EVALUATION AND ASSESSMENT PLAN
VERSION 1.4

C-Roads Platform

Working Group 3 Evaluation and Assessment

D2.6 - Evaluation and assessment methodology for C-ITS and ITS

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This document is dedicated to the memory of Gary Crockford, co-chair of Working Group 3, who played an active role in its preparation. His expertise, kindness, and collaborative spirit have been invaluable since the very beginning and have greatly contributed to the achievements of the Group.

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. 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. Review of the involvement of countries in the impact areas. 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	Final
1.4	30/08/2025	Enlargement of the set of Services/Use Cases considered, adopting as refererences the WG2 document “Common C-ITS Service Definitions - Version 3.0”.	Draft

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1. Introduction

1.1 Scope of the document

This "Evaluation and Assessment Plan" represents the deliverable D2.6 - Evaluation and assessment methodology for C-ITS and ITS of the C-Roads Extended project, which should be reached until 30/08/2025, 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 Extended.

Within C-Roads, Pilots will evaluate the impacts of C-ITS Services and a selection of their 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 approach is intended to ease 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 evaluation and assessment of Services and Use Cases. It should also be noted that guidelines for Technical Evaluation oversee by WG2 – Task Force 5 (validation of C-ITS services) and by individual pilots, for ensuring their C-ITS system is correctly functioning before performing the 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 experts.

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.

1.2 Structure of the Plan

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:

- 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 for a selection of Services and their Use Cases, as described in the document *C-ITS Service and Use Case definitions version 3.0.0* developed by *C-Roads Working Group 2 Technical Aspects - Taskforce 2 Service Harmonisation*. Day 1 Services are considered: RWW – Road Works Warning, IVS – In Vehicle Signage, HLN – Hazardous Location Notification, SI – Signalized Intersection. Other services considered are: NG – Navigation Guidance, CP – Collective Perception and POI – Point of Interest.
Beside these impact areas, guidelines about the evaluation and assessment of other specific impacts are provided for the Use Cases requiring a customized approach.

The plan suggests the data to be collected during the pilot phase of C-Roads for the evaluation of the Services and formulates links between these data and research questions. With these steps defined in the chapters of the plan, the Pilots get a guideline to assess and evaluate the main impacts of C-ITS service introduction and they can use the insights 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 allow the possibility to support the development of C-ITS and to check potential 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).

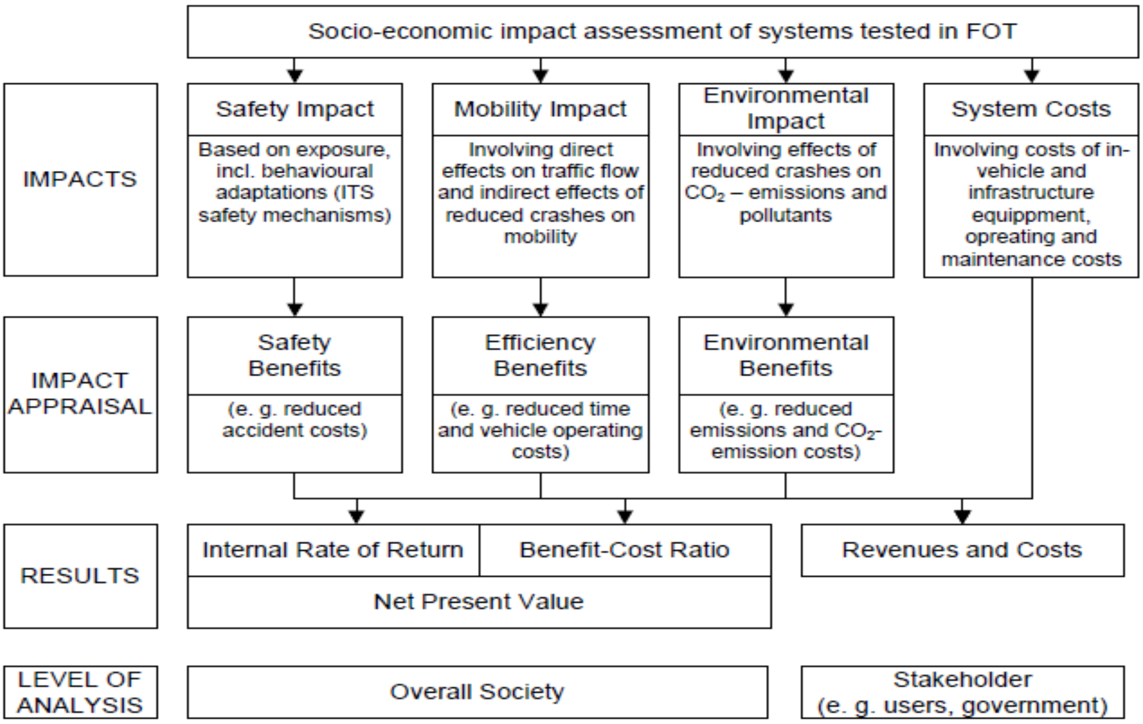

Figure 1 - Scope of impact assessment incl. socio-economic impact assessment (FOT-Net 2018)

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 1below maps a selection of these impact assessments against the included impact dimensions.

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Table 1 - Link between a selection of studies and 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

2.2.1 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.

2.2.2 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

2.2.3 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.

2.2.4 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

2.3.1 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.

2.3.2 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?

2.3.3 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

3.2.1 Evaluation Scope

In the document 'Common C-ITS Service Definitions' of Working Group 2 of the C-Roads platform specifications are available 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 the 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.

3.2.2 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 it is proposed to restrict the number of use cases to the following list:

Service	Use case
In-Vehicle Signage (IVS)	Dynamic Speed Limit Information (IVS-DSLI) Dynamic Lane Management (IVS-DLM)
Road Works Warning (RWW)	Closure of a lane (RWW-LC) Accident Zone (RWW-AZ)
Signalized Intersection (SI)	GLOSA (SI-GLOSA) Signal Phase and Timing Information (SPTI)
Hazardous Location Notification (HLN)	Traffic Jam Ahead (HLN-TJA) Obstacle on the Road (HLN-OR) Stationary Vehicle (HLN-SV)

3.3 Inputs per Pilot

3.3.1 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.

3.3.2 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	

[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.

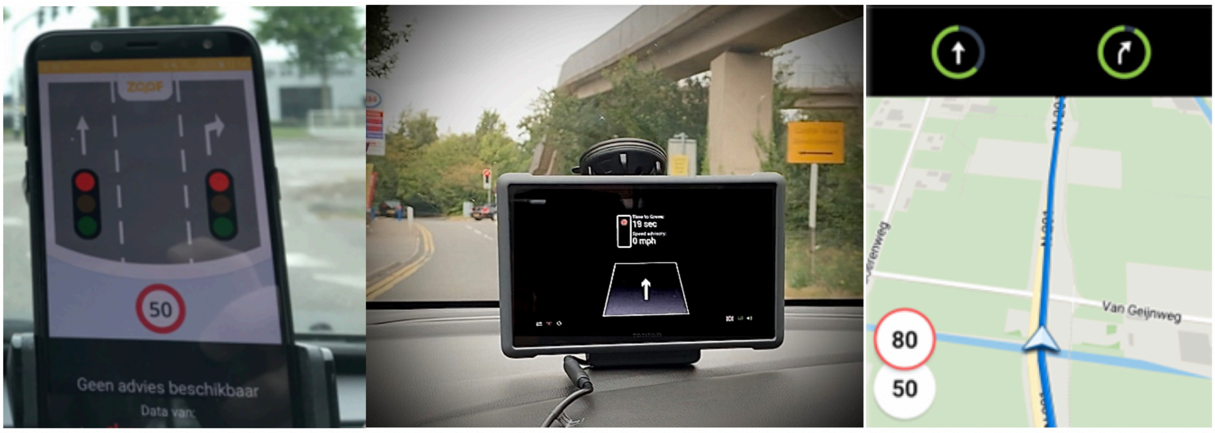

Figure 2 - Examples of different GLOSA HMI representations

4. Impact Assessment

4.1 Information gathering during C-ITS Pilots

4.1.1 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.

4.1.2 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

[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.

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.),
- 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, forexample 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 Road Works Warning

The 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.

The features of the Service RWW are currently (August 25) under revision by the C-Roads WG2. The references for the service are expected to be:

1. C-Roads WG2 - Common C-ITS Service Definitions - Version 3.0
2. C-Roads WG2 – Handbook for RWW

Changes in the content of this chapter could be determined by the finalization of the two references mentioned.

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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 2 - 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 3 - 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

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- 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 4 - 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.

[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).

- 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 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 5 - 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 6 - 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 CO2, 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 7 - 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 8 - 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)

4.3.3 Road Works Warning – Extensive Work Zone

C-Roads WG2 is currently (August 2025) 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.

4.4 In Vehicle Signage

The Service In-Vehicle Signage (IVS) currently includes, according to the WG2 list of Use Cases described in the document "Common C-ITS Service Definitions - Version 3.0", the following Use Cases:

1. Traffic Signs (Abbreviation: IVS – TS)
2. Free Text (Abbreviation: IVS – FT)
3. Smart Routing (Abbreviation: IVS – SR)

The service is intended to inform drivers on actual static or dynamic traffic signs (or additional information mimicking virtual traffic signs) via in-vehicle systems. The traffic signs can be regulatory (mandatory) or informational.

With the help of the IVS service, a more attentive driving is expected, leading to increased driver's awareness. The service is intended to determine an earlier and more comprehensive information to drivers by providing continuous signage information directly in the vehicle. This should result in better adaptation to current regulations and traffic conditions, increasing road safety.

Another benefit is the possibility to present information in the language chosen by the drivers or information only valid for the respective vehicle type (e.g., trucks), which increases the relevance of the information provided and can lead to less distraction.

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4.4.1 Use Case: Traffic Signs (TS)

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

The drivers (or driving systems) are informed, continuously and in advance, about current valid and applicable (dynamic) traffic signs, to improve traffic safety by using additional means and communication channels to inform drivers about traffic regulations and traffic advice otherwise provided via conventional signage on the road.. They can adapt their behaviour to be compliant with the applicable traffic regulations, as well as their position on the road, driving more attentive based on information received.

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 (if applicable)?
- Is the lane change manoeuvre smoother and less abrupt (if applicable)?

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

Table 9 - IVS-TS - 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 (if applicable)?	X	X	X
Is the lane change manoeuvre smoother and less abrupt (if applicable)?	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
- HMI log – Visualization and/or announcement details
- Fuel/Energy consumption – Source: Can Bus (l/100km or kWh/100km)

- Steering angle (Where applicable) – Source: Can Bus data

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 reduces sudden braking and consequent accelerations and thus limiting the creation and the propagation of shockwaves.
- Lane changes performed in advance at proper locations lead to smoother, safer manoeuvres.

Data Collection

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

Table 10 - IVS-TS - Relation between Sub Research Question for Safety and collected Data

Sub Research Question	Speed	Acceleration Deceleration	Braking power / moment of breaking	Position	Message data log	HMI log	Steering angle
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 (if applicable)?				X	X	X	X
Is the lane change manoeuvre smoother and less abrupt (if applicable)?			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 suggested speed limit is no longer relevant.
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point (if applicable)

Table 11 - IVS-TS - Relation between Field test indicator KPI for Safety and collected Data

Field test indicator KPI	Speed	Acceleration Deceleration	Braking power / moment of breaking	Position	Message data log	HMI log	Steering angle
Speed adaptation	X			X	X	X	
Speed standard deviation	X			X	X	X	
Instantaneous accelerations and decelerations		X	X	X	X	X	
Lane change point (if applicable)				X	X	X	X
Maximum steering angle (if applicable)				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 changes in driver behaviour due to C-ITS service?

Research hypotheses about Sub Research Questions

- The speed limits provided could be intended 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.
- Early lane changes and smoother manoeuvres improve flow and reduce disruptions

Data Collection

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

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Table 12 - IVS-TS - Relation between Sub Research Question for Traffic Efficiency and collected Data

Field test indicator KPI	Speed	Acceleration Deceleration	Braking power / moment of breaking	Position	Message data log	HMI log	Steering angle
Speed adaptation	x			x	x	x	
Speed standard deviation	x			x	x	x	
Instantaneous accelerations and decelerations		x	x	x	x	x	
Lane change point (if applicable)				x	x	x	x
Maximum steering angle (if applicable)				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
- Lane change point (if applicable)
- Maximum steering angle (if applicable)

Table 13 - IVS-TS - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

Field test indicator KPI	Speed	Acceleration Deceleration	Braking power / moment of breaking	Position	Message data log	HMI log	Steering angle
Speed adaptation	x			x	x	x	
Speed standard deviation	x			x	x	x	
Instantaneous accelerations and decelerations		x	x	x	x	x	
Lane change point (if applicable)				x	x	x	x
Maximum steering angle (if applicable)				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
- 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.
- 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 14 - IVS-TS - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel/Energy consumption	Speed	Acceleration Deceleration	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 suggested speed limit?	X	X		X		X
Is the lane change manoeuvre smoother and less abrupt (if applicable)?	X		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

- Maximum steering angle
- Lane change position

Table 15 - IVS-TS - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel/Energy consumption	Speed	Acceleration Deceleration	Position	Steering Angle	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
Maximum steering angle				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

4.4.2 Use Case: Free Text FT

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

The drivers are informed, with information will either reproduce what is presented on a physical VMS (e.g., variable text panel) or present a completely new message that does not mirror a physical VMS (a virtual VMS). They can adapt their driving behaviour to the applicable driving regulations, warnings, information, advice or guidance provided. This adaptation is performed 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 16 - IVS-FT - 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 17 - IVS-FT - 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 18 - IVS-FT - 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)

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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 19 - IVS-FT - 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 20 - IVS-FT - 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 21 - IVS-FT - 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 22 - IVS-FT - 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 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

4.4.3 Use Case: Smart Routing (SR)

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 23 - 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 24 - 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 25 - 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 change the distances travelled 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 26 - 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 distance travelled change?		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 27 - 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 distances		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

4.5 Hazardous Locations Notification

The Service HLN currently includes, according to the WG2 list of Use Cases described in the document "Common C-ITS Service Definitions - Version 3.0", 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 28.

Table 28 - 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)
Unsecured Bloackage of a Road, (HLN – UBR)[4]	Unsecured Bloackage of a Road, (HLN – UBR)[4]

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

[4] Location specific or Area based, according to the details of the message reported

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 can’t be directly linked to to these two 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.
- Use Case: Alert Wrong Way Driving, (Abbreviation: **HLN – AWWD**). The use case is expected to be more detailed with respect to an Area based event and referred to dynamic event (a vehicle driving wrong way), leading also to the deployment of emergency stops in a safe place.

4.5.1 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 29 - 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)

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- 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 30 - 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 31 - 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 32 - 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 33 - 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 34 - HLN - 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		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 35 - HLN - 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		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

4.5.2 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)

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4.5.3 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 Area 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/s2 – 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[5]

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)

[5] 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.

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Data Collection

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

Table 36 - 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 37 - 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:

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- 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

4.5.1 Use Case: Alert Wrong Way Driving (AWWD)

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 a vehicle that is driving in the wrong way) to raise his/her attention driving carefully and prepared, being prepared even to emergency stops in a safe place.

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 does the lane change point vary?
- Is the lane change manoeuvre smoother
- Does the time to collision increase?

The Sub Research Question are pertinent with the Impact Area 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
- Steering angle – source: Can Bus steering angle (For Location specific events only)
- Time To Collision - TTC
- 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

- Drivers can adapt their speed and trajectory, driving at the most right (right lane driving countries)
- Drivers can stop in a safe place (emergency lane, rest area, …)
- Reduced speed and increased attention while driving lead to a reduction in the risk of accident with vehicles driving wrong way

Data Collection

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

Table 38 - HLN-AWWD - Relation between Sub Research Question for Safety and collected Data

Sub Research Question	Speed	Acceleration Deceleration	Time	Position	Steering angle	Time to collision	Message data log
How does the speed change after message reception?	X	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
Does the time to collision increase?			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 hazard
- Lane change point (point where the vehicle performs the lane change manoeuvre)
- Maximum steering angle
- Time to collision

Table 39 - HLN-AWWD - Relation between Field test indicator KPI for Safety and collected Data

Field test indicator KPI	Speed	Acceleration Deceleration	Time	Position	Steering angle	Time to collision	Message data log
Average Speed	X	X	X	X			X
Lane change point			X	X	X		X
Maximum steering angle			X	X	X		X
Time to collision			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

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4.6 Signalized Intersection

The Service Signalized Intersection (SI) currently includes, according to the WG2 list of Use Cases described in the document “Common C-ITS Service Definitions - Version 3.0”, 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.

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4.6.1 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 40 - 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 41 - 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 42 - 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 43 - 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 stopping6 (with and without GLOSA)
- Time between the instant when the light turns green and the departure of the test vehicle7 (if it's the leading vehicle, that is the first vehicle stopped at the traffic light)
- Travel Time/Delay (intersection crossing time)

Table 44 - 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:

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

- Change in Bottleneck Congestion
- 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

- 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 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 45 - SI-GLOSA/SPTI - 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
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 46 - SI-GLOSA/SPTI - 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
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

4.6.2 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 47 - 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? 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[8]

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 48 - 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 49 - 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**

[8] 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.

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 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 50 - 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 51 - 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 52 - SI-TLP/EVP - 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
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 53 - 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

4.6.3 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 54 - 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

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- 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 55 - 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 56 - 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.

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Table 57 - 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 58 - 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 59 - 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 60 - 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

4.7 Point of Interests

The Service Point of Interests (POI) currently includes, according to the WG2 list of Use Cases described in the document "Common C-ITS Service Definitions - Version 3.0", this Use Case:

1. Parking Availability (POI-PA)

Guidelines for evaluation and assessment purposes are provided for this Use Case.

4.7.1 Use Case: Parking Availability Information (PA)

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 61 - POI-PA - 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 62 - POI-PA - 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?[9]						

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 63 - POI-PA - 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

[9] 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 64 - POI-PA - 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 65 - POI-PA - 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 66 - POI-PA - 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 67 - POI-PA - 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 Collective Perception

The Service Collective Perception (CP) currently includes, according to the WG2 list of Use Cases described in the document “Common C-ITS Service Definitions - Version 3.0”, the following Use Cases:

1. Collective Perception on Motorways (CP-MW)
2. Collective Perception at Urban/interurban Intersections (CP-UI)

Guidelines for evaluation and assessment purposes are provided for Collective Perception at Urban/interurban Intersections (CP-UI).

4.8.1 Use Case: Collective Perception on Urban/Interurban Intersections (UI)

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

This service delivers object perception data (about Vulnerable Road Users – VRU or objects) from infrastructure to vehicles on intersections. Drivers can benefit of an increased perception of static and dynamic obstacles present in their immediate environment. The use case is particularly valuable when the driver is distracted or in case of limited visibility. Approaching vehicles (drivers or driving systems) can adapt their speed and other behaviour quicker and thus avoid a possible collision.

Main Research Questions: Is Safety, affected by the use of this C-ITS service? Examples of Sub Research Questions

- How does the speed change immediately after message reception?
- Is driver's behaviour compliant with the warning?

The Sub Research Questions are pertinent with the Impact Area 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:

- 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

Safety

Main research question

- Is safety 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 and adjust the driving trajectory to avoid collision with VRU or object.
- If required, emergency stop can be performed to avoid collision.

Data Collection

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

Table 68 - CP-UI - 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 speed change immediately after message reception?	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:

- Average Speed - from the reception of the C-ITS message until the intersection
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Emergency stops

Table 69 - CP-UI - Relation between Field test indicator KPI for Safety and collected Data

Field test indicator KPI	Speed	Acceleration Deceleration	Braking power/ Moment of breaking	Position	Message data log
Average speed	x			x	x
Speed standard deviation	x			x	x
Instantaneous acceleration and decelerations		x		x	x
Emergency stops		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 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

4.9 Automated Vehicle Guidance

The Service Automated Vehicle Guidance (AVG) currently includes, according to the WG2 list of Use Cases described in the document “Common C-ITS Service Definitions - Version 3.0”, the following Use Cases:

1. SAE Level Guidance (AVG-SAELG)
2. Platoon Support Information (AVG-PSI)

Guidelines for evaluation and assessment purposes are provided for Automated Vehicle Guidance SAE Level Guidance (AVG-SAELG).

4.9.1 Use Case: SAE Level Guidance (SAELG)

The purpose of this use case is to provide guidance and information on the SAE levels of automation road operators consider unsuitable for partly automated vehicles (SAE levels 2, 3 and 4) on certain road or lane segments on their network, at a given point in time, considering overall road conditions and the current traffic situation.

The use case is strictly guidance, specified never to be understood as regulation or instruction. Any guidance provided is not a road operator's guarantee for safe operation of certain modes of automation nor is it a definitive statement that certain modes of automation are possible or impossible, allowed or not allowed. It is meant to aim to be an additional piece of information for the vehicle's decision-making process while engaging in modes of automation, transporting the road operator's view into the vehicle.

The objective of AVG-SAELG is to guide and inform vehicles about the road operators' assessment of currently unsuitable SAE automation levels in a specific area, and to provide detailed geographical information about the affected area as well as information about vehicles affected by this guidance: specific road segment, specific lane and specific vehicle type. The service informs vehicles about the start and end position of the guidance area, and (optionally, if available) provides additional speed recommendations for the affected road segments and lanes.

Desired behaviour for AVG-SAELG is that automated vehicles would consider the information in their driving plans (e.g., lane selection) or trajectories and in the selection of the level of automation used, and that the automated vehicle driver/operator would be informed about a change in the automation level recommendation from the infrastructure, especially when switching from higher to lower levels of automation (reasoning).

Pathway to impact

Driving automation system (levels 1 to 5) is hardware and software that are collectively capable of performing part or all of the dynamic driving task on a sustained basis. (For levels 3-5, the system is referred as Automated Driving System (ADS).) An ADS may have multiple features, each associated with a particular level of driving automation and operational design domain (ODD). ODD refers to conditions under which a given system or feature is designed to function. These conditions include e.g. environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics. (SAE 2021)

The driving behaviour of driving automation systems are likely to differ from human drivers. The system may drive using e.g. different headway in car-following situations and/or have different target speed. These differences affect traffic flow, road capacity and environmental impact of traffic. Additionally, the perception of the surrounding traffic situation may be affected by use of driving automation. Driving automation is expected to improve traffic safety. On the other hand, automation also poses new situations such as take-over control situations and transitions to minimal risk condition which may lead to new causes of accidents.

Different driving automation systems and features have different operational design domains (ODD). Whether the vehicle is within the ODD is currently defined based on information from the sensors in the vehicle and information received from the backend. The AVG-SAELG service aims to provide additional information in terms of guidance, not as regulation or instruction. Therefore, it left to driving automation system whether to use this information or not.

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It can be hypothesised that the AVG-SAELG service is most effective when guiding certain level of automation not to be used on a certain road section or lane when combined with named reasons for this guidance. In case the automated vehicle that is approaching this area is not aware of the potential ODD exit, it could make a take-over request to the user or initiate the transition to minimal risk condition earlier than without this service. The same holds for situations within the area where driving automation is guided not to be used in case the vehicle was not already aware of the condition leading to ODD exit. It seems very unlikely that an automated vehicle outside its ODD would allow automation based on this information alone – and if it would do so, the quality of information should be extremely high. Therefore, it is likely that the service would lead to (small) reductions in vehicle kilometres travelled with automation, not to an increase.

Traffic efficiency and environmental impacts result from the differences between the having driving automation being used in the fleet (effect size) and vehicle-kilometres travelled with driving automation (exposure). Traffic safety impact is result of both differences in accident risk and consequences between driving automation system and human driver, and on the frequency of take-over situations and transitions to minimal risk conditions and the additional risk posed by these new situations.

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

- Are the vehicle kilometres travelled per level of automation affected?
- Is the frequency of take-over requests affected?
- Is the location (urgency) of take-over requests affected?

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

Table 70 - AVG-SAELG - Relation between Sub Research Question and Impact Areas

Examples of Sub Research Questions	Safety	Traffic Efficiency	Environment
Is vehicle-km travelled per level of automation affected?	X	X	X
Is the frequency of take-over requests affected?	X		
Is the location (urgency) of take-over requests affected?	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:

- Driving automation system log (timing of take-over request, and transitions of control between driving automation and the user) – source: Driving automation system log
- Position – source: GPS data
- Speed – source: Can Bus data or GPS data
- Headway – source: Vehicle sensor data
- C-ITS message log (content, timing and position of the reception, etc.) – source: Vehicle ITS station log

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Safety

Main research question and its sub-questions

- Is safety affected by providing guidance and information on the SAE levels of automation road operators consider unsuitable for partly automated vehicles with a C-ITS service?
  - Is safety affected by a change in the vehicle kilometres travelled per level of automation?
  - What is the impact of the use of driving automation on accident risk per vehicle-km travelled?
  - What is the impact of a single take-over request situation on safety (per sub-type of situation)?
  - Is safety affected by a change in the frequency of take-over requests?
  - Is safety affected by a change in the location (urgency) of take-over request?

Sub-research-questions #2 and #3, related to differences in scenarios with and without driving automation, are not directly related to the C-ITS system under evaluation. However, to understand the impact of the service, the answers to these questions must be known, too.

Research hypotheses about Sub Research Questions

- Received information affects VKT when driving automation is used.
- Received information affects the frequency of take-over requests.
- Received information affects the location (urgency) of take-over requests, and consequently the frequency of transition to minimal risk condition.

Data Collection

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

Table 71 - AVG-SAELG - Relation between Sub Research Question for Safety and collected Data

Sub Research Question	Driving automation system log	Position	Speed	Headway	C-ITS message log
Is safety affected by a change in the vehicle kilometres travelled per level of automation?	X	X			X
What is the impact of the use of driving automation on accident risk per vehicle-km travelled?	X	X	X	X	
What is the impact of a single take-over request situation on safety?	X	X	X	X	
Is safety affected by a change in the frequency of take-over requests?	X	X			X
Is safety affected by a change in the location (urgency) of take-over requests?	X	X			X

Field Test Indicator/KPI

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

- Distance driven with driving automation – from driving automation system logs and position data (vehicles with and without C-ITS service)
- % of take-over requests initiated due to C-ITS message – from C-ITS and driving automation system logs (vehicles with C-ITS service)
- Number of take-over requests per distance driven - from driving automation system logs and position data (vehicles with and without C-ITS service)
- Frequency of safety critical situations – from accident data or speed and headway data, driving automation system logs (automated and non-automated vehicles)
- Location of take-over requests - from C-ITS and driving automation system logs and position data (vehicles with and without C-ITS service)

Table 72 - AVG-SAELG - Relation between Field test indicator KPI for Safety and collected Data

Field test indicator KPI	Driving automation system log	Position	Speed	Headway	C-ITS message log
Distance driven with driving automation	x	x			
% of take-over requests initiated doe to C-ITS message	x				x
Number of take-over requests per distance driven	x	x			
Frequency of safety critical situations	x	x	x	x	
Location of take-over requests	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 providing guidance and information on the SAE levels of automation road operators consider unsuitable for partly automated vehicles with a C-ITS service?

- Is traffic efficiency affected by a change in the vehicle kilometres travelled per level of automation?
- What is the impact of the use of driving automation on delays (per vehicle-km travelled)?
- What is the impact of the use of driving automation on the % of time spent in car-following?

Sub-research-questions #2 and #3, related to differences in scenarios with and without driving automation, are not directly related to the C-ITS system under evaluation. However, to understand the impact of the service, the answers to these questions must be known, too.

Research hypotheses about Sub Research Questions

- Received information affects vehicle-kilometres travelled when driving automation is used.
- Use of driving automation affects delays in traffic.
- Use of driving automation affects time spent in car-following.

Data Collection

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

Table 73 - AVG-SAELG - Relation between Sub Research Question for Traffic Efficiency and collected Data

Sub Research Question	Driving automation system log	Position	Speed	Headway	C-ITS message log
Is traffic efficiency affected by a change in the vehicle kilometres travelled per level of automation?	**x**	**x**			**x**
What is the impact of the use of driving automation on delays (per vehicle-km travelled)?	**x**	**x**	**x**	**(x)***	
What is the impact of the use of driving automation on the % of time spent in car-following?	**x**	**x**		**x**	

* needed if efficiency impact is simulated

Field Test Indicator/KPI

- Distance driven with driving automation – from driving automation system logs and position data (vehicles with and without C-ITS service)
- Delay per vehicle-km travelled – speed data, speed limit data, driving automation log (with and without driving automation)
- % of time spent in car-following – headway data, driving automation log (with and without driving automation)

Table 74 - AVG-SAELG - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

Field test indicator KPI	Driving automation system log	Position	Speed	Headway	C-ITS message log
Distance driven with driving automation	x	x			x
Delay per vehicle-km travelled	x	x	x		
% of time spent in car-following	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 environmental impact of transport affected by providing guidance and information on the SAE levels of automation road operators consider unsuitable for partly automated vehicles with a C-ITS service?
    - Is environmental impact of transport affected by a change in the vehicle kilometres travelled per level of automation?
    - What is the impact of the use of driving automation on emissions (per vehicle-km travelled)?
    - What is the impact of the use of driving automation on energy demand (per vehicle-km travelled)?

Sub-research-questions #2 and #3, related to differences in scenarios with and without driving automation, are not directly related to the C-ITS system under evaluation. However, to understand the impact of the service, the answers to these questions must be known, too.

Research hypotheses about Sub Research Questions

- Received information affects vehicle-kilometres travelled when driving automation is used.
- Use of driving automation affects emissions per vehicle-km travelled.
- Use of driving automation affects energy demand per vehicle-km travelled.

Data Collection

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

Table 75 - AVG-SAELG - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Driving automation system log	Position	Speed	Headway	C-ITS message log
Is environmental impact of transport affected by a change in the vehicle kilometres travelled per level of automation?	X	X			X
What is the impact of the use of driving automation on emissions (per vehicle-km travelled)?	X	X	X		
What is the impact of the use of driving automation on energy demand (per vehicle-km travelled)?	X	X	X		

Field Test Indicator/KPI

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

- Distance driven with driving automation – from driving automation system logs and position data (vehicles with and without C-ITS service)
- Amount of emissions per vehicle-km travelled – from speed pattern and position data (with and without driving automation)
- Energy demand by vehicle-km travelled – from speed pattern and position data (with and without driving automation)

Table 76 - AVG-SAELG - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Driving automation system log	Position	Speed	Headway	C-ITS message log
Distance driven with driving automation	X	X			X
Amount of emissions per vehicle-km travelled	X	X	X		
Energy demand by vehicle-km travelled	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 fuel/energy consumption
- Change in noise pollution
- Change in polluting emissions

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
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

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.

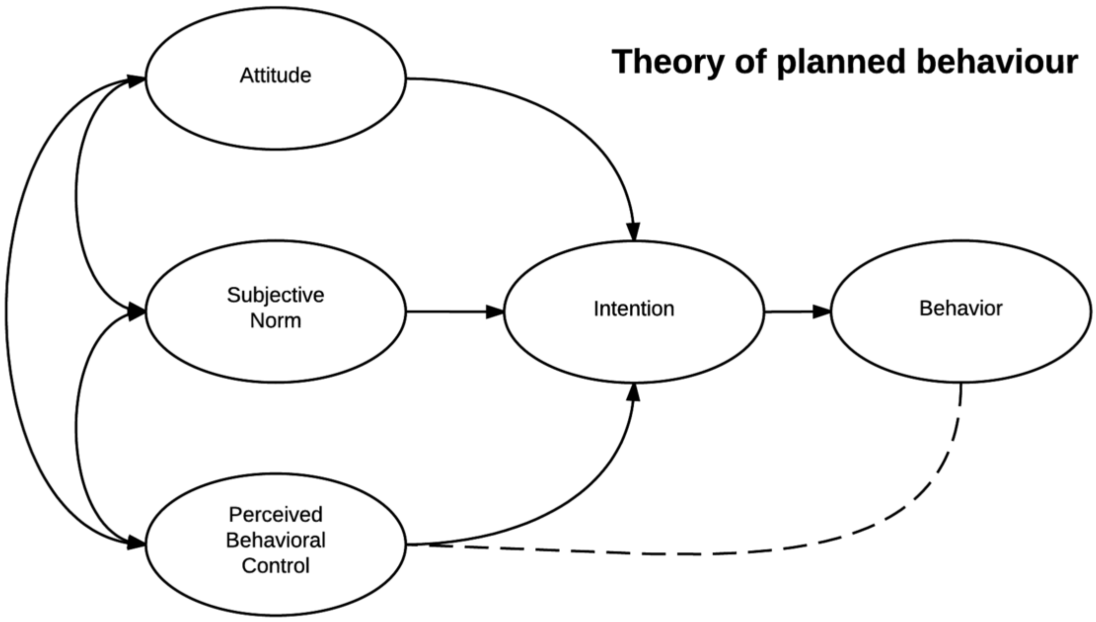
In the field of ITS, Ausserer and Risser (2005) define acceptance as a phenomenon that reflects to what extent potential users are willing to use a certain system. Hence, acceptance is linked closely to usage, and acceptance will depend on how user needs are integrated into the development of the system. 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.

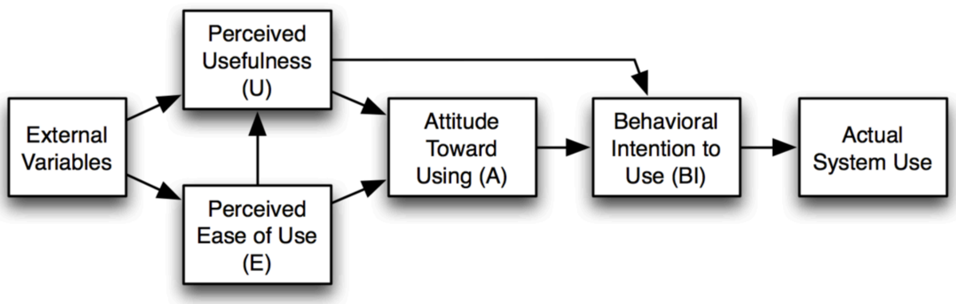
Theories and approaches in User Acceptance

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.

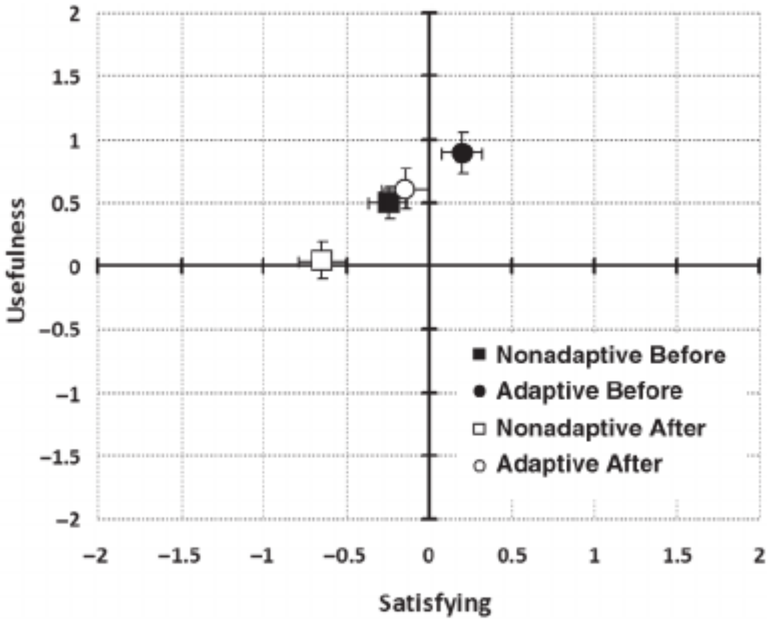
TPB has been used successfully to predict behaviour in a wide variety of applied research settings within different domains, including several studies dealing with driving behaviour and traffic safety, such as the effects of drinking and driving (Aberg, 1993; Parker et al., 1992a), driving violations (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.



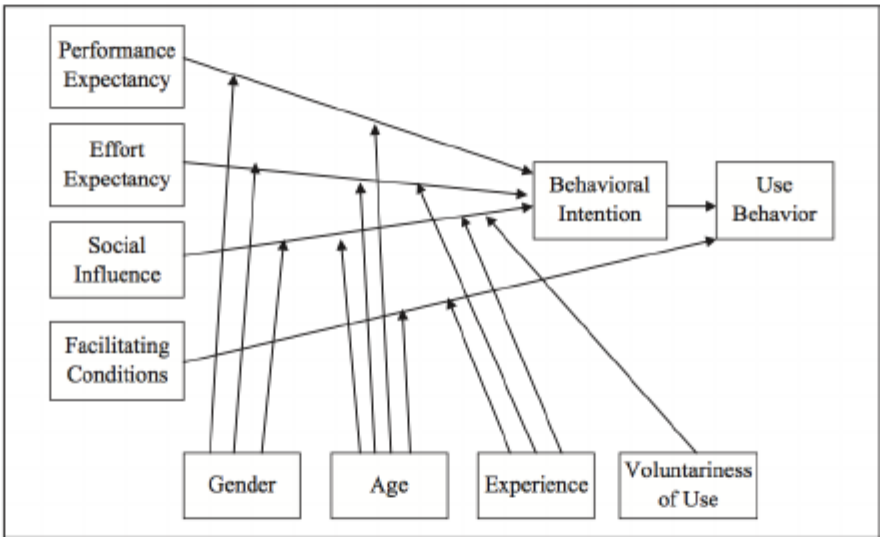
Another successful model is the Technology Acceptance Model (TAM) (Davis et al., 1989). TAM was designed to predict information technology acceptance and usage on the job. TAM assumes that perceived usefulness and perceived ease of use determine an individual's intention to use a system with the intention 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).



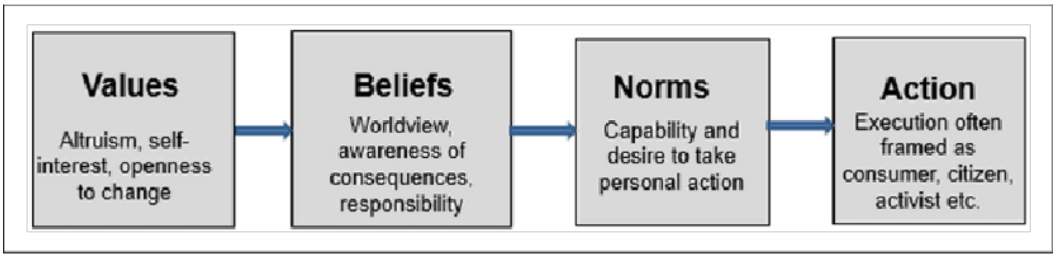
Van der Laan et al. (1996) published a simple method to define acceptance. Acceptance is measured by direct attitudes towards a system and provides a system evaluation in two dimensions. The technique consists of nine rating-scale items. These items are mapped on two scales, the one denoting the usefulness 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.



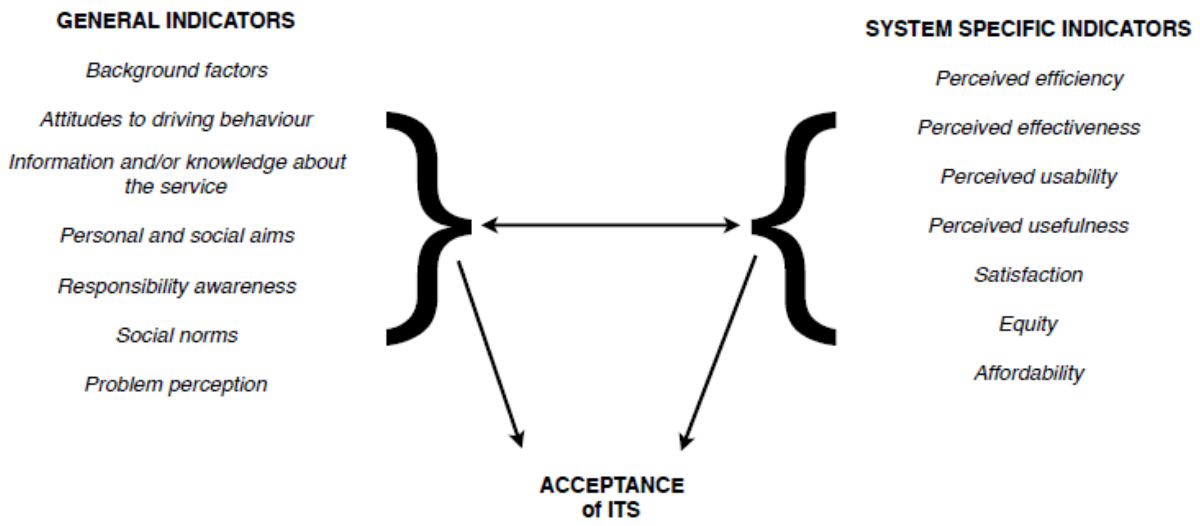
Stern (2000) developed the value–belief–norm (VBN) theory to examine which factors are related to acceptability of energy policies. Stern and colleagues proposed the VBN theory of environmentalism to explain environmental behaviour, including the acceptability of public policies. They proposed that environmental 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
C-ITS better than other info
Fuel consumption
Traffic efficiency
Safety
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
Completeness
Correctness
Accuracy
Consistency
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
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
Good
Effective

Assisting
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
Nice
Likeable
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.

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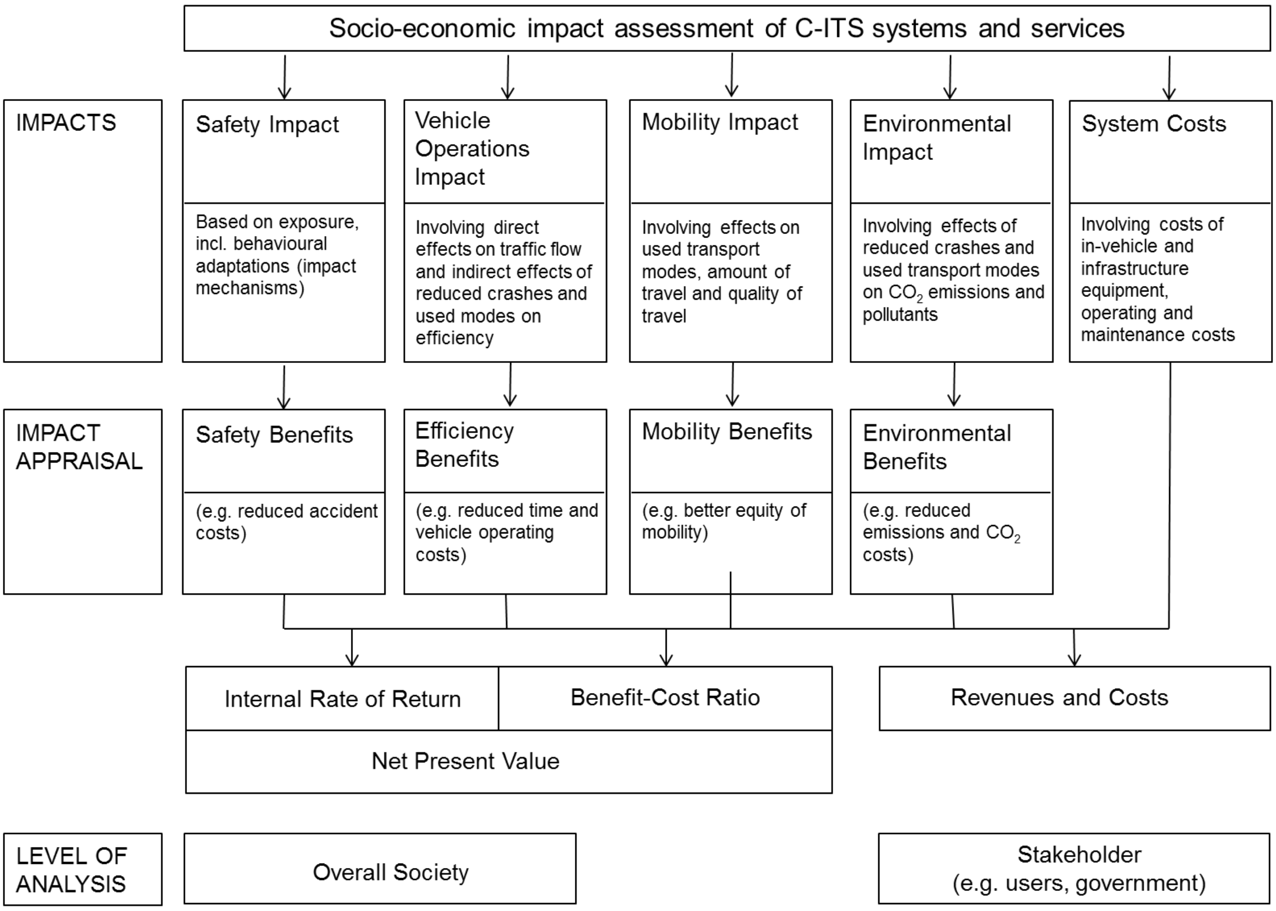

Figure 3 - Examples of the scope of impacts with-in socio-economic assessment (Modified from Figure in FESTA Handbook (2018))

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.

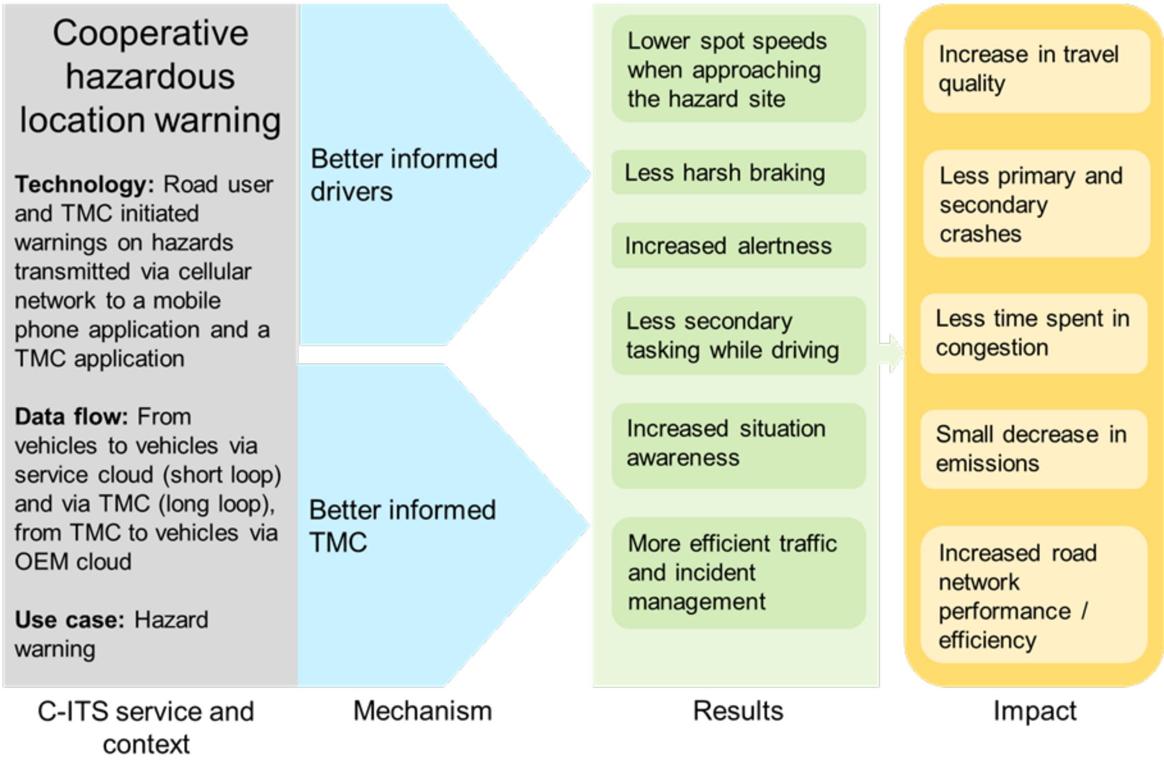

Figure 4 - Program theory of the C-ITS service 'Cooperative hazardous location warning' in the Finnish pilot in NordicWay (Innamaa et al. 2017)

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).

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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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