Evaluation and Assessment Plan

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Working Group 3 – Evaluation and Assessment
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List of Authors

Name	Member State
Luca Studer	I
Alexander Frötscher	A
Gary Crockford	UK
Paolo Gandini	I
Giovanna Marchionni	I
Bart Netten	NL
Sven Vlassenroot	B
HenkJan Kwakernaat	NL
Walter Zimmermann	A
Paul Wadsworth	UK
Sara Gutiérrez Lanza	E
Satu Innamaa	FI
Anna Schirokoff	FI
Lone Dörge	DK
Daniela Carvalho	P
Rudi Tegenbos	B
Gérard Chalhoub	F
Torsten Geißler	D
Bojan Merlin	SLO
Louis Nelen	B
Miroslav Vanis	CZ
José Ignacio Herrero Zarzosa	E
Ádám Nagy	H
Hasnaa Aniss	F
Marie Christine Esposito	F
Arthur Burianne	F
Jonathan Mann	UK

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1. Introduction

Scope of the document

This "Evaluation and Assessment Plan" fulfills the first milestone (M15) for C-Roads Working Group 3 (WG3) – Evaluation and Assessment – and describes the currently available documentation and assessment dimensions in C-Roads in regard to evaluation, Pilots and policy objectives that need to be targeted in the pilot phase of C-Roads.

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

- User Acceptance
- Safety
- Traffic efficiency
- Environment
- Organizational

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 in order to be able to fulfill 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 allows 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 or DENM) is a required basis for the service evaluation. It should also be noted that guidelines for Technical Evaluation/Functional Validation are the charge of WG2 – Task Force 5 (validation of C-ITS services) and individual pilots for ensuring their C-ITS system is functioning correctly before attempting evaluation.

Some documents of the service specifications are currently not completely finished and the inclusion of their additional output should be taken into consideration at a later point.

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 fulfillment of this task consists of Partners from all core Member States, plus a significant number of supporting persons[1].

Table 1 below gives an overview of the impact areas that will be faced by the different Pilot Studies, as planned in March 2018.

[1] https://www.c-roads.eu/nextcloud/index.php/s/LNKHnhQ8BuShJqa

Table 1 - Involvement of the Pilots in the Impact Areas

Pilot	Impact Areas				
	Organizational impacts[2]	User Acceptance	Safety	Traffic Efficiency	Environment
I	(+)	(+)	++	++	++
A		+	++	++	+
UK	+	++	+	+	+
NL		++	++	+	+
H		++	++	+	(+)
CZ	(+)	++	+	+	+
E		+	+	+	+
B/FL		++	++	+	(+)
B/W		++	++	+	+
D		+	+	++	+
F	++	++	++	++	(+)
NordicWay		++	++	+	+
NordicWay 2		++	(+)	(+)	(+)
P		+	++	+ +	+
SLO		+	+	+	(+)

Table legend:

- "++": Primary evaluation area for the Pilot.
  It implies a major effort and involvement in the evaluation of the impact area.
- "+": Secondary evaluation area for the Pilot.
  It implies a minor effort and involvement in the evaluation of the impact area.
- "(+)": Further internal investigation needed to confirm the symbol reported.
- Empty cell: impact area not investigated by the Pilot.

Milestones to be fulfilled by Working Group 3

Number	Date	Description
M15	Q1/2018	Evaluation and assessment plan
M32	Q4/2020	Detailed evaluation report

Future activities of C-Roads Working Group 3

Next steps of WG3 activities will focus on the completion of the common report template intended to facilitate an overview of the evaluation results across different pilots and the provision of a final C-Roads final report.

[2] Organizational impacts are related to management of road infrastructures by road operators. Further details regarding this topic will be analyzed by WG3 in its next activities.

Another planned action is the definition of a common base questionnaire for the evaluation of user acceptance, to provide a minimum set of questions that Pilots should consider.
Finally, further details and indication will be provided for the evaluation and assessment of Organizational impacts and Socio-Economic impacts. About this last topic, the first theoretical elements are presented in Annex 5.

This document remains open to new inputs and specification arising from WG2 activities. The evaluation approach for other Day 1 – Services and Use Cases will be further developed and presented in new releases of this document. A further deepening for the assessment of Key Performance Indicators on mobility and economic impacts, as descripted in the next chapters, will be provided.

Glossary

Following terminology is used in this deliverable. Any further discussions and considerations are provided in the referenced sections.

Term	Interpretation for application in WG3
Evaluation	Systematic and objective process of testing a system under different events and situations and measuring the (key) performance indicators. The objective is to compare the indicator values against standards, metrics or benchmarks or selected baseline
Assessment	Process of understanding and qualifying the functionality and behavior of the tested and evaluated systems and behavior of their users in relation to the impact areas. The objective is to improve the organizational, deployment and operational aspects and the specifications and to understand the implications of the service use.
Benchmark	Test protocol for measuring the functionality and performance of a service or system, and the minimum requirements as a reference point for accepting the service or system as successful and sufficiently conform and interoperable.
Interoperability	Ability of a communication unit, application or system to operate C-ITS services with those from different make or type, service or Pilot or administrative regions, without any (re)configuration or action.
User Acceptance	User acceptance is defined as a phenomenon that reflects the extent to which potential users are willing to use a certain system. User acceptance will be influenced by different parameters like usability, usefulness, satisfaction, etc.
C-ITS "Day 1 - Services"	Set of C-ITS services based on the implementation of standard messages (CAM, DENM, IVI and TLM & RLT) and mentioned in the phase one report of the EU C-ITS platform and further developed in detail in the C-Roads document releases of the Infrastructure communication profile. (release 1.0 from 14.09.2017 – available at https://www.c-roads.eu/fileadmin/user_upload/media/Dokumente/C-Roads-publishes_C-ITS_interface_specifications.pdf)

2. Plan structure

After the introductive part (Chapter 1) and a brief state of the art (Chapter 3), this Plan covers the various aspects of **User Acceptance** in Chapter 4, 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 from many factors. Additionally, social contexts in many transport environments, and - especially - service information concerning usability, usefulness of C-ITS services, user satisfaction are part of the assessment of user acceptance in C-ITS.

In Chapter 5 of the Plan the main areas of evaluation for C-ITS services are considered and covers the following policy objectives as impact areas in the Pilots:

- Road Safety
- Traffic efficiency
- Environment

These three areas of investigation are the main topic of C-ITS **Impact Assessment**, which needs to be addressed in this Plan and covers a defined approach how to achieve this for the "Day 1 C-ITS service list", based on service description from the document C-Roads "Common C-ITS Service Definitions - Version 1.4", released in early 2018, for every of the four subgroups of the Day 1 – Services. These Groups are RWW – Road Works Warning, IVS – In Vehicle Signage, HLN – Hazardous Location Notification and SI – Signalized Intersection.

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

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

3. Status 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. The most recent version of the FESTA handbook is Version 7 (FOT-Net 2017). 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 (behavioral) 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).

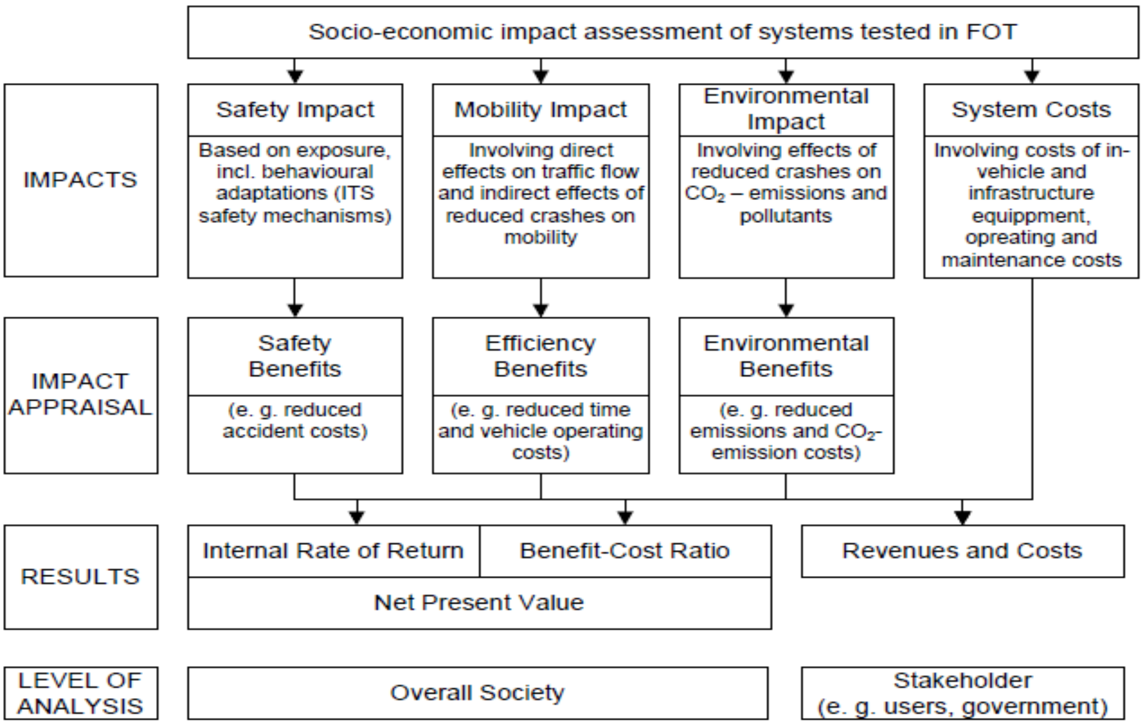

Figure 1 - Scope of impact assessment incl. socio-economic impact assessment (FOT-Net 2017)

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

Table 2 - Mapping of studied impacts to impact areas

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

4. User Acceptance

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-Road 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 (behavior)?
- 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 behavior (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 **Behavioral 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 behavior. 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 behavior or perceived changes in behavior. The change in behavior 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 behavioral intentions of the test users.

Preparing the research approach

Considering contextual aspects

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

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

- How the information will be displayed: Text, symbols, combination of text and symbols, the overall screen layout and allowed user interactions from the HMI.
- How the information will be 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 basic information will be reported to the driver: Speed limits, traffic signs, warnings, etc.
- 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 favor acceptance or by the contrary favor 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 tool", an inventory tool is proposed.

Frequency of measuring a priori acceptability, acceptance and appropriation

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

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

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

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

Defining topics that are part of the survey

These main topics should be covered in the questionnaire:

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

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

- **Use case service information**

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

Combining survey data with logged data

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

- Theory of planned behavior (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 your 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.

Detailed description of acceptance indicators

General (social) information

These questions are more related to the background factors of the user. These background factors can have an influence on the acceptance and driving behavior 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 signs 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 behavior**
    - Vehicle choice (brand, power, options like cruise control, ACC, etc.)
    - Driving style (as based on driving behavior 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 behavior
        - 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) 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 behavior).

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

General service information (and expectations)

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

Perceived efficiency

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

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

- Reduce fuel consumption
- Increase traffic efficiency
- Increase safety
- Avoiding tickets
- Reduce speeding

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 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 you would be willing to use the service?
-

Specific Questions, related to the use cases

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

Perceived effectiveness

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

Setup: Questions on C-ITS on the system performance

Availability:

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

Correctness:

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

Completeness:

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

Consistency:

- Was the service consistent and easy to understand when the service was active?
- Degree of consistency for the different use cases

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

Accuracy

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

Up-to-datedness

- Was the service up-to-date? Was the service available right on time
- Degree of up-to-datedness 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 analyzed by WG3 in its next activities.

5. Impacts Assessment

Information gathering during C-ITS Pilots

Evaluation of C-ITS impact in relation to baseline development

A core objective of Pilots is to better understand the effects of providing C-ITS services. This necessitates an impact evaluation approach that can compare the observed pattern of behavior 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.
So, 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's 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.

So, 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, that is traffic efficiency (such as traffic flow, density, speed, gaps etc.), traffic safety (such as speed, brakes, driver awareness etc. and the overall indicators such as number of crashes, injuries and fatalities) and also environmental issues (such as noise, pollution, CO_2 emissions etc.), are constantly changing, alone and without any C-ITS-involvement.

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

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

Involvement of planned user vehicles

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

Monitoring of unplanned user vehicles

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

General Approach

During the field tests, it will be possible to measure or calculate different parameters that can reveal a different behavior of the driver because of the receipt of information via C-ITS. Basically, just User Behavior 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 Behavior, 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

Insight analysis on safety could be addressed to the evaluation of distraction.
The data sources may include Vehicle ITS-Station, CAN Bus data[3], 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 analyzing possible effects of C-ITS Day 1 Services. To investigate the distraction gaze behavior measures could be used, as well as other indicators related to the psychophysical conditions of the drives. Those measures may be obtained by using eye or head tracking system, but also other useful information could be recorded by other wearable tools. Since this technology is relatively expensive and its use in field test is challenging, controlled studies using an instrumented vehicle in real road or test truck, using a driver simulator or any laboratory device may be conducted.

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

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

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 behavioral 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 modeling, 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 behavior because of warnings/information given by the service?
  The way the driver changes the driving behavior following the indication coming from the C-ITS is described;
- Sub Research Questions.
  The changes of the parameters that characterize the different driver behavior are investigated.
- Data collection (logging needs).
  Data/parameters that should be collected to be able to measure/calculate the changes in driver behavior 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 modeling 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 road accident resulting in death or injuries numbers”.
  Different scenarios could be developed considering different temporal checkpoints, for example 2025 and 2030.

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

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

Day 1 Service: Road Works Warning

The Day 1 Service Road Works Warning (RWW) currently includes, according to the WG2 list of Use Cases described in the document “Common C-ITS Service Definitions - Version 1.4”, 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)

For evaluation and assessment purposes, 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 behaviors
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 and beside warnings inviting to cautious driving, a lane change.
- Use Case related to **Area based events,** managed by more general messages, providing warnings inviting to cautious driving.

Based on this distinction, the Use Cases can be thus grouped as reported in Table 3.

Table 3 - Clusters of RWW Use Cases

Location specific events	Area based events
Lane Closure (and other restrictions), (RWW – LC)	
Road Closure, (RWW – PC)	
Road Works - Mobile, (RWW – RM)	

The investigation of the impact areas Safety, Traffic Efficiency and Environment is similar for both the clusters of Use Cases, despite for the analysis of issues related to lane change maneuvers, expected for “Location specific events” and not expected for “Area based events”.
For each impact area, the issue related to change lane are thus referred to as punctual events, as specified in the text.

All Use Cases

Top Research Question: How do drivers change their behavior 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 maneuver 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 behavior of the driver and the advice given by road side systems? Is the speed of test vehicles with the service different from the average speed in the section(s)?*
- How does the lane change point vary?
- Is the lane change maneuver smoother? *Do drivers make fewer sudden steering movements? Is the acceleration/deceleration of the vehicle lower? In any direction?*

Table 4 - 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 maneuver 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 behavior 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 maneuver (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother maneuver 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 5 - 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 maneuver smoother?		X		X	X	X

Field Test Indicator/KPI

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

- Speed adaptation (difference between the average speed of the vehicle and the speed limit suggested) - from the reception of the C-ITS message until the position of the hazard
- Travel Time / Average Speed - from the reception of the C-ITS message until the position of the hazard
- Maximum speed
- Speed standard deviation
- Instantaneous accelerations and decelerations
- Lane change point[4] (point where the vehicle performs the lane change maneuver - For Location specific events only)

[4] 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).

- Maximum steering angle (For Location specific events only)

Table 6 - 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 reduced sudden and relevant braking when the event is reached, thus more fluent traffic conditions.
- The speed limit, besides a more regular driving, involves smoother maneuvers 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 maneuver (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother maneuver 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 7 - 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 maneuver 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 8 - 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 behavior due to C-ITS service?

Research hypotheses about Sub Research Questions

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel consumption and therefore lower CO_2, pollutants and noise emissions.
- Higher compliance with speed limits leads to traffic condition more suitable for a section interested by road works, reducing sudden braking and consequent accelerations and thus limiting CO_2, pollutants and noise emissions.
- A lane change in a proper location leads to a more regular maneuver (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother maneuver 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 9 - RWW - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 maneuver 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 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 10 - RWW - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel 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 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 consumption

Day 1 Service: In Vehicle Signage

The Day 1 Service IVS currently includes, according to the WG2 list of Use Cases described in the document “Common C-ITS Service Definitions - Version 1.4”, the following Use Cases:

1. Dynamic Speed Limit Information (Abbreviation: IVS – DSLI)
2. Embedded VMS “Free Text” (Abbreviation: IVS – EVFT)
3. Other Signage Information (Abbreviation: IVS – OSI)
4. Dynamic Lane Management (Abbreviation: IVS – DLM)

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

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

In particular:

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

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

Use Case: In-vehicle signage Dynamic Speed Limit Information

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

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

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

Examples of Sub Research Questions

- How do the instant speed fluctuations change?
  Do drivers apply the break earlier, do drivers lift off the accelerator earlier, do vehicles slow earlier, do drivers apply the break less sharply?
- Is driver's speed more compliant with speed limit?
  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)

Table 11 - IVS-DSLI - Relation between Sub Research Question and Impact Areas

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

Data Collection

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

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

Safety

Main research question

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

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 12 - IVS-DSLI - Relation between Sub Research Question for Safety and collected Data

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

Field Test Indicator/KPI

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

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

Table 13 - IVS-DSLI - Relation between Field test indicator KPI for Safety and collected Data

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

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

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

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

Traffic Efficiency

Main research question

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

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 14 - IVS-DSLI - Relation between Sub Research Question for Traffic Efficiency and collected Data

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

Field Test Indicator/KPI

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

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

Table 15 - IVS-DSLI - 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 behavior due to C-ITS service?

Research hypotheses about Sub Research Questions

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel consumption and therefore lower CO_2, pollutants and noise emissions.
- Higher compliance with 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 16 - IVS-DSLI - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 suggested speed limit?	X	X		X	X

Field Test Indicator/KPI

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

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

Table 17 - IVS-DSLI - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel consumption	Speed	Acceleration Deceleration	Position	Message data log
Speed standard deviation		X		X	X
Instantaneous accelerations and decelerations			X	X	X
Fuel 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 consumption
- Change in polluting emissions

Use Case: In-vehicle Signage Embedded VMS "Free Text"

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

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

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

Examples of Sub Research Questions

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

Table 18 - IVS-EVFT - Relation between Sub Research Question and Impact Areas

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

Data Collection

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

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

Safety

Main research question

- Is safety affected by changes in driver behavior 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 19 - IVS-EVFT - Relation between Sub Research Question for Safety and collected Data

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

Field Test Indicator/KPI

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

Table 20 - IVS-EVFT - Relation between Field test indicator KPI for Safety and collected Data

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

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

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 behavior 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 21 - IVS-EVFT - Relation between Sub Research Question for Traffic Efficiency and collected Data

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

Field Test Indicator/KPI

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

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

Table 22 - IVS-EVFT - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

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

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

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

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

Environment

Main research question

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

Research hypotheses about Sub Research Questions

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel 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 23 - IVS-EVFT - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 consumption
- Speed adaptation (difference between the average speed of the vehicle and the speed limit)
- Noise level

Table 24 - IVS-EVFT - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel consumption	Speed	Acceleration Deceleration	Position	Message data log
Speed standard deviation		X		X	X
Instantaneous accelerations and decelerations			X	X	X
Fuel 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 consumption
- Change in polluting emissions

Use Case: In-vehicle Signage Other Signage Information

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

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

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

Examples of Sub Research Questions

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

Table 25 - IVS-OSI - Relation between Sub Research Question and Impact Areas

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

Data Collection

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

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

Safety

Main research question

- Is safety affected by changes in driver behavior 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 26 - IVS-OSI - Relation between Sub Research Question for Safety and collected Data

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

Field Test Indicator/KPI

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

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

Table 27 - IVS-OSI - Relation between Field test indicator KPI for Safety and collected Data

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

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

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

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

Traffic Efficiency

Main research question

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

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 28 - IVS-OSI - Relation between Sub Research Question for Traffic Efficiency and collected Data

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

Field Test Indicator/KPI

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

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

Table 29 - IVS-OSI - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

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

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

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

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

Environment

Main research question

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

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 30 - IVS-OSI - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 consumption
- Speed adaptation (difference between the average speed of the vehicle and the speed limit)
- Noise level

Table 31 - IVS-OSI - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel consumption	Speed	Acceleration Deceleration	Position	Message data log
Speed standard deviation		x		x	x
Instantaneous accelerations and decelerations			x	x	x
Fuel 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 consumption
- Change in polluting emissions

Use Case: In-vehicle Signage Dynamic Lane Management

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

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

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

Examples of Sub Research Questions

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

Table 32 - IVS-DLM - Relation between Sub Research Question and Impact Areas

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

Data Collection

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

- Vehicle speed - source: Can Bus data or GPS data (m/s – resolution 1Hz)
- Acceleration/Deceleration – source: Can Bus data or GPS data (m/s^2 – resolution 1Hz)
- Braking power, moment of breaking – source Can Bus data
- Vehicle position – source: GPS data

- C-ITS message data log (content, timing and position of the reception, etc.) and HMI (visualization and/or announcement) data log – source: vehicle ITS station or mobile device
- Fuel consumption – source: Can Bus data (l/100km)

Safety

Main research question

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

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 33 - IVS-DLM - Relation between Sub Research Question for Safety and collected Data

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

Field Test Indicator/KPI

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

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

Table 34 - IVS-DLM - Relation between Field test indicator KPI for Safety and collected Data

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

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

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

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

Traffic Efficiency

Main research question

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

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 35 - IVS-DLM - Relation between Sub Research Question for Traffic Efficiency and collected Data

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

Field Test Indicator/KPI

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

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

Table 36 - IVS-DLM - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

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

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

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

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

Environment

Main research question

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

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 37 - IVS-DLM - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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?	X	X		X			X
How does the lane change point vary?	X				X	X	X
Is the lane change maneuver smoother?			X		X	X	X

Field Test Indicator/KPI

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

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

Table 38 - IVS-DLM - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel 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 consumption	X	X	X				X
Noise level		X	X				X
Maximum steering angle						X	X
Speed adaptation		X		X			X
Lane change point					X	X	X

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

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

- Change in traffic CO_2 emissions
- Change in noise pollution
- Change in fuel consumption
- Change in polluting emissions

Day 1 Service: Hazardous Locations Notification

The Day 1 Service HLN currently includes, according to the WG2 list of Use Cases described in the document “Common C-ITS Service Definitions - Version 1.4”, the following Use Cases:

1. Accident Zone, (Abbreviation: HLN – AZ)
2. Traffic Jam Ahead, (Abbreviation: HLN – TJA)
3. Slow or Stationary Vehicle, (Abbreviation: HLN – SSV)
4. Weather Condition Warning, (Abbreviation: HLN – WCW)
5. Temporarily Slippery Road,(I2V), (Abbreviation: HLN – TSR)
6. Animal or Person on the Road (I2V), (Abbreviation: HLN – APR)
7. Obstacle on the Road (I2V), (Abbreviation: HLN – OR)

For evaluation and assessment purposes, 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 39.

Table 39 - Clusters of HLN Use Cases

Location specific events	Area based events
Slow or Stationary Vehicle, (OHLN – SSV)	Accident Zone, (OHLN – AZ)
Temporarily Slippery Road, (I2V) (OHLN – TSR)	Traffic Jam Ahead, (OHLN – TJA)
Obstacle on the Road (I2V), (OHLN – OR)	Weather Condition Warning, (OHLN – WCW)
	Animal or Person on the Road (I2V), (OHLN – APR)

The investigation of the impact areas Safety, Traffic Efficiency and Environment are similar for both the clusters of Use Cases, except for the analysis of issues related to lane change maneuvers, which apply for “Location specific events” and so not apply for “Area based events”. For each impact area, the issue related to a lane change are thus referred to punctual events, as specified in the text.

All Use Cases

Top Research Question: How do drivers change their behavior 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 behavior 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 maneuver 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 behavior 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 maneuver 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?

Table 40 - 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 maneuver smoother (if the lane of the event is specified)?	**X**	**X**	**X**
Does the average speed decrease?	**X**	**X**	**X**

Data Collection

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

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

Safety

Main research question

- Is safety affected by changes in driver behavior 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 maneuver (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother maneuver 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 41 - 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 maneuver 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 maneuver - For Location specific events only)
- Maximum steering angle (For Location specific events only)

Table 42 - 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 maneuvers 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 maneuver (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother maneuver 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 43 - 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 maneuver 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 44 - 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 behavior due to C-ITS service?

Research hypotheses about Sub Research Questions

- More homogeneous speeds and reduced acceleration and deceleration phases lead to lower fuel consumption and therefore lower CO_2, pollutants and noise emissions.
- A lane change in a proper location leads to a more regular maneuver (less accelerations and decelerations for the vehicle and for the overall traffic).
- A lane change with a smoother maneuver 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 45 - HLN - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 maneuver 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 consumption
- Noise level
- Lane change point (For Location specific events only)
- Maximum steering angle (For Location specific events only)

Table 46 - HLN - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel 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 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 consumption

Day 1 Service: Signalized Intersection

The Day 1 Service Signalized Intersection (SI) currently includes, according to the WG2 list of Use Cases described in the document "Common C-ITS Service Definitions - Version 1.4", 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.

Use Case: GLOSA (Green light optimal speed advisory)

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?

Table 47 - 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 consumption – source: Can Bus data (l/100km)

Safety

Main research question

- Is safety affected by changes in driver behavior 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 maneuver 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 48 - 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 49 - 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 behavior 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 maneuver 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 50 - SI-GLOSA/SPTI - Relation between Sub Research Question for Traffic Efficiency and collected Data

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

Field Test Indicator/KPI

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

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

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

Table 51 - SI-GLOSA/SPTI - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

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

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

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

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

Environment

Main research question

- Is the environmental impact of transport affected by changes in driver behavior 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 more smooth braking. This irregular behaviour of the driver affects fuel 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 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-GLOSA/SPTI - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 consumption
- Noise level

Table 53 - SI-GLOSA/SPTI - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel 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 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 consumption
- Change in polluting emissions

Use Case: Traffic Light Prioritisation (TLP)

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?

Table 54 - 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 consumption
- Pedestrian behavior – source: camera recordings[7]

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

Safety

Main research question

- Is Safety affected by changes in driver behavior 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 pedestrian encouraged to signal violation?

Data Collection

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

Table 55 - 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 pedestrian?	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 56 - 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 pedestrian	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 the number of accidents involving pedestrians

Traffic Efficiency

Main research question

- Is traffic efficiency affected by changes in driver behavior 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 57 - 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 58 - 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 behavior 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 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 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 59 - SI-TLP/EVP - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 consumption
- Noise level

Table 60 - SI-TLP/EVP - Relation between Field test indicator KPI for Environment and collected Data

Field test indicator KPI	Fuel 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 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 consumption
- Change in polluting emissions

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 behavior 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?

Table 61 - 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 behavior compliant with the warning?	X	X	X
What is the impact of rejecting the request?	X	X	
How do the instant speed fluctuations change?			X
What are the impacts immediately after message reception?			X

Data Collection

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

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

- Fuel consumption – source: Can Bus data (l/100km)

Safety

Main research question

- Is safety efficiency affected by changes in driver behavior 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 62 - 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 behavior 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 63 - 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 behavior due to C-ITS service?

Research hypotheses about Sub Research Questions

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

Data Collection

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

Table 64 - 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 behavior 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 behavior after receiving the warning

Table 65 - 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 behavior 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 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 66 - SI-ISVW - Relation between Sub Research Question for Environment and collected Data

Sub Research Question	Fuel 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 behavior 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 67 - SI-ISVW - Relation between Field test indicator KPI for Traffic Efficiency and collected Data

Field test indicator KPI	Fuel 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 consumption due to less traffic jams caused by accidents
- Reduction in CO_2 emissions

Annex 1: Examples of inventory tool

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

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 country?

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**
	☐	**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

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** **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** **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-Road 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)
Finland	How satisfied were you with the C-ITS service on a scale of 1 = very satisfied, 2 = somewhat satisfied, 3 = somewhat dissatisfied, 4 = very dissatisfied
	In your opinion, what is the order of importance of the warnings given by the C-ITS service? Please rate the following from 1 to 6, where 1 = the most important and 6 = least important (each score may be selected only once) a) Object on the road: 1 2 3 4 5 6 b) Poor visibility: 1 2 3 4 5 6 c) Slippery road: 1 2 3 4 5 6 d) Exceptional weather: 1 2 3 4 5 6 e) Accident: 1 2 3 4 5 6 f) Roadworks: 1 2 3 4 5 6

	What kind of impacts did the C-ITS service warning of an obstacle on the road generally have on your driving behavior? You may select several impacts. Note that further details will be asked of the impacts you select below. ☐ It had an impact on my driving speed. ☐ It had an impact on the distance I kept to the vehicle in front. ☐ It had an impact on my overtaking behavior. ☐ It had an impact on my secondary tasks while driving, e.g. use of radio, mobile phone or other device. ☐ It had an impact on where I focused my attention in traffic. ☐ It had an impact on my route choice, if there was an alternative route available. ☐ It had an impact on my driving comfort. ☐ It had no impact on my driving behavior.
	When using the C-ITS service, did any of the following happen? (You may select several alternatives.) ☐ It was hard to stay in lane ☐ My speed decreased for a while (unintentionally) ☐ The gap to the vehicle in front of me got too short ☐ I noticed another road user, object on the road or another vehicle too late ☐ None of the above ☐ Another driving error, what: ____________________

	On what kinds of trip do you think you would activate the C-ITS service if a production-phase service were available to you after this Pilot? You may select several options if needed. ☐ I'd try to activate it always ☐ I'd activate it when I have a tight schedule ☐ I'd activate it for longer trips ☐ I'd activate it when driving on congested routes ☐ I'd activate it for trips on which I either expect to receive a warning or experience situations worth warning others about
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 favorable 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.

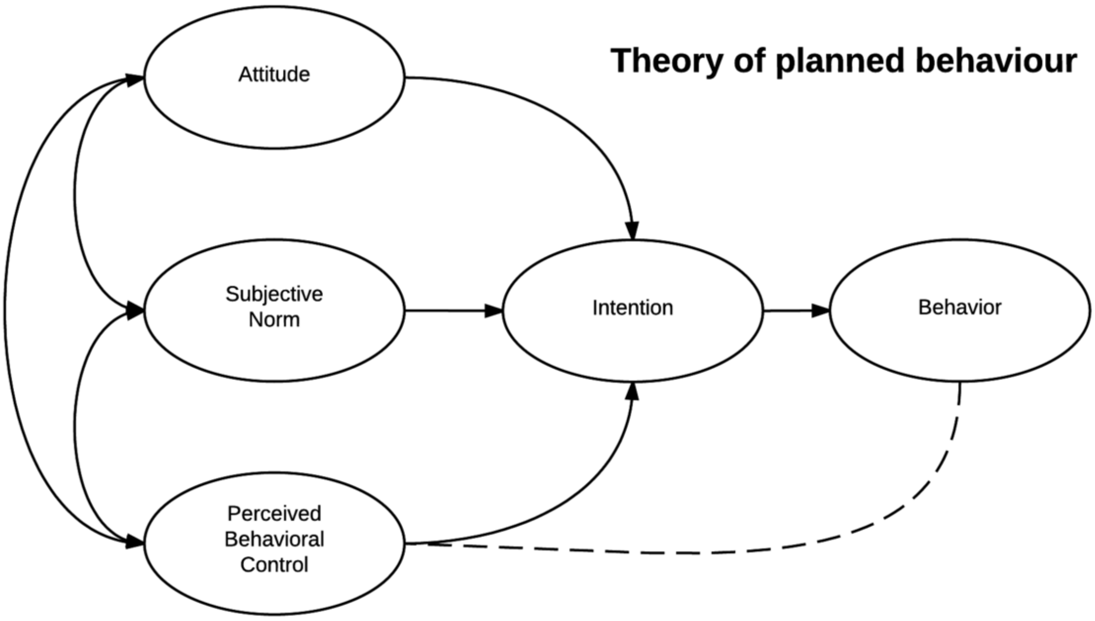
In another distinction between acceptance and acceptability, Schade and Schlag (2003) described acceptance as the respondents' attitudes, including their behavioral responses, after the introduction of a measure, and acceptability as the prospective judgment before such future introduction. In this case, 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

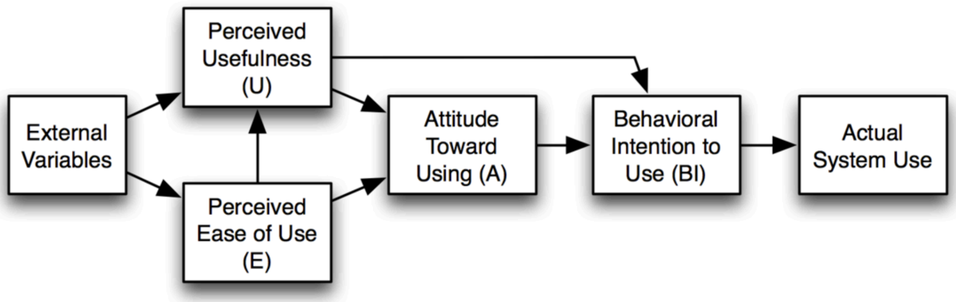
One of the most frequently used frameworks to define acceptance is the Theory of Planned Behavior (TPB). Based on the Theory of Reasoned Action (Fischbein & Ajzen, 1975), the TPB assumes that behavioral intentions, and therefore behavior, may be predicted by three components (Van Acker et al., 2007, 2010): attitudes towards the behavior, which are individuals' evaluation of performing a particular behavior; subjective norms, which describe the perception of other people's beliefs; and perceived behavioral control, which refers to people's perception of their own capability.

TPB has been used successfully to predict behavior in a wide variety of applied research settings within different domains, including several studies dealing with driving behavior 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 behavior (Elliot et al., 2005; Haglund et al., 2000). Warner and Aberg (2006) specifically used the TPB related to the use of ISA.

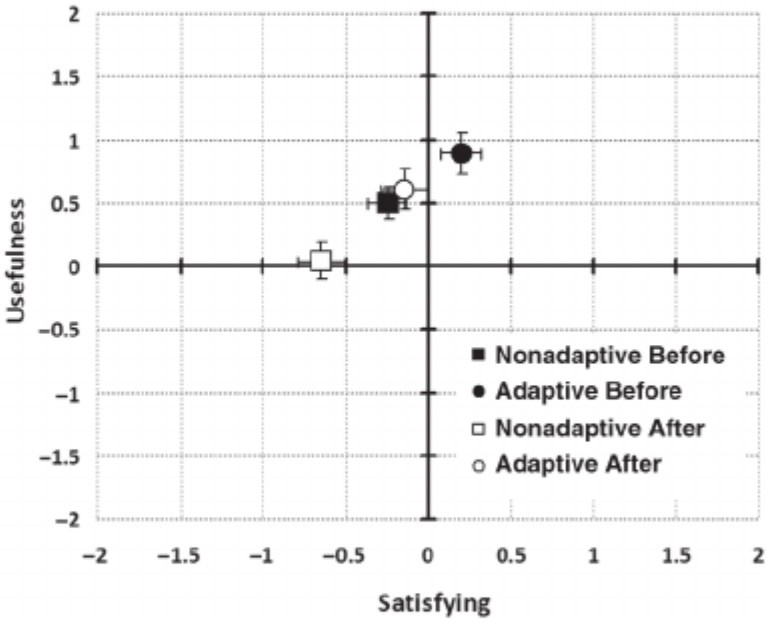
Comparing self-reported speeding of test drivers within an ISA trial with logged data explained 28% of the variance in logged speeding. In their study, Warner and Aberg (2006) noted that perceived behavioral control did not add significantly to the prediction of drivers' logged speed.



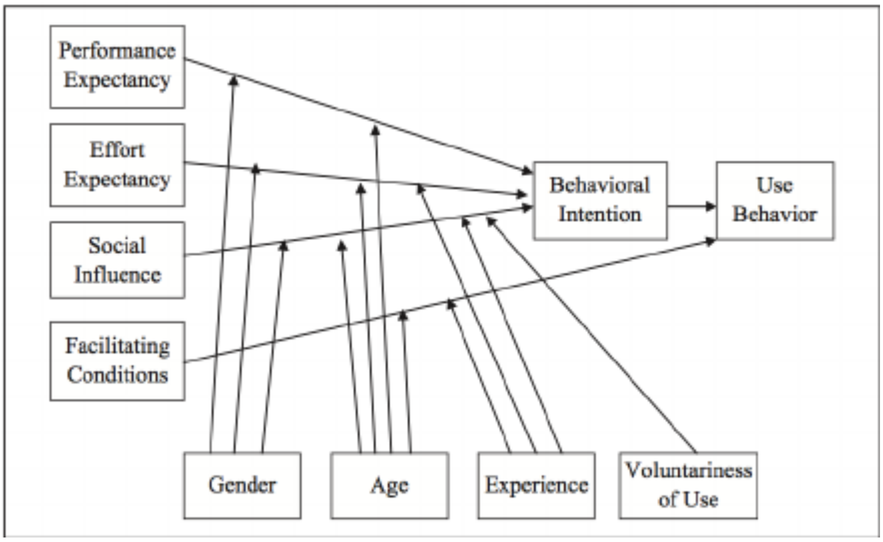
Another successful model is the Technology Acceptance Model (TAM) (Davis et al., 1989). TAM was designed to predict information technology acceptance and usage on the job. TAM assumes that perceived usefulness and perceived ease of use determine an individual's intention to use a system with the intention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



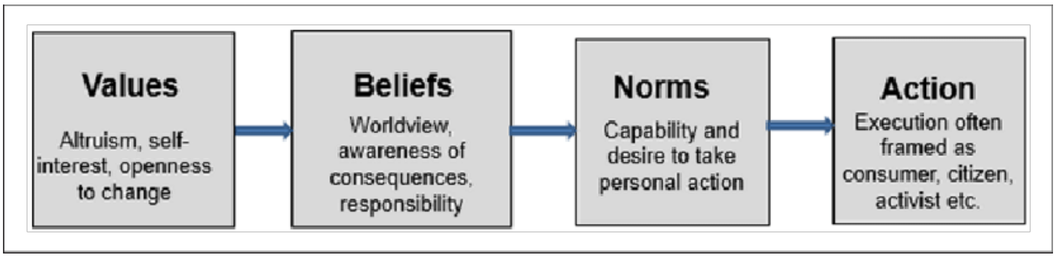
Van der Laan et al. (1996) published a simple method to define acceptance. Acceptance is measured by direct attitudes towards a system and provides a system evaluation in two dimensions. The technique consists of nine rating-scale items. These items are mapped on two scales, the one denoting the usefulness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



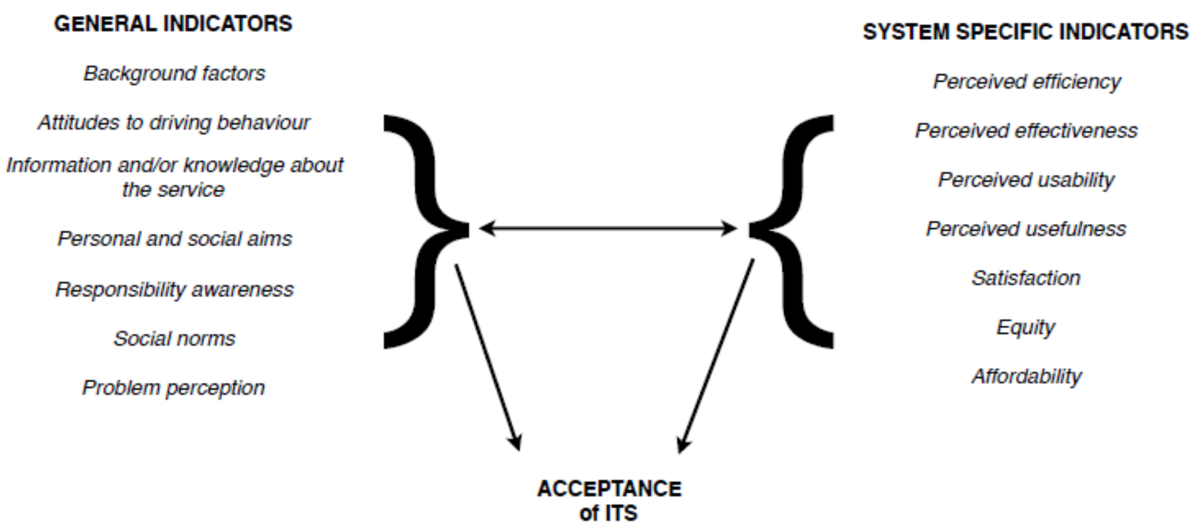
Stern (2000) developed the value–belief–norm (VBN) theory to examine which factors are related to acceptability of energy policies. Stern and colleagues proposed the VBN theory of environmentalism to explain environmental behavior, including the acceptability of public policies. They proposed that environmental behavior 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 behaviors, among which consumer behavior, 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 behavior.

Attitudes to driving behavior

Travel behavior, driving style and the choice of vehicle are also related to driving behavior.

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 behavior 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 behavior 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 behavior. 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 behavior. 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 2. Anyhow, it is a good practice to list also these other potential impacts. An impact table proposed by Batelle Memorial Institute (2003, p. 45) or by sketching the impact pathways proposed by Innamaa et al. (2018, p. 20) can be used for that.

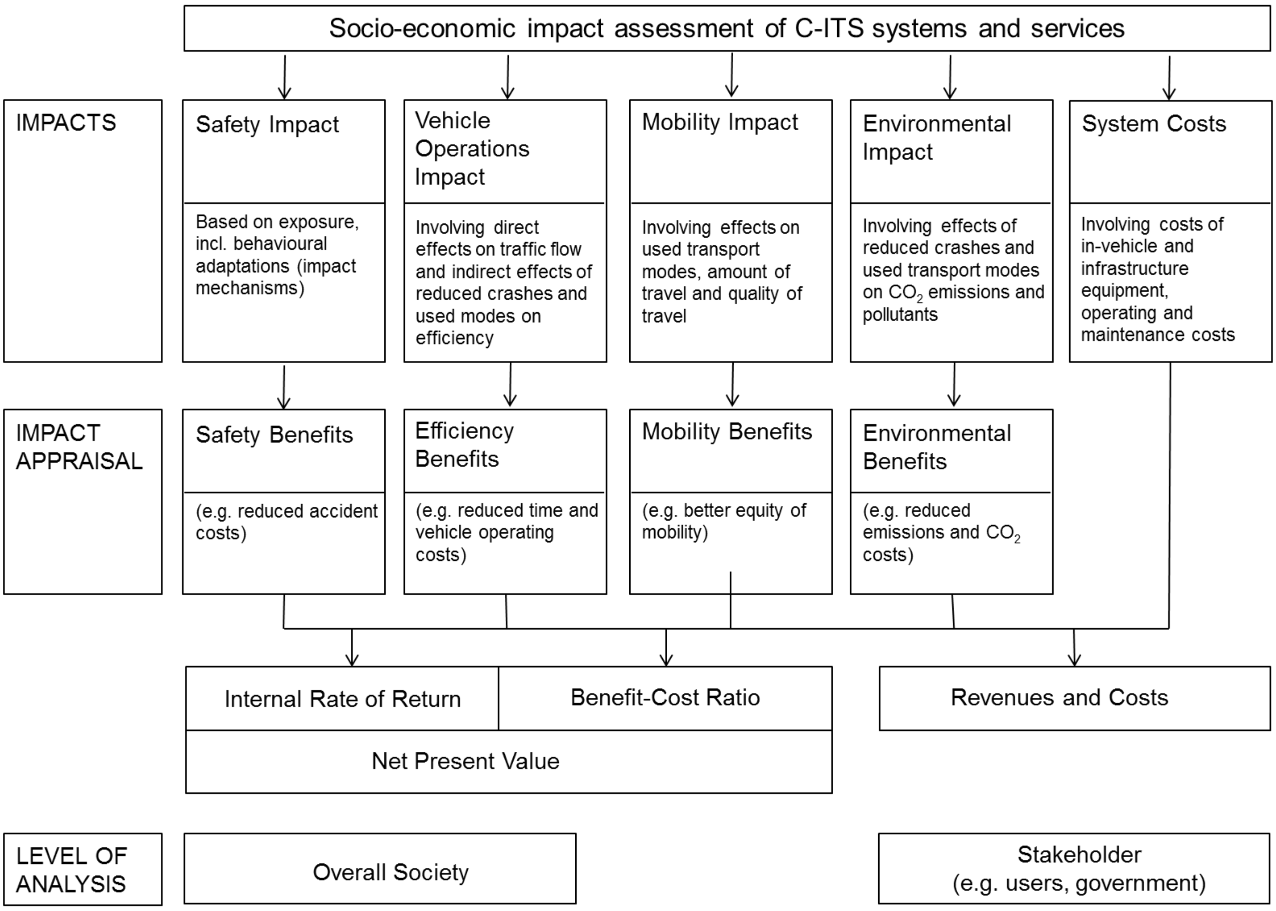

Figure 2 - Examples of the scope of impacts with-in socio-economic assessment (Modified from Figure in FESTA Handbook (2018))

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 3 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.

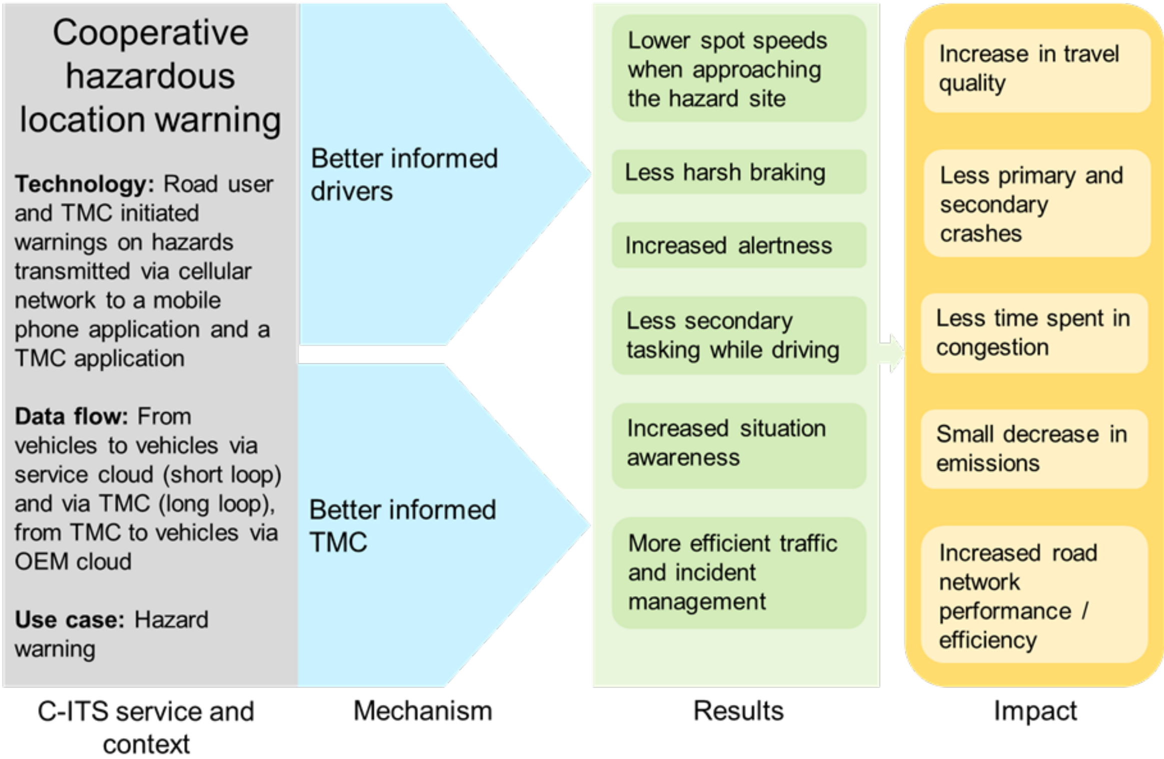

Figure 3 - Program theory of the C-ITS service 'Cooperative hazardous location warning' in the Finnish pilot in NordicWay (Innamaa et al. 2017)

In order not to limit the CBA only to the direct impacts but to take also the indirect impacts into account, a good practice is to consider all the impact mechanisms in the evaluation. The mechanisms below were defined for automated driving (Innamaa et al. 2018) but can be utilised also for C-ITS. They can be used for all impact areas.

1. Direct modification of the driving task, drive behaviour or travel experience
2. Direct influence by physical and/or digital infrastructure
3. Indirect modification of AV user behaviour
4. Indirect modification of non-user behaviour
5. Modification of interaction between AVs and other road-users
6. Modification of exposure / amount of travel
7. Modification of modal choice
8. Modification of route choice
9. Modification of consequences due to different vehicle design

The basis for the mechanisms was the nine safety impact mechanisms of intelligent transport systems of Kulmala (2010) which were adapted from the mechanisms formulated by Draskóczy et al. (1998). Kulmala (2010) aimed with his safety assessment framework to eliminate overlaps and thereby the risk of "double counting", to test the validity of any single mechanism, and to operationalise the mechanisms for assessment purposes. The same principles are also valid for studies on connected and automated driving. The aim was to make the mechanisms non-overlapping and all-inclusive, i.e., that all impacts would fall under some and (preferably) only one mechanism. In case an impact falls under two (or more) mechanisms, it is advised to select the most suitable one. Examples of use of the mechanisms can be found from the impact assessment framework by Innamaa et al. (2018).

In practice, for example, the safety impacts of a C-ITS service can be assessed based on

- Definition of target crashed (i.e. crashes that might be prevented by the use of the C-ITS service including relevant crash types, conditions in which the crashes take place, locations and participants)
- Coverage of service in terms of what part of e.g. hazardous locations can be covered by the corresponding C-ITS messages (detection of hazard, etc.)
- Effectiveness in prevention of the crash in terms of single driver receiving C-ITS message about the hazardous situation ahead
- Penetration of the C-ITS service in use in traffic flow (by the vehicle type)

The direct impacts are recommended to be supplemented by the indirect ones: changes in situations when there is no C-ITS message or service available, of the other road users and in interaction with them, and of the potential changes in our travel behaviour (like route choice).
It is good to note that some C-ITS services may have direct impact on the efficiency of the traffic on the road network or emissions caused by it. However, also those services that prevent crashes lead to reductions in delays and emissions as a side effect. For regions with low traffic volumes, the crashes may be the main cause of delays in the network. Thus, these impacts should not be overlooked.
Socio-economic impact assessment requires scaling up of impacts from single user or location level to larger penetration rates and wider road networks. For the scaling up, different EU-wide or national statistics and data are needed on crashes, emissions, mileages, time spent in congestion, fleet, etc. For example, CARE database provides European wide statistics on crashes with some details on the crash type, consequences, location and conditions. In practice, the availability of these data and statistics plays a role in the decision to what level to scale up the results.
For monetisation of impacts (benefits and dis-benefits), a decision is needed whether to use national or European unit values. Use of European values enables fair comparison of results between different countries. However, e.g. for decision making on national level, the use of national unit values provides better support and facilitates comparability with other measures/systems/services.

Costs

Estimation of costs is an essential part of socio-economic impact assessment, as from a socio-economic viewpoint, they are a (negative) part of the impact of systems and services. Cost estimation should take care of the following aspects (FESTA 2018):

- *Cost elements*: The system costs comprise the costs of in-vehicle, physical and digital infrastructure, nomadic devices, back-end systems, etc. Besides the direct investment costs, also the operating and maintenance costs have to be considered.
- *Relevant size of costs*: CBA applies a resource-based view. This means looking at potential savings of productive resources and, on the other hand, at the resources necessary to achieve this impact. The implication for cost estimation is that only the input of productive resources is relevant and not potential market prices. However, market prices are relevant for user-centred analyses.

Sensitivity analysis

It is advised to make sensitivity analysis on the main assumptions. For example, the SAFESPOT project recommended to vary the parameters by ±10% for the cost-benefit analysis, including the cost-unit rates (Geissler et al. 2011). Sensitivity analysis is a good tool for understanding, which the critical factors are for achieving the benefits and what the reliability of the results is.

The effect on cost-benefit ratio can be calculated in relative terms and, thus, reveal the magnitude of influence.

KPIs for socio-economic impacts

As result, FESTA Handbook (2018) recommends the reporting of following social KPIs:

- Net Present Value (NPV) where all discounted values of benefits (plus sign) and costs (minus sign) are summed up
- Benefit-Cost Ratio (BCR) where the total benefits are divided by the total costs; overall and “snapshot” BCR for target years where the costs will be transformed to annual values (using the discount rate) and will be compared to the target year benefits
- Benefits in monetary terms (€) per impact
  - Safety benefits
  - Environmental benefits (e.g. climate change, air quality, noise)
  - Other benefits to road users (e.g. time savings, operating cost savings and reliability gains)
  - Revenue to operators, including infrastructure and service operators

In addition, an international survey on key performance indicators (KPIs) rated with highest importance the following three indicators of economic impacts that fit for the assessment of C-ITS services (Innamaa & Kuisma 2018):

- Socio-economic cost-benefit ratio
- Work time lost from traffic crashes (hours per year, overall and per capita; monetary value)
- New established businesses / job creation

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