C-ROADS

# Evaluation and Assessment Plan

Working Group 3 – Evaluation and Assessment
Version 1.3
December 2023

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# Publication History

| Version | Date | Description, updates and changes | Status |
|---|---|---|---|
| 1.0 | 12/05/2018 | First release of the E&A Plan presenting the approach shared and adopted and applied to a first list of Use Cases. | Final |
| 1.1 | 14/06/2019 | Removal of the Chapter Technical Evaluation.<br>Enlargement of the set of Use Cases considered, in compliance with the WG2 document "Common C-ITS Service Definitions - Version 1.4". | Final |
| 1.2 | 08/12/2020 | Addition of the Functional Evaluation Chapter.<br>Review of the involvement of countries in the impact areas.<br>Enlargement of the set of Use Cases considered, in compliance with the WG2 document "Common C-ITS Service Definitions - Version 1.7". | Final |
| 1.3 | 24/05/2023 | Enlargement of the set of Services/Use Cases considered to a selection of Day 1.5 Services | Draft |

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# 1 Introduction

## 1.1 Scope of the document

This "Evaluation and Assessment Plan" fulfils the milestone M9 - Revision of C-Roads Evaluation and Assessment Plan (incl. urban), which should be reached until 31/12/2020, for C-Roads Working Group 3 (WG3) – Evaluation and Assessment – and describes the currently available documentation and assessment dimensions in C-Roads in regard to evaluation, Pilots and policy objectives that need to be targeted in the pilot phase of C-Roads.

Within C-Roads, Pilots will evaluate the impacts of Day 1 C-ITS Services and Use Cases implemented during the different Pilot Tests with respect of the following impact areas:

- User Acceptance
- Functional evaluation
- Safety
- Traffic efficiency
- Environment
- Socio-economic

The purpose of the plan is to create the common basis for evaluation and assessment of the C-Roads Pilots. However, the single aspects of assessment, reflected in the chapters of the report, will be defined and decided by the individual pilot implementation, to fulfil contract obligations and contribute to the assessment of C-ITS introduction on European roads.
The impact areas mentioned above should be considered as mandatory for each Pilot. This means that Pilot Tests must face, when evaluating, each impact area if possible. Otherwise they should explain why this is not investigated (e.g. not applicable, not contract obligation). This favours a common framework for C-Roads analysis.

It should be noted that Service Harmonization, as described in WG2 - Task Force 2, with the agreed specifications (containing a functional description of the single C-ITS Services and Use Cases and the communication between C-ITS stations based on standard messages, e.g. CAM, DENM and IVIM) is a required basis for the service evaluation. It should also be noted that guidelines for Technical Evaluation are in charge of WG2 – Task Force 5 (validation of C-ITS services) and individual pilots for ensuring their C-ITS system is functioning correctly before attempting evaluation.

This plan is the result of a wide series of inputs from all different WG3 Members, based on their contributions to projects, evaluation and impact assessment tasks in relation to ITS services.
The Working Group responsible for the fulfilment of this task consists of Partners from all core Member States, plus a significant number of supporting persons.

This Plan remains open to new inputs and specification arising from WG2 activities, and in particular to new releases of the document "Common C-ITS Service Definitions". New releases of this document could include new Use Cases as well as further indications for the assessment of Key Performance Indicators on mobility and economic impacts, as described in the next chapters.

Table 1 provides the overview of the involvement of the Pilot Studies in the impact areas considered, defining also the Use Cases analysed, as planned in October 2020.

## *Table 1 - Involvement of the Pilots in the Impact Areas*

| | | | | Safety | Traffic efficiency | Environment | User Acceptance | Functional Evaluation |
|---|---|---|---|---|---|---|---|---|
| IVS In Vehicle Signage | IVS | DSLI | Dynamic Speed Limit Information | Italy, NL, Spain, UK*, Austria, Ireland, PT *, Germany | Italy, France, Spain, UK, Austria, Ireland, PT | Italy, France, Spain, UK, Austria, Ireland, PT* | NL, Spain, UK, Ireland, PT | Italy, UK, Austria, Ireland, Spain |
| | | EVFT | Embedded VMS "Free Text" | Greece, Spain, UK*, Austria, Ireland | Greece, Spain, UK* | Greece, Spain, UK* | Greece, Spain, UK, Ireland | Greece, UK, Austria, Ireland, Spain |
| | | DLM | Dynamic Line Management | UK* | UK* | UK* | UK | UK, Austria |
| | | OSI | Other Signage Information | NW2*, Ireland, Germany | NW2*, Ireland | NW2*, Ireland | NW2**, Ireland | Austria, Ireland |
| | | SWD | Schock Wave Damping | Greece, PT * | Greece, PT* | Greece, PT* | Greece, PT | Greece |
| | | | | | | | | |
| HLN Hazardous Locations Notification | HLN | AZ | Accident Zone | Spain, NW2*, BE-FL, Slovenia | Spain, NW2* | Spain, NW2* | Spain, NW2**, BE-FL, Slovenia | NW2***, Austria, BE-FL, Spain |
| | | TJA | Traffic Jam Ahead | Spain, Ireland, BE-FL, PT , Germany, Slovenia | Spain, Ireland, PT* | Spain, Ireland, PT* | Spain, Ireland, BE-FL, PT, Slovenia | NW2***, Austria, Ireland, BE-FL, Spain |
| | | SV | Stationary Vehicle | Italy, Greece, Spain, Czech Republic, NW2*, Austria, Ireland, PT | Italy, Greece, Spain, NW2*, Austria, Ireland, PT* | Italy, Greece, Spain, NW2*, Ireland, PT* | Greece, Spain, Czech Republic, NW2**, Ireland, BE-FL, PT | Italy, Greece, NW2***, Austria, Ireland, BE-FL, Spain |
| | | WCW | Weather Condition Warning | Greece, Spain, NW2*, Austria, Ireland, PT , Slovenia | Greece, Spain, NW2*, Austria, Ireland | Greece, Spain, NW2*, Austria, Ireland, PT | Greece, Spain, NW2**,Ireland, PT, Slovania | Greece, NW2***, Austria, Ireland, Spain |
| | | TSR | Temporarily Slippery Road | NW2* | NW2* | NW2* | NW2** | NW2***, Austria |
| | | APR | Animal or Person on the Road | NW2*, Spain, PT | NW2*, Spain, PT* | NW2*, Spain, PT* | NW2**, Spain, BE-FL, PT | NW2***, Austria, BE-FL, Spain |
| | | OR | Obstacle on the Road | Greece, Spain, NW2*, Slovenia | Greece, Spain, NW2* | Greece, Spain, NW2* | Greece, Spain, NW2**, BE-FL, Slovenia | Greece, NW2***, Austria, BE-FL |
| | | EVA | Emergency Vehicle Approaching | Spain, Czech Republic, NW2*, Ireland, PT *, Germany | Spain, NW2*, Ireland, PT* | Spain, NW2*, Ireland, PT* | Spain, Czech Republic, NW2**, Ireland, PT | Spain |
| | | EVI | Emergency Vehicle in Intervention | Germany | | | | |
| | | RLX | Railway Level Crossing | Czech Republic | | | Czech Republic | Czech Republic |
| | | UBR | Unsecured Blockage of a Road | | | | | |
| | | AWWD | Alert Wrong Way Driving (HLN-AWWD) | PT * | PT* | PT* | PT | PT |
| | | PTVC | Public Transport Vehicle Crossing | Czech Republic | | | Czech Republic | Czech Republic |
| | | PTVS | Public Transport Vehicle at a Stop | Czech Republic | | | Czech Republic | |
| | | | | | | | | |
| RWW Road Works Warning | RWW | LC | Lane Closure | Italy, Spain, NW2*, UK*, Austria, Ireland, PT *, Germany | Italy, Spain, NW2*, UK*, Austria, Ireland, PT* | Italy, Spain, NW2*, UK*, Austria, Ireland, PT* | Spain, NW2**, UK, Ireland, PT | Italy, UK, Austria, Ireland, Spain |
| | | RC | Road Closure | Spain, NW2*, Ireland, PT *, Germany | Spain, NW2*, Ireland, PT* | Spain, NW2*, Ireland, PT* | Spain, NW2**, Ireland, PT | Ireland, Spain |
| | | RM | Road Works - Mobile | Czech Republic, NW2*, Ireland, Germany | NW2*, Ireland | NW2*, Ireland | Czech Republic, NW2**, Ireland, BE-FL | Czech Republic, BE-FL |
| | | WM | Winter Maintenance | NW2* | NW2* | NW2* | NW2** | |
| | | ROVI | Road Operator Vehicle in Intervention | | | | | |
| | | ROVA | Road Operator Vehicle Approaching | | | | | |
| | | | | | | | | |
| SI Signalized Intersections | SI | GLOSA | Green Light Optimal Speed Advisory | Italy, NW2*, UK*, PT *, Germany* | Italy, France, NW2*, UK, PT* | Italy, France, NW2*, UK, PT* | NL, NW2**, UK, PT | Italy, UK, Austria |
| | | TLP | Traffic Light Prioritisation | | | | | |
| | | SPTI | Signal Phase and Timing Information | Italy, Spain, NW2*, Austria | Italy, Spain, NW2*, Austria | Italy, Spain, NW2*, Austria | Spain, NW2** | Italy, Austria, Spain |
| | | ISVW | Imminent Signal Violation Warning | Czech Republic, NW2*, Spain, PT | NW2*, Spain, PT | NW2*, Spain, PT* | Czech Republic, NW2**, Spain, PT | PT, Spain |
| | | EVP | Emergency Vehicle Priority | Spain | Spain, PT* | Spain, PT* | Spain, PT | |
| | | | | | | | | |
| PVDProbeVeicleData | PVD | VDC | Vehicle Data Collection | Greece, Spain, Ireland, PT , Germany | Greece, Spain, Ireland, PT | Greece, Spain, Ireland | Greece, Spain,Ireland, PT | Greece, PT, Spain |
| | | EDC | Event Data Collection | Ireland | Ireland | Ireland | Ireland | |
| | | | | | | | | |
| DAY 1.5 services | | | Traffic Information and smart routing | Greece, Spain, NW2*, PT | Greece, Spain, NW2*, PT | Greece, Spain, NW2*, PT | Greece, Spain, NW2**, PT | Greece, Spain |
| | | | On Street Park Management & Information | NW2*, PT | NW2*, PT | NW2*, PT | NW2**, PT | |
| | | | Vulnerable road user protection | PT | PT | PT | PT | |
| | | | Connected & Cooperative navigation in/out city | PT | PT | PT | PT | |
| | | | Smart Slip Ramp | Spain | Spain | Spain | Spain | Spain |
| | | | Emergency brake light | Spain, Ireland | Spain, Ireland | Spain, Ireland | Spain, Ireland | |
| | | | off street parking information | PT, Spain | PT, Spain | PT*, Spain | PT, Spain | Spain |
| | | | Park &Ride information | PT | PT | PT* | PT | |
| | | | Information on AFV fuelling and charging stations | PT | PT* | PT* | PT | |
| | | | Zone access control for urban areas | PT | PT* | PT* | PT | |
| | | | Loading zone management | PT | PT* | PT* | PT | |
| | | | Cooperative collision risk warning | PT | | | PT | |
| | | | Motorcycle approaching indication | PT | | | PT | |

Note: NW2* = Only high-level assessment for CBA for effects considered significant among the marked evaluation areas and C-ITS services
NW2** = Survey to general public (non-test-participants)
NW2*** = Only mobile phone application functionality studied in Finland

(Czech Republic) = TBC

UK* = Subjective Impact

Germany* = C-Roads Urban Nodes

## 1.2 Plan structure

After the introductive part (Chapter 1) that reports a brief state of the art of evaluation methods for ITS/C-ITS, this plan covers the various aspects of **User Acceptance** in Chapter 2, where general information about user acceptance evaluation in ITS services, but especially in C-ITS is covered. The service delivery to end users may consist of contributions from many stakeholders with the consequence that the overall procedure for the evaluation of user acceptance can be complex and depends on many factors. Additionally, social contexts in many transport environments, and - especially - service information concerning usability, usefulness of C-ITS services, and user satisfaction are part of the assessment of user acceptance in C-ITS.

Chapter 3 is intended to provide guidelines and indication to develop the **Functional Evaluation** of C-ITS, with indication about how to gather lessons learned, per Use Cases, from different Pilots.

In Chapter 4 of the plan the main areas of evaluation for C-ITS services are considered, covering the following policy objectives as impact areas in the Pilots:

- Road Safety
- Traffic efficiency
- Environment

These three areas of investigation are the main topic of C-ITS **Impact Assessment**, which needs to be addressed in this plan and covers a defined approach how to achieve this for the "Day 1 C-ITS service list", based on service description from the document C-Roads "Common C-ITS Service Definitions - Version 1.7", released in June 2020, for four subgroups of the Day 1 – Services. These Groups are RWW – Road Works Warning, IVS – In Vehicle Signage, HLN – Hazardous Location Notification, SI – Signalized Intersection. Guidelines about the evaluation and assessment of other impacts are provided for a limited set of specific Use Cases.

The plan suggests the data to be collected during the pilot phase of C-Roads for the service evaluation of the four mentioned service groups and formulates links between these data and research questions. With these steps defined in the single chapters of the plan the Pilots get a guideline to assess and evaluate the main impacts of C-ITS service introduction and link the various aspects of this exercise to each other and use the insight of the pilot phase for the following next steps of C-ITS market introduction in the EU.

The single process steps and the comparison within and between Pilots in C-Roads have the possibility to support this development and check some critical aspects in the domain of cooperative, connected and automated mobility.

## 1.3 State of the art of evaluation methods for ITS/C-ITS

Impact assessment serves regularly as an integrated element of technology development projects. The role of impact assessment in Field Operational Tests (FOTs) and Pilots is pretty much obvious and crucial. To that end, existing practice has been arranged a decade ago in the FESTA Handbook, which provides a framework how to execute FOTs in general and updated several times after that. The most recent version of the FESTA handbook is Version 7 (FOT-Net 2018). Impact assessment is an integrated step in this methodology.

The methodological framework for impact assessment is provided in Figure 1. Impact assessment usually refers to the macro dimension, i.e. it refers to aggregated impacts on (road) safety, mobility and environmental performance. It should be noted that these impacts are triggered by (behavioural) responses and changes to the ITS service provision that take place on a micro level, i.e. on the level of individual drivers. How to deal with these changes, how to upscale from individual data to aggregated impacts, is also taken care for within the FESTA Handbook. These are however preceding steps in the V-model where impact assessment and socio-economics typically represent the last steps, i.e. the upper right of the V-model. It should be also noted that - in a subsequent step (impact appraisal) - impacts can be transformed to monetary values by making use of cost-unit rates per fatality, injury, vehicle hour lost etc. When the benefits have been calculated in such a way, information on costs can help to derive results in an economic dimension (e.g. benefit-cost ratio, net present value, internal rate of return).

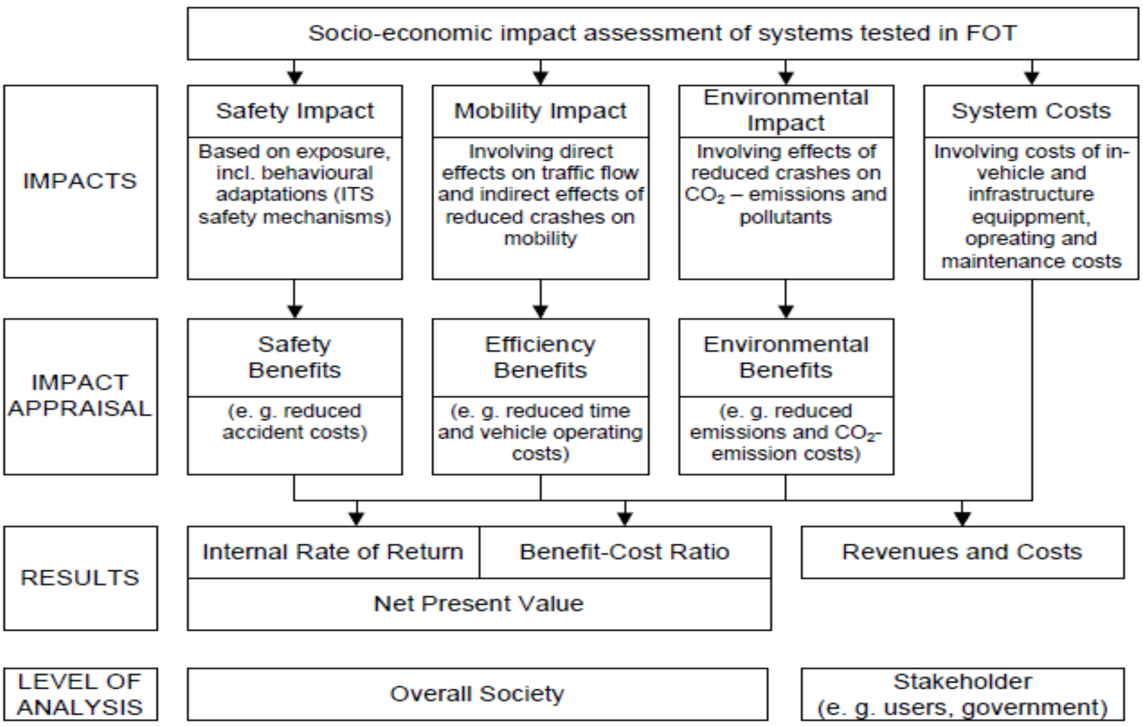


*Figure 1 - Scope of impact assessment incl. socio-economic impact assessment (FOT-Net 2018)*

The impact assessment framework has been practiced by a number of Field Operational Tests and also the first Pilots for deployment of C-ITS services (see Berndt et al. 2016 for an overview of initiatives). The impact assessment which has been prepared in the context of the C-ITS Platform (Ricardo 2016) is also included because of its general importance for the deployment of Day 1 C-ITS Services. Table 2 below maps a selection of these impact assessments against the included impact dimensions.

*Table 2 - Mapping of studied impacts to impact areas*

| FOT / Pilot | Publication year of results | Safety Impact | Mobility Impact | Environmental Impact | Socio-economic Impact |
|---|---|---|---|---|---|
| **DRIVE C2X** | 2014 | X | X | X | X |
| **FOTsis** | 2015 | X | X | X | |
| **Compass4D** | 2015 | X | X | X | |
| **Ricardo** | 2016 | X | X | X | X |
| **NordicWay** | 2017 | X | X | X | X |
| **InterCor** | 2019 | X | | X | |

# 2 User Acceptance

## 2.1 General Approach

In the field of ITS, acceptance is defined as a phenomenon that reflects the extent to which potential users are willing to use a certain system. The FESTA Handbook describes acceptance as the degree of approval of a technology by the users. It depends on whether the technology can satisfy the needs and expectations of its users and potential stakeholders. Within the framework of introducing new technologies, acceptance relates to social and individual aspects as well.

It is possible to distinguish a priori acceptability, acceptance and appropriation. A priori acceptability is studied before use, acceptance is studied in first use and appropriation is studied after several weeks or months of use.

Within C-Roads, the different partners were asked to propose their top 5 research questions on user acceptance. In “Annex 2: Examples of research questions as provided by the C-Roads members”, a list can be found with the major questions of some countries as an example. Based on the partners’ input the following high-level research questions/topics were derived:

- What information was provided, how often, over what time period, etc.?
- In which way will C-ITS be relevant in the user’s driving (behaviour)?
- Does the user understand how and when the system works?
- Does the C-ITS service support the user in driving when using it? Or does it distract the user when driving?
- How easy is the C-ITS service to use?
- How good (reliable, understandable, timely, …) is the information that the user receives?
- How does the service respect users’ integrity (privacy, etc.)?
- Did C-ITS change the driving behaviour (in general)?

In FESTA the following indicators on user acceptance are described:

- **The observed rate of use** of the system or of specific system parts represents an additional indicator for system acceptance and perceived usefulness.
- **Perceived system consequences** (perception of positive or negative consequences of the system's use) is another key indicator for system performance: the user expresses his/her impressions and attitudes regarding the potential consequences when using the system, which can be positive as well as negative. These impressions can best be collected via an interview and be exploited in focus groups, which have the advantage of group dynamics that can provide additional information on the subjective norm.
- **Motivation** (level of motivation/impetus to use the system) should be connected with the indicator **Behavioural intention** (level of intention to use the system). Both indicators can best be investigated via self-designed questionnaires based on established methodological findings (see “Annex 3: User Acceptance Theoretical background”)
- The **Response to perceived social control/response to perceived societal expectations** indicates the impact of perceived social control of the user’s behaviour. Indicator is a more sociological one, which should give an indication whether the user feels a social benefit (for example, social recognition) when using the system, or on the contrary, that he/she hesitates to use the system due to fear of social disapproval when using the system. This is referring to social norm and value granted to use of ITS.

- **Usability/level of perceived usability** concerns the aspects of the user's general capacity to interact with the system. For these indicators, a combination of in-depth interviews, focus groups and self-designed questionnaires based on established methodology is recommended.

In the next sections, this high-level approach is made more operational. Based on a variety of researches and methods, discussions with C-Roads partners and their approaches a framework was developed which can be used to construct the surveys or interviews. The main focus of the user acceptance evaluation in C-Roads is obtaining a better understanding on the users' perceived experiences with the system. Mainly, user acceptance is defined by holding questionnaires or equivalent tools, i.e. specific online or mobile applications to provide users' feedback related to the usage of the evaluated services. The results on the different items will then be compared with the measured change in driver behaviour or perceived changes in the behaviour itself. The change in behaviour will be discussed as part of the KPI on Impact.

When conducting surveys, it is necessary to take into account the General Data Protection Regulation (GDPR). More information can be found on https://www.eugdpr.org/.

The described parameters and questions should be considered as guidelines and not as mandatory aspects: within C-Roads, every country has his own research focus (some of them are more interested in technical evaluation, others have more interests in social aspects). Therefore, it was decided to cover as many aspects as possible within user acceptance. Every Pilot can decide for their own which aspects they should take into account. In "Annex 3: User Acceptance Theoretical background", the theoretical background has been described, mainly focused on the different models and approaches on user acceptance that are found in literature. This Annex can help Pilots to define the behavioural intentions of the test users.

## 2.2 Preparing the research approach

### Considering contextual aspects

As mentioned before, Acceptance is the user's evaluation of the system after their first experiences with the system.

Within C-Roads, the user acceptance should mainly focus on the service provided by the C-Roads network, however user acceptance will be influenced by the provided application, HMI and services that will be given to the driver. The application can be different from demonstration project to demonstration project, or differences can occur among C-ITS service/application providers, such as:

- On which device the C-ITS service is provided.
- How the information is displayed: Text, symbols, combination of text and symbols, the overall screen layout and allowed user interactions from the HMI.
- How the information is built up for the driver: E.g., one C-ITS solution may provide the information 5 km before an incident, while another C-ITS solution may provide the information 2 km before.
- How the C-ITS solution is combined with extra warning features.
- The environmental and situational conditions when receiving the messages.

All these aspects will influence on the perceived user acceptance. How intervening (informative, advisory warning, or assisting certain services) the messages are and what is the social

acceptance for these messages and their appearing rate may favour acceptance or by the contrary favour the system rejection.
Therefore, it would be good to make an inventory about these different aspects for every relevant use case or group of services in every country. In the “Annex 1: Examples of inventory template”, an inventory template is proposed.

### Frequency of measuring a priori acceptability, acceptance and appropriation

In many ITS projects, a questionnaire on user a priori acceptability, acceptance and appropriation is held before, during and after the trial depending on the research scope of the trial. The questionnaire before can give more insights in the expectations, knowledge, etc. on the service and to know if or if not, they are already in favour of using C-ITS solutions.

The questionnaire during trial will be focused more on the usage and findings when using C-ITS in different scenarios. The questionnaire after several weeks of use will be focused on the misuse or abandonment of use.

a) Questions on general C-ITS service
b) Questions related to the specific use-cases:

- Road work warnings
- In Vehicle Signage
- Other Hazardous Locations Notification
- Traffic Light Manoeuvres & Road and Lane Topology

### Defining topics that are part of the survey

These main topics should be covered in the questionnaire:

- **General (social) information**
  - Social/ID information
  - Information in relation to their driving behaviour
  - Information on their knowledge/experience about technology, traffic information and C-ITS

- **General service information (and expectations)**
  - Opinions, attitudes in general on C-ITS and how they influence their acceptance
  - Specific attitudes on C-ITS services in relation to application usage

- **Use case service information**

In the following chapter, it is described what is meant with every aspect or indicator and suggestions are made about what can be asked. Depending on the research setup, scope, etc. these topics/questions can differ or are not relevant.

### Combining survey data with logged data

After gathering the survey data, it is possible to combine the outcome of the user survey with the logged data, related to the impact assessment. In this way, certain user behaviour can be explained or predicted. Several acceptance models allow the combination or interaction of survey data on user acceptance with measured behavioural data. Most popular models are:

- Theory of planned behaviour (TPB)

- Technology acceptance model (TAM)
- Unified Theory of Acceptance and Use of Technology (UTAUT).

Recently, UTAUT has been used more often. A brief description of these models can be found in “Annex 3: User Acceptance Theoretical background”. Many of the described acceptance indicators in the next section can be used to construct such a model. It should be considered which theory is the most preferable for the research setup, before constructing the survey. This is important for not forgetting certain topics in the survey, or to avoid unnecessary questions, which are not usable in the model.

Other relevant aspects that can be considered deal with the organizational dimensions.

## 2.3 Detailed description of acceptance indicators

### General (social) information

These questions are more related to the background factors of the user. These background factors can have an influence on the acceptance and driving behaviour with C-ITS. E.g., older drivers could have more difficulties to cope with the new technology. Frequent speeders would not take into account in-vehicle sign messages, etc. Based on different ITS researches, the following topics **can be taken into account**.

It is suggested to take at least **age**, **annual mileage, professional vs non-professional drivers, and vehicle type into account**.

- **Additional individual factors**
  - Gender
  - Level of education
  - Having children (or not)
  - Income
  - Employment

- **Driving behaviour**
  - Vehicle choice (brand, power, options like cruise control, ACC, etc.)
  - Driving style (as based on driving behaviour questionnaire)
    - Maintain speed – exceeding speed limits (in relation to highway, urban area, etc.)
    - Flustered when faced with danger
    - Influence from other drivers
    - Distraction when driving
    - Planning journeys
    - Braking
    - Lane changing
  - Travel behaviour
    - Travel mode (pedestrian – bike – public transport – car) in relation to purpose (work – leisure – shopping - …). These aspects are good to know, if the test-user is a frequent driver or not.

- **Information and knowledge about C-ITS**

- Knowledge & information on driving options (traditional; already implemented) (e.g. Do you know cruise control?)
- Knowledge & information on navigation and additional information (e.g. Do you know traffic information services?) Even brands can be named (TomTom, Here, Waze, etc.)
- Knowledge & information on C-ITS: Describe the service as good as possible; do not use terms like C-ITS, In Vehicle Signage: e.g. a warning/advice on how you should react (slow down, change lane) when reaching road works.

- **Personal and social aims**
  - How users see the use of C-ITS: beneficial for general road safety, environment, etc. or more for their own safety, reducing fine, planning of alternative routes, getting faster at destination, …

- **Social norms**
  - The use of C-ITS will be influenced by:
    - Peers
    - Social pressure
    - Other road users

- **Responsibility awareness**
  - How do the test-drivers think about the level or responsibility for road safety, environment, etc.?
    - Themselves
    - Police
    - Other road users
    - Policy makers

- **Problem perception**
  - Recognition of the drivers that not having in-vehicle information can cause accidents, bad for environment, etc.
  - Noticed driving errors due to use of the system (can only be asked after the test)

It is suggested to use closed questions with Liker-scale (e.g. never 1 - 2 - 3 - 4 - 5 always), except of individual factors and some attitudes to driving behaviour).

These questions can be asked only at the beginning of the test. However, it can be relevant to ask some of these topics again at the end of the test-period; some changes could be identified.

## General service information (and expectations)

This approach is based on the described theories in acceptance in “Annex 3: User Acceptance Theoretical background”. The main impacts for a device as seen from a user point of view were also taken into account.

### *Perceived efficiency*

*Setup*: questions on C-ITS compared to other services and the effect users think C-ITS will/can have.

*General questions:*
In the users’ opinion, will the use of C-ITS:

- Reduce fuel consumption
- Increase traffic efficiency
- Increase safety
- Avoiding tickets
- Reduce speeding
- Increase situation awareness
- Increase comfort
- Reduce uncertainty

Is the C-ITS service better than other information services like:

- Radio information
- VMS signs
- Additional navigation information
- Google, Waze, or similar.

### *Perceived usability*

*Setup:* questions on the usability of the service

*General questions:*

- How did the user experience the usability of the service?
- What was the workload for the driver?
- How user-friendly/easy to use was the service?

### *Perceived usefulness*

*Setup*: questions on how the service support the driving of the user

*General questions (based on Vanderlaan-scale):*

- How useful was the C-ITS service to support the driver?
- How good was the service?
- How effective was the C-ITS service to support the driver?
- How assisting was the C-ITS service?
- Did it increase alertness of the driver or not?

### *Perceived Satisfaction*

*Setup*: questions on how satisfied the user is of the service

*General questions (based on Vanderlaan-scale):*

- How pleasant was it to use the service?

- How nice was the service?
- How likeable was the service?
- How desirable was the service?

**NOTE:** Usefulness and satisfaction can be measured combined by using the Vanderlaan method.

### Equity

*Setup:* To define under which circumstances the user would like to have the service

*General questions:*

- How does the user think that privacy, security, etc. of the user will be affected when using C-ITS?

### Affordability/willingness to pay

*Setup:* identify what and when the user will pay for the service

*General questions*:

- How much do you want to pay for purchase/use of the C-ITS service?
- Under which financial conditions would you be willing to use the service?

## Specific Questions, related to the use cases

It is assumed that the questions related to the effectiveness will differ from service to service, therefore, the following general questions are proposed:

### Perceived effectiveness

**NOTE:** These research questions are formulated so that mainly the service will be evaluated and not necessarily the used device or service provider. This could/should make comparison easier. It is proposed to focus these questions directly on the different use cases instead of asking it in general.

*Setup:* Questions on C-ITS on the system performance

Availability:

- Was the service available when the service was needed?
- Degree of availability (never to always) for the different use cases
- An additional checklist can be proposed to indicate why service was not available
    - Bad connection/not getting messages/…

Correctness:

- Was the information correct when the service was active?
- Degree of correctness for the different use cases
- An additional checklist can be proposed to indicate why service was not correct
    - Message received after incident; false spot; …

Completeness:

- Was the information complete when the service was active?
- Degree of completeness for the different use cases
- An additional checklist can be proposed to indicate why service was not complete (did not gave speed indication, changing lane, …)

Consistency:

- Was the service consistent and easy to understand when the service was active?

- Degree of consistency for the different use cases
- An additional checklist can be proposed to indicate why service was not consistent (some use cases information in text, other in symbols; change in kind of messages, …)

Accuracy

- Was the service accurate (geographical accuracy)?
- Degree of accuracy for the different use cases
- An additional checklist can be proposed to indicate why service was not accurate (not the right place, etc.)

Up-to-dateness

- Was the service up-to-date? Was the service available right on time?
- Degree of up-to-dateness for the different use cases
- An additional checklist can be proposed to indicate why service was not up-to-date

**Specific Questions related to road managers**

If users are employees of road managers, specific impact of ITS on their job can be evaluated. In this case, questions depend on the use case considered and deal with procedures of work. Further details regarding this topic will be analysed by WG3 in its next activities.

# 3 Functional Evaluation

## 3.1 General approach

Functional Evaluation in the context of this guidance document covers a number of distinct aspects based on the real world performance of the services/use cases as delivered into the vehicle. As such this aspect of evaluation covers: how the HMI performed displaying information/warnings to the user, the quality of service, the added value of the service and lessons learned (refer to Section 3.2 and 3.3 for further detail on the desired content and format of the inputs sought).

The value chain of traffic information can be broken down into four distinct steps:

I. Content Detection
II. Content Processing
III. Service Provision
IV. Service Presentation

The objective of C-Roads is to harmonise the Service Provision, so in C-Roads the road operators are working on the first three steps as part of their C-Roads pilots. The fourth step, Service Presentation, is left to the OEMs who provide the HMIs for each C-Roads Pilot.
Within the scope of Service Presentation includes the HMI and the information processing by the OBU. Functional Evaluation is therefore related to the quality of service presentation to the end user at the HMI. Although the presentation of the HMI is not in the scope of C-Roads, the design of the HMI may affect the results of the service provision.

An example is given to make such differences in quality of the presentation clearer. In a basic service presentation mode, the driver gets a warning on the screen of the HMI 'Congestion Ahead'. In a higher mode the driver gets a first warning 'congestion ahead' 1000m ahead, but to cover the case where the driver is not slowing down the driver also receives a second warning in 'blinking mode' together with an audible warning.
In the framework of C-Roads there are no specifications about the quality of service presentation. Therefore, it is not possible to evaluate the service presentation in a common way. Therefore, it has been agreed that the Functional Evaluation aspects be added to initially gather lessons learned instead of an evaluation based on KPIs.

## 3.2 Evaluation methodology

### Evaluation Scope

In the document 'Common C-ITS Service Definitions' of Working Group 2 of the C-Roads platform are specifications for each use case. Some of these specifications deal with quality of service. As such, the following aspects taken from these are to be used as inputs for the Functional Evaluation:

- Summary Description of use case
- Desired Behaviour
- Display/Alert principle
- Functional constraints/dependencies.

From examination of the WG2 document, it was observed that for all use cases these specifications are high level and outcomes based only. Examples include terms such as 'user adapts their behaviour compliant to..', 'information needs to be displayed early enough' etc. This will naturally lead to variations in the implementation in terms of the presentation of the information to the user.

This is also the reason why a Functional Evaluation comparing specifications with results is not possible. Within Working Group 3 (WG3), it has been agreed that the following items will be part of the Functional Evaluation under the heading of 'Lessons Learned':

- Lessons learned during the implementation of the service:
    - Observations that specifically relate to the what was learned during the evaluation to both deliver the service with respect to the criteria below but also in the overall evaluation of the service/use case.
- HMI:
    - Observations that specifically relate to the implementation of the HMI that were observed during the evaluation that could be improved.
- Quality of service:
    - Observations that specifically relate to the technical performance in the context of how messages/warnings were displayed in the vehicle e.g. timing (including when warnings were first displayed), their accuracy and overall timeliness.
- Added value of the service:
    - Observations that specifically relate to the added value of the use case, particularly with respect to those over and above existing ITS on road signage.

### Use cases

The Functional Evaluation is performed per use case so in order to avoid a lot of copy and paste which leads to an unreadable report, it is proposed to restrict the number of use cases the aspect of evaluation is applied to.
As such we would propose restricting the number of use cases in the C-Roads final report to the following list:

| Day 1 / 1.5 Service | Use case |
|---|---|
| In-Vehicle Signage (IVS) | Dynamic Speed Limit Information (IVS-DSLI)<br><br>Dynamic Lane Management (IVS-DLM) |
| Road Works Warning (RWW) | Closure of a lane (RWW-LC) |

| | |
|---|---|
| Signalized Intersection (SI) | GLOSA (SI-GLOSA)<br><br>Signal Phase and Timing Information (SPTI) |
| Hazardous Location Notification (HLN) | Traffic Jam Ahead (HLN-TJA)<br><br>Obstacle on the Road (HLN-OR) |

## 3.3 Inputs per Pilot

### General remarks

It has been agreed that if a Pilot has done an extended Functional Evaluation, that in the final C-Roads evaluation report containing all Pilot results, only a summary is used with a reference to the document of the Pilot for the more detailed results.

It is noted that not all Pilots are implementing all use cases mentioned in the table above. A Pilot will of course only be able to provide results on the implemented use cases and as such any Functional Evaluation results relating to the use cases tested.

In order to test the link between a back office and an OBU (via RSU or directly using 4G) it is not always needed to use a traffic information system in its real time live operating mode. Many Pilots may use only 'fake' messages for testing for the Pilot as well as for the interoperability tests. In order to test certain use-cases it might be necessary to use fake messages. For use cases tested in this way within a Pilot, the service presentation is deemed not essential.

The evaluation of these use cases within Pilots is more likely to be focused on technical evaluation than on user acceptance. For such testing regimes, it is understood that their contributions to Functional Evaluation will be more restricted and should be stated for clarity when submitting results on the type of message (real/fake) used during the evaluation.

### Template for Evaluation Report per use case

For each use case there is first a table with specifications of quality based on the WG2 service specification elements as shown below.

This will be populated in the C-Roads WG3 Functional Results Annex document which will be made available in the WG3 area on the C-Roads document cloud, where all results will be initially collated by the WG3 Functional Evaluation leads, as Pilot results are made available.

(https://www.c-roads.eu/nextcloud/index.php/apps/files/?dir=/Workgroups/WG3%20-%20Evaluation%20%26%20Assessment&fileid=128 ).

| | |
|---|---|
| **Summary:** | |
| **Desired behaviour :** | |
| **Display/Alert principle:** | |
| **Functional constraints/dependencies:** | |

Next per pilot, a table with the defined functional evaluation items is completed:

| | |
|---|---|
| **Service / Use Case** | |
| **Lessons Learned** | |
| **HMI**[1] | |
| **Quality of Service** | |
| **Added Value of the Service** | |

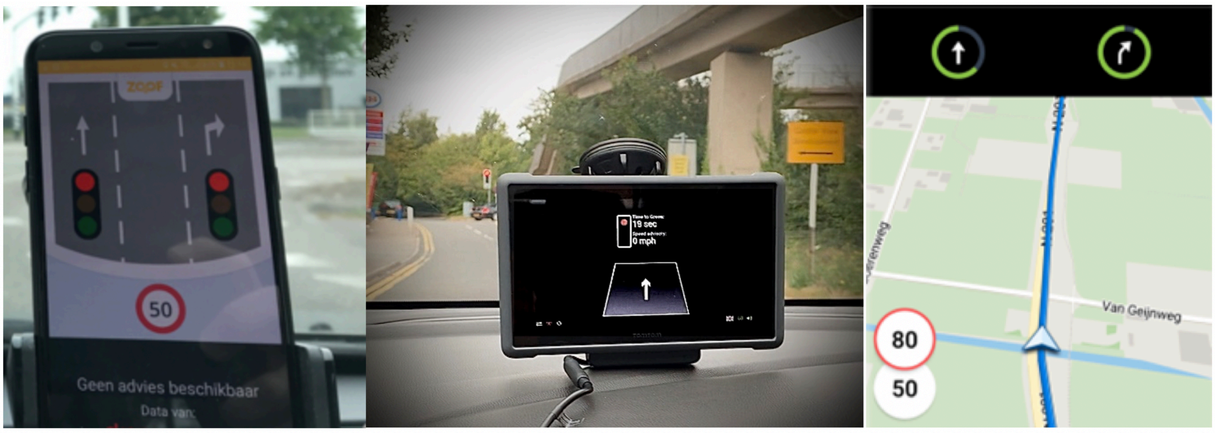


*Figure 2 - Examples of different GLOSA HMI representations*

[1] If relevant a picture of the HMI can be added. Examples of different GLOSA HMI representations are included in Figure 2 for illustrative purposes to show the potential variations displayed to the user to achieve the same end result.

# 4 Impact Assessment

## 4.1 Information gathering during C-ITS Pilots

### Evaluation of C-ITS impact in relation to baseline development

A core objective of Pilots is to better understand the effects of providing C-ITS services. This necessitates an impact evaluation approach that can compare the observed pattern of behaviour to some 'counterfactual' for what would have happened without the intervention. I.e. the impacts of C-ITS Services are the result of a comparison between a framework with C-ITS Services that are working or activated on the equipped vehicles/devices and other vehicles that do not have C-ITS services or have them switched off.
Parameters and Key Performance Indicators (KPIs) are defined as the comparison between revealed measures with C-ITS and the baseline that is the current framework without C-ITS services.
In principle, the following approaches could be deployed to establish a 'counterfactual'. They are listed in order of increasing robustness, but it will be important for each Pilot to design an approach that is suitable for their specific implementation:

- **Before and after** - comparing outcomes before and after offering C-ITS services. This necessitates the collection of baseline data should be collected in advance of the implementation of C-ITS services.
- **Simple difference in differences** - compares changes in outcomes measured on the scheme to those for other roads or for drivers not equipped with C-ITS services on the same roads. This necessitates the collection of data from a control group in addition to drivers provided with C-ITS services.
- **Regression difference in differences** - is similar to simple difference in differences, but uses statistical techniques to compare changes in outcomes for drivers receiving C-ITS guidance to those not receiving guidance, controlling for a range of other factors.
- **Randomized control trials** - randomly allocating drivers to either receive C-ITS information, or into a control group for comparison purposes from which data is collected, but no services are provided. Drivers could either be permanently allocated to a treatment or control group, or the randomization could be applied each time they trigger an item of C-ITS guidance. The latter approach may be particularly suitable for Pilots involving a small fleet of vehicles.

Further, it is important to mention that the basic factors that are checked during evaluation are dynamic in many terms - like change over a time period, through different roads, vehicle types etc.

Whenever there is an evaluation about C-ITS impact, it should be considered that this evaluation never happens versus static elements. In fact, all factors related to the three areas of evaluation mentioned are constantly changing, alone and without any C-ITS-involvement. This is valid for traffic efficiency (parameters such as traffic flow, density, speed, gaps etc.), traffic safety (parameters such as speed, brakes, driver awareness etc. and the overall indicators such as number of crashes, injuries and fatalities) and also environmental issues (parameters such as noise, pollution, $CO_2$ emissions etc.),

Whenever impact-evaluation takes place, it should not be measured against static, but a dynamic baseline (not C-ITS-influenced) development.

### Evaluation of differences between C-ITS- and non-C-ITS-related traffic developments

*Involvement of planned user vehicles*

From 2019 on, evaluation within C-Roads is done through Pilots, to be established throughout C-Roads Member States. Vehicles, properly equipped with C-ITS, collect data, and the output will then, among others, be used for impact-evaluation.

*Monitoring of unplanned user vehicles*

Data coming from unplanned user information is potentially by far outnumbering the data from planned user information – millions of cars are driving on European roads, and the number of vehicles which collect data output via the use of C-ITS is likely to grow rapidly in the near future, thus creating a massive amount of data. Monitoring and using these data is a matter of privacy and legal rules at time and place of use are to be considered.

## 4.2 General Approach

During the field tests, it will be possible to measure or calculate different parameters that can reveal a different behaviour of the driver because of the receipt of information via C-ITS. Just User Behaviour of single driver/vehicle will be measured, as it can be assumed that the impact on the whole traffic flow during a field test would be negligible.

The measurement of changes in User Behaviour, thanks to the use of Day 1 C-ITS, provides a first indication of the impacts, at a field test scale, of C-Roads implementation for the following impact areas:

- Safety
- Traffic efficiency
- Environment

Beside these three main impact areas, other impacts can be evaluated and assessed with reference to specific Use Cases and would be consequently considered in this Plan.

Insight analysis on safety could be addressed to the evaluation of distraction.
The data sources may include Vehicle ITS-Station, CAN Bus data[2], GPS logger, automatic in-vehicle driver monitoring and/or the traffic monitoring systems on the road. Data collection and parameters measurement and calculation during the field test should be designed with the aim of analysing possible effects of C-ITS Day 1 Services. To investigate the distraction gaze behaviour measures could be used, as well as other indicators related to the psychophysical conditions of the drives. Those measures may be obtained by using eye or head tracking system, but also other useful information could be recorded by other wearable tools. Since this technology is relatively expensive and its use in field test is challenging, controlled studies using an instrumented vehicle in real road or test truck, using a driver simulator or any laboratory device may be conducted.

The main objective of the evaluation is the estimation of the effects of C-ITS Services with respect to a “non-C-ITS” situation (see comparison approaches in the previous chapter). In order to achieve this, it is important to consider contextual conditions/boundary conditions such as:

- road typology (highway, rural, urban.),

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[2] However this source of data is very rich, the opportunity to access CAN Bus is uncertain and therefore methodology is independent from this source.

- speed limit
- number of lanes
- traffic flow
- visibility condition
- road structure data (materials and tilt), etc.

It should be noticed that the boundary conditions for the comparison should be similar.

Drivers should be familiar with the C-ITS service to avoid measurements during learning phase. Besides the assessment of the effects of C-ITS, data collection and analysis could also provide feedback for the specification of Day 1 Services that can be used to maximize the benefits of the services. For instance, results may improve features of the service like location and timing of the information provided to the drivers.

An additional step is to use the data measured or calculated during the field test for an estimation of impacts on the entire traffic flow when the penetration rate of C-ITS vehicle will be higher. This means moving from a behavioural change measured on single vehicle (within the Pilots) to an estimation of the overall consequences on traffic in general when Day 1 Services will be more diffused. Such estimation could be based on algorithms and traffic modelling, but even through qualitative assessment. Starting from these outputs economic analysis can be developed, to provide an economic quantification of the estimated impacts.

The following Guidelines for the Evaluation of impacts of Day 1 Services on the mentioned investigation areas (safety, traffic efficiency and environment) are structured for each Use Case based on the “Research Question” approach, which follows FESTA Handbook (FOT-Net 2017) whenever pertinent:

- Research Questions: How do drivers change their behaviour because of warnings/information given by the service?
  The way the driver changes the driving behaviour following the indication coming from the C-ITS is described;
- Sub Research Questions:
  The changes of the parameters that characterize the different driver behaviour are investigated.
- Data collection (logging needs):
  Data/parameters that should be collected to be able to measure/calculate the changes in driver behaviour are mentioned: e.g. dynamic parameter of the vehicle (speed, steering angle, …), information concerning messages (typology, time and position, …). All Data/parameters should be featured, as far as practicable, with information regarding time and position.
  In addition, it is reported how these data could be collected: e.g. GPS Can Bus, On Board Unit, loops …Video recording could be identified as supporting tool for data collection for the whole set of analysis.
- Performance indicators to be calculated from the field data.
  Based on the measurement or calculation of the mentioned parameters the Performance Indicators of the field test are defined: e.g. speed adaptation, change in acceleration, average speed change …
- Estimated KPIs on mobility (when C-ITS will be more widely diffused).
  This additional step, using the data measured or calculated during the field test, defines KPIs for a higher C-ITS penetration rate. This estimation could be based on algorithms, traffic modelling but even through qualitative estimation. The methods for the assessment should be described in detail.

These KPIs should be based on DG MOVE (https://ec.europa.eu/transport/sites/transport/files/themes/its/studies/doc/its-kpi-final_report_v7_4.pdf) and EU EIP list (https://www.its-platform.eu/highlights/kpis-defined).
A possible KPI could be, as example for road safety, “Change in number of road accident resulting in death or injuries numbers”.
Different scenarios could be developed considering different temporal checkpoints, for example 2025 and 2030.

- Assessment of the economic benefits of the C-ITS services generated by the KPI´s mentioned in the previous point.

Further activities of WG3 will be oriented to provide more details about the possible methods and techniques to investigate the last two points of this approach.

## 4.3 Day 1 Service: Road Works Warning

The Day 1 Service Road Works Warning (RWW) currently includes, according to the WG2 list of Use Cases described in the document "Common C-ITS Service Definitions - Version 1.7", the following Use Cases:

1. Lane Closure (and other restrictions), (Abbreviation: RWW – LC)
2. Road Closure, (Abbreviation: RWW – RC)
3. Road Works Mobile, (Abbreviation: RWW – RM)
4. Road Operator Vehicle in Intervention, (Abbreviation: RWW – ROVI)
5. Road Operator Vehicle Approaching, (Abbreviation: RWW – ROVA)

For evaluation and assessment purposes, these Use Cases can be grouped in two clusters, considering the events managed by the C-ITS messages.
The first four Use Cases are referred to events that drivers are expected to meet along the path they are following. These events are location-specific events, managed by detailed messages able to specify the location of the event even in terms of lane involved and to suggest, if needed and beside warnings inviting to cautious driving, a lane change.
The last Use Case, ROVA, deals with a different event – the approach of a Road Operator Vehicle, typically from behind – and it is supposed to mainly provide impacts for the Road Operator Vehicle, easing its passage.

The investigation of the impact areas Safety, Traffic Efficiency and Environment is developed for the first cluster of Use Cases, while for the Use Case ROVA indication about Other Impacts – Time of Intervention are provided.

### 4.3.1 Use Cases: Lane Closure (LC), Road Closure (RC), Road Works Mobile (RM), Road Operator Vehicle in Intervention (ROVI)

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed in advance and more precisely (e.g. lane/s involved and possible restrictions to traffic flow) of a lane closure due to road works. They know earlier than without this information about the need for lane change. This lane change is done in advance of the road works site and the traffic flow will be ready and constant for lane closure before the critical stretch. The lane change manoeuvre is hereby done in more regular and safe conditions (for both drivers and road operating agents).

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- In the approach of a road works site, how do the instant speed fluctuations of drivers change? *Do drivers apply the break earlier? Do drivers lift off the accelerator earlier? Do vehicles slow earlier? Do drivers apply the break less sharply?*
- Is driver's speed more compliant with speed limit in the approach of and passing by a Road works site? *What is the difference between the behaviour of the driver and the advice given by roadside systems? Is the speed of test vehicles with the service different from the average speed in the section(s)?*
- How does the lane change point vary?
- Is the lane change manoeuvre smoother? *Do drivers make fewer sudden steering movements? Is the acceleration/deceleration of the vehicle lower? In any direction?*

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 3 - RWW - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| In the approach of a road works site, how do the instant speed fluctuations of drivers change? | x | x | x |
| Is driver's speed more compliant with speed limit in the approach of and passing by a Road works site? | x | x | |
| How does the lane change point vary (if the lane of the event is specified)? | x | x | |
| Is the lane change manoeuvre smoother (if the lane of the event is specified)? | x | x | x |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 1Hz)

- Time between the reception of the C-ITS message in the vehicle (T0, the presentation on the HMI is in most relevant cases directly linked to it) and the arrival at hazardous location position (T1) – source: C-ITS device, Can Bus data or GPS data (s)
- Vehicle position – source: GPS data
- Steering angle – source: Can Bus steering angle (For Location specific events only)
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device

### Safety

#### *Main research question*

- Is safety affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to more fluent traffic conditions.
- Higher compliance with speed limits leads to traffic condition more suitable for a section interested by hazards, reducing sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.
- A lane change in a proper location leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less perturbations to the following vehicles.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 4 - RWW - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| In the approach of a road works site, how do the instant speed fluctuations of drivers change? | X | X | | X | | X |
| Is driver's speed more compliant with speed limit in the approach of and passing by a Road works site? | X | | X | X | | X |
| How does the lane change point vary? | | | | X | X | X |
| Is the lane change manoeuvre smoother? | | X | | X | X | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles):

- Speed adaptation (difference between the average speed of the vehicle and the speed limit suggested) - from the reception of the C-ITS message until the position of the hazard

- Travel Time / Average Speed - from the reception of the C-ITS message until the position of the hazard
- Maximum speed
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point[3] (point where the vehicle performs the lane change manoeuvre - For Location specific events only)
- Maximum steering angle (For Location specific events only)

*Table 5 - RWW - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| Speed adaptation | X | | X | X | | X |
| Average Speed | X | | X | X | | X |
| Maximum Speed | X | | X | X | | X |
| Speed standard deviation | X | | | X | | X |
| Instantaneous acceleration | | X | | X | | X |
| Lane change point | | | | X | X | X |
| Maximum steering angle | | | | | X | X |

*Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in road accident resulting in death or injuries numbers (number of accidents, %)
- Change in absolute number of all road accidents

### Traffic Efficiency

*Main research question*

- Is traffic efficiency affected by the use of C-ITS service?

*Research hypotheses about Sub Research Questions*

- The increased awareness about a hazardous event leads to lower speeds on the road and to reduce sudden and relevant braking when the event is reached, thus more fluent traffic conditions.
- The speed limit, besides a more regular driving, involves smoother manoeuvres and, thus, more fluent traffic conditions. This implies a reduction in sudden braking and

[3] The lane change point could be determined using GPS and time stamp tagged Video or analyzing steering angle with road angulation (requires a map for geo matching and algorithm).

consequent accelerations and thus limiting the creation and the propagation of shockwaves.
- An advanced lane change before a confined hazardous event leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less disturbances in the traffic flow of the following vehicles.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 6 - RWW - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | x | x | | x | | x |
| Is driver's speed more compliant with speed limit (if suggested)? | x | | x | x | | x |
| How does the lane change point vary (if the lane of the event is specified)? | | | | x | x | x |
| Is the lane change manoeuvre smoother (if the lane of the event is specified)? | | x | | x | x | x |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles):
- Speed standard deviation
- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the starting/ending position of road works
- Travel Time / Average Speed - from the reception of the C-ITS message until the starting/ending position of road works
- Instantaneous accelerations and decelerations
- Lane change point (For Location specific events only)
- Maximum steering angle (For Location specific events only)

*Table 7 - RWW - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| Speed adaptation | x | | x | x | | x |
| Travel Time/Average Speed | x | | x | x | | x |
| Speed Standard Deviation | x | | x | x | | x |
| Instantaneous acceleration | | x | | x | | x |
| Lane change point | | | | x | x | x |
| Maximum steering angle | | | | | x | x |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Bottleneck Congestion (Bottleneck residual capacity)
- Change in travel time
- Change in Total time spent by all vehicles in queue

## Environment

### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel/energy consumption and therefore lower $CO_2$, pollutants and noise emissions.
- Higher compliance with speed limits leads to traffic condition more suitable for a section interested by road works, reducing sudden braking and consequent accelerations and thus limiting $CO_2$, pollutants and noise emissions.
- A lane change in a proper location leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less disturbances in the traffic flow of to the following vehicles.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 8 - RWW - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energy consumption | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | | X | | X |
| Is driver's speed more compliant with speed limit (if suggested)? | X | X | | X | X | | X |
| How does the lane change point vary (if the lane of the event is specified)? | X | | | | X | X | X |
| Is the lane change manoeuvre smoother (if the lane of the event is specified)? | | | X | | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles):

- Speed standard deviation
- Instantaneous accelerations and decelerations
- Fuel/Energy consumption
- Noise level
- Lane change point (For Location specific events only)
- Maximum steering angle (For Location specific events only)
- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the starting/ending position of road works

*Table 9 - RWW - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energy consumption | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|---|
| Speed standard deviation | | X | | X | X | | X |
| Instantaneous accelerations and decelerations | | | X | | X | | X |
| Fuel/Energy consumption | X | X | X | | X | | X |
| Noise level | | X | X | | X | | X |
| Lane change point | | | | | X | X | X |
| Maximum steering angle | | | | | X | X | X |
| Speed adaptation | | X | | X | X | | X |

*Estimated KPIs on mobility (when C-ITS will be more widely diffused).*
The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in climate-change and polluting emissions ($CO_2$ emissions and other pollutants)
- Change in noise pollution
- Change in fuel/energy consumption

### 4.3.2 Use Case: Road Operator Vehicle Approaching (ROVA)

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*
The drivers are informed in advance about the presence of a road operator vehicle and can ease the road operator bypass. This allows a faster arrival to the desired site for the road operating agents.

*Data Collection*
In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected on the road operator vehicle:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 1Hz)
- Time between the sending of the C-ITS message (request of intervention) from the vehicle and the arrival at hazardous location position (T1) – source: C-ITS device, Can Bus data or GPS data (s)
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device

#### Other Impacts – Time of intervention

*Main Research Questions*

- Is the time of intervention of road operator vehicles affected by the use of this C-ITS service?

*Research hypotheses about Research Questions*

- Aware of the presence of the road operator vehicle, the road user can change lanes, move aside, or else so to ease the bypass of the vehicle and reduce the time of intervention

*Field Test Indicator/KPI*
The following Key Performance Indicators of the field test can be evaluated (difference between C-ITS- and non-C-ITS-road operator vehicles):

- Time of intervention – from the sending of the C-ITS message (request of intervention) from the vehicle and the arrival at hazardous location position (T1)

## 4.4 Day 1.5 Service: Road Works Warning – Extensive Work Zone

C-Roads WG2 is currently (May 2023) in the process of rationalising specifications for the implementation of day 1 RWW use-cases, such as Lane Closure and Road Closure. The need to rationalise has come about due to differing requirements across Member States, the C2C-CC and C-Roads as to how information on work zones should be communicated.

As such, a C-ITS European Handbook for RWW is currently being prepared by WG2, which aims to provide a guideline for implementing (i.e., digital twinning) RWW use-cases with various requirements.  The Handbook defines a common approach for implementing various road works scenarios including long duraration and complex work zones which is what the day 1.5 use case extensive work zone (EWZ) was set out to encompass.

It is important to understand the principal of the proposed common approach being defined in the Handbook in order that an appropriate methodology for its evaluation and assessment can be recommended. The approach encompasses the road works area and the approaching route/s to the road works area within a work zone. A work zone can comprise of one or multiple 'components'. A components relates to a specific situation, e.g. a lane closure, a carriageway crossover, an exit from the motorway within a work zone, narrow lane etc (instances are defined in the Handbook). For all of these situations, a warning DENM message will be sent (as is the case with LC and RC use cases) with additional information such as temporary speed limits, lane re-layout configuration (e.g., narrowed lane widths), etc. sent in separate IVIM and/or MAPEM message(s).

The key difference therefore between the EWZ and LC/RC use cases is that the EWZ use case can encompass multiple 'components', potentially over a longer section of road for a longer duration that are supported by the provision of additional traffic management information. These differences are not considered to materially affect the approach to evaluation and assessment of RC/LC use cases as described herein. The same approach to evaluation and assessment can therefore be applied to EWZ. The research questions, data collection and KPIs for the impact areas of safety, traffic efficiency and environment are all therefore considered relevant for the EWZ use case.

In applying this methodology to urban environments, it is important to consider a range of complexities that make evaluating and assessing the impact of this use case more challenging than in inter-urban environments. For example, road configurations are often more complex, awareness of road works is likely to be greater and the opportunity for alternative routes/modes to avoid disruption is greater which can make isolating any change as a result of the intervention very challenging. In these situations a bespoke approach to evaluation and assessment may be required.

## 4.5 Day 1 Service: In Vehicle Signage

The Day 1 Service IVS currently includes, according to the WG2 list of Use Cases described in the document "Common C-ITS Service Definitions - Version 1.7", the following Use Cases:

1. Dynamic Speed Limit Information (Abbreviation: IVS – DSLI)
2. Shock Wave Damping (Abbreviation: IVS – SWD)
3. Embedded VMS "Free Text" (Abbreviation: IVS – EVFT)
4. Other Signage Information (Abbreviation: IVS – OSI)
5. Dynamic Lane Management (Abbreviation: IVS – DLM)

Generally, In-Vehicle Information (IVI) is a message format to deliver information about the infrastructure to vehicles. It denotes a data structure, which is used by different Intelligent Transport System (ITS) services to convey information to vehicles and their drivers.

In-Vehicle Signage (IVS) is one of these services. It provides information about existing, fixed and dynamic traffic signs to passing vehicles by means of IVI messages. This information can be processed by driver assistance systems in the vehicles and relevant data can be presented to the driver. In this way, the driver can be informed about current traffic regulations and advices at all times and not only during brief moments when passing by fixed traffic sign or gantries.

In particular:

- **Dynamic Speed Limit Information** is used by road operators for traffic management measures (heavy traffic, road works, weather, pollution …).
- **Shock Wave Damping** provides in-car information to avoid emerging or ideally even accomplish the elimination of shockwave situation in highway traffic.
- **Embedded VMS "Free Text"** allows the "free text" message showed on a VMS to be displayed on-board, a completely new message can be delivered too and in the same way (virtual VMS).
- **Other Signage Information** transmits I2V signage information (using IVI) other than dynamic speed limit and free text information, e.g. bans on overtaking or lane advice, as set and distributed by the road operator
- **Dynamic Lane Management** enables a specific number of lanes in one direction at a given point of the network to vary.

With the help of the IVS service, it is expected to improve the driver's awareness and reduce both the number and severity of traffic accidents.

### 4.5.1 Use Case: Dynamic Speed Limit Information (DSLI), Shock Wave Damping (SWD)

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed, continuously and in advance, on a suggested speed limit. They can adapt their speed quicker and avoid speeding. This change is done in advance and the suggested speed can be updated with the change in downstream traffic flow. The driving is smoother and with lesser acceleration and deceleration.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How do the instant speed fluctuations change?
  *Do drivers apply the break earlier, do drivers lift off the accelerator earlier, do vehicles slow earlier, do drivers apply the break less sharply?*
- Is driver's speed more compliant with speed limit suggested?
  *What is the difference between the behaviour of the driver and the advice given by road side systems, is the speed of test vehicles with the service different from the average speed in the section(s)*

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 10 - IVS-DSLI/SWD - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How do the instant speed fluctuations change? | x | x | x |
| Is driver's speed more compliant with speed limit? | x | x | x |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 1Hz)
- Braking power, moment of breaking – source Can Bus data
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

### Safety

#### *Main research question*

- Is safety affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to fewer perturbations and more fluent traffic conditions.
- Higher compliance with speed limits suggested reduce sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 11 - IVS-DSLI/SWD - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X |
| Is driver's speed more compliant with speed limit? | X | X | X | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the suggested speed limit is no longer relevant.
- Speed standard deviation
- Instantaneous accelerations and decelerations

*Table 12 - IVS-DSLI/SWD - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Speed standard deviation | X | | X | X |
| Instantaneous accelerations and decelerations | | X | X | X |

#### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in road accident resulting in death or injuries numbers (number of accidents, %)
- Change in absolute number of all road accidents

### Traffic Efficiency

#### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- The speed limit suggested it's meant to ease the flow going towards a queue or a traffic jam or to lessen/prevent shockwaves and to avoid occurrence of a traffic jam. Higher compliance with this speed limit leads to an early dissipation of the traffic jam, reducing the number of acceleration and deceleration, granting a higher comfort for the driver and a smoother traffic flow on the road. Driver's speed can be more compliant to suggested speed with respect to a situation with dynamic speed limits provided via Variable Message Signs
- Having the dynamic speed limit showed on the HMI and continuously updated leads to more homogeneous speeds, reduced acceleration and deceleration phases. This involves fewer perturbations on the traffic flow and more fluent traffic conditions.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 13 - IVS-DSLI/SWD - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Is driver's speed (more) compliant with suggested speed limit? | X | | X | X |
| How do the instant speed fluctuations change? | X | X | | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the suggested speed limit is no longer relevant.
- Speed standard deviation
- Instantaneous accelerations and decelerations

*Table 14 - IVS-DSLI/SWD - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Speed standard deviation | X | | X | X |
| Instantaneous acceleration | | X | | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Journey Time
- Change in Total time spent by all vehicles in queue
- Change in Traffic Flow

## Environment

### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel/energy consumption and therefore lower $CO_2$, pollutants and noise emissions.
- Higher compliance with speed limits suggested lessen/prevent shockwaves and leads to an ease of the downstream congestion and an early dissipation of the queue, reducing the number of acceleration and deceleration and thus limiting $CO_2$, pollutants and noise emissions.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 15 - IVS-DSLI/SWD - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | | X |
| Is driver's speed (more) compliant with suggested speed limit? | X | X | | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be detected or calculated:

- Speed standard deviation
- Instantaneous accelerations and decelerations
- Fuel/Energy consumption
- Speed adaptation (difference between the average speed of the vehicle and the speed limit)
- Noise level

*Table 16 - IVS-DSLI/SWD - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| Speed standard deviation | | X | | X | X |
| Instantaneous accelerations and decelerations | | | X | X | X |
| Fuel/Energy consumption | X | X | X | | X |
| Speed adaptation | | X | | X | X |
| Noise level | | X | X | | X |

*Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/energy consumption
- Change in polluting emissions

### 4.5.2 Use Case: Embedded VMS "Free Text" (EVFT)

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed, continuously and in advance, on an event. They can adapt their speed and other behaviour quicker and thus avoid speeding and other disturbing behaviour. This change is done in advance and the reaction to the given information can be handled with the change in downstream traffic flow. Consequently, the driving is smoother and with lesser acceleration and deceleration.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How do the instant speed fluctuations change?
  *Do drivers apply the break earlier, do drivers lift off the accelerator earlier, do vehicles slow earlier, do drivers apply the break less sharply*
- Is driver's behaviour more compliant with ideal behaviour/speed?
  *What is the difference between the behaviour of the driver and the advice given by road side systems, is the speed of test vehicles with the service different from the average speed in the section(s)*
- Is driver's behaviour (more) compliant with suggested information from the text?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 17 - IVS-EVFT - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X |
| Is driver's speed more compliant with ideal behaviours/speed? | X | | X |
| Is driver's behaviour (more) compliant with suggested information from the text) | | X | |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 1Hz)
- Braking power, moment of breaking – source Can Bus data
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

### Safety

#### *Main research question*

- Is safety affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds as well as reduced acceleration and deceleration phases lead to fewer perturbations and more fluent traffic conditions.
- There is a higher compliance with speed limits, which leads to traffic condition more suitable for a section interested by road works, reducing sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 18 - IVS-EVFT - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X |
| Is driver's speed more compliant with ideal behaviours/speed? | X | X | X | X |

#### *Field Test Indicator/KPI*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 19 - IVS-EVFT - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Speed standard deviation | X | | X | X |
| Instantaneous accelerations and decelerations | | X | X | X |
| Lane change | X | X | X | X |

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the suggested speed limit is no longer relevant.
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point (point where the vehicle performs the lane change manoeuvre)

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in road accident resulting in death or injuries numbers (number of accidents, %)
- Change in absolute number of all road accidents

## Traffic Efficiency

### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- The information suggested in the text is meant to ease the flow going towards a queue or a traffic jam. Higher compliance with the consequences of the given information leads to an early dissipation of the traffic jam, reducing the number of acceleration and deceleration, granting a higher comfort for the driver and a smoother traffic flow on the road. Driver's speed can be more compliant to the optimal speed, with respect to a situation provided via the "free text"
- Having the information from the "free text" showed on the HMI and continuously updated leads to more homogeneous speeds, reduced acceleration and deceleration phases. This involves fewer perturbations on the traffic flow and more fluent traffic conditions.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 20 - IVS-EVFT - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Is driver's speed (more) compliant with optimal speed, following the text information? | X | | X | X |
| How do the instant speed fluctuations change? | X | X | | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the suggested speed limit is no longer relevant.
- Speed standard deviation
- Instantaneous accelerations and decelerations

*Table 21 - IVS-EVFT - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Speed standard deviation | X | | X | X |
| Instantaneous acceleration | | X | | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Journey Time
- Change in Total time spent by all vehicles in queue
- Change in Traffic Flow

## Environment

### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel/energy consumption and therefore lower $CO_2$, pollutants and noise emissions.
- Higher compliance with ideal speed limits leads to an ease on the downstream congestion and an early dissipation of the queue, reducing the number of acceleration and deceleration and thus limiting $CO_2$, pollutants and noise emissions.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 22 - IVS-EVFT - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energy consumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | | X |
| Is driver's speed (more) compliant with ideal speed? | X | X | | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be detected or calculated:

- Speed standard deviation

- Instantaneous accelerations and decelerations
- Fuel/Energy consumption
- Speed adaptation (difference between the average speed of the vehicle and the speed limit)
- Noise level

*Table 23 - IVS-EVFT - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| Speed standard deviation | | X | | X | X |
| Instantaneous accelerations and decelerations | | | X | X | X |
| Fuel/Energy consumption | X | X | X | | X |
| Speed adaptation | | X | | X | X |
| Noise level | | X | X | | X |

*Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/Energy consumption
- Change in polluting emissions

### 4.5.3 Use Case: Other Signage Information (OSI)

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed, continuously and in advance, on an event by a certain signal. They can adapt their speed and other behaviour quicker and thus avoid speeding and other disturbing behaviour. This change is done in advance and the reaction to the given information can be handled with the change in downstream traffic flow. Consequently, the driving is smoother and with lesser acceleration and deceleration.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How do the instant speed fluctuations change?
  *Do drivers apply the break earlier, do drivers lift off the accelerator earlier, do vehicles slow earlier, do drivers apply the break less sharply?*
- Is driver's behaviour more compliant with ideal behaviour/speed? *(What is the difference between the behaviour of the driver and the advice given by road side systems, is the speed of test vehicles with the service different from the average speed in the section(s)?*

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 24 - IVS-OSI - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How do the instant speed fluctuations change? | x | x | x |
| Is driver's speed more compliant with ideal behaviours/speed? | x | x | x |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 1Hz)
- Braking power, moment of breaking – source Can Bus data
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

### Safety

#### *Main research question*

- Is safety affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds as well as reduced acceleration and deceleration phases lead to fewer perturbations and more fluent traffic conditions.
- There is a higher compliance with speed limits, which leads to traffic condition more suitable for a section interested by road works, reducing sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 25 - IVS-OSI - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X |
| Is driver's speed more compliant with ideal behaviours/speed? | X | X | X | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed - source: Can Bus data or GPS data
- Acceleration/Deceleration – source: Can Bus data or GPS data
- Braking power, moment of braking – Source: Can Bus data
- Position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) – source: vehicle ITS station and HMI data log

*Table 26 - IVS-OSI - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Speed standard deviation | X | | X | X |
| Instantaneous accelerations and decelerations | | X | X | X |

#### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in road accident resulting in death or injuries numbers (number of accidents, %)

- Change in absolute number of all road accidents

## Traffic Efficiency

### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- The information suggested in the sign is meant to ease the flow going towards a queue or a traffic jam. Higher compliance with the consequences of the given information leads to an early dissipation of the traffic jam, reducing the number of acceleration and deceleration, granting a higher comfort for the driver and a smoother traffic flow on the road. Driver's speed can be more compliant to the optimal speed, with respect to a situation provided via the "free text"
- Having the information from the signs showed (and continuously updated) on the HMI leads to more homogeneous speeds, reduced acceleration and deceleration phases. This involves fewer perturbations on the traffic flow and more fluent traffic conditions.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 27 - IVS-OSI - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Is driver's speed (more) compliant with optimal speed, following the text information? | X | | X | X |
| How do the instant speed fluctuations change? | X | X | | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the suggested speed limit is no longer relevant.
- Speed standard deviation

*Table 28 - IVS-OSI - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Speed standard deviation | X | | X | X |
| Instantaneous acceleration | | X | | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Journey Time
- Change in Total time spent by all vehicles in queue
- Change in Traffic Flow

## Environment

### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel/energy consumption and therefore lower $CO_2$, pollutants and noise emissions.
- Higher compliance with (closer to) ideal speed limits leads to an ease on the downstream congestion and an early dissipation of the queue, reducing the number of acceleration and deceleration and thus limiting $CO_2$, pollutants and noise emissions.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 29 - IVS-OSI - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | | X |
| Is driver's speed (more) compliant with ideal speed? | X | X | | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be detected or calculated:

- Speed standard deviation
- Instantaneous accelerations and decelerations
- Fuel/Energy consumption
- Speed adaptation (difference between the average speed of the vehicle and the speed limit)
- Noise level

*Table 30 - IVS-OSI - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| Speed standard deviation | | X | | X | X |
| Instantaneous accelerations and decelerations | | | X | X | X |
| Fuel/Energy consumption | X | X | X | | X |
| Speed adaptation | | X | | X | X |
| Noise level | | X | X | | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/energy consumption
- Change in polluting emissions

### 4.5.4 Use Case: Dynamic Lane Management (DLM)

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed on a change in number of lanes in advance. They can change lane earlier than in proximity of the road works. This change is done in advance and traffic flow will be ready for lane closure before the critical stretch. Lane change manoeuvre is done in more regular and safe conditions. The driver should cross each single lane change area only once because knowing the exact position of the lane change would influences the behaviour during a second crossing.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How do the instant speed fluctuations change?
  *Do drivers apply the break earlier, do drivers lift off the accelerator earlier, do vehicles slow earlier, do drivers apply the break less sharply?*
- Is driver's speed more compliant with speed limit?
  *What is the difference between the behaviour of the driver and the advice given by road side systems, is the speed of test vehicles with the service different from the average speed in the section(s)?*
- How does the lane change point vary?
- Is the lane change manoeuvre smoother?
  *Do drivers make fewer sudden steering movements, do drivers apply less pressure to the steering, is the acceleration of the vehicle less sharp (in any direction), Do drivers exhibit less driving behaviour that could be considered risky?*

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 31 - IVS-DLM - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How do the instant speed fluctuations change? | x | x | x |
| Is driver's speed more compliant with speed limit? | x | x | x |
| How does the lane change point vary? | x | x | x |
| Is the lane change manoeuvre smoother? | x | x | x |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)

- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 1Hz)
- Braking power, moment of breaking – source Can Bus data
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

### Safety

#### *Main research question*

- Is safety affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to fewer perturbations and more fluent traffic conditions.
- Higher compliance with speed limits leads to traffic condition more suitable for a section interested by road works, reducing sudden braking as well as consequent accelerations and thus limiting the creation and the propagation of shockwaves.
- A lane change in a proper location leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less perturbations to the following vehicles.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 32 - IVS-DLM - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X |
| Is driver's speed more compliant with speed limit? | X | X | | X |
| How does the lane change point vary? | | X | | X |
| How do the instant speed fluctuations change? | | X | X | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the position of the actual change in number of lanes
- Travel Time / Average Speed - from the reception of the C-ITS message until the position of the change in number of lanes

- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point (point where the vehicle performs the lane change manoeuvre)
- Maximum steering angle

*Table 33 - IVS-DLM - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Average speed | X | | | X |
| Speed standard deviation | X | | X | X |
| Instantaneous accelerations and decelerations | | X | X | X |
| Lane change point | | X | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in road accident resulting in death or injuries numbers (number of accidents, %)
- Change in absolute number of all road accidents

## Traffic Efficiency

### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to fewer perturbations and more fluent traffic conditions.
- Higher compliance with speed limits leads to traffic condition more suitable for a section interested by road works, reducing sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.
- A lane change in a proper location leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less perturbations to the following vehicles.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

Table 34 - IVS-DLM - Relation between Sub Research Question for Traffic Efficiency and collected Data

| Sub Research Question | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | | X | | X |
| Is driver's speed more compliant with speed limit? | X | | X | | | X |
| How does the lane change point vary? | | | | X | X | X |
| Is the lane change manoeuvre smoother? | | X | | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the position of the actual change of number of lanes
- Travel Time / Average Speed - from the reception of the C-ITS message until the position of road works
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point (point where the vehicle performs the lane change manoeuvre)
- Maximum steering angle

Table 35 - IVS-DLM - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| Speed adaptation | X | | X | X | | X |
| Travel Time | X | | X | | | X |
| Speed standard deviation | X | | X | | | X |
| Instantaneous acceleration | | X | | X | | X |
| Lane change point | | | | X | X | X |
| Maximum steering angle | | | | | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Bottleneck Congestion (Bottleneck residual capacity)

- Change in Journey Time
- Change in Total time spent by all vehicles in queue

## Environment

### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel/energy consumption and therefore lower $CO_2$, pollutants and noise emissions.
- Higher compliance with speed limits leads to traffic condition more suitable for a section interested by road works, reducing sudden braking and consequent accelerations and thus limiting $CO_2$, pollutants and noise emissions.
- A lane change in a proper location leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less perturbations to the following vehicles.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 36 - IVS-DLM - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X |  | X |  | X |
| Is driver's speed more compliant with speed limit? | X | X |  | X |  |  | X |
| How does the lane change point vary? | X |  |  |  | X | X | X |
| Is the lane change manoeuvre smoother? |  |  | X |  | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be detected or calculated:

- Speed standard deviation
- Instantaneous accelerations and decelerations
- Fuel/Energy consumption
- Noise level
- Maximum steering angle
- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the position of the actual change in number of lanes
- Lane change point (point where the vehicle performs the lane change manoeuvre)

*Table 37 - IVS-DLM - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|---|
| Speed standard deviation | | x | | x | x | | x |
| Instantaneous accelerations and decelerations | | | x | | x | | x |
| Fuel/Energy consumption | x | x | x | | | | x |
| Noise level | | x | x | | | | x |
| Maximum steering angle | | | | | | x | x |
| Speed adaptation | | x | | x | | | x |
| Lane change point | | | | | x | x | x |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/energy consumption
- Change in polluting emissions

## 4.6 Day 1 Service: Hazardous Locations Notification

The Day 1 Service HLN currently includes, according to the WG2 list of Use Cases described in the document “Common C-ITS Service Definitions - Version 1.7”, the following Use Cases:

1. Accident Zone, (Abbreviation: HLN – AZ)
2. Traffic Jam Ahead, (Abbreviation: HLN – TJA)
3. Stationary Vehicle, (Abbreviation: HLN – SV)
4. Weather Condition Warning, (Abbreviation: HLN – WCW)
5. Temporarily Slippery Road, (Abbreviation: HLN – TSR)
6. Animal or Person on the Road, (Abbreviation: HLN – APR)
7. Obstacle on the Road, (Abbreviation: HLN – OR)
8. Emergency Vehicle Approaching, (Abbreviation: HLN – EVA)
9. Emergency Vehicle in Intervention, (Abbreviation: HLN – EVI)
10. Railway Level Crossing, (Abbreviation: HLN – RLX)
11. Unsecured Bloackage of a Road, (Abbreviation: HLN – UBR)
12. Alert Wrong Way Driving, (Abbreviation: HLN – AWWD)
13. Public Transport Vehicle Crossing, (Abbreviation: HLN – PTVC)
14. Public Transport Vehicle at a Stop, (Abbreviation: HLN – PTVS)

For evaluation and assessment purposes, most of these Use Cases can be grouped in two clusters, considering the events managed by the C-ITS messages. Lane-known events and lane-unknown events can lead to different features in terms of possible accuracy and level of detail of the C-ITS messages and, finally, to different desired expected behaviours.
The Use Cases are then divided according to this classification:

- Use Case related to **Location specific events,** managed by detailed messages able to specify the location of the event even in terms of lane involved and to suggest if needed a lane change, alongside warnings advising cautious driving.
- Use Case related to **Area based events,** managed by more general messages, providing warnings advising cautious driving.

Based on this distinction, the Use Cases can be thus grouped as reported in Table 38.

*Table 38 - Clusters of HLN Use Cases*

| Location specific events | Area based events |
|---|---|
| Slow or Stationary Vehicle, (HLN – SV) | Accident Zone, (HLN – AZ) |
| Temporarily Slippery Road, (HLN – TSR) | Traffic Jam Ahead, (HLN – TJA) |
| Obstacle on the Road, (HLN – OR) | Weather Condition Warning, (HLN – WCW) |
| Emergency Vehicle in Intervention, (HLN – EVI) | Animal or Person on the Road, (HLN – APR) |

The investigation of the impact areas Safety, Traffic Efficiency and Environment are similar for both the clusters of Use Cases, except for the analysis of issues related to lane change

manoeuvres, which apply for “Location specific events” and so not apply for “Area based events”.
For each impact area, the issue related to a lane change are thus referred to punctual events, as specified in the text.

A specific approach for the evaluation and assessment is required for use cases that do not belong to these groups. In particular:

- Use Case: Emergency Vehicle Approaching, (Abbreviation: **HLN – EVA**). The use case is supposed to provide impacts for the Emergency Vehicle, easing its passage. Then, beside the indication for the usual impact areas considered, that can still be applied for the surrounding vehicles involved, indication about Other Impacts – Time of Intervention are provided specifically for the Emergency Vehicle.
- Use Cases involving Public Transports: Railway Level Crossing, (Abbreviation: **HLN – RLX)**, Public Transport Vehicle Crossing, (Abbreviation: **HLN – PTVC**) and Public Transport Vehicle at a Stop, (Abbreviation: **HLN – PTVS**). The use cases are mainly supposed to increase attention and awareness of drivers in different scenarios. For these Use Cases, guidelines are provided just for the impact area Safety.

### 4.6.1 All Use Cases

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed about potentially hazardous events more precisely and in advance. Hence, they can adapt their driving behaviour in a more aware way. The warning contains, if available, information about the location and the duration of the events and can be linked to a speed advice. If an adaptation of speed is needed, this change is done in advance and the driver will be ready for the event, e.g. braking or change lane earlier. The manoeuvre is done in more regular and safe conditions.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How do the instant speed fluctuations change?
  *Do drivers apply the brake earlier? Do drivers lift off the accelerator earlier? Do vehicles slow earlier? Do drivers apply the brake less sharply?*
- Is driver's speed more compliant with speed limit in the approach of a hazardous location?
  *What is the difference between the behaviour of the driver and the advice given by road side systems? Is the speed of test vehicles with the service different from the average speed in the sections?*
- How does the lane change point vary? (For Location specific events only)
- Is the lane change manoeuvre smoother? (For Location specific events only)
  *Do drivers make fewer sudden steering movements? Do drivers apply less pressure to the steering? Is the acceleration of the vehicle less sharp? In any direction?*
- Does the average speed decrease?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 39 - HLN - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How do the instant speed fluctuations change? | x | x | x |
| Is driver's speed more compliant with speed limit (if suggested)? | x | x | |
| How does the lane change point vary (if the lane of the event is specified)? | x | x | |
| Is the lane change manoeuvre smoother (if the lane of the event is specified)? | x | x | x |
| Does the average speed decrease? | x | x | x |

### Data Collection

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 10 Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 10 Hz)
- Time between the reception of the C-ITS message in the vehicle (T0, the presentation on the HMI is in most relevant cases directly linked to it) and the arrival at hazardous location position (T1) – source: C-ITS device, Can Bus data or GPS data (s)
- Vehicle position – source: GPS data
- Steering angle – source: Can Bus steering angle (For Location specific events only)
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

## Safety

### Main research question

- Is safety affected by changes in driver behaviour due to C-ITS service?

### Research hypotheses about Sub Research Questions

- More homogeneous speeds and reduced acceleration and deceleration phases lead to fewer risky situations.
- Higher compliance with speed limits leads to traffic condition more suitable for a section prone for hazards, reducing sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.
- A lane change in a proper location leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less perturbations to the following vehicles.

### Data Collection

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 40 - HLN - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X | | X |
| Is driver's speed more compliant with speed limit (if suggested)? | X | | X | X | | X |
| How does the lane change point vary (if the lane of the event is specified)? | | | X | X | X | X |
| Is the lane change manoeuvre smoother (if the lane of the event is specified)? | | X | X | X | X | X |
| Does the average speed decrease? | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | X | | X | X | | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles):

- Speed adaptation (difference between the average speed of the vehicle and the speed limit suggested) - from the reception of the C-ITS message until the position of the hazard
- Travel Time / Average Speed - from the reception of the C-ITS message until the position of the hazard
- Maximum speed
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point (point where the vehicle performs the lane change manoeuvre - For Location specific events only)
- Maximum steering angle (For Location specific events only)

*Table 41 - HLN - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| Speed adaptation | X | | X | X | | X |
| Average Speed | X | | X | X | | X |
| Maximum Speed | X | | X | X | | X |
| Speed standard deviation | X | | X | X | | X |
| Instantaneous acceleration | | X | X | X | | X |
| Lane change point | | | X | X | X | X |
| Maximum steering angle | | | X | X | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in road accident resulting in death or injuries numbers (number of accidents, %)
- Change in absolute number of all road accidents

### Traffic Efficiency

#### *Main research question*

- Is traffic efficiency affected by the use of C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- The increased awareness about a hazardous event leads to lower speeds on the road and reduced sudden and relevant braking when the event location is reached, thus more fluent traffic conditions.
- The speed limit, besides a more regular driving, involves smoother manoeuvres and, thus, more fluent traffic conditions. This implies a reduction in sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.
- An advanced lane change before a confined location of the hazardous event leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less perturbations to the following vehicles.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 42 - HLN - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X | | X |
| Is driver's speed more compliant with speed limit (if suggested)? | X | | X | X | | X |
| How does the lane change point vary (if the lane of the event is specified)? | | | X | X | X | X |
| Is the lane change manoeuvre smoother (if the lane of the event is specified)? | | X | X | X | X | X |
| Does the average speed decrease? | X | | X | X | | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles):

- Speed adaptation (difference between the average speed of the vehicle and the speed limit - if suggested)
- Average and Maximum Speed
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point (For Location specific events only)
- Maximum steering angle (For Location specific events only)

*Table 43 - HLN - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|
| Speed adaptation | x | | x | x | | x |
| Average Speed | x | | x | x | | x |
| Maximum Speed | x | | x | x | | x |
| Speed standard deviation | x | | x | x | | x |
| Instantaneous acceleration | | x | x | x | | x |
| Lane change point | | | x | x | x | x |
| Maximum steering angle | | | x | x | x | x |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Journey Time
- Change in Total time spent by all vehicles in queue

## Environment

### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel/energy consumption and therefore lower $CO_2$, pollutants and noise emissions.
- A lane change in a proper location leads to a more regular manoeuvre (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother manoeuvre leads to less disturbances in the traffic flow of to the following vehicles.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 44 - HLN - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X | X | | X |
| How does the lane change point vary (if the lane of the event is specified)? | X | | | X | X | X | X |
| Is the lane change manoeuvre smoother (if the lane of the event is specified)? | | | X | X | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles):

- Speed standard deviation
- Instantaneous accelerations and decelerations
- Fuel/Energy consumption
- Noise level
- Lane change point (For Location specific events only)
- Maximum steering angle (For Location specific events only)

*Table 45 - HLN - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Time | Position | Steering angle | Message data log |
|---|---|---|---|---|---|---|---|
| Speed standard deviation | | X | | X | X | | X |
| Instantaneous accelerations and decelerations | | | X | X | X | | X |
| Fuel/Energy consumption | X | X | X | X | X | | X |
| Noise level | | X | X | X | X | | X |
| Lane change point | | | | X | X | X | X |
| Maximum steering angle | | | | X | X | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in climate-change and polluting emissions ($CO_2$ emissions and other pollutants)
- Change in noise pollution
- Change in fuel/energy consumption

### 4.6.2 Use Case: Emergency Vehicle Approaching (EVA))

*Top Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed in advance about the presence of an emergency vehicle and can ease the road operator bypass. This allows a faster arrival to the desired site for the emergency agents.

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected on the emergency vehicle:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 1Hz)
- Time between the sending of the C-ITS message (request of intervention) from the vehicle and the arrival at hazardous location position (T1) – source: C-ITS device, Can Bus data or GPS data (s)
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device

#### Other Impacts – Time of intervention

*Main Research Questions*

- Is the time of intervention of the emergency vehicles affected by the use of this C-ITS service?

*Research hypotheses about Research Questions*

- Aware of the presence of the emergency vehicle, the road user can change lanes, move aside, or else so to ease the bypass of the vehicle and reduce the time of intervention

*Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be evaluated (difference between C-ITS- and non-C-ITS-emergency vehicles):

- Time of intervention – from the sending of the C-ITS message (request of intervention) from the vehicle and the arrival at hazardous location position (T1)

### 4.6.3 Use Case: Railway Level Crossing (RLX), Public Transport Vehicle Crossing (PTVC), Public Transport Vehicle at a Stop (PTVS)

*Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The driver gets warned about the situation (presence of railway level crossing, risk of collision with PT vehicle, presence of a public transport vehicle at the stop) to raise his/her attention when approaching, driving carefully and prepared.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How does the speed change after message reception?
- How do the instant speed fluctuations change?
- What are the interactions with pedestrians in the surrounding of PT stops? (Use Case: PTVS)

The Sub Research Question are pertinent with the Impact Areas Safety.

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 10 Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data ($m/s^2$ – resolution 10 Hz)
- Vehicle position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device
- Pedestrian behaviour – source: camera recordings[4]

#### Safety

*Main research question*

- Is Safety affected by changes in driver behaviour due to C-ITS service?

*Research hypotheses about Sub Research Questions*

- Reduced speed and increased attention while driving reduce the probability of undue overcome of the level crossing
- Reduced speed and increased attention while driving lead to a reduction in the risk of accident with PT vehicles
- Reduced speed and increased attention while driving lead to a higher readiness for unexpected pedestrian behaviour in the surrounding of PT stops (Use Case: PTVS)

[4] Video recording is a useful supporting tool for all evaluation and assessment. It is explicitly mentioned here since considered as essential for the investigation of behaviour of pedestrian.

### Data Collection

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 46 - HLN-RLX/PTV/PTVS - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Time | Position | Message data log | Camera recording |
|---|---|---|---|---|---|---|
| How does the speed change after message reception? | X | X | X | X | | |
| How do the instant speed fluctuations change? | X | X | X | X | | |
| What are the interactions with pedestrians in the surrounding of PT stops? | | | X | X | X | X |

### Field Test Indicator/KPI

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles):

- Average Speed - from the reception of the C-ITS message until the position of the location communicated
- Maximum speed
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Number of potentially dangerous interactions with pedestrian (Use Case: PTVS)

*Table 47 - HLN-RLX/PTV/PTVS - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Message data log | Camera recording |
|---|---|---|---|---|---|---|
| Average Speed | X | | X | X | X | |
| Maximum Speed | X | | X | X | X | |
| Speed standard deviation | X | | X | X | X | |
| Instantaneous acceleration | | X | X | X | X | |
| Number of potentially dangerous interactions with pedestrian | | | X | X | X | X |

### Estimated KPIs on mobility (when C-ITS will be more widely diffused).

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in road accident resulting in death or injuries numbers (number of accidents, %) at level crossing and with PT vehicles
- Change in absolute number of all road accidents at level crossing and with PT vehicle
- Change in the number of accidents involving pedestrians

## 4.7 Day 1 Service: Signalized Intersection

The Day 1 Service Signalized Intersection (SI) currently includes, according to the WG2 list of Use Cases described in the document "Common C-ITS Service Definitions - Version 1.7", the following Use Cases:

1. Green Light Optimal Speed Advisory (Abbreviation: SI-GLOSA)
2. Traffic Light Prioritisation (Abbreviation: SI-TLP)
3. Signal Phase and Timing Information (Abbreviation: SI-SPTI)
4. Imminent Signal Violation Warning (Abbreviation: SI-ISVW)
5. Emergency Vehicle Priority (Abbreviation: SI-EVP)

For evaluation and assessment purposes, SI-GLOSA and SI-SPTI are grouped in SI-GLOSA use case. In fact, SI-GLOSA is an application case of SI-SPTI. In addition, SI-TLP and SI-EVP are grouped in SI-TLP. In fact, SI-TLP covers the SI-EVP use case.

### 4.7.1 Use Case: Green Light Optimal Speed Advisory (GLOSA), Signal Phase and Timing Information (SPTI)

*Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers approaching the traffic lights are provided with a speed advice and information about the phases, based on which they can accelerate to cross the intersection or decelerate to wait less for the upcoming green. This use case leads to a reduced number of stops at the red light and a faster restart when the light turns green. The level of congestion at the intersections chosen should be low or medium, to not hinder GLOSA's functions and resulting impacts.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How does the instant speed change immediately after message reception?
- Is driver's speed compliant with suggested speed?
- Does the driver start quicker after the traffic light turns green?
- How does the instant speed fluctuations change?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 48 - SI-GLOSA/SPTI - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How does the instant speed change immediately after message reception? | X | X | X |
| Is driver's speed compliant with suggested speed? | X | X | X |
| Does the driver start quicker after the traffic light turns green? | X | X | |
| How does the instant speed fluctuations change? | | | X |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Speed - source: Can Bus data or GPS data
- Acceleration/Deceleration – source: Can Bus data or GPS data
- Braking power, moment of braking – Source: Can Bus data
- Time between the reception of the C-ITS message and the arrival at the intersection – source: Can Bus data or GPS data
- Position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) – source: vehicle ITS station and HMI data log
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

## Safety

### *Main research question*

- Is safety affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- According to the received information, the driver can accelerate to reach the crossing before the red light or decelerate to wait less for the green. The abruptness of the manoeuvre can perturb the upstream traffic flow.
- Higher compliance with speed suggestions leads to less vehicles waiting to cross the intersection, reducing the number of acceleration and deceleration, queue's length and improving the crossing efficiency.
- Knowing when the light is becoming green leads to faster restart of the vehicles and quicker acceleration, impacting the traffic flow across the intersection.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 49 - SI-GLOSA/SPTI - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Braking | Time | Position | Message data log |
|---|---|---|---|---|---|---|
| How does the instant speed change immediately after message reception? | X | X | X | | X | X |
| Is driver's speed compliant with suggested speed? | X | | | | X | X |
| Does the driver start quicker after the traffic light turns green? | | X | | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS- and non-C-ITS-vehicles can be assessed depending on the penetration rate):

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the position of traffic light
- Travel Time / Average Speed - from the reception of the C-ITS message until the position of traffic light
- Speed standard deviation
- Instantaneous accelerations and decelerations

*Table 50 - SI-GLOSA/SPTI - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Travel time/Average speed | X | | X | X |
| Speed standard deviation | X | | X | X |
| Instantaneous accelerations and decelerations | | X | X | X |

*Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in number of accidents, fatalities and injuries

### Traffic Efficiency

*Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

*Research hypotheses about Sub Research Questions*

- According to the received information, the driver can accelerate to reach the crossing before the red light or decelerate to wait less for the green. The abruptness of the manoeuvre can perturb the upstream traffic flow.
- Higher compliance with speed suggestions leads to less vehicles waiting to cross the intersection, reducing the number of acceleration and deceleration, queue's length and improving the crossing efficiency.
- Knowing when the light is becoming green leads to faster restart of the vehicles and quicker acceleration, impacting the traffic flow across the intersection.

*Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 51 - SI-GLOSA/SPTI - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How does the instant speed change immediately after message reception? | X | X | X | X |
| Is driver's speed compliant with suggested speed? | X | | | X |
| Does the driver start quicker after the traffic light turns green? | | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the stop line
- Instantaneous accelerations and decelerations
- Percentage of test vehicles able to cross the intersection without stopping[5] (with and without GLOSA)
- Time between the instant when the light turns green and the departure of the test vehicle[6] (if it's the leading vehicle, that is the first vehicle stopped at the traffic light)
- Travel Time/Delay (intersection crossing time)

*Table 52 - SI-GLOSA/SPTI - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | x | | x | x |
| Instantaneous accelerations and decelerations | | x | x | x |
| % of test vehicles able to cross the intersection without stopping | x | | x | x |
| Time between the instant the light turns green and the departure | | x | x | x |
| Travel Time/Delay | x | | x | x |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Bottleneck Congestion
- Change in Journey Time
- Change in Traffic Flow
- Change in Total time spent by all vehicles in queue

[5] This evaluation can take advantages if combined with data describing congestion at traffic lights (magnetic loops or other sensors).
[6] This evaluation can take advantages if combined with traffic lights stop line position to know the first vehicle in lane.

### Environment

#### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- The suggested speed needed to reach the green light can lead to more abrupt and sudden acceleration, while knowing that the light is red leads to decelerations and smoother braking. This irregular behaviour of the driver affects fuel/energy consumption and therefore $CO_2$, pollutants and noise emissions.
- Abrupt accelerations or decelerations resulting from the advice, lead to perturbations on the traffic flow upstream.
- Higher compliance with speed suggestions leads to less vehicles waiting to cross the intersection, reducing the number of acceleration and deceleration, queue's length and reducing fue/energyl consumption, $CO_2$, pollutants and noise emissions.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 53 - SI-GLOSA/SPTI - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | x | x | x | x | x |
| How does the instant speed change immediately after message reception? | x | x | x | | x |
| Is driver's speed compliant with suggested speed? | x | x | | | x |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the stop line
- Instantaneous accelerations and decelerations
- Percentage of test vehicles able to cross the intersection without stopping (with and without GLOSA)
- Time between the instant when the light turns green and the departure of the test vehicle (if it's the leading vehicle, that is the first vehicle stopped at the traffic light)
- Fuel/Energy consumption
- Noise level

*Table 54 - SI-GLOSA/SPTI - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| Speed adaptation | | X | | X | X |
| Instantaneous accelerations and decelerations | | | X | X | X |
| % of test vehicles able to cross the intersection without stopping | | X | | X | X |
| Time between the instant the light turns green and the departure | | | X | X | X |
| Fuel/Energy consumption | X | X | X | | X |
| Noise level | | X | X | | X |

*Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/energy consumption
- Change in polluting emissions

### 4.7.2 Use Case: Traffic Light Prioritisation (TLP), Emergency Vehicle Priority (EVP)

*Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers of priority vehicles (buses, tramways, trucks) approaching the traffic light are provided with a confirmation indicating if their request for prioritisation was accepted (reduced red phase duration or extend green phase duration) or rejected. In addition, the drivers might also receive an indication about the time to green (or an advisory speed to reach the traffic light without stopping). This use case leads to a reduced delay for the priority vehicles. This use case might affect the GLOSA information for other drivers in case the light phases is adapted.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- What is the impact on pedestrians?
- How does the current speed change immediately after message reception?
- Is driver's speed compliant with suggested speed (if available)?
- What is the impact of rejecting the request?
- How do the instant speed fluctuations change?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 55 - SI-TLP/EVP - Relation between Sub Research Question and Impact Areas*

| Sub Research Question | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| What is the impact on pedestrians? | X | | |
| How does the current speed change immediately after message reception?<br>Is driver's speed compliant with suggested speed (if available)? | | X | X |
| What is the impact of rejecting the request? | | X | X |
| How does the current speed change immediately after message reception? | | X | |
| Is driver's speed compliant with suggested speed (if available)? | | | X |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Traffic light phases
- Speed - source: Can Bus data or GPS data

- Acceleration/Deceleration – source: Can Bus data or GPS data
- Braking power, moment of braking – Source: Can Bus data
- Time between the reception of the C-ITS message and the arrival at intersection – source: Can Bus data or GPS data
- Position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) – source: vehicle ITS station and HMI data log
- Fuel/Energy consumption
- Pedestrian behavior – source: camera recordings[7]

### Safety

#### *Main research question*

- Is Safety affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- Impact on the safety issues related to pedestrian should be investigated: would the system turn traffic to green while a slow pedestrian is crossing? Maybe pedestrians will prevent the system from giving priority to vehicles? Are pedestrians encouraged to signal violation?

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 56 - SI-TLP/EVP - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Camera recording | Position | Message data log |
|---|---|---|---|
| What is the impact on pedestrians? | **X** | **X** | **X** |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Number of accidents caused by signal violation of pedestrian

*Table 57 - SI-TLP/EVP - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Camera recording | Position | Message data log |
|---|---|---|---|
| Number of accidents caused by signal violation of pedestrians | **X** | **X** | **X** |

#### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

[7] Video recording is a useful supporting tool for all evaluation and assessment. It is explicitly mentioned here since considered as essential for the investigation of behaviour of pedestrian.

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in the number of accidents involving pedestrians

### Traffic Efficiency

#### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- According to the received information, the driver should make minimum modification to its current speed in order to maintain constant speed and make the journey for on-board passengers comfortable.
- Higher compliance with speed suggestions leads to less vehicles waiting to cross the intersection, reducing the number of acceleration and deceleration, queue's length and improving the crossing efficiency.
- In some situations, the request might be rejected because other priorities are granted. The driver should adapt his speed accordingly and rely on other use cases such as GLOSA.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 58 - SI-TLP/EVP - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How does the instant speed change immediately after message reception? | x | x | x | x |
| Is driver's speed compliant with suggested speed (if available)? | x | | | x |
| What is the impact of rejecting the request? | x | x | x | x |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the stop line
- Instantaneous accelerations and decelerations
- Percentage of test vehicles able to cross the intersection without stopping (with and without TLP)
- Travel Time/Delay (intersection crossing time)

*Table 59 - SI-TLP/EVP - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | x | | x | x |
| Instantaneous accelerations and decelerations | | x | x | x |
| % of test vehicles able to cross the intersection without stopping | x | | x | x |
| Travel Time/Delay | x | | x | x |

#### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Bottleneck Congestion
- Change in Journey Time
- Change in Traffic Flow
- Change in Total time spent by priority vehicles in queue

### Environment

#### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- If the request is accepted, the speed of the vehicle should remain constant and cross the intersection with no impact on current speed. In some situations, speed should be adapted in order to apply the prioritisation, in these cases speed fluctuations should be minimized. This irregular behaviour of the driver affects fuel/energy consumption and therefore $CO_2$, pollutants and noise emissions.
- Abrupt accelerations or decelerations resulting from the advice, lead to perturbations on the traffic flow upstream.
- Higher compliance with speed suggestions leads to less vehicles waiting to cross the intersection, reducing the number of acceleration and deceleration, queue's length and reducing fuel/energy consumption, $CO_2$, pollutants and noise emissions.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 60 - SI-TLP/EVP - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energyconsumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X | X |
| How does the instant speed change immediately after message reception? | X | X | X | | X |
| Is driver's speed compliant with suggested speed? | X | X | | | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated for priority vehicles and other users separately:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the stop line
- Instantaneous accelerations and decelerations
- Percentage of test vehicles able to cross the intersection without stopping (with and without TLP)
- Fuel/Energy consumption
- Noise level

*Table 61 - SI-TLP/EVP - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energy consumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| Speed adaptation | | X | | X | X |
| Instantaneous accelerations and decelerations | | | X | X | X |
| % of test vehicles able to cross the intersection without stopping | | X | | X | X |
| Fuel/Energy consumption | X | X | X | | X |
| Noise level | | X | X | | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/energy consumption
- Change in polluting emissions

### 4.7.3 Use Case: Imminent Signal Violation Warning (ISVW)

*Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

This service allows equipped vehicles that are about to cross a signalized intersection to be aware that they are about to violate a red light. Upon receiving the warning, the driver is expected to be aware of the violation he or she is about to commit and to reduce his speed and stop at traffic light (this is the main focus of investigation for ISVW).
Other users also are informed in case a violation has been committed. The drivers that receive this information should reduce speed and be aware that a vehicle is crossing a red light.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How does the current speed change immediately after message reception?
- Is driver's behaviour compliant with the warning?
- What is the impact of rejecting the request?
- How do the instant speed fluctuations change?
- What are the impacts immediately after message reception?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 62 - SI-ISVW - Relation between Sub Research Question and Impact Areas*

| Sub Research Question | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How does the current speed change immediately after message reception? | X | X | |
| Is driver's behaviour compliant with the warning? | X | X | X |
| What is the impact of rejecting the request? | X | X | |
| How do the instant speed fluctuations change? | | | X |
| What are the impacts immediately after message reception? | | | X |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Speed - source: Can Bus data or GPS data
- Acceleration/Deceleration – source: Can Bus data or GPS data
- Braking power, moment of braking – Source: Can Bus data

- Time between the reception of the C-ITS message and the arrival at the intersection – source: Can Bus data or GPS data
- Position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) – source: vehicle ITS station and HMI data log
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

### Safety

#### *Main research question*

- Is safety efficiency affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- According to the received information, the driver should reduce speed immediately and prepare to stop at traffic light. If the driver is informed of another vehicle violation, he or she should reduce speed and be mindful of the danger.
- Higher compliance with warning leads to less vehicles crossing red lights and more awareness for other drivers. Hence, this leads to less accidents.
- If the violating driver does not comply and crosses the red light, a warning is sent to the other users so that they be mindful of the violation and reduce their speed to avoid accidents.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 63 - SI-ISVW - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration/ Deceleration | Braking power/ Moment of breaking | Time | Position | Message data log |
|---|---|---|---|---|---|---|
| How does the current speed change immediately after message reception? | X | X | X | | X | X |
| Is driver's behaviour compliant with the warning? | | X | | X | X | X |
| What is the impact of rejecting the request? | X | X | X | | X | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the intersection

- Average Speed - from the reception of the C-ITS message until the intersection
- Speed standard deviation
- Percentage of compliant drivers (drivers who did not commit the violation after receiving the warning, drivers who reduced their speed after receiving a warning about another vehicle committing light violation)

*Table 64 - SI-ISVW - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | X | X | X |
| Average speed | X | | X | X |
| Percentage of vehicles that did not commit the violation after receiving the warning | | | X | X |
| Percentage of vehicles that reduced their speed after receiving the warning | | | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Reduction in the overall average number of traffic light violation
- Reduction in number of accidents

## Traffic Efficiency

### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- According to the received information, the driver should reduce speed immediately and prepare to stop at traffic light. If the driver is informed of another vehicle violation, he or she should reduce speed and be mindful of the danger. This will result in an overall reduction of speed.
- Higher compliance with warning leads to less vehicles crossing red lights and more awareness for other drivers. Hence, this leads to less accidents at the price of speed reduction.
- If the violating driver does not comply and crosses the red light, a warning is sent to the other users so that they be mindful of the violation and reduce their speed to avoid accidents. This will lead to speed reduction for other vehicles.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 65 - SI-ISVW - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How does the instant speed change immediately after message reception? | X | X | X | X |
| Is driver's behaviour compliant with the warning? | X | X | X | X |
| What is the impact of rejecting the request? | X | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the stop line
- Instantaneous accelerations and decelerations
- Percentage of vehicles that did not commit the violation after receiving the warning
- Percentage of vehicles that changed their behaviour after receiving the warning

*Table 66 - SI-ISVW - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Instantaneous accelerations and decelerations | | X | X | X |
| % of vehicles that did not commit the violation after receiving the warning | X | | X | X |
| Percentage of vehicles that reduced their speed after receiving the warning | X | | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Reduction in journey time crossing the intersection
- Changes in traffic flow crossing the intersection

## Environment

### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- Speed reduction and respecting traffic lights would result in less accidents and less congestions due to accidents and thus less $CO_2$ emissions.
- Abrupt accelerations or decelerations resulting from the advice, lead to perturbations on the traffic flow upstream and thus more fuel/energy consumption and $CO_2$ emissions.
- Higher compliance with warnings will result in speed reduction and stopping at red lights for vehicles that are about the commit a violation. For the other users this will require delay in starting or a deceleration to avoid the violating vehicle and then an acceleration which might cause an increase in $CO_2$ emissions.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 67 - SI-ISVW - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energy consumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X | X |
| What are the impacts immediately after message reception? | X | X | X | X | X |
| Is driver's behaviour compliant with the warning? | X | X | X | X | X |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated for violating vehicles and other vehicles:

- Percentage of test vehicles accepting to stop at the traffic light after receiving the warning
- Percentage of vehicles that changed their speed after receiving a warning that another vehicle committed a violation

*Table 68 - SI-ISVW - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Fuel/Energy consumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| Fuel consumption | X | | | X | X |
| % of test vehicles accepting to stop at the traffic light after receiving the warning | | X | X | X | X |
| % of vehicles that reduced their speed after receiving a warning that another vehicle committed a violation | | X | X | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Reduction in fuel/energy consumption due to less traffic jams caused by accidents
- Reduction in $CO_2$ emissions

## 4.8 Day 1.5 Service

Beside the Day 1.5 Service Road Works Warning – Extensive Work Zone, described in Chapter 4.4, this Evaluation and Assessment Plan also considers currently (September 2023) the following Day 1.5 Service and Use Cases

1. Navigation Information: Parking Information
2. Navigation Information: Smart Routing
3. Vulnerable Road User (VRU)

### 4.8.1 Navigation Information: Parking Information

*Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

The drivers are informed in real-time about parking places (location, availability, services, rates, etc) as well as potential specific information on parking spaces. This information could be about parking place (i.e. parking facility) or parking space (i.e. parking spot). The Use Case can be applied both for highways and for urban areas.

Drivers adapt their journey based on the received information, managing their driving time according to the availability of parking places and spaces and associated services. HGV drivers can plan their stops in compliance with regulations on maximal time of driving avoiding illegal/unsuitable parking.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- Do the time and distances spent looking for parking reduce?
- Is the driving activity smoother?
- Is the amount of illegal/unsuitable parking reduced?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 69 - Parking Information - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| Do the time and distances spent looking for parking reduce? | X | X | X |
| Is the driving activity smoother? | X | X | X |
| Is the amount of illegal/unsuitable parking reduced? | X | | |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Speed - source: Can Bus data or GPS data
- Acceleration/Deceleration – source: Can Bus data or GPS data
- Time between the reception of the C-ITS message and the arrival at the parking place/space – source: Can Bus data or GPS data
- Position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) – source: vehicle ITS station and HMI data log
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

## Safety

### *Main research question*

- Is safety affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- According to the received information, the driver can be focused on the driving activity without distractions caused by looking for a parking place/space.
- Drivers can reduce the time and distance looking for parking, driving in a smoother way.
- HGV drivers can plan their stops in compliance respecting regulations on maximal time of driving and thus in a safer way.
- Drivers can avoid illegal/unsuitable parking, that may lead to safety issues.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 70 - Parking Information - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Braking | Time | Position | Message data log |
|---|---|---|---|---|---|---|
| Do the time and distances spent looking for parking reduce? | | | | X | X | X |
| Is the driving activity smoother? | X | X | X | | | X |
| Is the amount of illegal/unsuitable parking reduced?[8] | | | | | | |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated (difference between C-ITS-vehicles and non-C-ITS-vehicles can be assessed depending on the penetration rate):

- Travel Time - from the reception of the C-ITS message until the parking place/space
- Distance covered - from the reception of the C-ITS message until the parking place/space
- Speed standard deviation
- Instantaneous accelerations and decelerations

*Table 71 - Parking Information - Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Message data log |
|---|---|---|---|---|---|
| Travel time | | | X | X | X |
| Distance covered | | | X | X | X |
| Speed standard deviation | X | | | X | X |
| Instantaneous accelerations and decelerations | | X | | X | X |

[8] To be evaluated with questionnaire

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in number of accidents, fatalities and injuries.

## Traffic Efficiency

### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

### *Research hypotheses about Sub Research Questions*

- Drivers can reduce the time and distance looking for parking, driving in a smoother way.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 72 - Parking Information - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Braking | Time | Position | Message data log |
|---|---|---|---|---|---|---|
| Do the time and distances spent looking for parking reduce? | | | | X | X | X |
| Is the driving activity smoother? | X | X | X | | | X |

### *Field Test Indicator/KPI*

- Travel Time - from the reception of the C-ITS message until the parking place/space
- Distance covered - from the reception of the C-ITS message until the parking place/space
- Speed standard deviation
- Instantaneous accelerations and decelerations

*Table 73 - Parking Information - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Time | Position | Message data log |
|---|---|---|---|---|---|
| Travel time | | | X | X | X |
| Distance covered | | | X | X | X |
| Speed standard deviation | X | | | X | X |
| Instantaneous accelerations and decelerations | | X | | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Journey Time
- Change in Traffic Flow
- Change in Total time spent by all vehicles in queue

### Environment

#### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- Drivers can reduce the time and distance looking for parking, driving in a smoother way.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 74 - Parking Information - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/ Energy consumption | Speed | Acceleration Deceleration | Braking | Time | Position | Message data log |
|---|---|---|---|---|---|---|---|
| Do the time and distances spent looking for parking reduce? | | | | | X | X | X |
| Is the driving activity smoother? | | X | X | X | | | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Travel Time - from the reception of the C-ITS message until the parking place/space
- Distance covered - from the reception of the C-ITS message until the parking place/space
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Fuel/Energy consumption
- Noise level

*Table 75 - Parking Information - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energy consumption | Speed | Acceleration Deceleration | Time | Position | Message data log |
|---|---|---|---|---|---|---|
| Travel time | | | | X | X | X |
| Distance covered | | | | X | X | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| Speed standard deviation | | x | | | x | x |
| Instantaneous accelerations and decelerations | | | x | | x | x |
| Fuel/Energy consumption | x | x | x | x | | x |
| Noise level | | | x | x | | x |

*Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/energy consumption
- Change in polluting emissions

### 4.8.2 Navigation Information: Smart Routing

*Research Question: How do drivers change their behaviour because of warnings/information given by the service?*
The drivers receive comprehensive real-time information related to their travel routes. The road users can adapt the route to the destination on the basis of perceived limitations and congestion levels on alternative options.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- Does the travel time reduce?
- Are the traffic flows in urban areas better balanced?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 76 - Smart Routing - Relation between Sub Research Question and Impact Areas*

| Examples of Sub Research Questions | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| Does the travel time reduce? | | x | x |
| Are the traffic flows in urban areas better balanced? | | x | x |

*Data Collection*
In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Time between the reception of the C-ITS message and the arrival to the destination – source: Can Bus data or GPS data
- Position – source: GPS data
- Data concerning congestion in urban areas (queue lengths, travel times, etc.)
- C-ITS message data log (content, timing and position of the reception, etc.) – source: vehicle ITS station and HMI data log
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)

### Traffic Efficiency

#### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- Drivers can reduce their travel time to reach their destinations, relying on alternative routes and avoiding situations of congestions on their path.
- Congestion in urban areas is reduced.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 77 - Parking Information - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Time | Position | Data describing congestion | Message data log |
|---|---|---|---|---|
| Does the travel time reduce? | X | X | | X |
| Are the traffic flows in urban areas better balanced? | | | X | X |

#### *Field Test Indicator/KPI*

- Travel Time - from the reception of the C-ITS message until the destination
- KPIs describing congestion in urban areas (queue lengths, travel times, etc.)

*Table 78 - Smart Routing - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Time | Position | Data describing congestion | Message data log |
|---|---|---|---|---|
| Travel time | X | X | | X |
| KPIs describing congestion in urban areas | | | X | X |

#### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in Journey Time
- Change in Traffic Flow
- Change in Total time spent by all vehicles in queue

### Environment

#### *Main research question*

- Is the environmental impact of transport affected by changes in driver behaviour due to C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- Drivers can reduce their travel time to reach their destinations, relying on alternative routes and avoiding situations of congestions on their path.
- Congestion in urban areas is reduced.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment of the impacts related to environment.

*Table 79 - Smart Routing - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energy consumption | Time | Position | Data describing congestion | Message data log |
|---|---|---|---|---|---|
| Does the travel time reduce? | | X | X | | X |
| Are the traffic flows in urban areas better balanced? | | | | X | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Travel Time - from the reception of the C-ITS message until the destination
- KPIs describing congestion in urban areas (queue lengths, travel times, etc.)
- Fuel/Energy consumption
- Noise level

*Table 80 - Smart Routing - Relation between Field test indicator KPI for Environment and collected Data*

| Field test indicator KPI | Fuel/Energy consumption | Time | Position | Data describing congestion | Message data log |
|---|---|---|---|---|---|
| Travel time | | X | X | | X |
| KPIs describing congestion in urban areas | | | | X | X |
| Fuel/Energy consumption | X | X | | | X |
| Noise level | | | | X | X |

#### *Estimated KPIs on mobility (when C-ITS will be more widely diffused).*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Change in traffic $CO_2$ emissions
- Change in noise pollution
- Change in fuel/energy consumption
- Change in polluting emissions

### 4.8.3 Vulnerable Road User (VRU)

*Research Question: How do drivers change their behaviour because of warnings/information given by the service?*

This service allows to inform equipped vehicles that there are pedestrians or cyclists to be expected on the road. The main goal of this use case is to detect pedestrians and cyclists and inform the drivers about the presence of vulnerable road users crossing the road. They can adapt their speed and other behaviour quicker and thus avoid a possible collision. This service can be very important in cases of limited visibility (night or fog). This service is provided in a small radius of the detection area. The drivers that receive this information should reduce speed and be aware that a pedestrian might cross their way through a red light or the crosswalk.

*Main Research Questions: Are Safety, Traffic Efficiency and Environment affected by the use of this C-ITS service?*

*Examples of Sub Research Questions*

- How does the current speed change immediately after message reception?
- Is driver's behaviour compliant with the warning?
- What is the impact of rejecting the request?
- How do the instant speed fluctuations change?
- What are the impacts immediately after message reception?

The following table defines if the Sub Research Question is pertinent with the Impact Areas considered.

*Table 81 - VRU - Relation between Sub Research Question and Impact Areas*

| Sub Research Question | Safety | Traffic Efficiency | Environment |
|---|---|---|---|
| How does the current speed change immediately after message reception? | X | X | |
| Is driver's behaviour compliant with the warning? | X | X | X |
| What is the impact of rejecting the request? | X | X | |
| How do the instant speed fluctuations change? | | | X |
| What are the impacts immediately after message reception? | | | X |

*Data Collection*

In order to evaluate the research questions and hypotheses during the C-Roads Pilots, based on the evidence collected, the following parameters/data can be collected:

- Speed - source: Can Bus data or GPS data
- Acceleration/Deceleration – source: Can Bus data or GPS data
- Braking power, moment of braking – Source: Can Bus data

- Time between the reception of the C-ITS message and the arrival at the intersection – source: Can Bus data or GPS data
- Position – source: GPS data
- C-ITS message data log (content, timing and position of the reception, etc.) – source: vehicle ITS station and HMI data log
- Fuel/Energy consumption – source: Can Bus data (l/100km – kWh/100km)
- Latency of detection: Log data of equipment [ms]
- Accuracy of detection: Log data of equipment [%]
- Latency / Accuracy compared to other equipment – *if there are more sensors*
- Detection type accuracy: Log data of equipment [% - compared to total detected elements]
- Number of pedestrians / cyclist crossing [1 / day]

## Safety

### *Main research question*

- Is safety efficiency affected by changes in driver behaviour due to this C-ITS service?

### *Research hypotheses about Sub Research Questions*

- According to the received information, the driver should reduce speed immediately and prepare to stop at a traffic light. If the driver is informed of another vehicle violation, he or she should reduce speed and be mindful of the danger.
- Higher compliance with warning leads to less vehicles crossing red lights and more awareness for other drivers. Hence, this leads to less accidents.
- If the violating driver does not comply and crosses the red light, a warning is sent to the other users so that they be mindful of the violation and reduce their speed to avoid accidents.

### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to safety.

*Table 82 - VRU - Relation between Sub Research Question for Safety and collected Data*

| Sub Research Question | Speed | Acceleration/ Deceleration | Braking power/ Moment of breaking | Time | Position | Message data log |
|---|---|---|---|---|---|---|
| How does the current speed change immediately after message reception? | X | X | X | | X | X |
| Is driver's behaviour compliant with the warning? | | X | | X | X | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| What is the impact of rejecting the request? | x | x | x | | x | x |

### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the intersection
- Average Speed - from the reception of the C-ITS message until the intersection
- Speed standard deviation
- Percentage of compliant drivers (drivers who did not commit the violation after receiving the warning, drivers who reduced their speed after receiving a warning about another vehicle committing light violation)

*Table 83 - VRU- Relation between Field test indicator KPI for Safety and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | x | x | x | x |
| Average speed | x | | x | x |
| Percentage of vehicles that did not commit the violation after receiving the warning | | | x | x |
| Percentage of vehicles that reduced their speed after receiving the warning | | | x | x |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused)*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Reduction in the overall average number of traffic light violation
- Reduction in number of accidents

## Traffic Efficiency

### *Main research question*

- Is traffic efficiency affected by changes in driver behaviour due to this C-ITS service?

### *Research hypotheses about Sub Research Questions*

- According to the received information, the driver should reduce speed immediately and prepare to stop at traffic light. If the driver is informed of another vehicle violation, he or she should reduce speed and be mindful of the danger. This will result in an overall reduction of speed.
- Higher compliance with warning leads to less vehicles crossing red lights and more awareness for other drivers. Hence, this leads to less accidents at the price of speed reduction.

- If the violating driver does not comply and crosses the red light, a warning is sent to the other users so that they be mindful of the violation and reduce their speed to avoid accidents. This will lead to speed reduction for other vehicles.

### Data Collection

The following parameters/data can be collected for the evaluation and assessment impacts related to traffic efficiency.

*Table 84 - VRU - Relation between Sub Research Question for Traffic Efficiency and collected Data*

| Sub Research Question | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| How does the instant speed change immediately after message reception? | X | X | X | X |
| Is driver's behaviour compliant with the warning? | X | X | X | X |
| What is the impact of rejecting the request? | X | X | X | X |

### Field Test Indicator/KPI

The following Key Performance Indicators of the field test can be calculated:

- Speed adaptation (difference between the average speed of the vehicle and the speed limit) - from the reception of the C-ITS message until the stop line
- Instantaneous accelerations and decelerations
- Percentage of vehicles that did not commit the violation after receiving the warning
- Percentage of vehicles that changed their behaviour after receiving the warning

*Table 85 - VRU - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|
| Speed adaptation | X | | X | X |
| Instantaneous accelerations and decelerations | | X | X | X |
| Percentage of vehicles that did not commit the violation after receiving the warning | X | | X | X |
| Percentage of vehicles that reduced their speed after receiving the warning | X | | X | X |

### Estimated KPIs on mobility (when C-ITS will be more widely diffused)

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Reduction in journey time crossing the intersection
- Changes in traffic flow crossing the intersection

### Environment

#### *Main research question*

- Is the environmental impacts of transport affected by changes in driver behaviour due to this C-ITS service?

#### *Research hypotheses about Sub Research Questions*

- Speed reduction and respecting traffic lights would result less accidents and less congestions and thus less $CO_2$ emissions.
- Abrupt accelerations or decelerations resulting from the advice, lead to perturbations on the traffic flow upstream and thus more fuel/energy consumption and $CO_2$ emissions.
- Higher compliance with warnings will result in speed reduction and stopping at red lights for vehicles that are about the commit a violation. For the other users this will require delay in starting or a deceleration to avoid the violating vehicle and then an acceleration which might cause an increase in $CO_2$ emissions.

#### *Data Collection*

The following parameters/data can be collected for the evaluation and assessment impacts related to environment.

*Table 86 - VRU - Relation between Sub Research Question for Environment and collected Data*

| Sub Research Question | Fuel/Energy consumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| How do the instant speed fluctuations change? | X | X | X | X | X |
| What are the impacts immediately after message reception? | X | X | X | X | X |
| Is driver's behaviour compliant with the warning? | X | X | X | X | X |

#### *Field Test Indicator/KPI*

The following Key Performance Indicators of the field test can be calculated for violating vehicles and other vehicles:

- Percentage of test vehicles accepting to stop at the traffic light after receiving the warning
- Percentage of vehicles that changed their speed after receiving a warning that another vehicle committed a violation

*Table 87 - VRU - Relation between Field test indicator KPI for Traffic Efficiency and collected Data*

| Field test indicator KPI | Fuel/Energy consumption | Speed | Acceleration Deceleration | Position | Message data log |
|---|---|---|---|---|---|
| Fuel consumption | X | | | X | X |
| Percentage of test vehicles accepting to stop at the traffic light after receiving the warning | | X | X | X | X |
| Percentage of vehicles that reduced their speed after receiving a warning that another vehicle committed a violation | | X | X | X | X |

### *Estimated KPIs on mobility (when C-ITS will be more widely diffused)*

The following Key Performance Indicators (based on EU EIP list) when C-ITS services (both on vehicles and on infrastructures side) will have a greater spread can be estimated starting from the outputs of the field test data:

- Reduction in fuel/energy consumption due to less traffic jams caused by accidents
- Reduction in $CO_2$ emissions

### 4.8.4 Automated vehicle guidance

Automated vehicle guidance describes the capability of traveling without human input. This section, far from being exhaustive, provides a collection of the key elements to perform the impact evaluation of this service.

Self-driving cars rely on perceiving the environment, monitoring important systems, and control, including navigation. Perception accepts visual and audio data from outside and inside the car and interprets the input in order to abstractly render the vehicle and its surroundings. The control system then takes actions to move the vehicle, considering the route, road conditions, traffic controls, obstacles and others.
There is the potential for significant disruption to the automotive industry, including health, welfare, urban planning, traffic, insurance, labour market, and other domains. Consequently, appropriate regulations are necessary for deployment.

Evaluating automatic driving, often referred to as autonomous or self-driving technology, is a complex task that involves assessing various aspects, including safety, traffic efficiency, environment, technology readiness, social impact as well as regulatory considerations.

Key points to consider through evaluating automatic driving are reported hereby, in compliance with the impact areas considered for the other Services and Use Cases considered in this Evaluation and Assessment Plan.

#### Safety

Safety is a key factor in autonomous driving. A thorough safety evaluation process is essential to mitigate risks and gain public trust in this transformative technology. Thus, evaluating a variety of driving conditions, including avoiding collisions and responding to unexpected situations, is most important. In a further step, assessment of whether automated driving reduces accidents compared to human drivers, needs to be performed. Concerning this topic, significant impacts are expected since human error represents a predominant factor in road traffic collisions that automated driving will seek to eliminate. Fields of investigation with evaluation on Safety may refer to:

- **Data Collection and Analysis**: Safety evaluation begins with the collection of (extensive) data, including sensor data, real-world driving scenarios, and simulation. Algorithms may analyse this data to identify potential safety risks, system performance, and areas that require improvement. This data-driven approach then allows a more holistic understanding of autonomous vehicle behaviour.
- **Functional Assessment**: Functional safety standards, such as ISO 26262, are adapted to autonomous driving systems. These standards define safety requirements, hazard analysis, and risk assessment procedures. Autonomous vehicle manufacturers must demonstrate compliance with these standards to ensure the safety of their systems.
- **Simulation and Testing**: (Extensive) simulation and testing play a crucial role in evaluating autonomous driving safety. Simulations can recreate complex driving scenarios that may be too dangerous to test in the real world. Additionally, testing on closed tracks and controlled environments helps assess system performance and safety under various conditions and at varying levels of market penetration.
- **Redundancy and Fail-Safe Mechanisms**: Autonomous vehicles must incorporate redundancy in their critical components, including sensors, processing units, and control systems. These mechanisms ensure that if one component fails, another can take over, preventing accidents. Fail-safe mechanisms, such as safe stopping or pulling over, should be part of the autonomous system's design.

- **Ethical Decision-Making**: Autonomous vehicles must make rapid decisions in critical situations. Ensuring the safety of passengers and pedestrians is a top priority. Ethical considerations and predefined rules for decision-making must be embedded into the autonomous driving algorithms. This also includes transparency in rules for gaining public trust.
- **Cybersecurity**: Protecting autonomous vehicles from cyber threats is a key requirement for safety. Robust cybersecurity measures, including intrusion detection systems and regular software updates, should be in place to prevent hacking attempts that could compromise vehicle safety.
- **Human-Machine Interaction**: It's critical for safety evaluation to understand how humans interact with autonomous vehicles. Vehicle-to-pedestrian communication systems, clear displays of vehicle intent, and user-friendly interfaces are essential to ensure that pedestrians, cyclists, and other drivers can predict and react to autonomous vehicles' actions.
- **Regulatory Compliance**: Autonomous vehicles must meet regulatory standards set by (government) agencies. These standards ensure that autonomous systems are in synch with safety and performance benchmarks. Regulatory bodies play a crucial role in defining and enforcing safety requirements.
- **Continuous Learning and Improvement**: Safety evaluation is an ongoing process. Autonomous driving systems should continuously gather data and use it to improve their algorithms and safety measures. Regular updates and over-the-air software improvements help address emerging safety concerns.

### Efficiency

Evaluating efficiency in autonomous driving is crucial for understanding the technology's impact on various aspects of transportation, including energy consumption, traffic flow, and environmental sustainability. Concerning autonomous driving, it is a multifaceted concept that encompasses not only energy savings but also improvements in traffic flow, reduced emissions, cost-effectiveness, and overall sustainability. Evaluating and optimizing these aspects is critical for realizing the full potential of autonomous vehicles in creating more efficient and sustainable transportation systems.
Key aspects are, among others:

- **Energy Efficiency**: Energy/Fuel consumption measures the amount of fuel or energy used by autonomous vehicles per kilometer traveled. Autonomous systems should aim to optimize energy use, whether the vehicle is electric or powered by internal combustion engines. Further more, eco-driving algorithms evaluate the effectiveness in autonomous vehicles. They can optimize speed, acceleration and deceleration patterns to minimize energy consumption.
- **Traffic Flow Optimization** assesses how autonomous vehicles affect traffic flow. It's evaluating whether they can reduce congestion, smooth traffic patterns, and minimize stop-and-go driving, which can improve overall (fuel and others, e.g. noise) efficiency. Going further, cooperative driving encompasses the ability of autonomous vehicles to communicate with each other and with traffic infrastructure (V2X, C-V2X, C-ITS communication) to coordinate actions, reduce unnecessary braking, and maintain smoother traffic flow.
- **Optimized Routes and Navigation** assesses the ability of autonomous systems to select the most efficient routes, taking into account real-time traffic conditions, road congestion, and others, while – in a next step – "Predictive Navigation" evaluates the use of predictive analytics to anticipate traffic conditions and proactively adjusts routes to minimize travel time (and energy consumption).

- **Energy Source**: it considers the integration of renewable energy sources, such as solar or wind, to power autonomous vehicle charging stations, reducing the carbon footprint of the charging process.

### Environment

Examines the environmental implications of autonomous vehicles and evaluates whether they contribute to reducing emissions through more efficient driving and, if applicable, their role in electric and sustainable transportation. Evaluating emissions in autonomous driving requires a comprehensive approach that considers not only tailpipe emissions but also energy source, traffic flow optimization, eco-driving algorithms, fleet electrification, and other factors. The goal is to maximize the environmental benefits of autonomous technology while minimizing its carbon footprint.

Autonomous vehicles have a huge potential to improve overall emissions, however, several factors must be considered during evaluation:

- **Emission reduction** evaluates the reduction in emissions, including carbon dioxide (CO2), nitrogen oxides (NOx) and particulate matter (PM) as well as noise, achieved by autonomous vehicles compared to human-driven vehicles. Assessment may also consider the transition to electric and hybrid vehicles, which emit fewer tailpipe pollutants:
- **The source of energy** considers the source of energy used by autonomous vehicles, i.e. the emissions associated with electricity generation. Cleaner energy sources such as renewables can significantly reduce emissions.
- **Traffic Flow Optimization**: as stated before, by reducing traffic congestion and optimizing speed profiles, autonomous driving can lead to smoother traffic patterns - and thus also to reduced emissions. Evaluation may consider these effects i.e. on urban and highway traffic.
- **Life Cycle Assessment (LCA)** provides a holistic view of a vehicle's environmental impact. It conducts a life cycle assessment of autonomous vehicles, considering emissions associated with manufacturing, operation and disposal.

# Annex 1: Examples of template for describing the pilot

## 1. General information

**Country:**

**Author:**

**Version:**

**Date:**

**DESCRIPTION (as described on C-Roads site)**

**LOCATION DESCRIPTION (as described on C-Roads site)**

## 2. Field trial information

**1. How many test-drivers:**

**1.1 Which type of drivers:**

Professional (Provide details)

non-professional

**2. In which area will the trial take place:**

urban

highways

rural roads

**3. How long will the drivers use C-ITS?**

weeks

**4. Which type of C-ITS**

| | |
|---|---|
| | G5 |
| | cellular |

## 3. Available services

Which Day 1 services will be tested in your pilot?

| | | |
|---|---|---|
| **Hazardous location notification** | ☐ | **Weather conditions** |
| | ☐ | **Road works warning** |
| | ☐ | **Slow or stationary vehicles** |
| | ☐ | **Emergency vehicle approaching** |
| | ☐ | **Emergency brake light** |
| | ☐ | **Other hazardous location notifications** |
| **Signage application** | ☐ | **Traffic jam ahead warning** |
| | ☐ | **In-vehicle signage** |
| | ☐ | **In-vehicle speed limits** |
| | ☐ | **Probe vehicle data** |
| | ☐ | **Shockwave damping** |
| | ☐ | **Signal Phase and Timing Information** |
| | ☐ | **Green Light Optimal Speed Advisory** |
| | ☐ | **Signal violation/intersection safety** |

How will the information be given to the user: (i) pictures/symbols; (ii) text; (iii) combination; (iv) other?

| | |
|---|---|
| **Weather conditions**<br>**Road works warning**<br>**Slow or stationary vehicles**<br>**Emergency vehicle approaching**<br>**Emergency brake light**<br>**Other hazardous location notifications**<br>**Traffic jam ahead warning**<br>**In-vehicle signage**<br>**In-vehicle speed limits**<br>**Probe vehicle data**<br>**Shockwave damping**<br>**Signal Phase and Timing Information**<br>**Green Light Optimal Speed Advisory**<br>**Signal violation/intersection safety** | |

Which basic information will be given: speed limits, traffic sign, …?

**Weather conditions**

**Road works warning**

**Slow or stationary vehicles**

**Emergency vehicle approaching**

**Emergency brake light**
**Other hazardous location notifications**

**Traffic jam ahead warning**

**In-vehicle signage**

**In-vehicle speed limits**

**Probe vehicle data**

**Shockwave damping**

**Signal Phase and Timing Information**

**Green Light Optimal Speed Advisory**

**Signal violation/intersection safety**

Are there advanced features in the information? Sound & light, signals, …?

**Weather conditions**

**Road works warning**

**Slow or stationary vehicles**

**Emergency vehicle approaching**

**Emergency brake light**
**Other hazardous location notifications**

**Traffic jam ahead warning**

**In-vehicle signage**

**In-vehicle speed limits**

**Probe vehicle data**

**Shockwave damping**

**Signal Phase and Timing Information**

**Green Light Optimal Speed Advisory**

**Signal violation/intersection safety**

How would you categorize the service: INFORMATIVE: Only providing information of the situation to the driver; ADVISORY: Besides basic info, extra information on e.g. speed, lane, … ASSISTING: Besides basic info, providing extra support (sound & light) if e.g. driver is speeding, audio signal?

**Weather conditions**

**Road works warning**

**Slow or stationary vehicles**

**Emergency vehicle approaching**

**Emergency brake light**
**Other hazardous location notifications**

**Traffic jam ahead warning**

**In-vehicle signage**

**In-vehicle speed limits**

**Probe vehicle data**

**Shockwave damping**

**Green Light Optimal Speed Advisory**

**Signal violation/intersection safety**

# Annex 2: Examples of research questions as provided by the C-Roads members

Project INTERCOR suggested the following general remark:

*Please keep in mind that the questions that were selected are main research questions. It has not the intention to give the impression that by addressing only these questions, the whole area of user acceptance is covered. In order to answer these top questions, various sub questions need to be listed. It depends on many factors such as Pilot length, budget, etcetera what type of study (questionnaire, interview …) should be conducted to obtain the answers. It is important to first determine what you want to know and why you want to know it, before being able to determine how you are going to tackle the questions.*

| Source | Question |
|---|---|
| Intercor | Do drivers report perceiving the information presented? |
| | Do drivers feel like they use the services and that the service influences their behavior? If so, how? |
| | How do drivers value the services? |
| | Do drivers believe the services improve their overall trip quality? If so, how? |
| | How do drivers value the HMI and could it be improved? (distracting/easy to use) |

**Spain**

Below questions are aimed to be addressed for the Spanish Pilots. Final questionnaires are to be elaborated yet:

- What are the factors influencing users´ acceptability towards Cooperative Intelligent Transportation Systems (C-ITS)?
- Are perceptions determined by the need or ability of the user?
- What is the potential impact of ITS services on the mobility and independence of vulnerable social groups?
- How the access to ITS services is related to people with varying needs and abilities?
- Is there any evidence to conclude that Cooperative Intelligent Transportation Systems are equitable?
- Is this transport policy making transport more affordable to the less wealthy people/regions and to vulnerable groups?
- Is there any evidence of discrimination against the most economically and socially disadvantaged regions/people?
- How is the distribution (and the perception of the distribution) of gains and losses of the proposed services for the disadvantaged users?

According to the Spanish stakeholders' preliminary survey, the main interests from the C-ITS product owner relies on the perceived utility and usability of the C-ITS services. Therefore these aspects will have priority in the questionnaires.

| | TOTAL |
|---|---|
| Perceived efficiency | 39 |
| Perceived effectiveness | 39 |
| Perceived usability | 40 |
| Perceived usefulness | 49 |
| Satisfaction | 37 |
| Equity | 21 |
| Affordability/willingness to pay | 37 |

# Annex 3: User Acceptance Theoretical background

## Common definitions and differences between public acceptance and user acceptance

Acceptance, acceptability, social acceptance, public support, social support, etc. are all terms frequently used to describe a similar phenomenon, how potential users will react and act if a certain measure or device is implemented. The interest in defining acceptance or acceptability lies in the precondition that the effectiveness and success of a measure will increase if there is public/social support for it. Under favourable conditions a positive assessment leads to an increased willingness to accept a measure and even to support it actively (Nelissen & Bartels, 1998; Goldenbeld, 2002). Although it is recognized that acceptance, acceptability, and support are important, a clear definition of what acceptance and acceptability are and precisely how they should be measured is still absent (Adell, 2008a; Regan et al., 2006; Vlassenroot, 2006).
To a certain extent the terms acceptance and support are strongly related. Goldenbeld (2002), however, introduces an important nuance between both concepts. The basic idea is that even if acceptance exists, it would not necessarily lead to the support of a measure.

In the field of ITS, Ausserer and Risser (2005) define acceptance as a phenomenon that reflects to what extent potential users are willing to use a certain system. Hence, acceptance is linked closely to usage, and acceptance will depend on how user needs are integrated into the development of the system. Nielsen (cited in Young et al., 2003) described acceptability as related to the question of whether the system is good enough to satisfy all the needs and requirements of the users and other potential stakeholders. More generally, in Rogers' (2003) diffusion of innovations, acceptability research is defined as the investigation of perceived attributes of an ideal innovation in order to guide research and development to create such an innovation. Van der Laan et al. (1997) distinguished between user acceptance and social acceptance. User acceptance is directed more towards evaluation of the ergonomics of the system while social acceptance is a more indirect evaluation of consequences of the system.

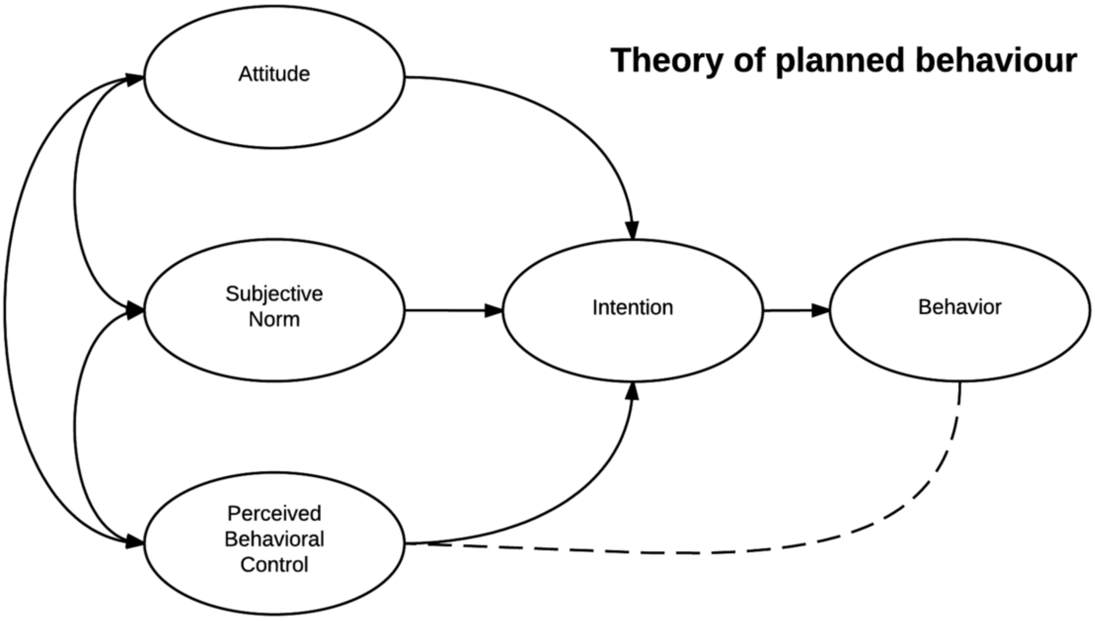
In another distinction between acceptance and acceptability, Schade and Schlag (2003) described acceptance as the respondents' attitudes, including their behavioural responses, after the introduction of a measure, and acceptability as the prospective judgment before such future introduction. In this case, the respondents will not have experienced any of the measures or devices in practice, which makes acceptability a construction of attitude.

## Theories and approaches in User Acceptance

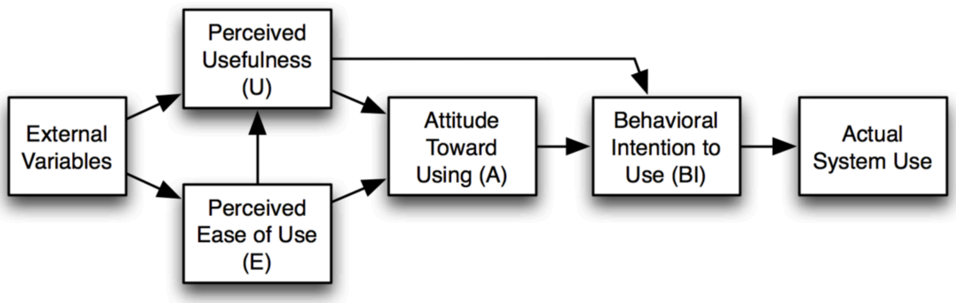
One of the most frequently used frameworks to define acceptance is the Theory of Planned Behaviour (TPB). Based on the Theory of Reasoned Action (Fischbein & Ajzen, 1975), the TPB assumes that behavioural intentions, and therefore behaviour, may be predicted by three components (Van Acker et al., 2007, 2010): attitudes towards the behaviour, which are individuals' evaluation of performing a particular behaviour; subjective norms, which describe the perception of other people's beliefs; and perceived behavioural control, which refers to people's perception of their own capability.

TPB has been used successfully to predict behaviour in a wide variety of applied research settings within different domains, including several studies dealing with driving behaviour and traffic safety, such as the effects of drinking and driving (Aberg, 1993; Parker et al., 1992a), driving violations (Parker et al., 1992b), and speeding and speed behaviour (Elliot et al., 2005; Haglund et al., 2000). Warner and Aberg (2006) specifically used the TPB related to the use of

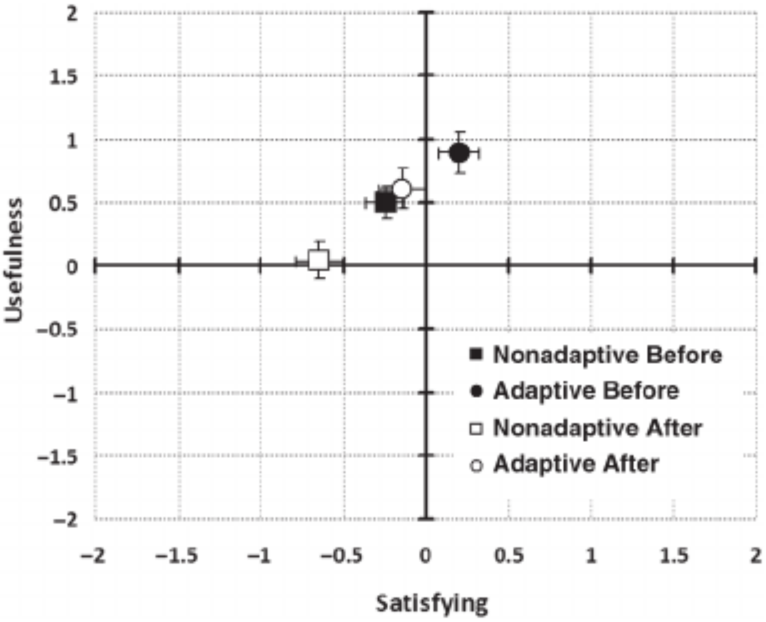
ISA. Comparing self-reported speeding of test drivers within an ISA trial with logged data explained 28% of the variance in logged speeding. In their study, Warner and Aberg (2006) noted that perceived behavioural control did not add significantly to the prediction of drivers' logged speed.



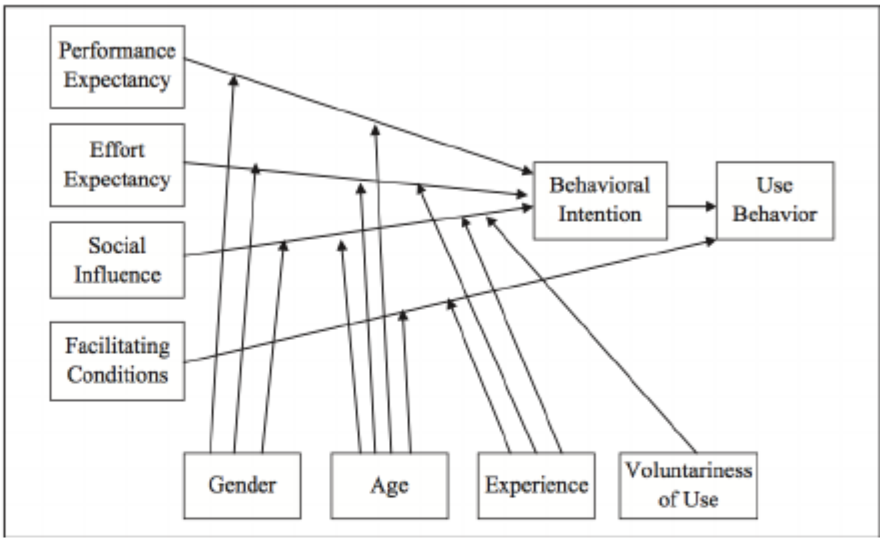

Another successful model is the Technology Acceptance Model (TAM) (Davis et al., 1989). TAM was designed to predict information technology acceptance and usage on the job. TAM assumes that perceived usefulness and perceived ease of use determine an individual's intention to use a system with the intention to use serving as a mediator of actual system use. TAM has been used – in the field of ITS – in the prediction of electronic toll collection (Chen et al., 2007).



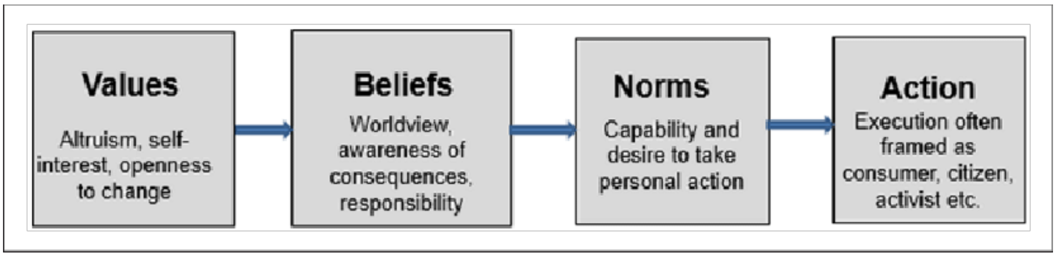

Van der Laan et al. (1996) published a simple method to define acceptance. Acceptance is measured by direct attitudes towards a system and provides a system evaluation in two dimensions. The technique consists of nine rating-scale items. These items are mapped on two scales, the one denoting the usefulness of the system, and the other satisfaction.




Venkatesh et al. (2003) noted that there are several theories and models of user acceptance of information technology, which presents researchers with difficulties in choosing the proper model. Venkatesh et al. (2003) found different underlying basic concepts in acceptance models by means of a detailed description and analysis of different models such as TPB, the motivational model, TAM, innovation diffusion theory, and combined models. Based on these theories, they constructed a unified model they named the Unified Theory of Acceptance and Use of Technology (UTAUT). In the UTAUT, four constructs play a significant role as direct determinants of user acceptance: (i) performance expectancy – the degree to which an individual believes that using the system would help him or her to attain gains in job performance; (ii) effort expectancy – the degree of convenience with the use of the system; (iii) social influence – the importance of other people's beliefs when an individual uses the system; and (iv) facilitating conditions – how an individual believes that an organizational and technical infrastructure exists to support use of the system. The supposed key moderators within this framework are gender, age, voluntariness of use, and experience. Although in several models, 'attitude towards use', 'intrinsic motivations', or 'attitude towards behavior' are the most significant determinants of intention, these are not mentioned in the UTAUT. Venkatesh et al. (2003) presumed that attitudes towards using the technology would not have a significant influence.



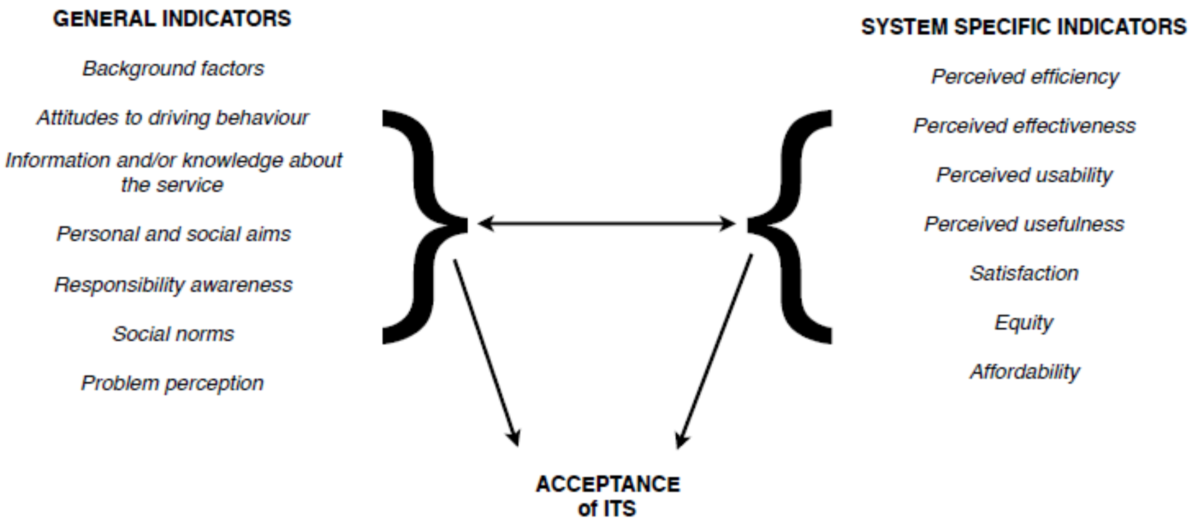

Stern (2000) developed the value–belief–norm (VBN) theory to examine which factors are related to acceptability of energy policies. Stern and colleagues proposed the VBN theory of environmentalism to explain environmental behaviour, including the acceptability of public policies. They proposed that environmental behaviour results from personal norms, that is, a feeling of moral obligation to act pro-environmentally. These personal norms are activated by beliefs that environmental conditions threaten the individual values (awareness of consequences) and beliefs that the individual can adopt to reduce this threat (ascription of responsibility). VBN theory (Steg et al., 2005) proposes that these beliefs are dependent on general beliefs on human–environment relations and on relatively stable value orientations. VBN theory was successful in explaining various environmental behaviours, among which consumer behaviour, environmental citizenship, willingness to sacrifice, and willingness to reduce car use (Stern et al., 1999; Nordlund & Garvill, 2003).




Schlag and Teubel (1997) defined the following essential issues determining acceptability about traffic measures: problem perception, important aims, mobility-related social norms, knowledge about options, perceived effectiveness and efficiency of the proposed measures, equity (personal outcome expectation), attribution of responsibility, and socio-economic factor.

## Inventory and main indicators in Acceptance/Acceptability research

This inventory an approach is based on the above-described theories in acceptance.




In the figure above a distinction is made between general indicators (related to the context awareness of the system) and system-specific indicators (directly related to the characteristics of the device). The 14 indicators are considered to be the most relevant that can or will influence acceptance. These general and specific indications will influence each other and the level of acceptance. A brief description of every indicator is given.

## General indicators

**Individual factors**

Gender, age, level of education, and (income) employment are considered to influence how people think ITS and the use of C-ITS. Gender and age are considered as relevant determinants within the performance of driving behaviour.

**Attitudes to driving behaviour**

Travel behaviour, driving style and the choice of vehicle are also related to driving behaviour.

**Personal and social aims**

Social aims have been described as the dilemma between social or personal aims and benefits. They assume that a higher valuation of common social aims will be positively related to acceptance.

**Social norms**

Perceived social norms and perceived social pressure refer to the (assumed) opinions of their peers multiplied by the importance of the others' opinions for the individual. In other words, social norms refer to an individual's assumptions about whether peers would think that he or she should accept the device. It is assumed that peers, e.g. co-workers or specific other road users, will influence the attitudes and behaviour of individuals

**Problem perception**

The extent to which not having certain information or guidance is perceived as a problem is a necessary indication in defining acceptance.

**Responsibility awareness**

Responsibility awareness explains how individual stands in respect to the issue of whether it is the government (others/extrinsic) or the individual (own/intrinsic) that is deemed to be responsible. It is assumed that environment-preserving behaviour becomes more likely if individuals perceive the damaging consequences of their own actions on the environment and others, and at the same time ascribe the responsibility for the consequences to themselves.

**Information and knowledge about the device/service**

The level of acceptance can depend on how well informed the respondents are about the problem and about any new device that is to be introduced to solve the problem. The hypothesis may be that the more that people are informed, the higher the acceptance will be. However, better knowledge about a problem can also lead to less acceptance for a specific solution caused by, for instance, awareness of alternatives to solve the problem.

## Device-specific indicators

Device-specific beliefs are directly related to the characteristics of the system. Seven indicators could have the potential to define acceptance and how user needs are integrated into the system.

**Perceived efficiency**

Perceived efficiency indicates the possible benefits users expect of a concrete measure (or device) as compared with other measures.

| |
|---|
| C-ITS better than VMS<br>C-ITS better than other info<br><br>Fuel consumption<br>Traffic efficiency<br>Safety<br>Avoiding fines |

**Perceived effectiveness**

Effectiveness refers to the system's functioning according to its design specifications, or in the manner it was intended to function. In most ITS trials, this was found through an evaluation of the technical/ergonomic issues. The main question in these trials remained whether the system assisted the driver in their driving. The level of effectiveness can depend on how interventionist a system is or was.

| |
|---|
| Availability<br>Completeness<br>Correctness<br>Accuracy<br>Consistency<br>Up-to-dateness |

**Perceived usability**

Perceived usability is the ability to use the system successfully and with minimal effort. Usability is also an indication for how users understand how the system works. User friendliness can be associated with usability: the users will expect a service that does not distract or overload them with information and (difficult) tasks.

| |
|---|
| Workload<br>HMI (?) |

**Perceived usefulness**

Perceived usefulness is related to how the system supports the drivers' tasks and driving behaviour. Usefulness is, in a certain way, different from effectiveness. A potential user can find C-ITS effective in general but not for his own driving behaviour. Usefulness is also defined as the degree to which a person believes that using a particular system will enhance his or her performance.

| |
|---|
| Useful<br>Good<br>Effective<br>Assisting<br>Alertness |

**Satisfaction**

Satisfaction is one of two factors derived from the items within the ITS acceptance scale that Van der Laan et al. (1997) developed to study user acceptance.

| |
|---|
| Pleasant<br>Nice<br>Likeable<br>Desirable |

**Equity**

In general, equity refers to the distribution of costs and benefits among affected parties. However, from a psychological viewpoint, perceived justice, integrity, privacy, etc., are basic requirements for acceptability. This may differ from the objective costs and benefits, but equity is an important indicator influencing personal perceptions. The integrity of driver information, privacy, and loss of certain freedom in driving can be an issue for willingness to use C-ITS.

| Privacy |
|---|

**Affordability/willingness to pay**

It may be assumed that socio-economic status will affect acceptance and acceptability, as users will consider ITS as a symbol of status, or they will want to be among the early adopters. On the other hand, affordability will depend on the individual's budget and/or public/private funding.

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# Annex 4: User Acceptance evaluation - starting from end-user needs

User Acceptance will be mainly defined on how the end-user needs are integrated in the service. Throughout a market point view, these aspects are important to define.

- *Status/relevance of the service:* The user needs to have a clear understanding of the role of the in-car service: The road traffic regulations are legally binding, the C-ITS service has a supportive and purely informative role. The service can be subject to errors.
- *User friendliness/distraction:* The user expects a service which does not distract or overload him with information, e.g.:
    - The driver should receive concise but comprehensive information.
    - No over-burdening, otherwise there will be non-observance
    - No other graphical designs than those agreed by international agreements should be used, in order to prevent misunderstandings
- *Service availability:* The user expects a sufficiently high proportion of driving situations where the service is technically operational including coverage. In particular, service interoperability between regions and country is important.
- *Good informational content of service:*
    - Where the service is operational the end user expects a high rate of completeness of content.
    - Correctness of content including availability of additional information.
- *Accurate timing of the information:* The user expects timely information, i.e. sufficient time for reading and understanding, reaction time, decision time, response time of brakes, time for covering the distance until new information will be provided.
- *Integrity of driver information and respect for drivers' privacy*
- *Integration in different services and platforms:* The user can expect it to be available on different platforms and devices.

The above described theories and approaches, allows to define evaluation approach on user acceptance.

# Annex 5: Socio-economic impact assessment

## Introduction

The term '*socio-economic*' is defined as "*relating to or concerned with the interaction of social and economic factors*" (Oxford Dictionaries 2019). *Socio-economic impact assessment* evaluates the benefits (and dis-benefits) taking place, e.g. due to introduction of a C-ITS service and relates these benefits to the costs.

Socio-economic impact assessment is usually done in form of *cost-benefit analysis* (CBA). CBA can be defined as define as "*a systematic approach to estimating the strengths and weaknesses of technology alternatives*" (International Records Management Trust 2006). In CBA, the benefits are turned into their monetary values, which are compared to the costs. Another method for evaluation of socio-economic impacts is *cost-effectiveness analysis*, which relates the costs to the key outcomes or benefits without turning them to monetary values (Cellini et al. 2015).

CBA helps to predict whether the benefits outweigh the costs and by how much, allowing also ranking of alternatives (Wiener 2013). Usually, the alternative with higher *benefit–cost ratio* will take priority over those with lower ratios (Britannica 2019).

## Approaches

For performing the cost-benefit analysis for socio-economic assessment, there are alternative approaches: either to do a (full) life-cycle analysis or a snapshot analysis (i.e. prediction of one or several years but not full period).

The *life-cycle analysis* is made for the full life-cycle of the product or service under evaluation or for a period of e.g. 10 or 30 year. This approach is used e.g. when the main aim is to clarify whether an investment is a good way of using society's resources and whether to invest or not. By assigning economic values to the impacts of a service, implementation or product under evaluation over a specific time-period, the net present value is calculated. This value represents the total present value of the benefits minus the present value of all costs over the life cycle. The net present value is obtained by applying a discount rate to all benefits and costs of a project for a common base year. Therefore, the future benefits and costs have a lower weight/value than the benefits and costs in the base year. (Metz et al. 2019)

In the *snapshot* approach, one may use *a future target year or years* (single years) to which the impacts and costs are assessed, i.e. looking single years from the life-cycle of the service. In this case, the costs are transformed to annual values using discount rate and compared to the target year benefits (Geissler et al. 2011).

A challenge for both the life-cycle approach and for using future target years as a snapshot is that the analyst needs to predict the future. In practice, this means the assessment of the baseline situation for the future years including the impacts of other trends affecting transport, like electrification, automation, other development of vehicle technology, shared mobility, urbanization, climate change, etc. Particularly, long-term predictions involve high uncertainties, which are naturally reflected in the reliability of the evaluation outcome. In addition, the impacts, potentially measured in the (small scale) field-test today, should be assessed in context of the future transport system, which form another source of uncertainty or flaw. The benefit of looking into the future is that if successful predictions can be made, it can provide the results e.g. for the whole life-cycle of the service or system.

One may also use *current situation* for a snapshot assuming that certain proportion of current traffic would be equipped with the technology or service under evaluation (Metz et al. 2019). This approach is naturally purely theoretical. However, especially in case when it is hard to time the introduction of the technology in the future and/or when the overall situation is affected by

many (other) factors in parallel, the current traffic snapshot approach may be a good simplification.
In addition to the time dimension to be used in the analysis, the analyst needs to decide whether the future of all markets in the economy is predicted to get the full picture of the benefits and costs or whether to include only for parts of economy - such as the market for C-ITS services. This simplifies greatly by keeping all other things equal. The stakeholders for the CBA include:

- Travellers
  - Direct users of vehicles with the relevant ADFs
  - Other travellers
- Producers / Service providers
- Government
- Rest of society

Stakeholder analysis can be made to supplement the cost-benefit analysis. This may include break-even analysis for users where the benefits from an individual end-user viewpoint are confronted with the market price to buy the system with the pay-off period corresponding to the annual mileage of the driver. Another example is the analysis of the financial effects for the public authorities. (Geissler et al. 2011)
As all of the approaches above include strengths and weaknesses. The selection of principles for CBA should be made case by case based on related uncertainties and on the objectives of the evaluation. For example, a current situation snapshot combined with analysing only the C-ITS service market (partial economy analysis) could work as a simplified scenario to give an indication of the benefits and costs on annual level. An advantage of this approach is that the current traffic scenario is known (i.e. no need for prediction), the impacts of other trends can be excluded, and the evaluation can be limited to the direct object of evaluation (in this case, the C-ITS service users and providers). However, looking at single snapshot of benefits for only parts of the economy, does not provide the full picture whether a public investment into a C-ITS service is beneficial or not and after how long period. In reality, it may be that the costs come first and the benefits are gained later.

## Evaluation scenario

In the socio-economic impact assessment, scenario(s) with the new technology (with-scenario) is compared to the situation without it, i.e. current situation (without-scenario, baseline).
When assessing the socio-economic impacts of C-ITS, this scenario description must include (but is not limited to):

- Description of the C-ITS service(s) in terms of information content and whether these services are provided as isolated single services or as bundle, sketch of ecosystems behind the services
- Technology to which the services are based on (message transmission, in-vehicle devices, etc.)
- Methods of information sourcing of the C-ITS service, event coverage (e.g. of the objects of warning), quality of information (timeliness, location accuracy, etc.)
- Road network on which the C-ITS services are available
- Penetration rates in terms of fleet (vehicles that have the system/service) and traffic flow (actual use), heavy vehicles and professional drivers separate from light vehicles and non-professional drivers, i.e. deployment scenario
- Target years for evaluation including base year (all assessments) and the time horizon of the assessment (if applicable); the whole life cycle of the considered C-ITS service or only for selected target years depending on scope of evaluation
- The evolvement of the items above in terms of time for the evaluation period (unless the evaluation is addressing a single current traffic snapshot).

Often several scenarios are evaluated in the CBA. If the chosen assessment approach requires future prediction, FESTA Handbook (2018) recommends to create alternative scenarios with different “futures”, including the development path from the present to the target years. One must bear in mind that the scenario that gives the highest benefit-to-cost ratio may not be the most probable one. However, these scenarios can be utilized in the analysis on how sensitive the outcome is to different factors and the assumptions made. In addition, scenario analysis should be made to identify obstacles to the pursuit of the scenario with the most beneficial outcome (FESTA 2018).

In addition to the evaluation scenario (a period or a single future or current year snapshot(s)), the assessment requires definition of the baseline scenario. In case of C-ITS, a decision is needed on:

- Which traffic information services (incl. radio, variable message signs, dynamic navigators) to be included in the baseline
- With what kind of fleet penetration and use rates
- Estimates of the coverage of events and quality of information provided through these channels, and how much these services overlap (in terms of audience, event coverage, use purpose, etc.) with the C-ITS service.

The assumption on using 100% uninformed drivers as baseline is not realistic in most cases. The definition of the baseline situation affects the expected impact potential of the C-ITS service, being larger in network without any other information services and smaller for network with already some other services.

## Benefits

Ideally, the assessment would include all the benefits and dis-benefits of the system/service no matter how small they are: safety, travel behaviour, transport network efficiency, environment, productivity and workforce, land use, wellbeing and equity, etc. However, as it is not feasible to assess everything, FESTA Handbook (2018) advices to narrow the scope of the assessment by excluding minor or insignificant impacts, as long as the exclusion of these impacts will not bias the appraisal. Some examples of the scope of socio-economic impact assessment are illustrated in Figure 3. Anyhow, it is a good practice to list also these other potential impacts. An impact table proposed by Batelle Memorial Institute (2003, p. 45) or by sketching the impact pathways proposed by Innamaa et al. (2018, p. 20) can be used for that.

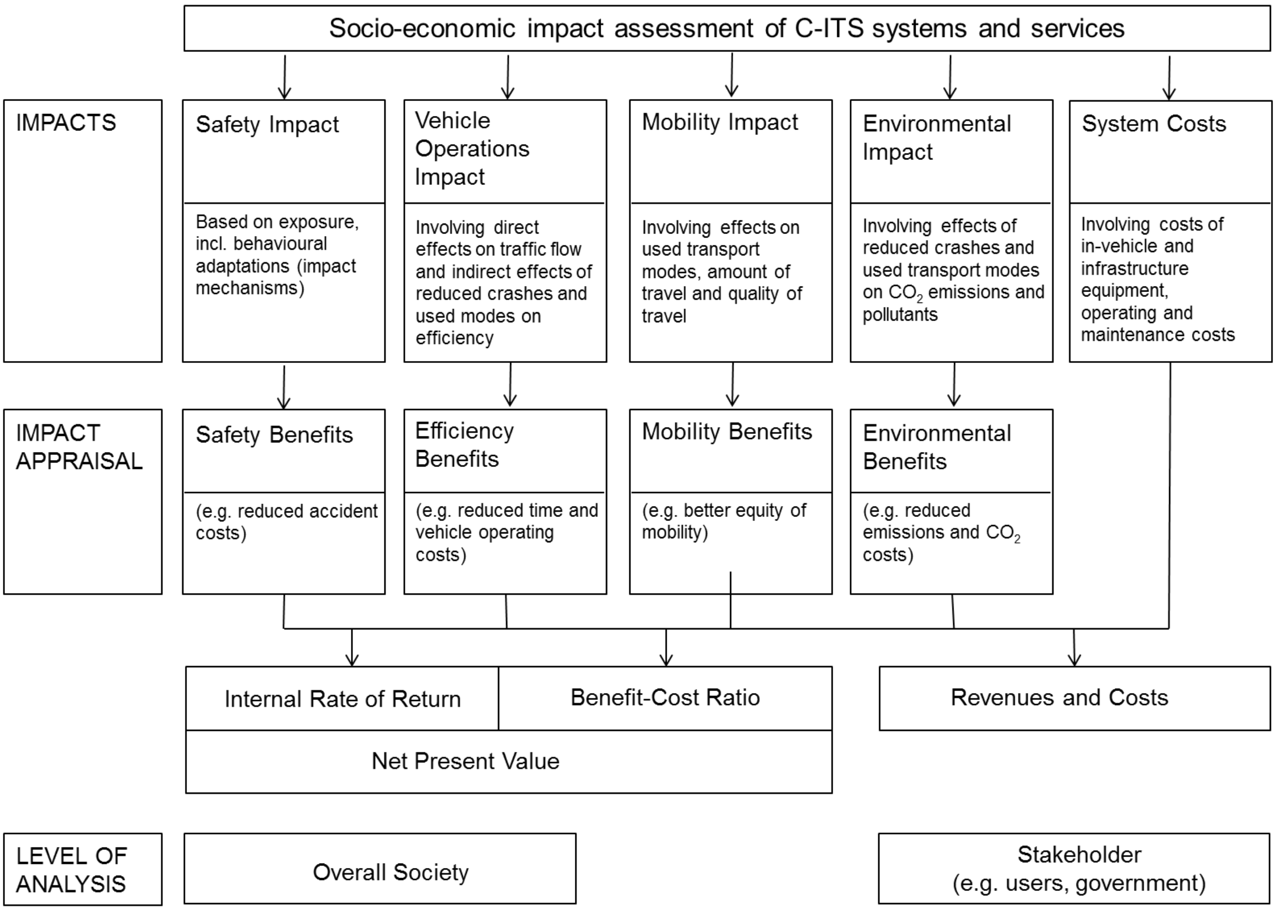


*Figure 3 - Examples of the scope of impacts with-in socio-economic assessment (Modified from Figure in FESTA Handbook (2018))*

First, the impacts or implications that the C-ITS service has on mobility, safety, efficiency, environmental, etc. need to be assessed. Even there would be data from a real-world pilot implementation, these assessments typically require simulation or other tools/methods. For example, the infrequency of crashes, natural variation in the number of crashes on a single road section and the effects of external factors like weather does not allow reliable estimates of the safety impact to be measured directly from the field. Some impacts are also indirect or take long time to take place making the direct measurement of the impact challenging. Thus, surrogate measures and expertise to convert them into KPIs needed for the socio-economic impact assessment are required. Figure 4 shows an example of program theory how the impacts in driving or user behaviour are linked implications on safety, efficiency, environment and mobility in general.

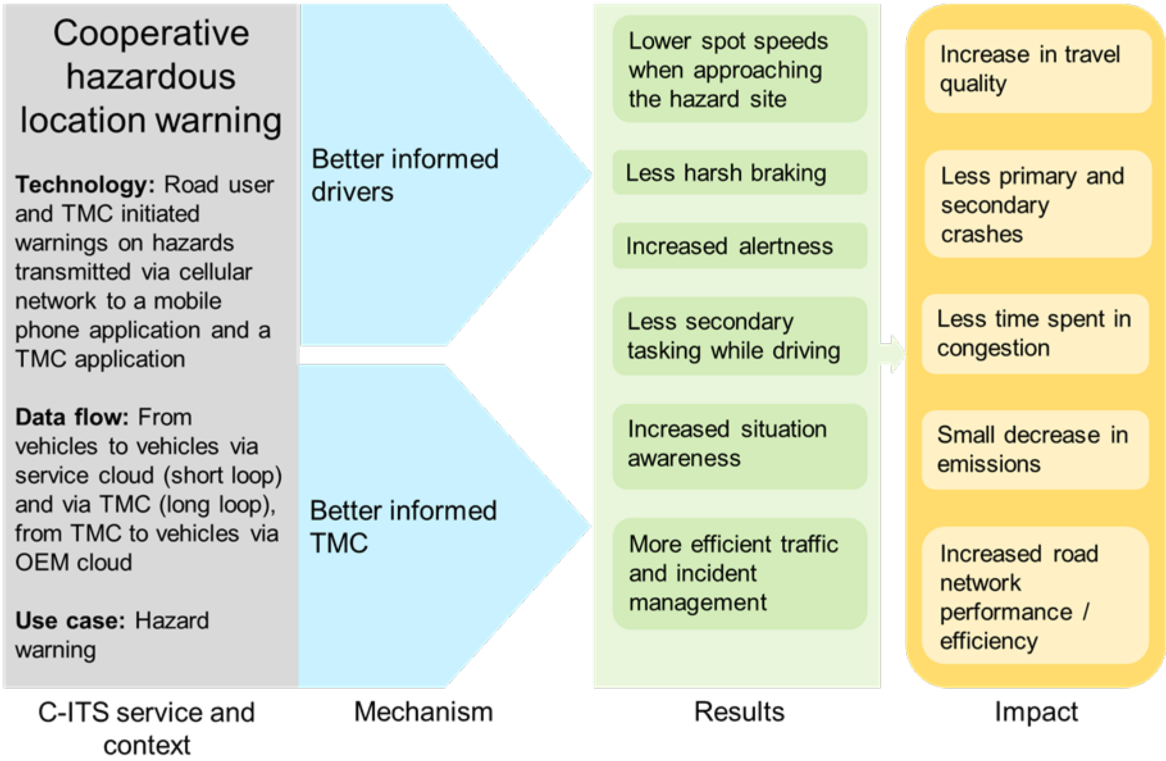


*Figure 4 - Program theory of the C-ITS service 'Cooperative hazardous location warning' in the Finnish pilot in NordicWay (Innamaa et al. 2017)*

In order not to limit the CBA only to the direct impacts but to take also the indirect impacts into account, a good practice is to consider all the impact mechanisms in the evaluation. The mechanisms below were defined for automated driving (Innamaa et al. 2018) but can be utilised also for C-ITS. They can be used for all impact areas.

1. Direct modification of the driving task, drive behaviour or travel experience
2. Direct influence by physical and/or digital infrastructure
3. Indirect modification of AV user behaviour
4. Indirect modification of non-user behaviour
5. Modification of interaction between AVs and other road-users
6. Modification of exposure / amount of travel
7. Modification of modal choice
8. Modification of route choice
9. Modification of consequences due to different vehicle design

The basis for the mechanisms was the nine safety impact mechanisms of intelligent transport systems of Kulmala (2010) which were adapted from the mechanisms formulated by Draskóczy et al. (1998). Kulmala (2010) aimed with his safety assessment framework to eliminate overlaps and thereby the risk of "double counting", to test the validity of any single mechanism, and to operationalise the mechanisms for assessment purposes. The same principles are also valid for studies on connected and automated driving. The aim was to make the mechanisms non-overlapping and all-inclusive, i.e., that all impacts would fall under some and (preferably) only one mechanism. In case an impact falls under two (or more) mechanisms, it is advised to select the most suitable one. Examples of use of the mechanisms can be found from the impact assessment framework by Innamaa et al. (2018).

In practice, for example, the safety impacts of a C-ITS service can be assessed based on

- Definition of target crashed (i.e. crashes that might be prevented by the use of the C-ITS service including relevant crash types, conditions in which the crashes take place, locations and participants)
- Coverage of service in terms of what part of e.g. hazardous locations can be covered by the corresponding C-ITS messages (detection of hazard, etc.)
- Effectiveness in prevention of the crash in terms of single driver receiving C-ITS message about the hazardous situation ahead
- Penetration of the C-ITS service in use in traffic flow (by the vehicle type)

The direct impacts are recommended to be supplemented by the indirect ones: changes in situations when there is no C-ITS message or service available, of the other road users and in interaction with them, and of the potential changes in our travel behaviour (like route choice).
It is good to note that some C-ITS services may have direct impact on the efficiency of the traffic on the road network or emissions caused by it. However, also those services that prevent crashes lead to reductions in delays and emissions as a side effect. For regions with low traffic volumes, the crashes may be the main cause of delays in the network. Thus, these impacts should not be overlooked.
Socio-economic impact assessment requires scaling up of impacts from single user or location level to larger penetration rates and wider road networks. For the scaling up, different EU-wide or national statistics and data are needed on crashes, emissions, mileages, time spent in congestion, fleet, etc. For example, CARE database provides European wide statistics on crashes with some details on the crash type, consequences, location and conditions. In practice, the availability of these data and statistics plays a role in the decision to what level to scale up the results.
For monetisation of impacts (benefits and dis-benefits), a decision is needed whether to use national or European unit values. Use of European values enables fair comparison of results between different countries. However, e.g. for decision making on national level, the use of national unit values provides better support and facilitates comparability with other measures/systems/services.

## Costs

Estimation of costs is an essential part of socio-economic impact assessment, as from a socio-economic viewpoint, they are a (negative) part of the impact of systems and services. Cost estimation should take care of the following aspects (FESTA 2018):

- *Cost elements*: The system costs comprise the costs of in-vehicle, physical and digital infrastructure, nomadic devices, back-end systems, etc. Besides the direct investment costs, also the operating and maintenance costs have to be considered.
- *Relevant size of costs*: CBA applies a resource-based view. This means looking at potential savings of productive resources and, on the other hand, at the resources necessary to achieve this impact. The implication for cost estimation is that only the input of productive resources is relevant and not potential market prices. However, market prices are relevant for user-centred analyses.

## Sensitivity analysis

It is advised to make sensitivity analysis on the main assumptions. For example, the SAFESPOT project recommended to vary the parameters by ±10% for the cost-benefit analysis, including the cost-unit rates (Geissler et al. 2011). Sensitivity analysis is a good tool for understanding, which the critical factors are for achieving the benefits and what the reliability of the results is.

The effect on cost-benefit ratio can be calculated in relative terms and, thus, reveal the magnitude of influence.

## KPIs for socio-economic impacts

As result, FESTA Handbook (2018) recommends the reporting of following social KPIs:

- Net Present Value (NPV) where all discounted values of benefits (plus sign) and costs (minus sign) are summed up
- Benefit-Cost Ratio (BCR) where the total benefits are divided by the total costs; overall and "snapshot" BCR for target years where the costs will be transformed to annual values (using the discount rate) and will be compared to the target year benefits
- Benefits in monetary terms (€) per impact
  - Safety benefits
  - Environmental benefits (e.g. climate change, air quality, noise)
  - Other benefits to road users (e.g. time savings, operating cost savings and reliability gains)
  - Revenue to operators, including infrastructure and service operators

In addition, an international survey on key performance indicators (KPIs) rated with highest importance the following three indicators of economic impacts that fit for the assessment of C-ITS services (Innamaa & Kuisma 2018):

- Socio-economic cost-benefit ratio
- Work time lost from traffic crashes (hours per year, overall and per capita; monetary value)
- New established businesses / job creation

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