.5 services and the evolution of cellular networks, it is possible that this service could be offered via both ITS-G5 or cellular networks, provided it offers sufficiently low latency.

2.23.3 Impact data

To our knowledge, there are no publically available studies that specifically examine the impacts of this service.

2.23.3.1 Traffic efficiency

No data was identified for this impact category in the reports reviewed. However, the primary purpose of this service is to offer safety benefits to drivers and, given the relative infrequency of near-collision events, it is assumed that this service will not have an impact on traffic efficiency for the purposes of modelling.

2.23.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed. However, the primary purpose of this service is to offer safety benefits to drivers and, given the relative infrequency of near-collision events, it is assumed that this service will not have an impact on fuel consumption/CO_2 emissions for the purposes of modelling.

2.23.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed. However, the primary purpose of this service is to offer safety benefits to drivers and, given the relative infrequency of near-collision events, it is assumed that this service will not have an impact on emissions for the purposes of modelling.

2.23.3.4 Safety

The primary purpose of this service is to offer safety benefits to drivers. No data was identified for this impact category in the reports reviewed, however in the eIMPACT study a number of services were assessed, which if combined could provide similar functionality to the cooperative collision risk warning described above. The services that could be combined are lane change assistant, emergency braking and intersection safety. Intersection safety impacts will only be relevant on urban and non-motorway non-urban roads, whereas lane change assist functionality will only be appropriate on motorways.

For lane change assistant, the impact on safety at a 100% penetration level in 2020 for the EU-25 are as follows:

- Impact on fatalities: 2.2% reduction
- Impact on injuries: 4.8% reduction

The lane change assistant figures were added to the average values obtained for emergency brake light and signal violation / intersection safety, which were discussed in earlier sections.

The total impact on safety on **motorways** was estimated as follows:

- Impact on **fatalities**: 2.2% (lane change assist) + 2.74% (emergency brake light) = **4.94% for all vehicle types**
- Impact on **injuries**: 4.8% (lane change assist) + 2.46% (emergency brake light) = **7.26% for all vehicle types**

The total impact on safety on **urban roads and non-motorway non-urban roads** was estimated as follows:

- Impact on **fatalities**: 2.74% (emergency brake light) + 3.8% (signal violation / intersection safety) = **6.54% for all vehicle types**
- Impact on **injuries**: 2.46% (emergency brake light) + 7% (signal violation / intersection safety) = **9.46% for all vehicle types.**

Clearly there is considerable overlap between cooperative collision risk warning and other Day 1 services, such as emergency brake light and signal violation / intersection safety. These overlaps are accounted for in the service weighting used in the modelling, as described in Section 3.

2.23.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

2.24 Motorcycle approaching indication (MAA)

2.24.1 Service overview

This service is intended to increase safety and prevent collisions between motorcycles and other vehicles.

2.24.2 Technical information

- Day 1.5 V2V service, likely to be based on ITS-G5 communication technology
- Bundle 8

The motorcycle approaching indication has many similarities to the *Cooperative collision risk warning* service described above. Continual communication between the motorcycle and vehicle allows the driver to be informed of motorcycles that are passing, or about to pass. Positional and movement information is automatically compared to determine whether there is a safe driving distance between the vehicle and motorcycle. In the event of a possible collision being detected, drivers can be warned and adjust their driving accordingly. The service can also assist with blind spots. This service is applicable to all road and vehicle types, although it is mainly expected to be effective in urban areas where most motorcycle-related accidents occur. Given the uncertainty around Day 1.5 services and the evolution of cellular networks, it is possible that this service could be offered via both ITS-G5 or cellular networks, provided it offers sufficiently low latency.

2.24.3 Impact data

To our knowledge, there are no publically available studies that specifically examine the impacts of this service. As a result, additional desk research was carried out to identify data that could be used to estimate the impacts of the wrong way driving service from first principles. A number of sources were used to estimate the impact of this service, as referenced below.

2.24.3.1 Traffic efficiency

No data was identified for this impact category in the reports reviewed. As wrong way driving incidents are relatively rare occurrences, it is assumed that this service will not have an impact on traffic efficiency at an EU level.

2.24.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed. As wrong way driving incidents are relatively rare occurrences, it is assumed that this service will not have an impact on fuel consumption/ CO_2 emissions at an EU level.

2.24.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed. As wrong way driving incidents are relatively rare occurrences, it is assumed that this service will not have an impact on emissions at an EU level.

2.24.3.4 Safety

Safety benefits are expected to be the primary goal of this services. Whilst no data was directly identified for this impact category in the reports reviewed, a number of alternative sources enabled an estimation of the impact of this service on safety from first principles:

- Identify total number of motorcycle accidents in Europe: 5,500 motorcycle deaths in 2010 (CARE database, European Commission, 2015), assume half reduction rate achieved overall in DRIVEC2X, gives death rate of 3,960/year in 2025 (launch year).
- Identify primary types of accidents targeted (ACEM, 2009; Honda, 2014):
    - Motorcycle (MC) into other vehicle (OV) impact at intersection; paths perpendicular: 9% of motorcycle accidents
    - OV into MC impact at intersection; paths perpendicular: 6% of motorcycle accidents

    - OV turning left in front of MC, MC perpendicular to OV path: 9% of motorcycle accidents
    - MC & OV in opp. dir., OV turns in front of MC, MC impacting: 9% of motorcycle accidents
    - Total = 33% of all motorcycle accidents = 1,307 deaths per year in 2025
- Assume MAI impacts this death rate at effectiveness of 44.4% (eImpact, 2008)
- Total reduction in EU accidents in 2025 = **3.8% for all vehicle types, on urban roads** only (as c. 90% of all motorcycle accidents occur in urban areas)

Note that in the absence of data distinguishing between fatalities, injuries and material damages, the 3.8% impact was applied to all of these accident types.

2.24.3.5 Other impacts

No data was identified for this impact category in the reports reviewed.

2.25 Wrong way driving (WWD)

2.25.1 Service overview

The wrong way driving service is a Day 1.5 V2I safety focussed application intended to prevent accidents caused by wrong way driving. Incidents of wrong way driving can lead to serious accidents on high speed roads as approaching drivers perform swerving manoeuvres to avoid the oncoming vehicle. Advance warning of wrong way driving has two main functions: firstly, to alert the driver that they are driving in the wrong direction, and secondly, to warn surrounding vehicles of the danger.

2.25.2 Technical information

- Day 1.5 V2I service, likely to be based on ITS-G5 communication technology
- Bundle 9

Communication between vehicles and roadside units will enable the detection of wrong way driving and a notification will be sent to the vehicle warning of the danger. This service is suitable for all vehicle and road types. Given the uncertainty around Day 1.5 services and the evolution of cellular networks, it is possible that this service could be offered via both ITS-G5 or cellular networks, provided it offers sufficiently low latency.

2.25.3 Impact data

To our knowledge, there are no publically available studies that specifically examine the impacts of this service. As a result, additional desk research was carried out to identify data that could be used to estimate the impacts of the wrong way driving service from first principles. A number of sources were used to estimate the impact of this service, as referenced below.

2.25.3.1 Traffic efficiency

No data was identified for this impact category in the reports reviewed. As wrong way driving incidents are relatively rare occurrences, it is assumed that this service will not have an impact on traffic efficiency at an EU level.

2.25.3.2 Fuel consumption and CO_2

No data was identified for this impact category in the reports reviewed. As wrong way driving incidents are relatively rare occurrences, it is assumed that this service will not have an impact on fuel consumption/ CO_2 emissions at an EU level.

2.25.3.3 Environmental and emissions impacts

No data was identified for this impact category in the reports reviewed. As wrong way driving incidents are relatively rare occurrences, it is assumed that this service will not have an impact on emissions at an EU level.

2.25.3.4 Safety

Safety benefits are expected to be the primary goal of this services. Whilst no data was directly identified for this impact category in the reports reviewed, a number of alternative sources enabled an estimation of the impact of this service on safety from first principles:

- Identify number of wrong way driving incidents and fatalities in a Member State.
    - In 2013 in Germany, there were 2,000 incidents, of which 22 led to fatalities (DriveEuropeNews, 2014)
- Scale this number of fatalities to the EU level, based on total vehicle kilometres driven on motorways (EU-28) from the ASTRA/TRUST modelling baseline.
    - Gives an estimated 92 fatalities per year in the EU-28 caused by wrong way driving
- Apply an effectiveness factor to the WWD C-ITS service.

- Based on expert opinion, a 60% reduction in fatalities and a 40% reduction in injuries in WWD incidents was applied.
- Use these numbers to estimate the total reduction in fatalities from deploying WWD to all vehicles at an EU level.
  - **0.37% reduction in fatalities and 0.24% reduction in injuries on motorways only, applied to all vehicle types** in EU-28 countries used as an input to the model
  - It is assumed that the benefits of this service are likely to be seen on motorways and it is therefore assumed that the service will have zero impact at an EU-level on non-motorway non-urban roads and urban roads.

2.25.3.5 Other impacts

No data related to other impacts was identified in the reports reviewed.

3 Overlap between services

A number of C-ITS services covered in this study have similar functionality, therefore multiple services are likely to overlap and be applicable to the same driving scenarios. For example, on approaching a traffic jam, both the emergency electronic brake light service and traffic jam ahead warning service will be applicable. Therefore in practice, when two or more similar services are deployed, the impacts may not be additional and further benefits from adding additional services may only be a fraction of each additional service if deployed individually.

In order to accurately estimate overall modelling impacts, it is important to capture this interaction between services, to avoid over-optimistic estimation of benefits from bundles of multiple services.

To this end, service overlap was accounted for in the modelling using a service weighting matrix, as shown in Table 3-1. This matrix applied a percentage weighting from 0-100% to each service, based on which services would be deployed before it in the progression of scenarios from Scenario A to E. Weightings were applied in increments of 25%, in an attempt to account for different amounts of overlap between different services.

When assessing potential overlap between C-ITS services, it was assumed that the same overlap would apply for all impacts, i.e. if a service eliminates 50% of the safety impacts of another service, it will also eliminate 50% of the fuel consumption impacts.

A full list of overlaps is described below:

- **Traffic jam ahead warning:** it is assumed that 25% of the impacts of traffic jam ahead warning would be eliminated due to the emergency electronic brake light service.
- **Roadworks warning:** it is assumed that 25% of the impacts of roadworks warning would be eliminated due to the emergency electronic brake light service and a further 25% of the impacts would be eliminated due to the traffic jam ahead warning.
- **Weather conditions:** it is assumed that there is significant overlap with hazardous location warning and that 50% of the impacts will be eliminated.
- **Probe vehicle data:** it is assumed that the function of this service is to collect vehicle data to aid road operators and to improve the performance of various other services. Furthermore, it will not be present as a specific service for end-users. All impacts are assumed to be accounted for by other services (100% overlap with other services).
- **Shockwave damping:** it is assumed that 25% of the impacts of shockwave damping would be eliminated due to the emergency electronic brake light service.
- **Off street parking information and management:** it is assumed that there is 100% overlap with other parking services (on street parking information and management and park & ride information), so no distinction is made when modelling the impact of these services.
- **Park & Ride information:** it is assumed that there is 100% overlap with other parking services (on street parking information and management and off-street parking information and management), so no distinction is made when modelling the impact of these services.
- **Cooperative collision risk warning:** it is assumed that 75% of the impacts of this service would be eliminated due to the intersection safety service and emergency electronic brake light services.

Table 3-1. Service overlap matrix. Percentages equal the fraction of impacts included in the modelling. Red text signifies overlaps with another service

Service	1_EB L-1	2_EV A-1	4_SS V-1	5_TJ W-1	24_HL N-1	3_RW W-2	6_WT C-2	9_VSP D-2	8_VSG N-2	10_PV D-2	11_SW D-2	7_GLO SA-3	12_Sig V-3	13_TS P-3	14_iFu el-4	15_Pin fo-4	16_PMa ng-4	17_P&Ri de-4	18_Sma rtR-5	25_ZA CM-6	20_LZ M-6	19_VR U-7	21_CC RW-8	22_M CA-8	23_WW D-9
	1_EBL-	_EVA-	_SSV-	_TJW-4	_HLN-	_RWW-	_WTC-	_VSPD-	_VSGN-0	_PVD-1	_SWD-	_GLOSA-2	_SigV-3	_TSP-4	_iFuel-5	_Pinfo-6	_PMang-7	_P&Ride-8	_SmartR-5	_ZACM-0	_LZM-9	_VRU-1	_CCRW-2	_MCA-3	_WWD-
New vehicles																									
Retrofit																									
Infrastructure																									
Fuel consum	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
CO	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
NOx	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
VOC	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
PM	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
Fatalities	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
Serious injuries	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
Light injuries	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
Material damages	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%
Average speed	100%	100%	100%	75%	100%	50%	50%	100%	100%	0%	75%	100%	100%	100%	100%	100%	0%	0%	100%	100%	100%	100%	25%	100%	100%

EBL = emergency brake light, EVA = emergency vehicle approaching warning, SSV = slow or stationary vehicle warning, TJW = traffic jam ahead warning, HLN= hazardous location notification, RWW = roadworks warning, WTC = weather conditions warning, VSPD = in-vehicle speed limits, VSGN = in-vehicle signage, PVD = probe vehicle data, SWD = shockwave damping, GLOSA = green light optimal speed advisory/time to green, SigV = signal violation /intersection safety, TSP = traffic signal priority request by designated vehicles, iFuel = information on alternative fuelled vehicle charging and recharging stations, Pinfo = on-street parking information and management, PMang = off-street parking information and management, P&Ride = Park & Ride information, SmartR = Traffic information and smart routing, ZACM = zone access control management, LZM = loading zone management, VRU = vulnerable road user protection, CCRW = cooperative collision risk warning, MCA = motorcycle approaching indication, WWD = wrong way driving warning.

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